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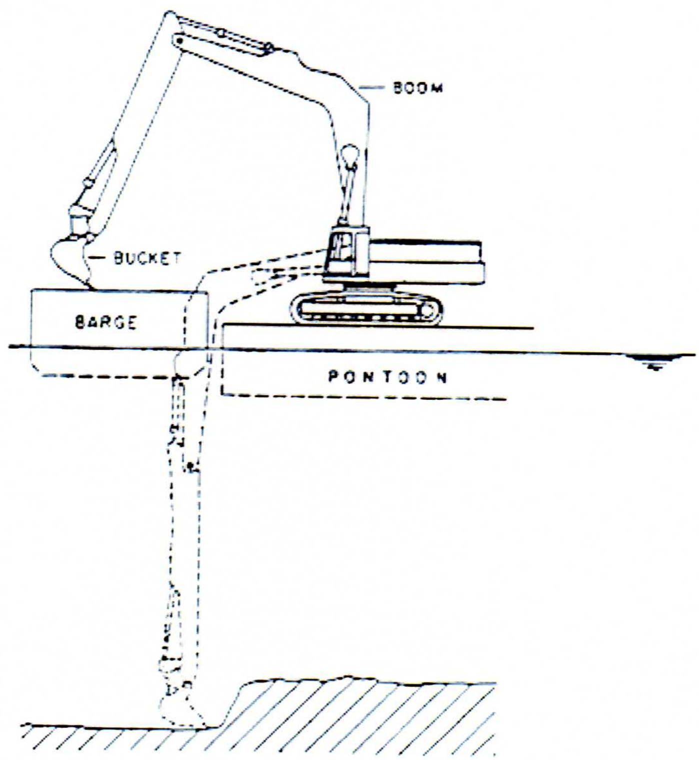
SWAMP

Storm Water Management Facility Sediment Maintenance Guide

Job #: 97-G-1149



Source: MOE 1994b

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Foreword

Similar to other municipal infrastructure such as roads, water supply, sanitary sewers, wastewater treatment plants, etc., the effective long-term operation of Storm Water Management Facilities, or SWMFs, requires maintenance. However, unlike most municipal infrastructure, the widespread application and science of storm water treatment facilities and their maintenance has been evolving very rapidly. Until early in the 1990s, widespread water quality treatment of storm water (water generated directly by rainfall and snowmelt) was not deemed necessary. Since then, SWMFs have become common technologies that improve the quality of runoff generated in urban areas through storage detention prior to release to streams or other receiving water bodies. If SWMFs are not maintained, runoff will enter rivers and other receiving waterbodies without adequate treatment, causing significant harm to water quality and to the aquatic ecosystems that depend on it. Current regulations require the use of SWMFs, and proper maintenance is a logical step in ensuring their effectiveness.

This study has evaluated the removal and disposal of sediment accumulated in Storm Water Management Facilities to provide a starting point for developing an action plan. It will serve as a guide for owner/operators responsible for the maintenance of the facilities. At the same time, this report is in no way the ultimate word on SWMF maintenance. Storm water treatment and the maintenance of treatment facilities is an evolving practice. Also, we recognize that documents such as the 1994-MOEE's Storm Water Management Practices (SWMP) Planning and Design Manual provide good guidance for design. However, our own experience has taught us that there are numerous constraints and opportunities faced during facility design and construction that result in variable configurations. Due to these variances and accounting for the different levels of resources that may be available for maintenance, prospective operators may need to consider other different and innovative methods for completing the sediment removal maintenance work. In addition, some of the information provided may not be applicable in their particular case but at the least, can be 'considered' during the planning process. This report is a first step towards optimizing the long-term maintenance of SWM facilities.

Much of the information has been extracted from case studies dealing with sediment removal in Ontario. The information provided by participants in these projects is acknowledged and appreciated. Other sources include technical reports, laboratory data sets (sediment quality/grain size distribution), and various Internet and scientific/engineering journal sources. We encourage operators to document new clean-up experiences and transfer the information to other users. Greenland International Consulting Inc. is committed to distribute any new information we receive.

To obtain a copy of the document or updated information or to provide case study data, please contact: Ms. Sonya Meek, Toronto and Region Conservation Authority, Tel: (416) 661-6600 or Mr. Edward Graham, Greenland International Consulting Inc.: Tel: (905) 738-1818 or through the Internet at www.grnland.com.

We believe that this team approach will greatly assist all users and ultimately, our environment.

Acknowledgements

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Consultants:

- Mr. Dave Leighton - Cosburn Patterson Mather and Urban Development Institute

[1] The SWAMP (Stormwater Assessment Monitoring and Performance) Program is an initiative of Environment Canada's Great Lakes 2000 Clean-up Fund, the Ministry of the Environment, Ministry of Transportation, Toronto and Region Conservation Authority, and a number of individual municipalities. It is designed to monitor and evaluate new and innovative stormwater management technologies and disseminate study findings.

[2] The Great Lakes 2000 Cleanup Fund is a component of the Federal Government's Great Lakes 2000 program. The Cleanup Fund provides resources to demonstrate and implement technologies and techniques to assist in the remediation of Areas of Concern and other priority areas in the Great Lakes. The report that follows was sponsored by the Great Lakes 2000 Cleanup Fund and addresses stormwater management issues in the Toronto and Region Area of Concern in Toronto, Ontario. Although the report was subject to technical review, it does not necessarily reflect the views of the Cleanup Fund or Environment Canada.

EXECUTIVE SUMMARY

(Operator's Guide)

I. INTRODUCTION

Urban storm water management facilities (SWMFs), which are used for water quality treatment, are designed to accumulate sediment over time. Because of a limited storage capacity, this sediment must be removed to maintain the treatment effectiveness and environmental protection.

In addition to this environmental reason, owners are also legally required to keep the SWMF in proper working order. For example, two standard construction conditions in the Ministry of the Environment's (MOE) 'Certificate of Approval', issued under Section 53 of the *Ontario Water Resources Act* specify that:

a. "The owner must ensure that sediment is removed from the storm water management works at such a frequency as to prevent the excessive buildup and potential overflow of sediment into the receiving watercourse";

and,

b. "Regular removal of sediment from the approved storm water management works is required to mitigate the impacts of sediment on the downstream receiving watercourse. It is also required to ensure that adequate storage is maintained in the storm water management facilities at all times as required by the design."

As stated by a local environmental lawyer, "It does help by clearly stating that prudent municipalities can limit their exposure to negligence claims by anticipating potential areas of concern and developing policies to deal with these concerns" Shier (1998).

II. LEGISLATION

A SWMF sediment removal project can involve permits and approvals from various agencies. A review of case studies and current regulations in Ontario indicates that:

- The responsibility of the owner to operate and maintain SWMFs is stipulated in the *Ontario Water Resources Act* (OWRA).
- Sediment disposal is regulated through the *Environmental Protection Act* and other MOE guidelines.

- Sites where fishery or fishery habitat will be at risk require approval from the Federal Department of Fisheries and Oceans (DFO) or its agent in the jurisdiction.
- Regulation of water with dams/weirs or diversions and the placing of fill within a fill-regulated area is under the jurisdiction of the local Conservation Authority (CA). With on-line storage facilities, permits would be required for dewatering, blocking and diverting flows around the facility to a downstream location. Permits from the CA would also be required for both on-line and off-line facilities, if located within a flood plain and/or a valley corridor (fill regulated areas).
- The Ontario Ministry of Natural Resources (MNR) administers the Lakes and Rivers Improvement Act, which regulates activities within a watercourse such as construction and modification of dams and weirs, and the protection of interests of the riparian owners.
- The Municipal Act assists communities in the regulation of various activities, which may affect the local environment (e.g. solid waste disposal, sewer use, land use, etc.).
- The project may have to follow the procedures set out in Schedule B of the Class Environmental Assessment (EA) for Municipal Water and Wastewater Projects if the work includes modifications to the original design, including 'retrofitting' structures or other improvements (e.g. volume changes). The project would follow Schedule A of the Class EA, if it only involves maintenance for cleaning, relining, or repairing the facility to its original design and construction specifications. In this case, the project would be part of "on-going" maintenance activities.

III. SWMF DESIGN/OPERATING CRITERIA

There are many design and operating factors that influence the SWMFs treatment performance. These include: geometry (shape, surface area, volume, relative location of inlet(s) and outlet(s)), wind exposure, vegetation, and suspended sediment characteristics (particle size and densities). The main factor that can be controlled through maintenance is the volume available.

With all other factors relatively constant, the storage available for treatment will decrease with sediment accumulation over time with a corresponding reduction in treatment efficiency. The relationship between storage and efficiency provides the basis for determining when maintenance is required. The treatment efficiency or solids removal rate target is typically established prior to design and must be known when evaluating the need for maintenance. Ontario's MOEE Storm Water Management Practices (SWMP) manual (1994) uses the level protection of a specific type of aquatic habitat when specifying the solids removal rate required for mitigating lethal and chronic effects. The MOEE SWMP manual Total Suspended Solids (TSS) removal targets for each habitat type are as shown in ***Table i.***

Table i: TSS Removal Criteria

Habitat Protection Level	Target TSS Removal Rate[1]
1	80%
2	70%
3	60%
4	50%

1–From Figures 4.2-4.5 in MOEE SWMP manual (1994).

In the MOEE SWMP design approach, once the protection level is established, the sizing criteria is obtained as a function of the tributary area's imperviousness and type of facility. ***Table ii*** shows the design storage volumes for wetlands, wet ponds, and dry ponds. Note that for wet ponds and wetlands, the volumes shown include 40 cubic meters/hectare that must be provided for 'extended detention storage'. This storage is located 'above' the permanent pool volume.

Table ii: MOEE SWMP Design Volumes (m^3/ha)

Protection Level	SWMP Type	Tributary Area Imperviousness			
		35%	55%	70%	85%
1	Wetland	80	105	120	140
	Wet Pond	140	190	225	250
2	Wetland	60	70	80	90
	Wet Pond	90	110	140	150
3	Wetland	60	60	60	60
	Wet Pond	60	75	85	95
	Dry Pond	90	150	200	240
4	Wetland	60	60	60	60
	Wet Pond	60	60	60	65
	Dry Pond	35	50	60	70

Note: For Wetlands and Wet Ponds, 40 m^3/ha of the volume is extended detention volume. (Ref: Table 4.1 - MOEE SWMP Manual, 1994)

The SWMP manual recommends a maximum 5% reduction in treatment efficiency due to sediment accumulation. ***Table iii*** shows the corresponding minimum storage volume, below which sediment removal maintenance is required.

Table iii: Minimum Required SWMF Storage Volume Prior to Maintenance (m^3/ha)

Protection Level	SWMP Type	Tributary Area Imperviousness			
		35%	55%	70%	85%
1	Wetland	68 (28)	85 (45)	94 (54)	107 (67)
	Wet Pond	103 (63)	138 (98)	164 (124)	190 (150)
2	Wetland	55* (15)	60 (20)	64 (24)	72 (32)
	Wet Pond	73 (33)	90 (50)	103 (63)	114 (74)
3	Wetland	55* (15)	55* (15)	55* (15)	55* (15)
	Wet Pond	55* (15)	100 (60)	111 (71)	116 (76)
	Dry Pond	50	81	89	107
4	Wetland	55* (15)	55* (15)	55* (15)	55* (15)
	Wet Pond	55* (15)	55* (15)	55* (15)	60* (20)
	Dry Pond	22	34	39	66

() – Volume per hectare that must be present as 'permanent pool'.
Note: These values have been interpolated from the MOEE SWMP figures 4.2 to 4.5, based on the recommended allowable 5% reduction in original design storage volume due to sediment accumulation. For Wetlands and Wet Ponds, 40m^3/ha of the values are extended detention storage. * Values cannot be interpolated from volume vs. treatment relations – approximate extrapolated values used.

IV. FORECASTING MAINTENANCE

The primary objective of sediment removal maintenance is to restore the available storage and the corresponding treatment efficiency to the original design values. The need for maintenance at any time, therefore, can be evaluated by comparing the current available storage with the volumes shown in ***Table***

iii. However, if sufficient storage volume is available, predicting (i.e.'forecasting') future maintenance requires knowledge of not only the available volume and the minimum required volume, but also the rate of sediment accumulation.

Sediment accumulation rate can be estimated either with the MOEE SWMP 'desk-top' approach, which uses 'typical' annual sediment export and expected removal rates, or from field measurements of actual accumulation. The desk-top approach uses reported literature values of sediment export rates as a function of tributary area imperviousness and accumulation rates based on expected trap efficiency of the facilities, as listed in ***Table i.*** Please refer to the main section of this report or to the MOEE SWMP manual for details on this method.

The sediment measurement approach requires additional resources but can significantly increase accuracy. ***Figure i*** conceptually illustrates how measurements of sediment accumulation can be used to project when maintenance will be required. This example corresponds to a wet-pond sized for Level 1 habitat protection with a lumped tributary area imperviousness of 55%. Using ***Table ii***, the original design volume will be 190 cubic meters per hectare ('total' storage volume), which includes 40 cubic meters per hectare of 'extended detention' storage. In other words, the 'permanent pool' volume at design time will be 150 cubic meters. From ***Table iii***, the minimum allowable 'total' volume before maintenance will be 138 cubic meters per hectare, which includes 40 cubic meters per hectare of 'active' volume. Assuming that none of the active storage volume is lost to sediment accumulation, the minimum allowable permanent pool will be 98 cubic meters per hectare.

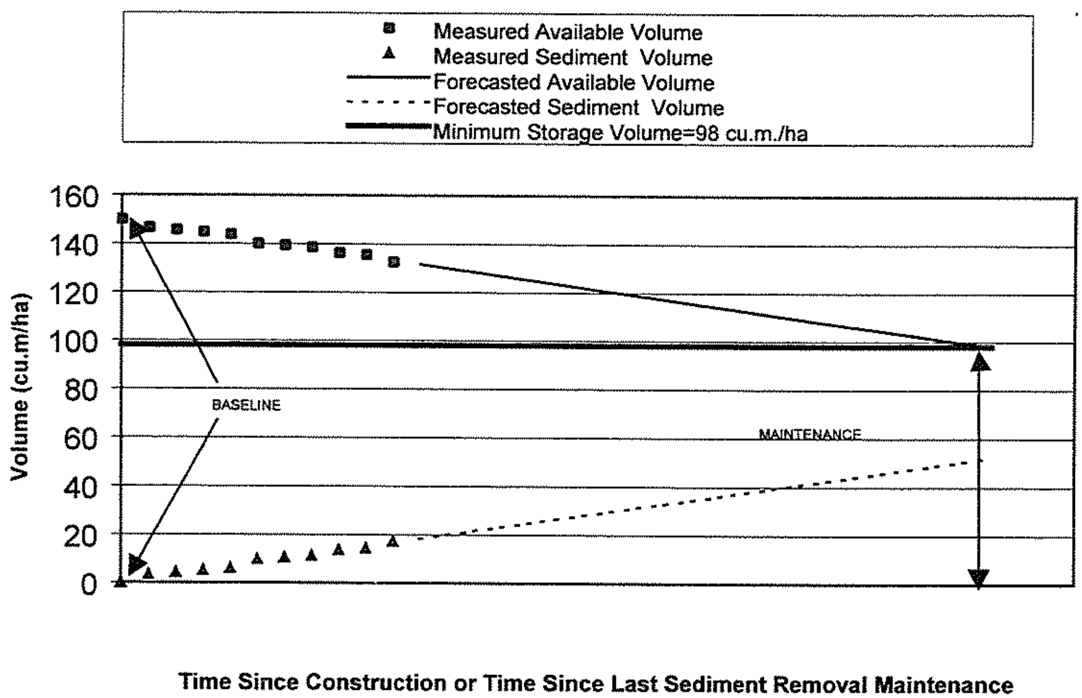


Figure i: Example of Sediment Removal Maintenance Forecasting using In-Situ Measurements

Figure i also illustrates the 'point' measurements of available storage and accumulated sediment at regular intervals from the time of construction (or since the facility was last maintained)[1]. The maintenance forecast thus consists of projecting the previous accumulation rates and comparing and matching the available storage volume with the minimum required volume.

A third, 'hybrid', approach is derived from a combination of field measurements and desk-top method. This is simply a refined desktop approach using site-specific results of accumulation rates. However, previous field data results should be carefully interpreted prior to 'regionalizing' the approach to account for possible special site-specific or temporary conditions (e.g. construction sediment exports).

V. SEDIMENT MEASUREMENTS, SAMPLING, AND ANALYSIS TECHNIQUES

V.I Locations for Measurement and Sampling

Results from previous field monitoring work have shown that the accumulated sediment is typically not uniformly distributed within a facility. Consequently, several locations should be measured within the facility to obtain the depth distribution and corresponding volume. Keeping good sampling records including the locations of previous measurements and sampling is important for comparison with future surveys.

V.II Depth Measurement Techniques

One or two types of depth measurement may be required: 1) Depth to sediment such as from permanent pool water level (for wet ponds and wetlands); or 2) Depth of sediment, from top of sediment layer to the bottom of the facility. Tracking the 'available' storage by measuring the depth to the sediment layer and subtracting from the 'initial' or design volume can facilitate the evaluation process. The following depth measuring techniques will be useful to quantify volumes and plan the removal and disposal:

- <u>Core Sampling:</u> Core samples are collected by pushing a special tube through the sediment layer, holding the sediment sample with suction, and withdrawing it. This method can be relatively simple and is a popular technique used for depth measurements. Getting core samples has an advantage in that the samples obtained can also be used for chemical evaluation. However, it is important to recognize that core sampling also has disadvantages. For example, core sampling can be relatively labor-intensive and time-consuming compared to the other methods. Also, the sampling tube used in core collection can cause significant sediment compaction, particularly if the sediment is not consolidated, resulting in the underestimation of sediment volumes.

[1] As discussed later, it is easier to obtain field measurements of 'available' volume compared to sediment volumes and therefore it will be of great advantage to obtain the 'initial' or 'design' volume from which to 'calculate' the sediment accumulation.

- Disc/Rod Measurement: This method requires adaptation of a disc and a rod (e.g. survey rod) (Nepean 1997). A disc can be attached to a string or a light rod calibrated in centimeters, and lowered into the water until it rests on the surface of the undisturbed sediment. After the depth has been recorded, the rod alone is lowered into the water, allowing it to pass through the loose sediment onto the firm native soil. The first measurement to the surface of the sediment with the disc should avoid compaction of the layer and the second measurement with the rod should actually reach down to the native soil.

- Depth Sounding: Depth sounding (or fish finding) equipment can be used to locate the surface of soft sediment layer and the firmer basin parent material. Compact units may be mounted on the side of a boat and used to produce numerical measurements and graphical images of the basin depth lines. Equipment calibration and verification is advised using manual measurements particularly with regard to the location of the native soil layer.

V.III Sediment Sampling

Standard methods and equipment used for sediment collection are well-documented and illustrated in a number of instructional manuals such as the *Dredged Material Sediment Sampling and Analysis Handbook*, MOEE (1994c). Two important sampling and analysis considerations can be highlighted:

a) A pre-inspection of the tributary area is useful to identify potential contaminant sources (e.g. special industrial/commercial activities, sewer outlets, etc.). Also, MOE staff can be contacted with regard to spills that may have been reported within the catchment area. This information will assists in predicting contaminant types and levels to be expected prior to selecting a sample collection and laboratory analysis plan.

b) Field observations and records can be useful to document the site conditions and potential actions during sampling. For example, unusual odor and oily sheen can reveal important information regarding the contaminant types present and provides guidance for the selection of analysis parameters.

V.IV Sediment Chemical and Geotechnical Analysis

The primary objective of the sediment chemistry analysis is to identify disposal options and/or restrictions based on the *Environmental Protection Act* (EPA) Regulation 347-Leachate Test and the *Guidelines For Use At Contaminated Sites In Ontario (GCSO)*, (MOEE 1997). The recommended chemistry analysis approach is illustrated in ***Figure ii*** and ***Drawings 1 - 5*** and described below.

V.IV.I Leachate Test

The Leachate Test, **'A'**, shown in ***Figure ii***, is the first step to determine whether the substance must be disposed in a landfill (municipal landfill or registered landfill) or if it can be disposed elsewhere. The Leachate Test provides concentrations of 33 constituents including trace metals, organic compounds, and nutrients. Based on the results, a sample and parent material is classified as either registered waste or as non-registerable waste. Registered waste must be disposed in a registered landfill (hazardous or non-hazardous depending on the degree of contamination). Based on the location, landfill disposal will require a significant tipping fee. Non-registerable waste does not require landfill disposal.

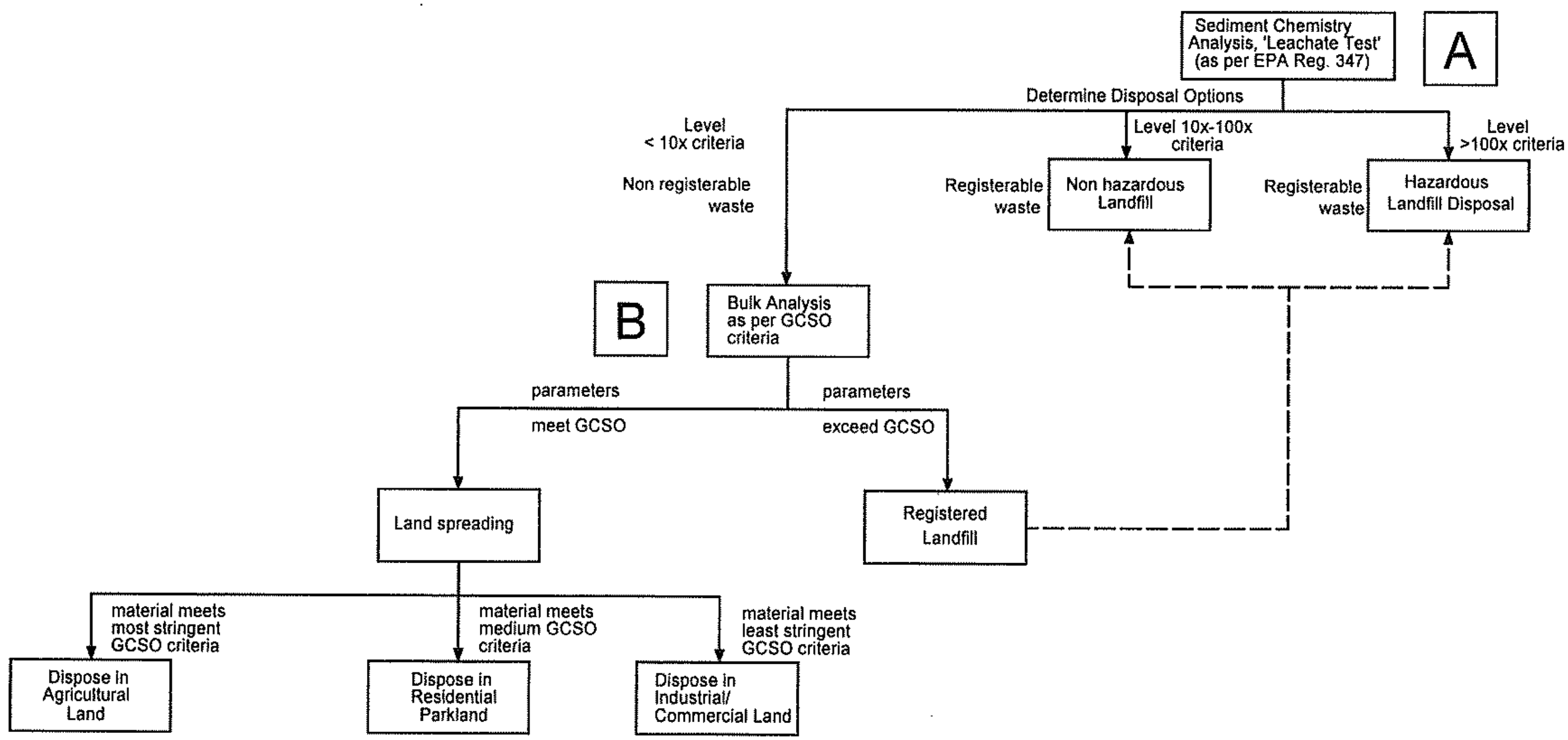
Results from the eight case studies investigated for this report of stormwater sediment removal projects suggest that, in most cases, the contaminant concentration in runoff sediment will exceed background levels but does not necessarily require disposal at registered landfills (see also Schueler 1994, Marsalek *et al.* 1998). However, in two of the sites, or 25%, did require landfill disposal. These SWMFs were 'primarily' servicing industrial land uses.

V.IV.II Analysis for Upland Disposal

Based on sediment chemistry results and agency regulations, sediment can also be used as a resource or disposed in a cost-effective manner (e.g., used as residential fill, daily landfill cover, etc.). However, the availability of this disposal option will depend on the results of a second set of sample analysis completed in accordance with the *'Guidelines For Use At Contaminated Sites In Ontario'* (GCSO), shown as **'B'** in ***Figure ii.*** If the GCSO criteria are exceeded, landfill disposal will still be required.

Under the GCSO, a soil may be suitable for use in agricultural fields, or as 'fill' in residential/park lands or in industrial/commercial areas. To protect against food contamination the most stringent criteria apply to agricultural uses. The relatively less stringent residential/parkland criteria protects against the potential exposures risks of large populations. The least stringent criteria apply to commercial/industrial sites.

The number of GCSO parameters is significantly greater than the number of leachate criteria (117 versus 33). However, in most cases it is not necessary to test for all 117 contaminants listed in the GCSO document. Conversely, it may also be necessary to test for contaminants that are not listed in the GCSO document. For example, in other cases, pesticides were added to the list after considering site-specific conditions (e.g. Silver Lake in Kitchener). Therefore, it is highly recommended to contact local MOE staff to discuss and agree upon applicable parameters in the context of local conditions prior to testing (e.g. land use in contributing tributary area, potential reported spills, and other local experiences). Typical laboratory testing costs are provided in ***Appendix F***.



Notes: GCSO – 'Guidelines for Use at Contaminatied Sites in Ontario

EPA – 'Environmental Protection Act

Figure ii: Chemical Analysis for Sediment Disposal in Ontario

V.IV.III Geotechnical Properties

In addition to the chemical composition of the sediment, there are other important properties to consider when evaluating removal and disposal requirements and options. For example, in addition to the Leachate Test, EPA Regulation 347 requires a standard 'Slump Test' to classify the material as either solid or liquid waste. Sediment is considered liquid if the slump is greater than 150 millimeters. The sediment slump test procedure is described in *EPA Regulation 347, Schedule 4, Test Methods for the Determination of Liquid Waste for Solid Waste Landfilling.*

In general, saturated sediment behaves as a liquid rather than solid. This condition can be problematic for both transportation and surface disposal. Solid waste landfill operators will not accept sediment that does not pass the EPA Regulation 347 slump test criteria. Therefore, some form of dewatering may be required prior to disposal. It should be noted that the process of sediment dewatering can be more difficult and expensive for silts and clays than for sands. Therefore, project planners should consider determining saturation levels, soil types, and their de-watering requirements.

Sediment grain size, saturation and bulk density can also be important. For example, sandy sediment with low saturation and high densities can be capable of supporting heavy earth moving equipment. Conversely, the same equipment has difficulty operating in highly saturated, low density, silt and clay soils. Consequently, it may be easier to remove 'sandy' sediment while silts and clays may require more time and/or specialized techniques.

VI. SEDIMENT REMOVAL

VI.I Removal Methods

Traditional sediment removal techniques can be 'mechanical' or 'hydraulic'. Mechanical methods are either 'excavation' or 'dredging', depending if the removal is from a water-filled reservoir or from a drained basin. Hydraulic methods means are also be referred to as 'suction' dredging.

In reservoirs with permanent pool storage, there may be a tendency to select mechanical excavating and dredging over hydraulic removal because of the familiarity, availability, relative size of equipment and accessibility to sites. However, hydraulic methods may be better suited for the work, particularly if used repeatedly in several locations or for larger sites. An equipment productivity analysis and cost estimates of alternatives is highly recommended during planning.

VI.I.I Mechanical Excavation/Dredging

Both mechanical excavation and dredging involve the use of traditional earthmoving equipment such as excavators, clamshell diggers, etc.. The mechanical approach is most effective removing sediment with firm consistencies. Mechanically excavated sediment does not entrain substantial excess water as compared with hydraulic (suction) dredging. Also, the material may be deposited directly on-shore, or if the water content is not high, can be loaded directly into trucks and transported to the disposal site. If the water content is high and leaching occurs, sealed truck bodies are required to prevent slurry leakage along the haulage route.

Some of the advantages and disadvantages of mechanical dredging are as follows:

Advantages

- Commonly used and widely available at reasonable rates.
- Small working areas are accessible by smaller mechanical units.
- Entrains less water compared to hydraulic dredging, reducing de-watering costs.

Disadvantages

- Accessibility/operating constraints can occur if sediment is too soft to support the weight of mechanical excavation equipment.
- Limited reach reduces accessibility from shore to wide basins.
- Mechanical dredging of un-drained ponds can cause significant sediment resuspension.

Mechanical excavating or dredging equipment includes: Excavators (Front and Backhoe), Clamshell Buckets, and draglines.

VI.I.II Hydraulic (Suction) Dredging

In comparison to mechanical methods, hydraulic dredging is a relatively new technology. Equipment can consists of a cutting head that loosens the sediment and mixes it with water, and a pumping system that pumps the slurry either to a barge or a shore-based area. Hydraulic dredges need to entrain significant amounts of water (80-95%) to achieve a slurry for pumping (MOEE 1994a). Equipment varies in size, depending on the needs or access restrictions and most are designed to operate at variable depths of up to 10 meters. When the basin cannot be de-watered, hydraulic dredges offer advantages over mechanical dredging because they cause less turbidity. As a result, the cost for 'screening' (pool fencing) can be reduced.

Advantages and disadvantages of hydraulic dredging are:

Advantages

- Works well in soft, silty sediment
- Particularly well suited to larger basins.
- Suctioning mechanism minimizes sediment resuspension and transport downstream, requiring less screening.
- Removes sediment evenly throughout the basin.

Disadvantages

- Slurry has very highly water content, which increases subsequent dewatering costs.
- Equipment accessibility to smaller ponds.
- Requires higher expertise. Equipment and crews may need to be brought from long distances requiring careful planning.

VI.II Avoiding Sediment Resuspension

Sediment resuspension and subsequent transport downstream is of particular concern during and after sediment removal. Although it is not always possible, the best way to eliminate resuspension and transport is by cutting the flow to the facility by providing an inlet by-pass. In most cases, this is not possible due to the constraints related to topography, available area, and construction costs. Examples of by-pass design are available in most areas (e.g. Killian-Lamar in Vaughan).

Sediment resuspension and transport can also be mitigated using other methods. For example, silt curtains can isolate work areas from the rest of the storage allowing excavation or dredging on one side while avoiding the inlet and outlet areas. Also, resuspension can be minimize in undrained reservoirs using cutter suction dredges which allow sediment losses near the cutter head level and may not appear in the surface waters. Re-suspension can also be reduced through operational controls, including reducing rotation speed, slowing movement, and increasing suction rate. However, these controls reduce production rates and increase the volume of water removed, thereby increasing the cost for dewatering/disposal. In comparison, excavators and clamshells cause more resuspension, especially in unconsolidated fine-grained sediment. Sediment spillage typically occurs as the buckets are raised through the water column and swung toward the storage area on shore or to receiving trucks.

Scheduling the removal maintenance during the driest month in the year (e.g. August) or during winter conditions are planning considerations that can reduce resuspension and transport.

VII. SEDIMENT DISPOSAL

VII.I Water Content and Sediment Dewatering

Dewatering (drying) or bulking can reduce sediment water content. Dewatering refers to the extraction of liquid from the bulked mass while bulking refers to reducing the percentage of water by adding water-adsorbing solid matter.

Either dewatering or bulking will be necessary when:

- Sediment does not meet the EPA Regulation 347 "slump test" criteria for landfill disposal as solid waste.
- Sediment needs to meet other criteria for disposal such as fill and daily landfill cover;
- Sediment cannot be easily transported without spilling on the road; or,
- It is necessary to minimize the weight of sediment to be disposed (should de-water only).

Note however that dewatering or bulking is not always necessary such as when transporting with sealed trucks and disposing in open fields with proper spreading and suitable erosion control methods. For example, sediment removal case studies in Kitchener and in Waterloo did not require dewatering. In Kitchener, the sediment was deposited directly into a closed gravel pit while in Waterloo sediment was spread directly onto agricultural fields.

Other sediment removal projects used both methods for reducing the sediment water content. In Nepean and Mississauga, the preferred methods were bulking with straw and sawdust. At the Toogood Pond in Markham, Bluffers Park in Toronto, and at the Lincoln pond in Uxbridge, evaporative air drying techniques were used.

As recommended by Dainty (1998), drying techniques may be used effectively by following these recommendations:

i) Fine sediment requires a drying space of approximately 2.5 m^2/m^3, spreading to a maximum depth of 425 mm for a drying period of approximately 6 days.

ii) Course sediment requires approximately 1 m^2/m^3 of sediment, spreading to a maximum depth of 1 m for a drying period of 3 days.

In both cases, drying periods are approximate with fluctuations due to climate conditions such as solar radiation, wind speed, relative humidity, etc., and also assume no rain.

VII.II Sediment Chemistry

Regulations and guidelines related to sediment chemistry and disposal have been discussed in ***Section V.IV*** and ***Section 5.3*** of the report. As indicated in ***Section V.IV***, the primary objective of the chemical analysis is to identify disposal options based on Regulation 347-Leachate Test and the Guidelines For Use At Contaminated Sites In Ontario (GCSO), (MOEE 1997). The recommended approach is illustrated in ***Figure ii*** and in ***Drawings 1 - 5***. Disposal options are:

1. Registered landfill disposal (non-hazardous or hazardous).
2. Upland disposal (land spreading in commercial or industrial areas, residential, or agricultural land).

Two of eight case study projects used registered landfills for disposal. Upland options include agricultural soil supplement, residential construction fill, landfill cover, or other open space areas such as abandoned pits.

VIII. REMOVAL AND DISPOSAL COST ESTIMATES

Cost estimating is important during planning for determining the feasibility of single or multiple-projects and for site-specific budgeting and scheduling prior to tender. The total project cost from each of the eight projects (refer to ***Appendix D***) has been translated into a unit cost (\$ per m^3), and summarized in ***Table iv*** for comparison. Values are also adjusted to 1997 dollars.

Table iv: Summary of Sediment Removal and Disposal Case Studies

Facility, Location	Year Cleaned	Removal Method	Dewatering Method	Disposal Method	Cost [1] (S/m^3)
Merivale Pond, City of Nepean	1997	Mechanical	Bulking	Landfill	124
Bentley Pond, City of Nepean	1997	Mechanical	Bulking	Landfill	669
Lake Aquitaine, City of Mississauga	1994	Mechanical	Bulking	Daily Cover[2]	62
Toogood Pond, Town of Markham	1997	Mechanical	Air Dried	Residential	32
Bluffers Park Facility, City of Toronto	1995	Mechanical/Hydraulic	Air Dried	Residential	162
Lincoln Pond, Town of Uxbridge	1994	Mechanical	None	Daily Cover[2]	33
Victoria Lake, City of Kitchener	1997	Mechanical	Air Dried	Gravel Pit	18
Silver Lake, City of Waterloo	1997	Mechanical	None	Agricultural	14

Note: [1] Costs are in 1997 dollars based on a construction cost index of 1.6% per annum. [2] - Daily landfill cover.

Note that the uncharacteristically high unit costs at Bentley Pond in Nepean ($669/cubic meter) was a result of high hydrocarbon contamination from industrial requiring special protective removal equipment and disposal methods. At the Bluffers Park project, the use of hydraulic dredging equipment was experimental and also contributed to the higher unit cost. Furthermore, there is a large range for mechanically excavated ponds (non-hazardous material) from $14 /m^3 to $62 /m^3. This variability reflects the bulking method, transportation from each facility to the disposal site, and/or the amount of restoration required after completion. The overall cost per cubic meter (m^3) is significantly affected by the disposal location. Landfill disposal significantly increases the project cost. There are also other special circumstances which is why the values should be interpreted with care.

The detailed breakdown of sediment removal costs for an off-line facility providing 80% removal efficiency (Level 1 treatment) and a 50 hectares tributary area with a removal cycle of 15 years was also estimated in ***Appendix I***. In this hypothetical example, a present value unit cost of $65/m^3 of sediment was obtained. If the present value removal cost now is $65/m^3, the future cost after 15 years value based on 2% per annum (construction cost index) is about $87/m^3. If funds are set aside on a yearly basis, based on 5% interest rate, the yearly cost will be about $4/m^3, or $42/m^3 if a lump sum is set aside and invested at this rate over the 15 years.

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SECTION I. BACKGROUND

1 Introduction

1.1 Background

Multi-objective end-of-pipe Storm Water Management Practices (SWMP) have been introduced in Ontario municipalities to mitigate negative impacts of storm water runoff from urban and urbanizing watersheds. One of the primary objectives of SWMPs is the protection of aquatic habitats from harmful chemical and biological effects of suspended solids and other runoff pollutants. Storm Water Management Facilities (SWMF), and in particular those designed according to recent guidelines, can be very effective in the removal of suspended solids and other associated pollutants. Some monitoring studies have reported removal rates as high as 90% (Marsalek 1998).

This degree of treatment success has encouraged enormous investment of resources towards the widespread implementation of SWMFs. For example, the Toronto and Region Conservation Authority has compiled a list of more than 400 existing and committed SWMFs in their jurisdiction. Typical construction costs range between $100,000.00 for the smallest ponds to over $1,500,000.00 for larger, centralized facilities. Because of the environmental and flood-related constraints associated with the construction in flood plains, many of these SWMF are located on tablelands adding significant cost. Using $250,000.00 as a conservative present-value estimate of construction and land value of each facility, the SWMF capital value in the TRCA area alone would be more than $100,000,000.00 (one hundred million dollars).

In return for this considerable commitment to the environment, the SWMFs provide sufficient treatment to urban storm water quality to achieve tangible protection of receiving waters and associated aquatic and terrestrial habitats. However, the treatment level achieved depends on how well the SWM facility is maintained in relation to the original design condition. For example, one of the principal design components of a SWMF is the storage volume. However, storage volume is progressively lost over time to the accumulation of solids. The rate of accumulation, and loss in stormwater storage, depends on the amount of solids that enter the facility and its effectiveness. Higher effectiveness yields more and faster accumulation. This apparent dichotomy is the desired operating condition. Therefore, sediment removal is a key component of maintenance to ensure that the SWMFs continue to operate as intended.

The need for sediment removal maintenance is well recognized. Quoting two standard conditions included in the 'Certificate of Approval' issued by the Ministry of the Environment under Section 53 of the Ontario Water Resources Act (also discussed in section 2), regarding the construction and operation of SWMFs:

> *"The owner shall ensure that, at all times, the works and related equipment and appurtenances which are installed or used to achieve compliance with this Certificate are properly operated and maintained..."*

> *"The owner shall ensure that sediment is removed from the above noted stormwater management works at such a frequency as to prevent the excessive buildup and potential overflow of sediment into the receiving watercourse."*

The reason for the above conditions is further clarified in the MOE Certificate of Approval, that is, to:

> *"...ensure that the works will be operated, maintained, funded, staffed and equipped in a manner enabling compliance with the terms and conditions of this Certificate, such that the environment is protected and deterioration, loss, injury or damage to any person or property is prevented."*

And also to ensure that,

> *"...regular removal of sediment from the approved stormwater management works is required to mitigate the impacts of sediment on the downstream receiving watercourse. It is also required to ensure that adequate storage is maintained in the stormwater management facilities at all times as required by the design."*

However, the removal and disposal of sediment can be a challenging and costly undertaking. Up to now, there is little SWMF sediment accumulation evaluation, removal and disposal experience and similar undertakings have been inconsistent in their approach and documentation for them to be useful in the context of SWMF settings and constraints. With increasing age of SWMF the urgency to implement sediment management plans has become more apparent. Many of the facilities are reaching the stage where many questions require answers. For example, some of the questions posed are:

- What legislation regulates pond maintenance, sediment removal, and sediment disposal?
- How does one evaluate the need for sediment management or SWMF maintenance? Is a desktop method for calculating sediment accumulation enough? Is there a more reliable way that would prevent premature or late maintenance?
- What is the most effective way to monitor sediment accumulation?
- What should be considered before removing the sediment? What methods can be used?
- Where can the sediment be disposed of or stored?

Failure to properly deal with one or more of these issues can result in significant cost-overruns or damage to the environment. Although each case is different, this report presents information to help answer these questions and could be used as a guide to find other answers.

1.2 Objectives

This document addresses fundamental elements that should be considered in sediment removal and disposal decision making processes. In particular, the following objectives are fulfilled:

1) Document current guidelines and objectives related to the removal, disposal and quality analysis of SWMF sediment.

2) Review current pond design practices and suggest ways to improve future maintenance efforts and expenses.

3) Document preventative maintenance techniques.

4) Document typical sediment accumulation rates and clean-out interval estimations.

5) Document and assess existing data pertaining to the physical and chemical characteristics of SWMF sediment representing residential, commercial and industrial catchments.

6) Discuss and document relevant sediment removal and disposal experiences and research conducted by peers within the field of storm water management.

7) Document methods of minimizing disturbance to vegetation surrounding storm water facilities.

8) Document optional methods of sediment quality/quantity assessment, removal, dewatering and disposal. Research and review alternative technologies that can be adapted to achieve further cost-savings.

9) Review current disposal practices and factors that should be considered prior to decision making.

This document should also provide the foundation for further research for optimizing and producing an action plan for maintenance of SWMFs.

1.3 Review Approach

The primary task of this project was to document and evaluate all relevant information pertaining to the maintenance and management of SWMF accumulated sediment. Soon into the project, it became apparent that this information was to be collected from many different sources including: government documents (legislation, guidelines, etc.), technical consulting reports, engineering/scientific journals, sediment removal technology marketing brochures and personal communication with experienced individuals throughout Ontario and the United States.

This information may answer some of the most important questions regarding the removal and disposal of accumulated SWMF sediment, in addition to illustrating the potential use of sediment management technologies. The following approaches were used to gather the relevant information.

Literature Search and Evaluation

An extensive literature review was conducted to identify and document relevant local and/or international research, data, technologies, legislation, guidelines and/or approval criteria. The information sources included engineering and scientific journal searches, Internet searches and many personal conversations with individuals affiliated with universities, government agencies, municipalities, engineering firms and construction companies. The findings of the literature search and evaluation are discussed throughout relevant sections of this report.

In particular, the methodology for establishing the need for maintenance was evaluated, clarified, and documented in light of current design standards. Specific approaches for determining when sediment should be removed were derived using established design criteria and treatment targets.

Identification of Current SWMF Maintenance Projects

Available case studies in Ontario were researched and documented. Since most SWMFs (i.e. end-of-pipe SWM ponds) are owned and maintained by municipalities, a case study questionnaire was distributed to municipal agencies throughout Ontario (see ***Appendix A*** for a sample of questionnaire). In the interest of promoting a good return rate, it was decided that the survey should be kept as brief as possible while answering the most pertinent questions (e.g. have they carried-out a sediment removal and disposal project).

The three-page check-box format questionnaire was sent to 83 of the larger municipalities throughout the province. A total of eight jurisdictions were identified as having experience with at least one relevant SWMF sediment removal and disposal project. Of the 32 returned surveys, five were identified as potential case studies for this project. However, three additional case studies were also identified through personal communications with individuals in both government and consulting agencies. A summary of the preliminary questionnaire is given in ***Appendix B***.

Documentation of Case-Studies

An eight page detailed case study form (see ***Appendix C*** for a sample) was designed to collect information regarding: SWMF descriptions, catchment area, regulatory approvals, sediment removal and disposal methodologies, site remediation, project costs, etc.. This information was compiled using survey information and technical reports available for each of the identified case studies. The completed reports were then forwarded to the case study managers for confirmation of accuracy and completion of missing values where possible. A summary of the detailed sediment removal and disposal case studies is given in ***Appendix D***.

Compilation and Evaluation of Sediment Data

One of the major objectives of this study was to characterize the levels and accumulation rates of SWMF sediment in relation to watershed land use types. Sediment chemistry data sets were compiled from nineteen Ontario SWMFs located within eight residential, two commercial, two commercial/industrial, five industrial and one highway catchment areas. The data sets were compared with the provincial criteria for disposal.

Report Format

In order to properly answer the foregoing questions, this report has been organized into four main parts. This format will also aid the operator in formulating a work plan for SWMF sediment removal and disposal.

SECTION I: BACKGROUND

Chapters 1, 2, and 3

SECTION II: DATA COLLECTION

Chapters 4 and 5

SECTION III: SEDIMENT REMOVAL AND DISPOSAL

Chapters 6, 7 and 8

SECTION IV: CONCLUSIONS AND RECOMMENDATIONS

Chapters 9 and 10

2 Review Of Current Legislation, Regulations And Guidelines

This section summarizes relevant legislation, regulations, and guidelines that may affect the construction and maintenance of Storm Water Management Facilities (SWMF) as well as the removal and disposal of sediment.

2.1 Fisheries Act

The federal *Fisheries Act*, administered by the Department of Fisheries and Oceans (DFO), has broad applicability to various land use activities including sediment removal and disposal operations that can potentially affect fish habitat. The *Fisheries Act* applies to all aquatic habitats including those that may not directly support fish but enhance water quality or provide nutrients or other food sources. The aquatic habitat is defined as spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes.

Sections 35 and 36 of the *Fisheries Act* are of particular relevance:

<u>Section 35</u>

Section 35 regulates activities which may result in the harmful alteration, disruption or destruction of aquatic habitat. However, where these effects cannot be avoided or mitigated, DFO or a representative agency of the DFO may authorize the means and conditions for allowing projects to take place.

It should be noted that although Section 35 had been administered by the Ontario Ministry of Natural Resources (MNR), some Conservation Authorities are now allowed, under specific agreements, to administer Section 35 approvals on behalf of DFO. Under interim agreement from March 1989 to September 1997, DFO had delegated the review and enforcement responsibilities of Section 35 to the MNR. DFO and MNR are still working towards a long term agreement for implementation of section 35. In the interim, DFO should be consulted since any harmful alteration, disruption or destruction of fish habitat can only be authorized by DFO. They, in turn, can direct inquiries to the local conservation authority if appropriate.

<u>Section 36</u>

Section 36 regulates the deposition of any substance, including sediment, which is deemed to be harmful to aquatic habitats. It should be noted that although the *Fisheries Act* is the responsibility of DFO, the actual administration of Section 36 is carried out by Environment Canada.

Section 36 would apply in cases when it is proposed to dispose of SWMF sediment into an aquatic habitat. This request would be unlikely since it contradicts one of the primary objectives for which SWMF have been introduced. In Ontario, approvals for open water disposal and acceptable contaminant concentrations are primarily determined in accordance with the *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario* (MOEE August 1992). As discussed later in this report, Ontario's sediment quality guidelines have replaced the Open Water Disposal Guidelines.

2.2 *Ontario Water Resources Act*

The Ontario Water Resources Act (OWRA), administered by the Ministry of Environment (MOE), has special relevance to the construction and maintenance of SWMFs. It is an offense under the OWRA to discharge any substance into water that "may impair the quality of the water". Charges are often laid by prosecutors under both the *Ontario Environmental Protection Act* (EPA) and the OWRA (Shier 1998).

The OWRA defines "sewage" to include drainage, storm water, commercial wastes and industrial wastes; and "sewage works" as any works for the collection, transmission, treatment and disposal of sewage or any part of such works. With these two definitions, the MOE has jurisdiction over the design and operation of storm water works including storm water management facilities. In particular, the province approves and issues a 'Certificate of Approval' (C of A) for the construction of a SWMF under Section 53 of the act with the objective to provide treatment to urban storm water prior to discharge to receiving waters. Any modifications, alteration, construction of sewage works must be approved, and a C of A must be issued. Through the application process, technical information is submitted and the ministry verifies that the SWMF complies with their criteria. Since 1994, this has meant general conformity with the guidance provided in MOE SWMP Design Manual.

Since all communal sewage works must be owned and operated by a municipality or, through an agreement, by a municipality-approved proponent, the ministry considers the municipality as ultimately responsible for the operation. Although MOE has not introduced specific criteria for compliance with performance, it is the obligation of the municipalities to provide maintenance and keep the SWMF performance as per the original design requirements. As indicated in Section 61 of the OWRA, 'works shall at all times be maintained, kept in repair and operated in such manner and with such facilities'. Quoting two standard conditions for issuance the Certificate of Approval under Section 53 of the *Ontario Water Resources Act*:

> *"The owner shall ensure that, at all times, the works and related equipment and appurtenances which are installed or used to achieve compliance with this Certificate are properly operated and maintained..."*

> *"The owner shall ensure that sediment is removed from the above noted stormwater management works at such a frequency as to prevent the excessive buildup and potential overflow of sediment into the receiving watercourse."*

The reasons for including these conditions in the MOE Certificate of Approval are, to:

> *"...ensure that the works will be operated, maintained, funded, staffed and equipped in a manner enabling compliance with the terms and conditions of this Certificate, such that the environment is*

protected and deterioration, loss, injury or damage to any person or property is prevented" and to ensure that,

> *"... regular removal of sediment from the approved stormwater management works is required to mitigate the impacts of sediment on the downstream receiving watercourse. It is also required to ensure that adequate storage is maintained in the stormwater management facilities at all times as required by the design."*

Furthermore, prioritizing the need for maintenance should consider that the act stipulates that anyone who discharges materials of any kind into any waters such that the quality may be impaired will be guilty of an offence. As stated by Shier (1998), "It does help by clearly stating that prudent municipalities can limit their exposure to negligence claims by anticipating potential areas of concern and developing policies to deal with these concerns". It should be noted that the MOE has delegated responsibility for review of Certificates of Approval to some regional municipalities but actual issuance of the certificate comes from MOE.

2.3 Environmental Protection Act

The Ontario *Environmental Protection Act* (EPA), administered by the MOE, has broad applicability to SWMF sediment disposal because it regulates the disposal of pollutants into the natural environment. Under the Act, Regulation 347-Schedule 4, describes leachate quality criteria and analysis procedures used to determine if the contamination level of the material tested is too high and requires landfilling at a registered non-hazardous or hazardous waste management facility. In addition, registered sediment waste must pass the slump test in order to qualify as a solid waste rather than as liquid waste. Sediment with high liquid content must be dewatered if it is to be accepted at a solid waste disposal facility. The slump test used to determine if the material should be landfilled as a solid or liquid waste is described later in ***Section 5.3.***

2.4 Conservation Authorities Act

The restriction or regulation of water through the construction of dams/weirs or diversions and the placing and dumping of fill within the watershed is placed under the jurisdiction of the local Conservation Authority. With on-line SWMFs, permits would be required for basin dewatering, dams/weirs and the diversion/by-passing of flows around the facility to downstream areas. Permits would also be required for both on-line and off-line facilities, if they are located within a flood plain and/or a valley corridor (fill regulated areas). Conversely, basin dewatering of off-line SWMFs located outside fill regulated areas would not require Conservation Authority approval. Excavated sediment must also be disposed outside the flood plain and valley corridor. Clarification from the Conservation Authority should be obtained during planning to verify the facility's classification and latest permit requirements.

2.5 Lakes and Rivers Improvement Act

The *Lakes and Rivers Improvement Act* (LRIA) is administered by the Ministry of Natural Resources (MNR). Its purpose is to provide for the following:

- the use of waters of the lakes and rivers of Ontario, including the regulation thereof;
- the preservation and equitable exercise of public rights in or over such waters;
- the protection of interests of the riparian owners;
- the use, management and perpetuation of the fish, wildlife and other natural resources dependent on such waters;
- the preservation of the natural amenities of such waters and on the shores and banks thereof; and,
- ensuring the suitability of the location and nature of improvements in such waters, including their efficient and safe maintenance and operation.

The LRIA is most relevant to open water sediment disposal, in addition to the methodology used in SWMF basin flow diversions. In these aspects, the restrictions and approval requirements of the *Lakes and Rivers Improvement Act* overlap with those of the *Fisheries Act* and the *Conservation Authorities Act.*

Conservation Authorities may also screen LRIA applications under the MNR referral process, on behalf of the MNR. The Conservation Authority is the primary contact during the project's planning stage and will verify the latest permit requirements and the status of regulatory jurisdiction. Typically LRIA applications are made once Conservation Authority approval is given.

2.6 Municipal Act

The *Municipal Act* assists communities in the regulation of various activities which may affect the local environment (e.g. solid waste disposal, sewer use, land use, etc.). A key aspect of the Act is that it provides individual municipalities the freedom to adopt by-laws, policies and guidelines to suit the unique goals and needs of each local community. In cases where someone other than the municipality undertakes the SWMF sediment removal and disposal project, the proponent should contact the appropriate municipal office during the initial planning stages of the project to ascertain their particular approval requirements. Contacting the municipal office will also permit the proponent to assess the need for public consultation, particularly with SWMF abutting private properties or integrated into park or public access areas.

2.7 Additional Guidelines and Documents

A number of supporting guidelines and documents have been prepared by the Ontario MOE which discuss sediment quality and disposal.

2.7.1 Guideline for Use at Contaminated Sites in Ontario

The *Guideline for Use at Contaminated Sites in Ontario* (GCSO) (MOEE 1996, revised February 1997) provides general advice to property owners and consultants when assessing the environmental conditions of a property, to determine if and what kind of restoration is required to allow continued use or reuse of the site.

The GCSO is relevant to SWMF sediment management because it defines various soils, groundwater and sediment clean-up guidelines based on three land use categories: i) agricultural, ii) residential/parkland, iii) commercial/industrial. The guidelines also refine the criteria based on the presence of potable or non-potable groundwater conditions at each land use site. SWMF sediment disposal options could be inferred using this criterion. The GCSO does not specify remediation technologies, but directs that exceedingly contaminated soil or sediment be remediated in-situ or removed and disposed of in an approved manner.

Although the document includes an extensive list of chemical parameters, additional analysis may also be required for unlisted compounds which are suspected or known to be present at a particular site. Sediment quality criteria from Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario are also included in the document. A detailed discussion of the GCSO contaminant criteria is included later in the sediment quality section of this report.

2.7.2 Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario

The Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario (PSQG) (MOE 1992, latest reprint in January 1996) set safe levels of metals, nutrients, and organic compounds to protect the aquatic environment. The PSQG replaced the former Open Water Disposal Guidelines (MOE 1976). These guidelines were developed to determine if dredged material was suitable for open water disposal, based on contamination levels of metals, nutrients, pesticides, PCBs, PAHs and other parameters.

As indicated the summary section, the PSQG establish three levels of effect:

1) No Effect Level (NEL);
2) Lowest Effect Level (LEL); and,
3) Severe Effect Level (SEL).

The LEL and SEL are evaluated in relation to the long-term effects the contaminants may have on the sediment-dwelling organisms. The NEL is based on concentrations so low that no contaminants are passed through the food chain.

Using these levels, the sediment can be classified as: a) clean, b) acceptable for short periods of time while the source of contamination is being controlled and cleanup plans are being developed, and c) severe enough to consider the possibility of either removing the sediment or capping it (covering it with a layer or two of cleaner sediment). A more detailed discussion of the PSQG contaminant criteria is included in Chapter 5 of this report.

2.7.3 Proposed Policy for Management of Excess Soil, Rock and Like Materials

The Proposed Policy for Management of Excess Soil, Rock and Like Materials (MOE 1992), defines four categories of material for contaminated soil and/or sediment based on the level of contamination of metals, VOCs, PAHs, phenols and any other elements or compounds likely to be of concern. Disposal options and required approvals are defined according to the category assigned; inert, urban residential, urban industrial or controlled fill. This document is cited often in the literature, but it is unknown whether MOE plans to implement it as a set of guidelines.

2.7.4 Evaluating Construction Activities Impacting on Water Resources, Part III A

Evaluating Construction Activities Impacting on Water Resources, Part III A, Handbook for Dredging and Dredged Material Disposal in Ontario - Legislation, Policies, Sediment Classification and Disposal Options (MOEE 1994) discusses municipal legislation and policies regarding sediment classification and disposal options. Dredged material must be classified prior to approval for disposal based on chemical and physical characteristics. The classification process applies to commercial, industrial and public sector undertakings, excluding agricultural options.

2.7.5 An Integrated Approach to the Evaluation and Management of Contaminated Sediment

An Integrated Approach to the Evaluation and Management of Contaminated Sediments (MOEE 1996) provides guidance for the assessment of sediment contamination and the ways in which a management strategy may be designed.

2.7.6 Regulatory Agency Consultation

It should be noted that at the time of this investigation, no specific legislation, regulations or guidelines were found to apply directly to the removal and disposal of sediment originating from SWMFs. However, there are a number of documents that are relevant to sediment removal and disposal in general. Our review plus the case studies investigated, indicate that depending on the site-specific conditions, a SWMF sediment removal project may require permits and/or approvals from various agencies.

It is recommended that proponents of sediment removal and disposal projects review the documents summarized in this section and become familiar with the legal issues related to sediment removal and disposal. Site specific conditions, such as chemical composition of sediment and local jurisdictions, may provide opportunities to optimize the maintenance plan. Local MOE, MNR and Conservation Authority offices should be consulted early in the project's planning stage to identify and obtain updated information regarding necessary permits and approvals.

3 Review of Current SWMF Design Criteria

Well-designed stormwater ponds provide effective treatment through good hydraulic characteristics and sufficient stormwater storage volume. In the process of sedimentation, fast flowing storm water's turbulent stream enters the SWMF's quiescent storage. From the same principles as primary sedimentation tanks for waste-water treatment, pollutant removal in quiescent stormwater management facilities occurs primarily through gravitational settling of suspended solids (typically referred to as Total Suspended Solids or TSS). However, inherently in the treatment process, ponds will retain sediment and other adsorbed constituents such as phosphorus, heavy metals, trace organic matter and hydrocarbons with a corresponding loss in stormwater storage. As with most non-reactive treatment processes, removal does not mean disappearance but rather storage. The rate of solid accumulation, and loss in stormwater storage, depends on the amount of pollutants entering the facility and its effectiveness. Higher effectiveness yields more and faster solid accumulation. This apparent dichotomy is the desired operating condition. Therefore good design criteria must account for solids accumulation by allowing some loss in stormwater storage without negatively impacting the treatment target.

The SWMFs thus provide treatment and storage functions. Treatment is needed prior to releasing stored water to a sensitive habitat downstream, while storage is necessary to hold the solids until maintenance is provided. Over time, a critical volume of stormwater storage will be lost and the treatment target will be compromised.

In other cases, sediment removal will be necessary due to excessive pollutant concentrations and the potential risk to ground or surface water downstream and/or wildlife. Groundwater problems can develop in the long-term through leaching and downward infiltration. Surface water problems can occur through dissolution into the water column and sub-sequent transport downstream. At some sites, pollutant concentrations in SWMF sediment were found to seriously exceed MOE's contaminated soils guidelines and required prompt and expensive remediation.

Therefore, in addition to SWMF maintenance to restore the treatment efficiency, sediment removal will be warranted in special circumstances if the pollutant concentrations of accumulated sediment get too high and pose a significant pollution potential to receiving surface or ground water and habitats downstream. Although some guidance is provided in this document regarding contamination potential from different land uses, these are not readily foreseeable and quantifiable but should be considered through a periodic sampling and analysis program. Under normal conditions, guidance for planning sediment removal should be driven primarily for restoring the treatment efficiency to acceptable levels.

The current MOE SWMP manual describes an approach for SWMF design, used to establish the target treatment efficiency, which is presented in the following section. This approach is only suggested in areas where, for a variety of reasons, development is allowed to proceed without a subwatershed plan

3.1 SWMF Volume and Treatment Efficiency

There are many factors that influence the performance of SWMFs in terms of sediment treatment. These include geometry (shape, surface area, volume, location of inlets and outlets), vegetation growth, suspended solid particle size and densities. However, the main factor that can be controlled through maintenance is the restoration of the volume loss to solids accumulation. Therefore, relating the volume loss to a minimum treatment efficiency provides a basis for determining *when* maintenance is required. To this end, the MOE SWMP design approach relates the solids removal rate required for mitigating lethal and chronic effects on a specific type of downstream aquatic habitat. Although the MOE SWMP manual does expand on the derivation, the minimum TSS removal efficiency for each habitat type are as follows.

Table 1: TSS Removal Criteria

Habitat Protection Level	Target TSS Removal Rate[1]
1	80%
2	70%
3	60%
4	50%

[1] Values obtained from Figures 4.2 to 4.5 in MOE SWMP manual (1994).

In the MOE SWMP design approach, once the habitat level of protection is established, the sizing criterion is obtained as a function of the tributary area's imperviousness and type of facility. It is recognized that there are several concerns regarding the conceptual modeling approach (i.e. assuming conditions similar to sedimentation tanks for wastewater treatment) for determining the volume versus treatment performance relations of real SWMF. For example, Marsalek and Larkin (1998) list typical simplifying assumptions such as: a) within the settling zone of the pond, sedimentation takes place exactly as in a quiescent container of equal depth; b) the flow is steady and suspended solids are uniformly distributed with respect to size and location along the cross-section at right angles to the flow; c) particles entering the sludge zone (i.e. sediment bed) stay removed. The MOE SWMP manual has been generally accepted in Ontario for SWMF design. Therefore, it is considered below in the development of an evaluation method for justifying the need for SWMF sediment maintenance.

The table below presents the MOE SWMP manual design storage volumes for water quality as a function of the tributary area's imperviousness for wetlands, wet ponds and dry ponds (not under batch operation).

Table 2: MOE SWMP Design Sizing Criteria (m^3/ha)

Protection Level	SWMP Type	Tributary Area Imperviousness			
		35%	55%	70%	85%
1	Wetland	80	105	120	140
	Wet Pond	140	190	225	250
2	Wetland	60	70	80	90
	Wet Pond	90	110	140	150
3	Wetland	60	60	60	60
	Wet Pond	60	75	85	95
	Dry Pond	90	150	200	240
4	Wetland	60	60	60	60
	Wet Pond	60	60	60	65
	Dry Pond	35	50	60	70

Note: For wetlands/wetponds, 40 m^3/ha of the volume is extended detention volume. (Ref: MOEE SWMP Manual, 1994)

For example, a wet pond is located at the outlet of a 300 hectare tributary area with 70% imperviousness. The pond was designed for Level 1 habitat protection (corresponding to 80% TSS removal efficiency in SWMP TSS removal curves). Accordingly, the required water quality volume is 225 m^3/ha, with 185 m^3/ha of this being permanent pool volume.

The MOE SWMP manual recommends 5% as the acceptable reduction in treatment efficiency due to sediment accumulation. The rationale for the 5% is discussed in the manual.

Other maintenance evaluation studies (Yousef et al 1991; CG&S 1997) have chosen to differentiate clean-out criteria based on reduction in sediment treatment efficiency and reduction in storage volume. However, for this study, using the MOE SWMP premise that a SWMF for water quality treatment is implemented to remove (and hence store) suspended sediment (and other pollutants), the need for differentiation is not necessary since sediment storage in itself is a desirable condition and should be considered as criteria to assist in the determination of how the accumulated volume affects treatment. In other words, except for extreme pollution cases, the ultimate goal of sediment removal maintenance is to restore storage treatment to the desirable level.

The allowable deviation from the design treatment rate thus provides the information necessary to define the minimum volume at which the SWMF requires maintenance. Using the target treatment rates and the allowable deviation, the limiting removal rates are 75%, 65%, 55%, and 45% for habitat protection levels 1, 2, 3, and 4, respectively. ***Table 3*** shows the corresponding minimum storage volumes, below which maintenance should be undertaken. Note that for wetlands and wetponds, the 40m^3/ha extended detention storage has been subtracted, leaving the permanent pool volume. This table should be used when evaluating the need for regular sediment removal maintenance.

Table 3: Minimum SWMF Permanent Pool (Extended Detention for Dry Ponds)Volumes Prior to Maintenance (m^3/ha)

Protection Level	SWMP Type	Tributary Area Imperviousness			
		35%	55%	70%	85%
1	Wetland	28	45	54	67
	Wet Pond	63	98	124	150
2	Wetland	15*	20	24	32
	Wet Pond	33	50	63	74
3	Wetland	15*	15*	15*	15*
	Wet Pond	15*	20	31	36
	Dry Pond	50	81	89	107
4	Wetland	15*	15*	15*	15*
	Wet Pond	15*	15*	15*	20*
	Dry Pond	22	34	39	66

Note: These values have been interpolated from the MOE SWMP Manual Figures 4.2 to 4.5, based on the recommended allowable 5% reduction in original design storage due to sediment accumulation. Wetpond/wetland values listed are permanent pool volumes (i.e. 40 m^3/ha extended detention storage has been omitted) * Values cannot be interpolated from volume vs. treatment relations –approximate and/or extrapolated values used.

The difference between the design and maintenance volume criteria in the two previous tables is equal to the volume of sediment that can accumulate before removal is required, if no excess storage is provided. The next table summarizes these volumes. Note that higher sediment accumulation and lower frequency of maintenance will be possible if excess storage is provided.

Table 4: Maximum Allowable Sediment Accumulation (m^3/ha) in SWMFs

Protection Level	SWMP Type	Tributary Area Imperviousness			
		35%	55%	70%	85%
1	Wetland	12	20	26	33
	Wet Pond	37	52	61	60
2	Wetland	5*	10	16	18
	Wet Pond	17	20	37	36
3	Wetland	5*	5*	5*	5*
	Wet Pond	5*	15	14	19
	Dry Pond	40	69	111	133
4	Wetland	5*	5*	5*	5*
	Wet Pond	5*	5*	5*	5*
	Dry Pond	13	16	21	4

Note: These values are based on the MOE SWMP Manual Figures 4.2 to 4.5, which recommended an allowable 5% reduction in original design storage due to sediment accumulation. (*) Values cannot be interpolated from volume vs. treatment relations –approximate and/or extrapolated values used.

The average reductions in storage from the design criteria for wet ponds are 26% for Level 1 protection, 22% for Level 2, and 19% for Level 3. The larger sediment accumulation percentage allowed for higher levels of protection reflect the asymptotic nature of the performance-storage curves: with larger SWMFs a large increase in storage loss is required to reduce the treatment efficiency by 5%.

This approach highlights the need to know the minimum volume that must be present in each facility to achieve the desired treatment level. For new facilities designed using the MOE SWMP manual criteria the minimum volume can be determined from the original design brief. Facilities constructed prior to the introduction of the 1994 MOE SWMP manual will provide treatment and accumulate sediment but will likely have different volume design criteria. As discussed before, if the current facility design criteria is accepted, it should be used as the basis for evaluating the need for maintenance. Under the present guidelines in Ontario, the operating conditions and available volumes of older facilities could be evaluated in light of the most recent MOE design criteria and/or local watershed specific requirements. If possible, additional volume could be provided during maintenance to approximate the latest treatment guidelines. If it is not possible to implement the latest criteria, the objective for maintenance could be based on restoring or maximizing the original storage volume.

Although there may be significant amounts of solids accumulation, there may still be sufficient volume available to provide the desired treatment, in some cases. Therefore the minimum storage volume should be clearly understood in light of:

1. The level of habitat protection sought;

2. The characteristics of the tributary area, and;

3. The type of facility being evaluated (wet pond, wetland, dry-pond, etc.).

3.2 Sediment Forebay Considerations

To this point, the methodology for evaluating the need for maintenance of SWMFs has focused on maintaining or restoring the overall treatment efficiency to an acceptable level, such as the minimum storage levels in ***Table 3.*** From a treatment performance viewpoint, no distinction has been made between sediment removal maintenance of the entire facility and the sediment forebay.

The sediment forebay is a feature that '*facilitates maintenance and improves pollutant removal by trapping larger particles near the inlet of the pond'* (MOEE 1994). It is not clear how the overall removal is significantly improved by trapping larger particles in the forebay, but a close examination of the design concept suggests that maintenance within the forebay can be facilitated due to its proximity to the access way. The forebay also enhances treatment in the main pond area by allowing the flow to disperse and become quiescent.

The manual recommends a forebay design to remove particles 150 μm and larger and a sufficient forebay storage to allow for ten years of sediment accumulation. From the particle size distribution table (SWMP manual p. 89), the proportion that will be retained in the forebay should store somewhere between 20 and 40% of the total mass influx. A cursory review of case studies of sediment depth distribution collected at six facilities does not provide significant evidence that a higher proportion of solids will accumulate in the vicinity of the inlet (Refer to ***Appendix D***). However, there is evidence that larger particle sizes (e.g. sand and gravel) will concentrate near the inlet, which, after drying, could facilitate movement of tracked loaders or excavators. These findings, although originating from sites designed and constructed prior to the 1994 SWMP manual, should not be unexpected given the turbulent conditions expected at SWMF inflow points. Therefore, in the absence of sufficient detailed field sampling data and due to the variability in treatment (and storage) characteristics of the SWMF, the need to remove accumulated sediment from the forebays should be evaluated together with the results from a field measurement program. This further emphasizes the need to conduct field measurements to characterize the effectiveness of forebays for trapping larger sediment particles and facilitate maintenance.

In terms of a hard liner in the forebay bottom, the 1994 MOE SWMP manual only suggests liners in the context of minimizing erosion potential near the inlets. Although hard liners may provide some benefits in terms of defining the boundary for excavation and stability to excavation equipment, these liners can deteriorate over time and be damaged. Stability will not be provided anyway if the bottom is covered with a wet layer of sediment. A field method such as careful surveying during excavation or dredging can be a cost-effective alternative to hard bottom liners.

3.3 Preventative Maintenance

Preventative maintenance techniques are designed to reduce pollutant discharges to end-of-pipe SWMFs, by limiting the at-source buildup of pollutants on impervious surfaces, or those collected locally in storm water gullies or catchpits. The obvious benefits of preventative maintenance would be to reduce the rate of sediment accumulation within SWMFs, thereby reducing clean-out frequencies and associated costs.

Since the early 1980's, street sweeping/washing has been used as the most common preventative maintenance method. However, the method is widely considered to be an ineffective means of water quality protection, largely due to the finding of a 1983 US NURP street sweeping/washing efficiency study (US EPA 1983). The NURP study concluded that street sweeping/washing provided an effective means for removing debris and gross pollutants from the street surface, but was ineffective at reducing the event mean concentration of pollutants in urban runoff. This inefficiency was primarily due to the technological limitations of sweepers/washers to pick up the finer (less than 63 microns), more contaminated particles.

However, a 1996 study indicates that more recent designs of vacuum-assisted dry sweepers are substantially more effective than the earlier NURP-era technologies (Sutherland & Jelen 1996). The abilities of several different street-sweeping technologies were evaluated with reductions of up to 80% in annual total suspended solids and associated pollutants by using bimonthly to weekly sweepings. The effectiveness is highly dependent upon the operator's procedure (speed and frequency). Frequencies of sweeping and associated reductions are dependent upon patterns of precipitation, sediment accumulation and re-suspension.

3.3.1 Current Preventative Maintenance Technologies

i) Vacuum-assisted Dry Sweepers

The Sutherland & Jelen study concluded that vacuum-assisted dry sweepers are an effective method of fine particulate removal. This technology uses rotating sweeper brooms within a vacuum head to provide both mechanical and aerodynamic particulate removal.

ii) Mechanical Sweepers

The study also found mechanical sweepers (e.g. broom and conveyor belt) to be another effective method of fine particle collection. This method involves two successive cleaning passes, first by a mechanical (e.g. broom and conveyor belt) sweeper, then immediately followed by a vacuum-assisted sweeper.

iii) Regenerative Air Sweeper

A third preventative maintenance technology includes the regenerative air sweeper which blows air onto the pavement while immediately vacuuming it back in order to entrain and capture accumulated sediment. Regenerative air sweepers are generally considered to be good at removing fine sediment if the accumulated loading is not too large.

SECTION II. DATA COLLECTION

4 Sediment Removal Maintenance Forecast

It is essential to adopt an acceptable measuring approach to evaluate the SWMF performance over time and subsequently the required frequency of sediment removal. The following section describes approaches to evaluating the state of a SWMF with respect to the treatment target:

4.1 Modeling Approach

Sediment accumulations and maintenance frequency can be estimated by modeling the suspended solids loading rate and SWMF removal efficiency. With this theoretical approach, the sediment mass accumulation rate can be estimated from simple mass balance:

Sediment Accumulation = Sediment Inflow – Sediment Outflow

The volume and corresponding annual loss in storage is calculated by dividing by wet density. The pond design sizing criteria and approximate maintenance frequencies in the MOE SWMP manual were both derived through continuous computer simulation of suspended solids settling.

Although modeling has been accepted for design, the use of models for purposes other than forecasting screening and prioritizing sediment monitoring in existing SWMFs is not recommended. That is because several significant concerns remain with the approach. For example, modeling does not account for common upstream conditions such as urban development and poor erosion and sediment control. Furthermore, the approach does not incorporate the variability in sediment source generation (build-up and wash-off) between different and stable land uses, sediment wet densities, or unpredictable circumstances that may arise within a catchment. The use of models requires good data about the SWMF and tributary area and 'the effort and expense that would be required to develop a model and collect sufficient data to ensure its validity might be better spent on a sediment depth monitoring program' (CG&S 1997). Even if it would be possible to properly characterize the many variables that affect sediment accumulation, field measurement will ultimately be necessary because depth distribution and total volume data are necessary for planning and undertaking the removal and disposal. These arguments suggest that the use of modeling alone might lead to premature and costly maintenance or failure to identify other sites in dire need of maintenance. Therefore, the alternative method is based on actual measurements and associated forecasts of sediment accumulation (volume) within the same or similar treatment facilities and tributary areas.

4.2 Measuring Available Volume

If the basis for maintenance is to restore the volume for stormwater treatment, then normally, it is the available storage volume that must be obtained when evaluating the need for maintenance. Measurements of the SWMF bottom are necessary to determine the storage available and ultimately to infer the treatment provided. Using the MOE SWMP Manual criteria, maintenance is justified if the treatment rate falls below 5% from the original criteria. ***Table 3*** list the minimum volumes of storage for each type of facility before maintenance is required. Therefore, in order to determine whether sediment removal maintenance is required, it is not necessary to know the volume of accumulated sediment. However, the sediment depth and volume will be needed for planning the actual removal and disposal. Knowing both volumes (available volume and accumulated sediment) can be used to verify the original design conditions. There are several field techniques for measuring available volume and sediment depths and these are discussed later in the document.

Therefore, the basic data required to assess the need for sediment removal are:

1. SWMF's treatment efficiency versus storage relation;
2. The minimum efficiency allowed (or corresponding minimum volume that must be available); and,
3. Current storage available.

The first two items should be available from design briefs and/or they can be determined using the MOE SWMP manual data.

4.3 Forecasting Sediment Accumulation

Forecasting sediment accumulation can be very useful for planning field work and budgeting long-term maintenance. A desk-top computational (simulation) approach (MOEE 1994) and a measurement-based approach for forecasting maintenance have been proposed by CG&S(1997).

4.3.1 Desk-Top Approach

The MOE outlines a computational or 'desk-top' approach that can be used to estimate the frequency of maintenance (see ***Table 5***). As outlined previously, the use of modeling for purposes other than screening and/or prioritizing sediment monitoring in existing SWMFs is not recommended. Actual measurements are preferred for forecasting.

Table 5: Sediment Frequency Removal in MOE SWMP Manual

From pages 208 to 212, MOE SWMP Manual (1994b):

Curves of maintenance frequency by SWMP type, storage and different levels of upstream imperviousness were calculated based on the continuous simulation results and the requirements for maintenance within a 5% loss in TSS removal performance. Plots of these curves indicated that there is a linear relationship between maintenance frequency and SWMP storage. This linear relationship is shown in Figure 5.1 through 5.4 . The straight lines in these figures are best-fit lines based on linear regression. Figures 5.1 through 5.4 only display maintenance frequencies up to a maximum of 50 years. It is anticipated that any comparison between SWMP options would not be based on a timeframe longer than 50 years recognizing the rapid evolvement of this discipline.

Figures 5.1 through 5.4 can be used to determine the required sediment removal frequency given the SWMP type and storage volume.

The figures also indicate the longer maintenance interval given additional storage. This is somewhat deceiving, however, since these curves represent the maintenance frequency for a 5% reduction in performance. If additional storage is provided, the maintenance frequency would be based on a larger reduction in performance. In order to allow users to calculate the required maintenance frequency for oversizing a SWMP, annual suspended solids loading in runoff from catchments with different levels of imperviousness, and estimated sediment density, are provided in Table 5.3. The values of suspended solids loading in Table 5.3 were derived from SWMM simulation results and are intended to be used as estimates for planning purposes only. The density of suspended solids was based on a review of the literature of stormwater sediment characteristics and recent pond sediment removal data.

Fig. 5.1 Storage Volume vs. Removal Interval (for 35% Impervious Catchments)

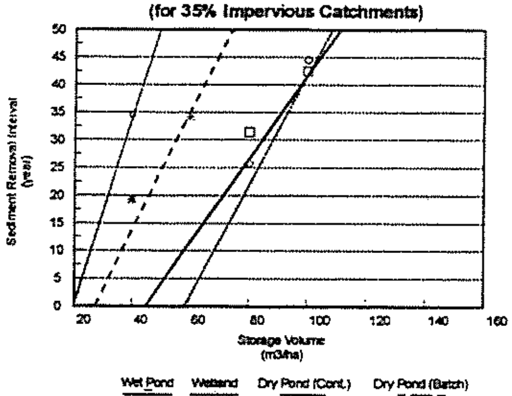


Fig. 5.2 Storage Volume vs. Removal Interval (for 55% Impervious Catchments)

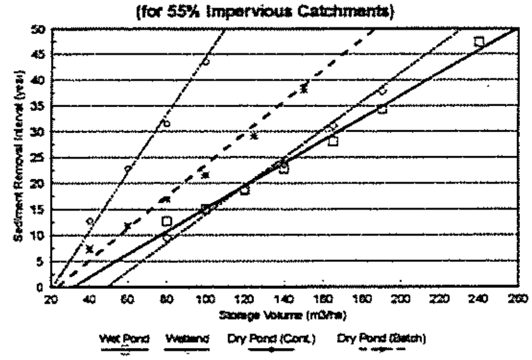


Fig. 5.3 Storage Volume vs. Removal Interval (for 70% Impervious Catchments)

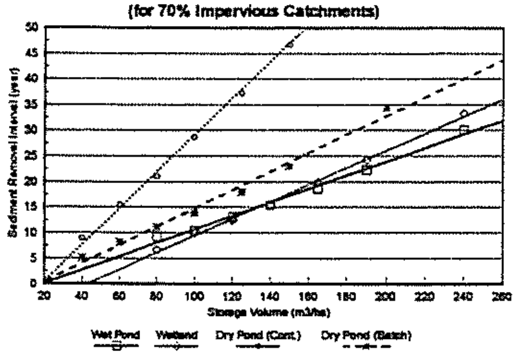
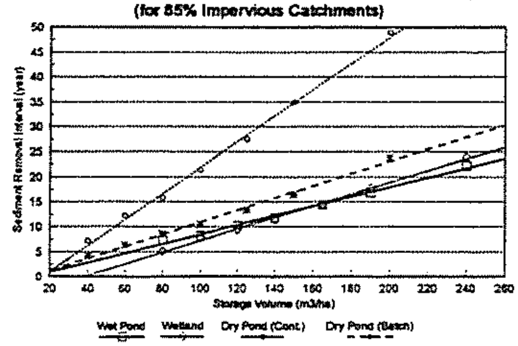


Fig. 5.4 Storage Volume vs. Removal Interval (for 85% Impervious Catchments)



The following methodology should be used to calculate the maintenance frequency if the SWMP storage is oversized.

1) Determine the appropriate TSS removal efficiency based on Habitat Type.
2) Subtract 5% to obtain the target maintenance removal efficiency.
3) Determine the projected TSS removal efficiency based on the storage provided.
4) Calculate the loss in removal performance and loss in storage for each year based on the removal performance at the start of the year, the suspended solids loading rate, and the sediment density. The removal efficiency at the start of the next year will be based on the resulting available storage volume at the end of the year. These calculations are continued until the removal efficiency of the facility at the start of the

year is equal to the target maintenance removal efficiency. This calculation can be easily automated in a spreadsheet format. (Given the large maintenance intervals a conservative estimate would be to assume a constant removal rate each year equal to the initial removal rate such that only one calculation has to be performed. Following this method, a linear calculation is made to determine how long it takes to accumulate the difference in storage volumes between the initial storage and the target maintenance storage volume).

Table 5.3 Annual Sediment Loading

Catchment Imperviousness	Annual Loading (kg/ha)	Wet Density (kg/m^3)	Annual Loading (m^3/ha)
35%	770	1230	0.6
55%	2300	1230	1.9
79%	3495	1230	2.8
85%	4680	1230	3.8

Table 5.3 provides a conservative estimate of annual sediment accumulation in a SWMP by multiplying the annual loading of suspended solids (m^3/yr) by the long term removal efficiency for the particular SWMP, level of imperviousness, and storage provided.

4.3.2 In-Situ Measurements Approach

A good forecast of sediment accumulation can be obtained by plotting accumulated sediment versus time and projecting the measurements in time until the volume criteria is violated. This approach has been proposed for managing the maintenance of stormwater facilities in the City of Nepean (CG&S 1997). The criteria used there in the Nepean evaluation to determine when maintenance is required is different than proposed here. For example, the Nepean study chose a 15% target for reduction of storage as the criteria for when the SWMF should be cleaned out. For several reasons, it was felt that the retroactive application of a treatment efficiency–based criterion was not appropriate for those facilities. They also proposed to measure sediment accumulation volumes directly as a way of forecasting. Although the criteria used to evaluate the need for maintenance and the measures proposed for Nepean are different, the basic forecasting concept is the same.

Although ***Figure 4.1*** is only a concept, it illustrates the forecasting approach in a new wet-pond, sized using the MOE SWMP manual criteria for Level 1 habitat protection. As shown in ***Figure 4.1***, the maintenance criterion is based on comparing the available volume (above the sediment bed) with the target volume. Measuring available volume has more advantages as compared with sediment depth measurements in cost-savings by simplifying the collection method.

However, a well-referenced 'baseline' survey is highly recommended right after the SWMF is constructed (or sediment is removed) to establish the 'as-built' or 'initial' bottom of the facility. This initial bottom will provide the reference for determining future changes in volume and sediment distributions, eliminating the need for direct sediment depth measurements. Having an initial baseline survey also provides an additional point in the accumulation line. Care should be taken during the initial survey to establish a regular and reproducible grid of points, for later use as a guide. The baseline survey will allow comparison and verification with the design criteria, and if excess volume beyond the design criteria is provided, further savings could be realized by delaying the initial operational survey. Note however, that 'all is not lost' if a properly referenced baseline survey is not available from the onset of SWMF operation. Retroactive measurement of sediment depth, together with the effective-bottom survey (i.e. top of sediment bed) will provide the information required to use the simplified approach in the future. Techniques for effectively measuring sediment depths are discussed later in the document.

The in-situ measurement data should also yield the information necessary to characterize the pond-specific accumulation rate allowing for further refinement in the monitoring program. This refinement can reduce future data collection efforts in terms of frequency of measurements and density of survey points without loosing predictive accuracy.

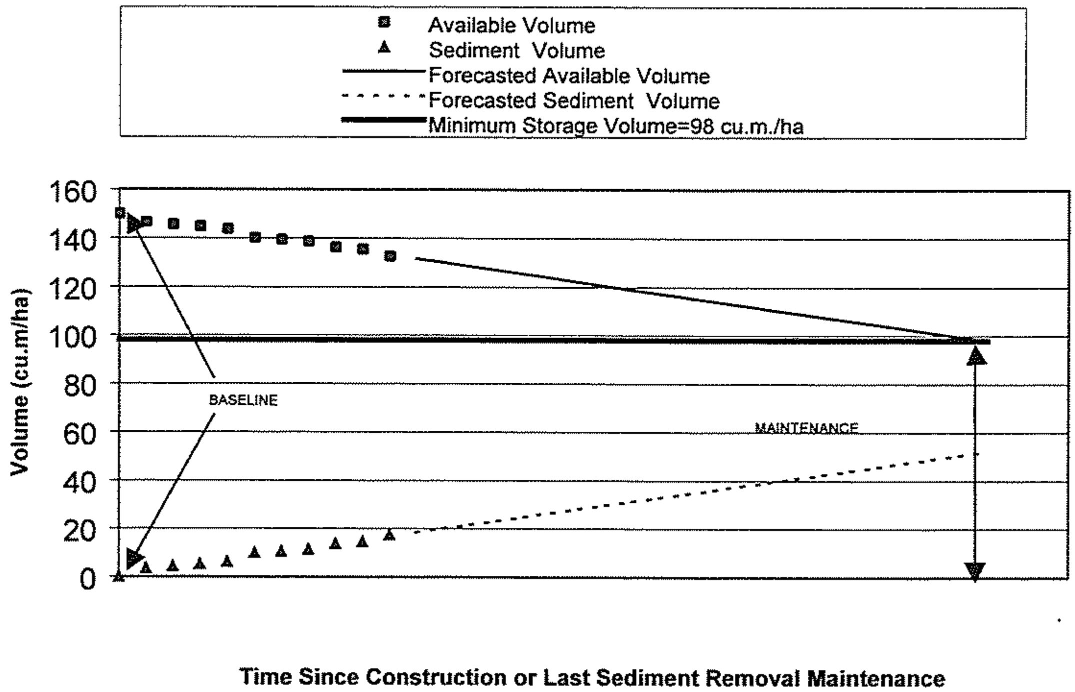


Figure 4-1: Hypothetical Example of a Maintenance Forecast Using Measurements

Single or sporadic field measurements of available storage (or sediment volumes) is also useful, particularly when the rate of accumulation is relatively constant, such as that illustrated in ***Figure 4-1***. An "average accumulation approach" has been used for each of the case studies in the present study to estimate their rate of sediment accumulation whereby the total volume of sediment removed from each pond was divided by the contributing drainage area and years since last cleanout. For example, the average sediment accumulation rates in ***Table 6***, collected from several case studies, can be used to estimate future maintenance frequency for each individual SWMF and evaluate general performance as a function of size and upstream conditions.

Table 6: SWMF Case Studies Sediment Accumulation Rate

SWMF Case Study	Location	Predominant Land Use	SWMF Drainage Area (ha)	Volume of Sediment Removed (m^3)	Years Since Last Clean-out	Average Sediment Accumulation (m^3/ha/yr)
#1 Merivale	Nepean	Industrial	30.5	2,300	13	5.8
#2 Bentley	Nepean	Industrial	20	345	15	1.2
#3 Aquitaine	Mississauga	Residential	107	2,550	13	1.8
#4 Toogood	Markham	Residential	NA	5,500	16	NA
#5 Bluffers	Scarborough	Residential	NA	7,000	22	NA
#6 Lincoln	Uxbridge	Residential	11	387	6	5.9
#7 Victoria	Kitchener	Residential	1500	23,900	22	0.7
#8 Silver	Waterloo	Residential	5200	27,000	27	0.2

Sediment loading rates for catchments with different levels of imperviousness given in the MOE SWMP Manual range from 0.6 m^3/ha/yr to 3.8 m^3/ha/yr. Level 1 SWMFs, for example, would trap 80% of the loadings giving an accumulation range from 0.5 m^3/ha/yr to 3.0 m^3/ha/yr. The above accumulation rates suggest that some of the SWMFs may be subject to higher loading rates than previously observed in other studies while other SWMFs may be operating with low removal efficiencies. However, caution must be exercised in applying the above information to the management of other SWMFs without detailed data on the type, age, size and configuration of the SWMF, and size and characteristics of the drainage area, such as percent imperviousness, land use and climate.

Although a single measurement after a few years of operation provides useful information about the average rate of accumulation, changes in the treatment efficiency can be obtained only with more regular measurements. For example, ***Figure 4-2*** illustrates (hypothetically) the impacts of one year of construction activities (year 13) with poor sediment and erosion control upstream. In this case, the impact on the timing of maintenance is dramatic, reducing the period before maintenance by 14 years from 31 to 17. Please note that these values are hypothetical for illustration purposes only and should not be used to evaluate any real facility. The argument in favor of plotting volume as a function of time rather than taking sporadic measurements is also raised in the Nepean evaluation. For example, ***Figure 4-3*** illustrates the benefits of regular measurements during a reduction in sediment accumulation rates. This situation could indicate a problem with the treatment, reduction in street sanding, implementation of source SWMPs (e.g. effective street sweeping, source infiltration practices, etc.), or changes in land-use. In this case, a closer examination of the SWMF and upstream may be warranted to determine the exact cause and mitigate potential problems. This examination may entail undertaking water quality monitoring at the inlet to verify the characteristics of the inflow stream. If less sediment is entering the facility (e.g. due to effective upstream controls), reducing the sediment removal maintenance frequency would be justified.

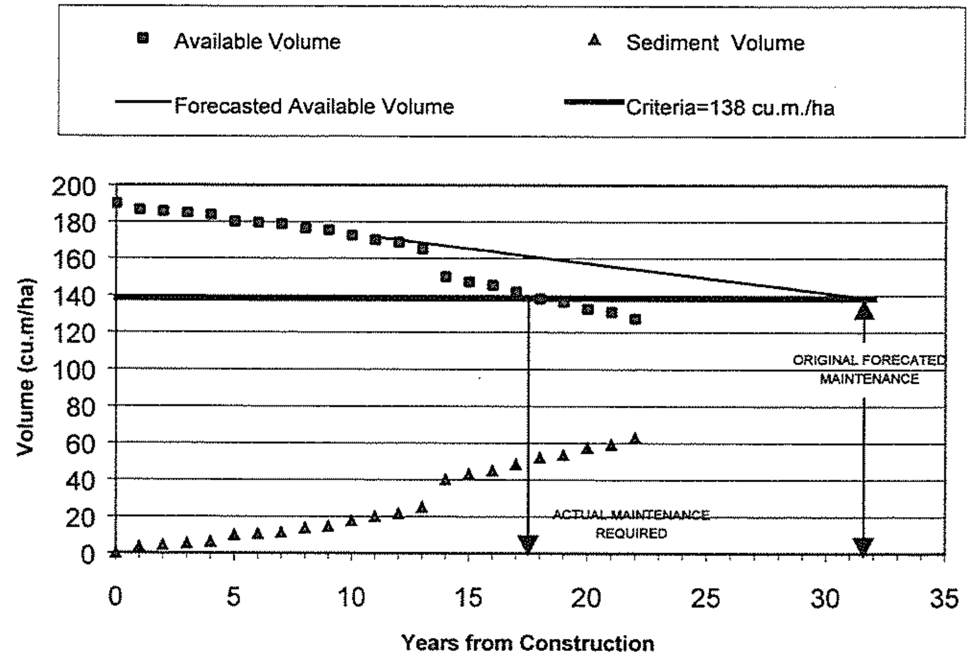


Figure 4-2 Impact on Maintenance Forecast with Poor Upstream Sediment Control

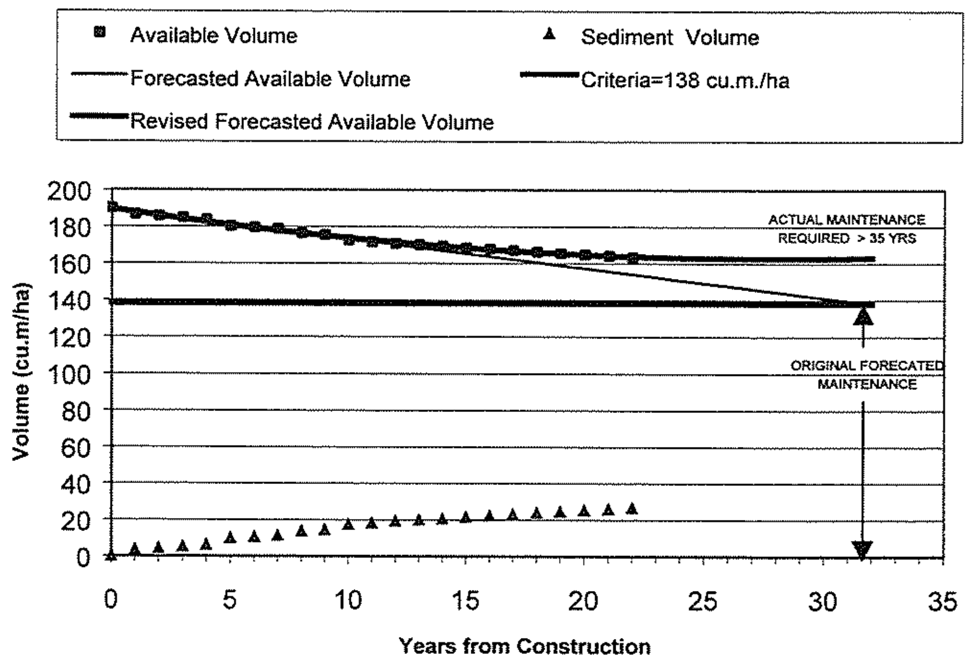


Figure 4-3 Benefits of Regular Field Measurements During Period of Reduced Sediment Loading

5 Depth Measurement and Sampling Techniques

Statistical and mathematical modeling rely heavily on the availability of field data. Capital expenditures on field data collection, processing and analyses are relatively small as compared to long term savings in the management of a well understood and prepared SWMP removal and disposal program. Quality on-site data could reinforce the modeling data and eventually fine-tune the management program. The following section summarizes the current measurement technologies that could form part of a management program.

5.1 Sediment Depth Measurement

5.1.1 Determining Sediment Depth Measurement Locations

Sediment depth measurements should be undertaken using a predetermined grid pattern to provide an adequate representation of sediment distributions and average accumulated depths. Past monitoring programs have observed that sediment accumulations are not typically uniform through the entire basin. These variations are likely due in part to variations in basin configurations and non-ideal flow regimes. Therefore, an appropriate number of measurements in varying locations in the SWMF should be made to obtain a representative picture of sediment distributions. It should also be noted that well kept records of sample station locations are essential in maintaining consistent patterns during future depth surveys.

5.1.2 Sediment Depth Measurement Techniques

The manual measurement of sediment depth may appear to be a relatively simple and straight forward task. However, some measurement procedures can produce results which significantly underestimate or overestimate the volume of accumulated sediment. It is therefore important to choose a measurement strategy that will produce the most accurate results.

i) Common Core Sampler and Depth Measurement Method

A common method of sediment depth measurement involves the use of a core sampler, which consists of a clear tube attached to a support rod. One end of the tube is open and the other end is equipped with a cap or internal plunger which maintains the suction necessary to hold the sediment sample in place. The sample is collected by pushing the open end of the tube through the accumulated sediment layer into the native soil layer of the pond basin. The tube is then withdrawn and the accumulated sediment layer and native soil interface is visually identified by the obvious differences in color, consistency and texture. The accumulated sediment layer is typically dark brown or black in color with a very soft consistency and fibrous texture. Depending on the grain size composition (e.g. gravel, sand, clay, etc.) the parent material is lighter in color with a firm consistency and a granular texture. Based upon these visual differences, the accumulated sediment layer is identified and measured directly through the clear core sampler tube.

The core sampling method is relatively simple and inexpensive and as such, it is the most popular technique used in sediment depth measurement. However, it should be noted that the sampling tube can cause some sediment compaction, thereby reducing the depth measurement and ultimately resulting in an underestimation of accumulated sediment volumes.

ii) Disc Depth Measurement Method

An alternative method for obtaining in-situ depth measurements involves the use of a disc and a standard survey rod (CG&S 1997). The disc is a circular steel plate generally used for obtaining water turbidity measurements. It should be noted that any similar circular metal plate may be used in its place.

A disc is attached to a light line or rod calibrated in centimeters, and lowered into the water until it rests under its own weight on the surface of the undisturbed sediment. After the depth of the disc has been recorded, a survey rod is lowered into the water, allowing its own weight to pass through the loose sediment and onto the firm parent soil. The difference between the disc and rod depth readings is then used to determine the depth of accumulated sediment. A caution with this method is that it the rod may pass through less firm upper layers of the parent material, resulting in an overestimation of accumulated sediment depth and volume measurements.

iii) Depth Sounding Method

Bathimetric surveys of sediment accumulations may also be conducted through the use of depth sounding equipment, otherwise known as fish finder equipment (Paragon 1993). Most depth sounding units are sensitive enough to distinguish the soft sediment layer from the firmer basin parent material which is displayed as a faded shadow layer over an obviously darker layer, as indicated on the visual display screen. These compact units may be mounted on the side of a boat and used to produce numerical measurements and graphical images of the basin depth contour lines.

Regardless of the chosen measurement technique, it is highly recommended that all sediment depth measurement activities be cross-checked with design drawing elevations as a method of ensuring field measurements are correct. Basin elevations should be surveyed to ensure that the interface between the basin parent material and the accumulated sediment layers are being correctly distinguished. It is also recommended that the water depth above the sediment be recorded while the sediment depth measurements are taken, so that the existing water storage volume of the SWMF can be checked against the design specifications. The water surface should be checked against an elevation benchmark, and then the total of the current sediment volume plus water volume compared to the design specifications.

The benefits of establishing true sediment depths are demonstrated by Case Study #4 (Toogood Pond, Town of Markham). The estimated accumulated sediment volumes were determined by pushing a rod through the sediment layer to what was mistakenly thought to be the basin parent material. In actuality, the sediment depth measurement was greatly overestimated. The overestimation was corrected when the measured basin depth was compared to the design specifications, ultimately resulting in a project budget reduction of approximately 30%.

5.2 *Sediment Sampling Methodologies*

5.2.1 Pre-sampling Site Inspection

The SWMF site and the surrounding catchment area should be inspected prior to the initiation of sampling activities, in order to ensure that the historical information is representative of the existing conditions. The catchment and facility inspections should identify any new potential contaminant sources such as industrial/commercial developments, and outfalls. It is also recommended that the MOE be contacted to determine if any contaminant spills have been reported within the catchment area. This information will assist in the prediction of contaminant types and levels for the purpose of designing a sound sampling strategy.

5.2.2 Sample Collection

Standard methods and equipment used for sediment collection are well-documented and illustrated in a number of instructional manuals such as the MOEE (1994c*) Dredged Material Sediment Sampling and Analysis Handbook.* This handbook includes detailed descriptions of sediment sampling and processing techniques for submission to chemical and geotechnical laboratories.

However, the actual sampling plan requires more consideration because the numbers, locations and types of samples taken must accurately reflect the unique physical and chemical characteristics of each site. It is therefore recommended that sediment sampling plans be developed in consultation with the appropriate MOE regional office in order to meet the following objectives:

i) to ensure that the sampling program meets the most recent regulatory requirements;

ii) to address issues raised by the site inspection exercise; and

iii) to provide the basis for review of disposal requirements and options.

5.2.3 Field Observation Records

The importance of recording accurate and detailed field notes cannot be overemphasized. In some cases, the most routine field observations can reveal critically important information regarding treatment performance, contamination levels and sediment characteristics. For example, sediment contamination concerns were raised when maintenance crews noticed the presence of an unusual odor and oily sheen during routine sediment depth measurements of Case Studies #1 & #2 (Merivale and Bentley Ponds, City of Nepean). To address these concerns, petroleum hydrocarbons were added to the routine chemical parameter list, and were found to be in excess of the Guideline for Use at Contaminated Sites, Table B (MOEE 1997). As a result, the sediment was immediately removed and disposed at a non-hazardous landfill site.

Sediment texture field observations can also be helpful in identifying questionable grain size analyses laboratory results. For example, the Case Study #3 (Lake Aquitaine, City of Mississauga) preliminary engineering report documented the sediment composition as being 75% sand, 25% silt, with low saturation. Based on these results, it was concluded that the sediment was firm enough to support excavation equipment and that it would not have to be dewatered for disposal. During excavation however, it was discovered that the sediment was 75% silt, 25% with a pudding-like texture that was highly incapable of supporting excavation equipment. The sediment was ultimately dewatered at an additional cost of $40,000.

5.2.4 Sediment Description Categories

Odor can be distinguished according to the following categories:

- Odorless
- Chemical: chlorine, petroleum, medicinal (e.g. iodine), sulfurous
- Decaying Organic: manure, sewage
- Natural: earthly, peat, grassy, mouldy

Color can be best determined by comparison of the sediment to the Munson color code system. If that is not available, each color zone or depth of core should be described. Colors will range from reddish-brown to jet black.

Texture can be manually determined according to the following categories:

Clay: Extremely fine-grained, consolidated material composed of particle diameter sizes of less than 1/256 mm. Clay may be visually identified as those fine soils that will maintain a consolidated shape if squeezed and/or rolled in one's hands.

Silt: Fine-grained, loose material composed of particle diameter sizes of 1/16 to1/256 mm. Silt has a very soft consistency which prevents it from holding a consolidated shape if manually rolled or squeezed.

Sand: Loose granular material composed of particle diameter sizes of 1/16-2 mm. Sand may be visually identified as those granular soils that will maintain a consolidated shape if manually squeezed but will fall apart when rolled in one's hands.

Gravel: Unconsolidated granular material composed of particle diameter sizes of 1-100 mm.

5.3 *Sediment Chemistry And Geotechnical Analysis*

This section presents the results and conclusions of numerous SWMF sediment chemistry and geotechnical studies. Of special note are five separate studies conducted by: Marsalek et. al. (1998), Marsalek et al. (1997), Mayer et. al. (1996), Pitt (1995) and Schueler (1994). The findings of these studies are discussed in comparison to the nineteen storm water pond data sets which were specifically compiled for this report. These results indicate a number of relationships between land use patterns, grain size distribution and sediment chemistry (see ***Appendix E***). These predictive relationships provide important insights regarding sediment removal and disposal options and restrictions.

This section also expands on some of the information first introduced in Section 2 (Legislation, Regulations and Guidelines) and presents empirical data from case studies in Ontario.

5.3.1 Ontario Regulatory Requirements and Guidelines

The primary purpose of conducting sediment chemistry analysis is to identify disposal options and/or restrictions as determined by EPA Regulation 347 Leachate Test, *Guidelines For Use At Contaminated Sites In Ontario* (MOEE 1997), and *Guidelines For The Protection And Management Of Aquatic Sediment Quality In Ontario* (MOE 1992). Contaminated sediment that is classified as registered waste must be deposited in a registered landfill facility, with the associated tipping fees. Less contaminated sediment that is classified as non-registerable waste may be disposed in a variety of other, less expensive ways (e.g., residential fill, daily landfill cover, etc.).

Identifying acceptable sediment disposal options can be a complicated process since contamination guidelines and/or criteria have not been developed specifically for SWMF sediment disposal. However, it may be said that the primary disposal options may be distinguished as landfill facility disposal, land spreading, and open water disposal. The methods used to evaluate each of these options are included in the following detailed discussion.

5.3.1.1 Landfill Disposal

The leachate test determines the concentrations of 33 standard leachate contaminants including certain trace metals, organic compounds and nutrients. The primary purpose of the leachate test procedure is to determine if waste material contaminant concentrations are high enough to significantly pollute receiving ground water resources. Wastes are classified according to the following system:

- Where contaminant concentrations are less than 10 times the leachate criteria, wastes are classified as non-registerable waste and do not require landfill disposal.
- Where contaminant concentrations are between 10 and 100 times the criteria, wastes must be disposed at a registered non-hazardous waste disposal facility.

- Where contaminant concentrations are greater than 100 times the criteria, wastes are classified as hazardous waste and must be disposed at a hazardous waste facility.

5.3.1.2 Land Spreading

As stated previously in Chapter 2, there are no regulations, guidelines or criteria dedicated specifically to the disposal of non-registerable SWMF sediment. As an alternative, the MOE currently relies on the GCSO contaminant criteria to evaluate the most suitable sediment disposal options. The GCSO document offers guidance on the evaluation and remediation of contaminated sites. The document offers four different sets of soil contamination criteria which are designed to protect human health, and the natural environment.

The number of GCSO criteria (117) are much greater than the number of leachate criteria (33), and therefore offer a much more detailed sediment quality characterization. The GCSO criteria should be used for the following reasons:

- To detect the presence and levels of contaminants that are not included in the standard list of leachate parameters. Excessively high contaminant concentrations may require that the sediment removal protocols include precautionary measures used for the removal of hazardous wastes.

- For relatively low contaminant levels, the GCSO criteria may be used to determine if the sediment is clean enough to be spread on agricultural, residential/parkland or commercial/industrial lands.

The GCSO criteria offer varying degrees of protection, based upon the following two risk factors:

1) Exposure risks according to land use types: agricultural, residential/parkland and industrial/ commercial uses.

   The most stringent GCSO soil contamination criteria apply to agricultural lands in order to protect against food contamination health risks. The comparatively less stringent residential/parkland criteria are intended to protect against the potential risks associated with the exposures of large populations to high contamination levels. The least stringent criteria apply to commercial/industrial sites which represent a lower risk of exposure to food production and community health.

2) Ground water contamination risks

   Criteria are also provided for potable and non-potable groundwater use, to ensure that groundwater may be used as a source of drinking water. As may be expected, the most stringent criteria apply to lands with potable groundwater sources, while the less stringent criteria apply to non-potable groundwater sources. The GCSO document organizes the criteria according to land use and ground water use risk factors into the following four tables:

Table A:	Surface soil and groundwater criteria for agricultural, residential/ parkland, industrial/commercial land use for a potable groundwater condition.
Table B:	Surface soil and groundwater criteria for agricultural, residential/parkland, industrial/commercial land use for a non-potable groundwater condition.
Table C:	Subsurface soil criteria for residential/parkland, industrial/commercial land use for a potable groundwater condition.
Table D:	Subsurface soil criteria for residential/parkland, industrial/commercial land use for a non-potable groundwater condition.

Table A is the most stringent and with table D being the least. A comparison of the GCSO criteria with the contaminants tested for each of the Case Studies is given in ***Appendix E***. It should be noted that in most cases it is not necessary to test for all 117 contaminants given in the GSCO document. Conversely, it may also be necessary to test for contaminants that are not listed in the GSCO document. For example, in most of the Case Studies contaminant groups such as metals, TSS, and conventional parameters were tested for, whereas pesticides were added to the list in the Silver Lake SWMF. It is suggested that prior to testing for contaminants, the local MOE office be consulted to determine which contaminants are applicable for the contributing area, based on their local experience. Typical laboratory testing costs are provided in ***Appendix F*** for reference purposes.

5.3.1.3 Open Water Disposal

The 1993 PSQG replaced the MOEs 1976 *Open Water Disposal Guidelines*. The purpose of the PSQGs is to protect the aquatic environment by setting safe levels for metals, nutrients and organic compounds. As such they are used to determine if removed sediment is clean enough to be safe for open water disposal.

Three levels of effect are defined in the document:

1. No Effect Level (NEL)

Sediment contaminant concentrations that are below the NEL are considered to be clean, with no risk of contaminant transfers into the food chain or negative impacts to water quality, water uses or benthic organisms. It should be noted that the sediment must be disposed of off-site if the contaminant levels are above background concentrations.

2. Lowest Effect Level (LEL)

The LEL is based upon the long-term effects of contaminants on aquatic sediment-dwelling organisms. Sediment concentrations above the LEL are considered to be minimally polluted with no long-term effects on the majority of benthic organisms.

3. Severe Effect Level (SEL)

The SEL is based upon the long-term effects of contaminants on aquatic sediment dwelling organisms. Sediment concentrations in exceedence of the SEL are considered to be heavily polluted and are likely to affect benthic organism health.

5.4 *Literature Review and Case Studies*

5.4.1 SWMF Sediment Contaminant Sources and Types

SWMFs receive pollutants from various land use types including residential, highway, commercial, and industrial. The background literature and 19 Ontario SWMF sediment data sets identify residential ponds as being the least contaminated, followed by commercial and highway ponds. Industrial ponds are identified as being the most polluted (Mayer 1996; Pitt 1995; Schueler 1994). The sources and types of pollutants are determined by the land use practices that are characteristic of each catchment area. For example, residential SWMF sediment is often contaminated by landscaping fertilizers, pesticides, vegetation cuttings, animal droppings and road salt. One study conducted by Bannerman et al. (1983) also noted high zinc concentrations in roof runoff caused by leaching of zinc from galvanized roof drainage components.

Automobile related land uses include highways, commercial parking lots and automotive servicing areas. These sources contribute hydrocarbons, PAHs and trace metals through gasoline/oil drips or spills in addition to exhaust residuals and the wear of tire, brake and pavement materials. Although industrial pollutants can vary widely depending on the type of activity, comparative land use studies consistently report industrial SWMFs as having the highest concentrations of the following trace metals: cadmium, chromium, copper, lead, nickel and zinc (Mayer 1996; Pitt 1995; Schueler 1994).

5.4.2 Typical Waste Classifications and Disposal Options

Leachate Analysis and Waste Classification

The background literature and eight sediment removal project case studies indicate that although sediment contaminant concentrations often exceed background levels, they are not typically high enough to require disposal at registered landfill sites (see also e.g., Schueler 1994; Marsalek et al. 1998). However, the exception to this trend occurred in two case study SWMFs that were located within industrial catchment areas. Although both facilities passed the Regulation 347 Leachate criteria, they were above the GCSO Tables A, B, C and D petroleum hydrocarbon criteria. As a result, the sediment was sent to a non-hazardous landfill facility.

Land Spreading Options and GCSO Criteria

For the purposes of this study, sediment quality data sets were compiled from nineteen different residential, commercial, industrial and highway storm water ponds throughout Ontario. As illustrated in ***Appendix E***, there is a great deal of variation in the types of parameters analyzed for each facility. Regardless of these variations, the following sediment chemistry and land use trends may be noted (see ***Table 7***):

1) Sixteen of the nineteen SWMFs were clean enough that the sediment would not require landfill disposal.

2) Eight of the eight residential SWMFs exceeded the GCSO chloride criteria (as measured by electrical conductivity [EC]). These levels are most likely due to winter road salting. In cases such as these, land spreading may be restricted to subsurface soils at depths below root zones to prevent chloride uptake and damage to vegetation.

3) Residential SWMFs - With the exception of the chloride levels, seven of eight residential SWMFs met the most stringent GCSO Table A, with one facility exceeding the petroleum hydrocarbon criteria.

4) Highway SWMFs - The single highway data set was limited to only six trace metals and electrical conductivity. Of these parameters, only electrical conductivity exceeded the GCSO.

5) Commercial SWMFs - one of two commercial facilities exceeded one of the Table A criteria for chromium VI.

6) Commercial/Industrial SWMFs - one of two commercial/industrial facilities exceeded one of the Table A criteria for chromium VI and selenium.

7) Industrial SWMFs - In contrast, the industrial facilities were more contaminated with 3 of 5 exceeding six of the Table A criteria for cadmium, copper, lead, mercury, molybdenum, zinc and petroleum hydrocarbons.

Based on this sediment data, it may be stated that the residential sediment would be expected to have fewer disposal restrictions as compared to commercial or industrial facilities. It may also be stated that industrial facility sediment would be expected to have the most land disposal restrictions.

Table 7: Comparison of Ontario SWMF Sediment Data to MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO)

PARAMETERs	UNITS	GCSO "Table A" Criteria			Residential # of SWMFs in exceedence of GCSOs / # of ponds with data			Commercial # of SWMFs in exceedence of GCSOs / # of ponds with data			Commercial/Industrial # of SWMFs in exceedence of GCSOs / # of ponds with data			Industrial # of SWMFs in exceedence of GCSOs / # of ponds with data			Highway # of SWMFs in exceedence of GCSOs / # of ponds with data		
		Agric.	Res./Park.	Ind./Com	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.
Electrical Conductivity	mS/cm	0.7	0.7	1.4	3/4	3/4	2/4	--	--	--	--	--	--	2/2	2/2	1/2	1/1	1/1	1/1
SAR		5.0	5.0	12.0	2/4	2/4	2/4	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
CONVENTIONALS																			
Free Cyanide	ug/g	100	100	100	0/2	0/2	0/2	--	--	--	--	--	--	--	--	--	--	--	--
METALS																			
Antimony (Sb)	ug/g	13	13	44	0/3	0/3	0/3	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
Arsenic (As)	ug/g	25	25	50	0/8	0/8	0/8	0/3	0/3	0/3	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Barium (Ba)	ug/g	1000	1000	2000	0/4	0/4	0/4	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
Beryllium (Be)	ug/g	1.2	1.2	1.2	0/4	0/4	0/4	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
Cadmium (Cd)	ug/g	4	12	12	0/8	0/8	0/8	0/3	0/3	0/3	0/2	0/2	0/2	1/5	0/5	0/5	0/1	0/1	0/1
Chromium (Cr) (VI)	ug/g	10	10	10	0/4	0/4	0/4	1/1	1/1	1/1	1/1	1/1	1/1	0/2	0/2	0/2	--	--	--
Chromium (Cr) (Total)	ug/g	1000	1000	1000	0/8	0/8	0/8	0/1	0/1	0/1	0/1	0/1	0/1	0/5	0/5	0/5	0/1	0/1	0/1
Cobalt (Co)	ug/g	50	50	100	0/4	0/4	0/4	0/1	0/1	0/1	0/1	0/1	0/1	0/2	0/2	0/2	--	--	--
Copper (Cu)	ug/g	200	300	300	0/6	0/6	0/6	0/2	0/2	0/2	0/2	0/2	0/2	1/4	0/4	0/4	--	--	--
Lead (Pb)	ug/g	200	200	1000	0/8	0/8	0/8	0/2	0/2	0/2	0/2	0/2	0/2	1/5	1/5	0/5	0/1	0/1	0/1
Mercury (Hg)	ug/g	200	10	10	0/8	0/8	0/8	0/1	0/1	0/1	0/1	0/1	0/1	0/5	0/5	0/5	--	--	--
Molybdenum (Mo)	ug/g	200	40	40	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	1/2	0/2	0/2	--	--	--
Nickel (Ni)	ug/g	200	200	200	0/8	0/8	0/8	0/2	0/2	0/2	0/2	0/2	0/2	0/5	0/5	0/5	0/1	0/1	0/1
Selenium (Se)	ug/g	2	10	10	0/4	0/4	0/4	--	--	--	1/1	1/1	1/1	0/2	0/2	0/2	--	--	--
Silver (Ag)	ug/g	200	25	50	0/4	0/4	0/4	0/1	0/1	0/1	0/1	0/1	0/1	0/2	0/2	0/2	--	--	--
Vanadium (V)	ug/g	200	250	250	0/3	0/3	0/3	0/1	0/1	0/1	0/1	0/1	0/1	0/2	0/2	0/2	--	--	--
Zinc (Zn)	ug/g	800	800	800	0/8	0/8	0/8	0/2	0/2	0/2	0/2	0/2	0/2	1/5	1/5	1/5	0/1	0/1	0/1
PURGEABLE HYDROCARBONS																			
Benzene	ug/g	0.24	25	25	--	--	--	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
Toluene	ug/g	2.1	150	150	--	--	--	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
Ethylbenzene	ug/g	0.28	500	1000	--	--	--	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--
Xylenes	ug/g	25	210	210	--	--	--	--	--	--	--	--	--	0/2	0/2	0/2	--	--	--

Table 7: Comparison of Ontario SWMF Sediment Data to MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO)

PARAMETERs	UNITS	GCSO "Table A" Criteria			Residential # of SWMFs in exceedence of GCSOs / # of ponds with data			Commercial # of SWMFs in exceedence of GCSOs / # of ponds with data			Commercial/Industrial # of SWMFs in exceedence of GCSOs / # of ponds with data			Industrial # of SWMFs in exceedence of GCSOs / # of ponds with data			Highway # of SWMFs in exceedence of GCSOs / # of ponds with data		
		Agric.	Res./Park.	Ind./Com	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.	Agric.	Res/Park	Ind/Com.
EXTRACTABLE HYDROCARBONS																			
Petroleum Hydrocarbons (gas/dies	ug/g	100	1000	2000	--	--	--	--	--	--	--	--	--	2/2	2/2	2/2	--	--	--
Petroleum Hydrocarbons (heavy oi	ug/g	1000	1000	5000	1/1	1/1	0/1	--	--	--	--	--	--	--	--	--	--	--	--
POLYCYCLIC AROMATICS																			
Acenaphthene	ug/g	15	1000	1300	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/2	0/2	0/2	--	--	--
Acenaphthylene	ug/g	100	100	840	0/3	0/3	0/3	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Anthracene	ug/g	28	28	28	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Benzo(a)anthracene	ug/g	6.6	40	40	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Benzo(a)pyrene	ug/g	1.2	1.2	1.9	0/2	0/2	0/2	0/2	0/2	0/2	0/1	0/1	0/1	0/3	0/3	0/3	--	--	--
Benzo(b)fluoranthene	ug/g	1.2	12	18	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Benzo(k)fluoranthene		1.2	12	18	0/3	0/3	0/3	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Benzo(ghi)perylene	ug/g	1.2	40	40	0/3	0/3	0/3	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Chrysene	ug/g	1.2	12	17	0/3	0/3	0/3	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Dibenzo(a,h)anthracene	ug/g	1.2	1.2	1.9	0/3	0/3	0/3	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Fluoranthene	ug/g	1.2	40	40	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Fluorene	ug/g	1.2	340	340	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Indeno(123-c,d)pyrene	ug/g	1.2	12	19	0/3	0/3	0/3	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Naphthalene	ug/g	1.2	4.6	4.6	0/4	0/4	0/4	0/2	0/2	0/2	0/1	0/1	0/1	0/4	0/4	0/4	--	--	--
Phenanthrene	ug/g	1.2	40	40	0/3	0/3	0/3	0/1	0/1	0/1	0/1	0/1	0/1	0/3	0/3	0/3	--	--	--
Pyrene	ug/g	1.2	250	250	0/3	0/3	0/3	0/1	0/1	0/1	0/1	0/1	0/1	0/3	0/3	0/3	--	--	--
PCBs (total)	ug/g	0.5	5.0	25	0/5	0/5	0/5	0/2	0/2	0/2	0/1	0/1	0/1	1/4	0/4	0/4	--	--	--
Hexachlorobenzene	ug/g	0.46	0.46	0.76	0/1	0/1	0/1	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--
Heptachlor	ug/g	0.12	0.12	0.15	0/1	0/1	0/1	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--
Aldrin	ug/g	0.05	0.05	0.05	0/2	0/2	0/2	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--
Total Chlordane	ug/g	0.29	0.29	0.29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dieldrin	ug/g	0.05	0.05	0.05	--	--	--	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--
P,P-DDE	ug/g	1.6	1.6	2.4	--	--	--	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--
Endrin	ug/g	0.05	0.05	0.05	--	--	--	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--
Total Endosulfan	ug/g	0.18	0.18	0.18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total DDT	ug/g	1.6	1.6	2.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Methoxychlor	ug/g	4.0	4.0	4.0	0/1	0/1	0/1	0/1	0/1	0/1	--	--	--	0/1	0/1	0/1	--	--	--

GCSO - Guidelines For Use At Contaminated Sites In Ontario, Table A: Surface Soil & Groundwater Criteria for Agricultural, Residential/Parkland, Industrial/Commercial Land Use For A Potable Groundwater Condition.

x/y - GCSO criteria exceeded by x out of y SWMFs

-- - No data

Open Water Disposal Options as Determined by the PSQG Criteria

As illustrated in ***Table 8***, the nineteen sediment data sets exceeded many more of the PSQG criteria as compared to the GCSO criteria. The PSQG exceedence trends are as follows:

1) The following LEL criteria were consistently exceeded by all land use types: TOC, TKN, total phosphorus, cadmium, chromium, iron, copper, lead, manganese, nickel, zinc, benzo(ghi)perylene, chrysene, dibenzo(a,h)anthracene, indeno(123-c,d)pyrene, phenanthrene, pyrene and PCBs).

The SEL criteria were not exceeded by any of the fourteen residential, highway, commercial or commercial/industrial facilities. However, two of the five industrial facilities exceeded the following SEL criteria: total phosphorus, chromium, copper, lead, manganese and zinc.

Based on this data, open water disposal would not be approved for any of SWMF land use types.

5.5 Geotechnical Properties

The relevant geotechnical properties of the sediment pertain to moisture content and grain size composition, as described in the following documents.

i) *Environmental Protection Act, Regulation 347, Schedule 4 - Test Method for the Determination of A Liquid Waste (Slump Test)*

EPA Regulation 347 requires that a standard Slump Test be conducted to classify a particular material as either solid or liquid waste. Under this regulation, sediment is considered to be liquid if it has a slump of greater than 150 millimeters. Sediment slump is determined according to the procedures described in *EPA Regulation 347, Schedule 4, Test Methods for the Determination of Liquid Waste for Solid Waste Landfilling.*

ii) Guideline for Use at Contaminated Sites in Ontario, (MOEE 1996, revised 1997)

In this document, certain contaminants are given two different criteria based upon whether the soil is composed of fine (clay and silt) or coarse (sand and gravel) material. Typically the medium to fine textured soils have higher allowable contaminant levels than the coarse soils. This allowance is due to the ease with which plants and animals will take in contaminants which have adhered to soil particles. Contaminants which adhere to coarse material are usually more available for uptake than those which adhere to fine textured materials. A general distinction of soil texture may be made through the field investigation methods discussed in an earlier section of this report.

Table 8: Comparison of Ontario SWMF Sediment Data to Provincial Sediment Quality Guideline (PSQG)

PARAMETER	UNITS	PSQG		Residential # of SWMFs in exceedence of PSQGs / # of ponds with data		Commercial # of SWMFs in exceedence of PSQGs / # of ponds with data		Commercial / Industrial # of SWMFs in exceedence of PSQGs / # of ponds with data		Industrial # of SWMFs in exceedence of PSQGs / # of ponds with data		Highway # of SWMFs in exceedence of PSQGs / # of ponds with data	
		LEL	SEL	LEL	SEL	LEL	SEL	LEL	SEL	LEL	SEL	LEL	SEL
CONVENTIONALS													
Free Cyanide	ug/g	0.1	*	0/2	0/2	--	--	--	--	--	--	--	--
TOC	%	1	10	2/3	0/3	2/2	0/2	1/1	0/1	2/2	0/2	--	--
TKN	ug/g	550	4800	5/6	0/6	2/2	0/2	1/1	0/1	2/2	0/2	--	--
Total P	ug/g	600	2000	5/5	0/5	2/2	0/2	1/1	0/1	2/2	1/2	--	--
Oil & Grease	%	15	*	0/3	0/3	0/1	0/1	0/1	0/1	0/2	0/2	--	--
METALS													
Arsenic (As)	ug/g	6	33	0/8	0/8	1/3	0/3	0/1	0/1	0/4	0/4	--	--
Cadmium (Cd)	ug/g	0.6	10	2/8	0/8	2/3	0/3	2/2	0/2	3/5	0/5	1/1	0/1
Chromium (Cr) (Total)	ug/g	26	110	5/8	0/8	1/3	0/3	0/1	0/1	4/5	2/5	1/1	0/1
Cobalt (Co)	ug/g	50	*	0/5	0/5	--	--	0/1	0/1	0/2	0/2	--	--
Copper (Cu)	ug/g	16	110	5/6	0/6	3/3	0/3	2/2	0/2	3/4	1/4	0/1	0/1
Iron (Fe)	% dw	2	110	0/1	0/1	1/1	0/1	--	--	--	--	--	--
Lead (Pb)	ug/g	31	250	5/8	0/8	2/3	0/3	2/2	0/2	4/5	1/5	0/1	0/1
Mercury (Hg)	ug/g	0.2	2	0/8	0/8	0/3	0/3	0/1	0/1	0/4	0/4	--	--
Manganese (Mn)	ug/g	460	1100	1/1	0/1	1/1	0/1	1/1	0/1	1/1	1/1	--	--
Nickel (Ni)	ug/g	16	75	6/8	0/8	2/3	0/3	1/2	0/2	3/5	0/5	1/1	0/1
Silver (Ag)	ug/g	0.5	110	0/4	0/4	--	--	1/1	0/1	2/2	0/2	--	--
Zinc (Zn)	ug/g	120	820	6/8	0/8	2/3	0/3	2/2	0/2	5/5	1/5	1/1	0/1
POLYCYCLIC AROMATICS													
Anthracene	ug/g	0.22	370	0/4	0/4	0/2	0/2	0/1	0/1	0/4	0/4	--	--
Benzo(a)anthracene	ug/g	0.32	1,480	2/4	0/4	1/2	0/2	0/1	0/1	0/4	0/4	--	--
Benzo(a)pyrene	ug/g	0.37	1,440	1/2	0/2	1/2	0/2	0/1	0/1	0/3	0/3	--	--
Benzo(k)fluoranthene	ug/g	0.24	1,340	1/3	0/3	1/2	0/2	0/1	0/1	0/4	0/4	--	--
Benzo(ghi)perylene	ug/g	0.17	320	2/3	0/3	1/2	0/2	1/1	0/1	2/4	0/4	--	--
Chrysene	ug/g	0.34	460	2/3	0/3	1/2	0/2	1/1	0/1	1/4	0/4	--	--
Dibenzo(a,h)anthracene	ug/g	0.06	130	1/3	0/3	1/2	0/2	0/1	0/1	2/4	0/4	--	--

Table 8: Comparison of Ontario SWMF Sediment Data to Provincial Sediment Quality Guideline (PSQG)

PARAMETER	UNITS	PSQG		Residential		Commercial		Commercial / Industrial		Industrial		Highway	
		LEL	SEL	# of SWMFs in exceedence of PSQGs / # of ponds with data		# of SWMFs in exceedence of PSQGs / # of ponds with data		# of SWMFs in exceedence of PSQGs / # of ponds with data		# of SWMFs in exceedence of PSQGs / # of ponds with data		# of SWMFs in exceedence of PSQGs / # of ponds with data	
				LEL	SEL	LEL	SEL	LEL	SEL	LEL	SEL	LEL	SEL
Fluoranthene	ug/g	0.75	1,020	**2/4**	0/4	**1/2**	0/2	0/1	0/1	0/4	0/4	--	--
Fluorene	ug/g	0.19	160	0/4	0/4	0/2	0/2	0/1	0/1	0/4	0/4	--	--
Indeno(123-c,d)pyrene	ug/g	0.2	320	**1/3**	0/3	**1/2**	0/2	0/1	0/1	**1/4**	0/4	--	--
Phenanthrene	ug/g	0.56	950	**2/3**	0/3	**1/1**	0/1	0/1	0/1	0/3	0/3	--	--
Pyrene	ug/g	0.49	850	**3/3**	0/3	**1/1**	0/1	0/1	0/1	**1/3**	0/3	--	--
PCBs (total)	ug/g	0.07	530	**2/5**	0/5	**1/2**	0/2	**1/1**	0/1	**2/4**	0/4	--	--
Hexachlorobenzene	ug/g	0.02	24	0/1	0/1	0/1	0/1	--	--	0/1	0/1	--	--
Aldrin	ug/g	0.002	8	0/2	0/2	0/1	0/1	--	--	0/1	0/1	--	--
Total Chlordane	ug/g	0.007	6	--	--	--	--	--	--	--	--	--	--
Dieldrin	ug/g	0.002	91	0/1	0/1	0/1	0/1	--	--	0/1	0/1	--	--
P,P-DDE	ug/g	0.005	19	0/1	0/1	0/1	0/1	--	--	0/1	0/1	--	--
Endrin	ug/g	0.003	130	0/1	0/1	0/1	0/1	--	--	0/1	0/1	--	--
Total DDT	ug/g	0.007	12	--	--	--	--	--	--	--	--	--	--

PSQG - Provincial Sediment Quality Guidelines

x/y (shaded) - PSQG criteria exceeded by x out of y SWMFs

* - No criteria

-- - No data

Grain Size Distribution, Water Content and Bulk Density

SWMF sediment grain sizes typically include various combinations of coarse particles (sand and gravel) and fine particles (silt and clay). Grain size distribution studies conclude that the heavier sands and gravels consistently settle within forebays or inlets, while the lighter silts and clays settle throughout the pond with the greatest volumes accumulating at the outlet.

The case study reports discuss water content and bulk density in general terms by describing the sediment as being highly saturated with pudding-like consistencies. One study by Marsalek (1997) does however provide quantified observations of a SWMF located in Kingston, Ontario. The inlet sediment was composed of sand with a water content of 48% by volume and a bulk density of 2,200 kg/m^3. In contrast, the silts and clays located at the outlet had a higher water content of 78% and a lower bulk density of 1,400-1,600 kg/m^3. This study therefore concluded that less saturated, more dense sediment accumulated at the inlet, while highly saturated, less dense sediment accumulated throughout the basin and the outlet.

Implications to SWMF Maintenance Projects

Sediment grain size, saturation and bulk density are key factors in determining sediment removal and disposal methods and options. For example, sandy sediment with low saturation levels and high densities is more capable of supporting heavy equipment such as dozers and back hoes. However, these types of equipment cannot operate in the soggy conditions of highly saturated, low density, silt and clay sediment. Consequently, sandy sediment may be removed by simple excavation methods such as in-situ dozers and back hoes, while silts and clays may require more specialized and expensive techniques (to be further discussed in Chapter 6).

The disposal and/or utilization of SWMF sediment is also influenced by grain size, saturation levels and bulk densities. When initially removed, saturated sediment consistencies are more liquid than solid, which can be problematic for on-land disposal options. For example, solid waste landfill operators will not accept sediment that does not pass the EPA Regulation 347 slump test criteria. The process of sediment dewatering to meet disposal requirements can be more difficult and expensive for highly saturated silts and clays than for less saturated sands and gravels. Better project planning may therefore be achieved by determining saturation levels and dewatering requirements prior to sediment removal.

SECTION III. SEDIMENT REMOVAL AND DISPOSAL

6 Sediment Removal Methods

There are a variety of sediment removal and disposal methods suitable for storm water sediment. The best option will depend on several factors such as: design, environmental criteria, social, and monetary aspects. In terms of sediment removal methodology, a feasible project must:

- have a reasonable budget and time frame;
- overcome site-specific obstacles (e.g. re-routing stormwater runoff, working with limited areas for access, or de-watering, working with neighbours with regard to noise, odour and aesthetics);
- minimize re-suspension of sediment into the water column and impacts to downstream water quality (fish, recreational objectives);
- identify and remove only sediment (unless purposely increasing depth to provide additional storage volume and extend the maintenance cycle – at the expense of having a deeper facility with the concerns associated); and,
- provide for disposal of the removed sediment in a safe and acceptable manner.

Traditional removal techniques have employed either: a) 'mechanical' dredging/excavators, or b) 'hydraulic' (or suction) dredging. The advantages and disadvantages of each technique are discussed below.

Operators may have an initial tendency to consider mechanical excavating and dredging for SWMF sediment removal. This preference is primarily due to familiarity, relative size of equipment and accessibility to the sites. However, operators should not dismiss the use of alternative dredging equipment that can be better suited for this type of operation, particularly if it will be used repeatedly in several locations. An economic analysis that uses up-to-date cost estimates and detailed scheduling of the different alternatives is highly recommended during the overall planning stage.

6.1 Mechanical Dredging/Excavating

Mechanical dredging is a century-old sediment removal process used routinely for creating or maintaining suitable depths for navigation in harbors, rivers, and canals, and for foundations for marine and river construction. Mechanical dredging involves the removal of sediment from undrained water basins, while mechanical excavating involves the removal of sediment from drained basins. Both mechanical dredging and excavation projects involve the use of traditional earthmoving equipment such as excavators, clamshell diggers, etc., which are most effective in the removal of sediment with firm consistencies and substantial depths. By definition, mechanical dredging using a conventional clamshell bucket is typically limited by inefficient cuts into the bottom which creates potholes. This requires multiple excavation cycles to complete the job. The multiple excavation cycles impose additional costs, while the incomplete capture of sediment can produce considerable sediment loss and re-entrainment (Priore et al. 1996).

With mechanical dredging, sediment is excavated without entraining substantial volumes of excess water. The sediment may be deposited directly on-shore, or it may be loaded into trucks and transported to the disposal site. Sealed truck bodies are required to prevent sediment leakage along the haulage route.

A comparison of the advantages and disadvantages of mechanical dredging is as follows.

Advantages

- Commonly used and widely available at reasonable rates.
- Small working areas are accessible by smaller mechanical units.
- Produces a drier material compared to hydraulic dredging, thereby reducing the costs required for subsequent sediment dewatering.

Disadvantages

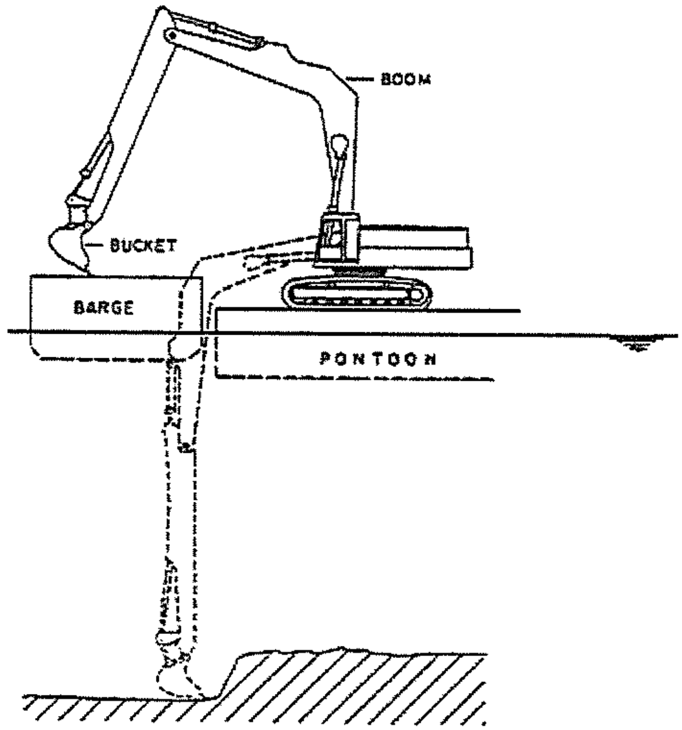
- Basin accessibility problems can occur if sediment is too soft to support the weight of mechanical excavation equipment.
- Limited reach distances reduces accessibility to wide basins by on-shore equipment.
- Mechanical dredging of undrained ponds can cause sediment re-suspension and transport to downstream areas.

Mechanical excavating/dredging equipment includes: Excavators (Front and Backhoe), Clamshell Buckets, and draglines.

6.1.1 Excavator

Front excavators (see ***Figure 6-1***) scoop 'back' and 'up' into the digging face with a semi-open bucket on an articulating boom. The distance of on-shore excavation activities is limited by reach of the boom, therefore various excavator dealers should be contacted prior to the selection of this methodology so that the machine specifications can be confirmed. Excavators have more control and less sediment spillage than occur with draglines (see ***Section 6.1.3***). Excavators combine the agility of the clamshell and digging force of the power shovel.

Special excavator adaptations are also available. For example, amphibious excavators work well in shallow marine environments and can remove debris and sediment. This type of technology is also used year round for ice-breaking and averting ice jams. The average removal rate with mechanical dredging is about 50 m^3/hour, with a work cycle of less than one minute. This technology was used at Bluffers Park in Scarborough (City of Toronto), to remove about 35,000 m^3 of silty sand build-up.



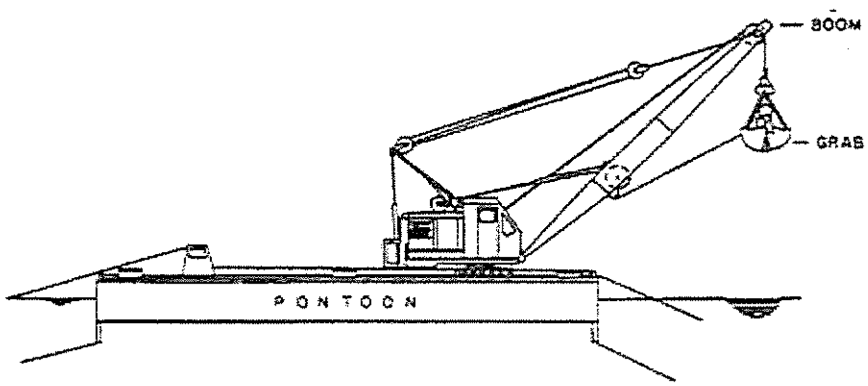
(Source: MOE 1994b)

Figure 6-1 Excavator

6.1.2 Clamshell Bucket

The clamshell bucket (see ***Figure 6-2***) mechanically digs, captures, and lifts sediment which is either dropped into a barge and transported to a disposal site or sidecast from the bucket onto land or into a land-based vehicle for transport. For a 3.8 m^3 bucket digging a 50% volume of solids over a 2-minute cycle, a production rate of 57 m^3/hr would be expected (Cushing 1998).

Mechanical excavating equipment and operational procedures do not minimize resuspended material or the volume of over-dredged material, both of which are important in maintenance projects. Because conventional excavator accuracy is typically 15 cm, several passes may be necessary at successively greater depths to remove sediment in layers. The bottom pass can result in overdredging, as can extending the dredgehead laterally beyond the target area. Also dredging in passes consumes time, thereby increasing costs and prolonging the effects of resuspension



(Source: MOE 1994b)

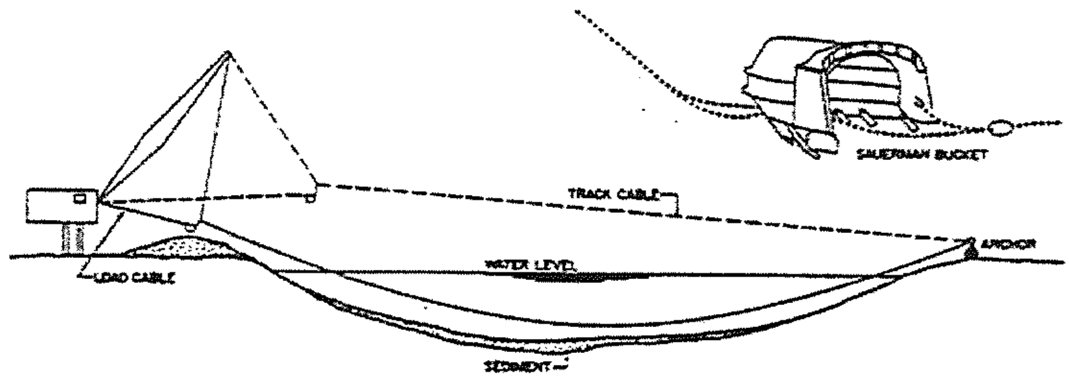
Figure 6-2 Clamshell dredge.

Cable Arm Environmental Clamshell

The main advantage of this technology is that it removes sediment layers with less disturbance than a conventional bucket. The fixed arms of traditional buckets are replaced by cables yielding a lighter bucket with a horizontal bite that does not pit the bottom. During the lowering phase, water trapped in the bucket is allowed to flow out, reducing the pressure on the sediment as the bucket nears the bottom, thereby preventing a turbidity plume from developing. As the bucket is raised, overlapping seals prevent sediment loss and water gain. The extra wide footprint and level cut minimize the windowing effect common with other clamshell buckets. When the clamshell reaches the surface, water trapped above the sediment prior to the cut is allowed to drain, further reducing sediment dewatering needs. The clamshell removes sediment in virtually all *in-situ* moisture levels. During lifting, the bucket creates 10 times less turbidity than conventional products. The excavated sediment may then be loaded into transportation vehicles and taken to the disposal site, (Priore et al. 1996).

6.1.3 Dragline

Dragline dredging (see ***Figure 6-3***) uses wire ropes from the top and base of the boom to the bucket, to cast the bucket forward and then pulls the bucket back through the material to be excavated. Digging force is a function of the bucket weight, the winching force and the relative slope of the excavation face to the bucket. The bucket does not have any moving parts and cannot close around the load. When working with non-cohesive materials, this becomes a disadvantage due to washout. It is frequently used to remove coarse sands and gravels.



(Source: MOE 1994b)

Figure 6-3 Dragline dredge

6.2 Hydraulic (Suction) Dredging

In comparison with mechanical methods, hydraulic dredging is a relatively new technology. Equipment is typically comprised of a cutting head that loosens the sediment and mixes it with water, and a pumping system that pumps the slurry either to a barge or a shore-based holding area. Hydraulic dredges typically entrain volumes of water of 80-95%, in order to achieve a slurry for pumping (MOEE 1994a). The equipment can vary in size, depending on the needs or access restrictions of the site. Most removal equipment has been designed to operate at depths of up to 10 m. When the basin cannot be de-watered, hydraulic dredges offer the advantage over mechanical dredging because they produce much lower turbidity than mechanical diggers. As a result, cost for screening can be reduced.

A comparison of the advantages and disadvantages of hydraulic dredging is as follows.

Advantages

- Works well in soft, silty sediment
- Particularly suited to larger basins.
- Suctioning mechanism minimizes sediment resuspension transport downstream, requiring less screening.
- Removes sediment more evenly throughout the basin.

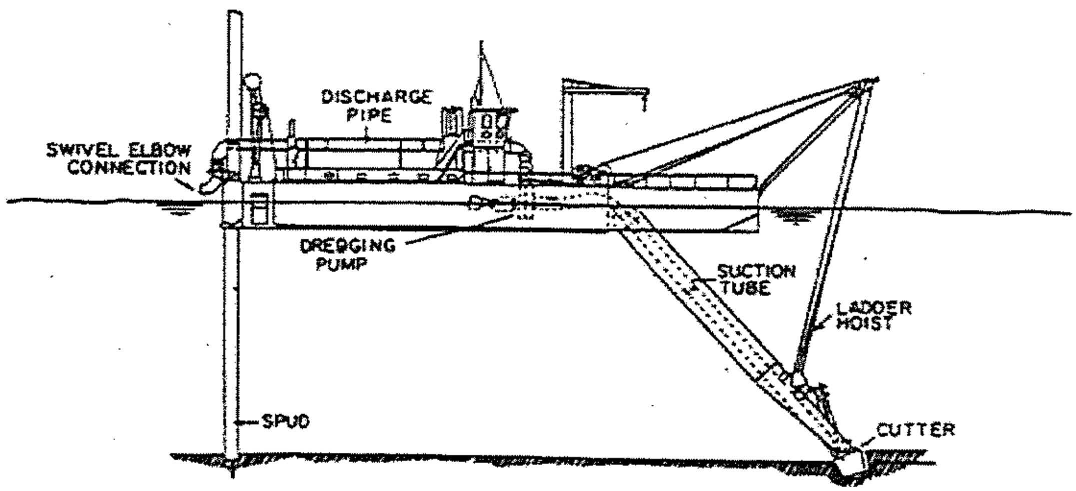
Disadvantages

- Slurry process produces highly water-saturated sediment, which increases subsequent dewatering costs.
- Limited equipment accessibility to smaller ponds.
- Requires specialized equipment and higher expertise. Suction dredging equipment and operation crews may need to be brought in from extended distances, which requires more detailed and careful planning.

Hydraulic dredging equipment includes: Cutterhead hydraulic dredge, Cutter Suction Dredge, Horizontal Auger Hydraulic Dredge, and Mud Cat Hydraulic Dredge.

6.2.1 Cutterhead Hydraulic Dredging

A common hydraulic dredge is the cutterhead dredge (see ***Figure 6-4***), which uses revolving blades to loosen sediment, suctions the sediment-water slurry through a pipe, and transports the material into a discharge pipeline to a holding container or transportation vehicle. The cutterhead digs into the sediment in an arc-shaped sweeping motion initiated by the pulling motion of anchored swing winches. At the end of the cut, the dredge is walked forward for the next cut by the pivoting action of two rear cylindrical spud-piles, which would be alternatively lifted from and anchored into the pond bottom (Cushing 1998).



(Source: MOE 1994b)

Figure 6-4 Cutter Suction Dredge

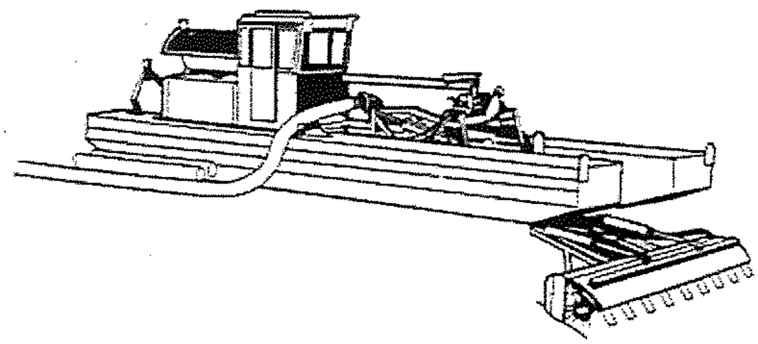
This is a costly and time intensive technology typically used for large projects such as harbor dredging and is not considered to be suitable for smaller projects (MOEE 1994a). One drawback of cutterhead dredging is that it can undercut banks. Also, underwater vegetation should be removed before hydraulic dredging begins to avoid production delays caused by the tangling of plants around the cutterhead or auger. The cutterhead dredge requires a minimum of 0.6 to 0.9-meter water depth. Because the cutterhead and the pump suction head are physically separated, the intervening space allows some suspended sediment to escape into the water column.

6.2.2 Horizontal Auger Hydraulic Dredge

Another common type of hydraulic dredge is a horizontal auger dredge, equipped with a cutterhead that cuts layers of sediment and has spiral augers that move sediment laterally toward the center of the augers. From here the sediment is removed by a suction pipe and pump.

6.2.3 Mud Cat Hydraulic Dredge

The Mud Cat is a portable suction dredge (see ***Figure 6-5***) with shallow water capabilities and is better suited to SWMF sediment removal projects.



(Source: MOE 1994b)

Figure 6-5 Mud Cat Dredge.

6.2.4 Pneuma Hydraulic Dredge

This technology uses hydrostatic pressure to fill containers with sediment. When the cylinders are full, the sediment is forced up a delivery tube by compressed air. The pump has no rotating parts or mechanisms in contact with the sediment, minimizing resuspension problems. The unit is compact and portable, which is beneficial to mobile operations from a small barge or an on-shore crane. In loose sediment, the pump inlets are lowered directly into the deposit. In more cohesive materials, a scoop or cutterhead is mounted to the pump body to feed loosened material to the suction inlet and the unit is winched through the deposit. Sediment is pumped as slurry (up to 70%) through the discharge line to the on-shore transportation vehicles.

6.3 Sediment Re-suspension Controls

Sediment resuspension is of particular concern when significant sediment transport can occur downstream or when habitat protection within the reservoir is necessary. The former is especially important in ponds where flow by-pass cannot be provided at the inlet. Habitat protection may be necessary in older, multi-purpose reservoirs not strictly designed for storm water treatment.

If the pond cannot be drained, several approaches to prevent sediment resuspension can be considered. Re-suspension is lowest with cutter suction dredges. With cutter suction dredges the sediment losses occur predominantly at the cutter head level and may not appear in the surface waters. Practitioners can minimize re-suspension disturbances through operational controls, including reducing cutterhead rotation speed, slowing dredgehead movement, increasing suction rate, slowing movement and placement of spud piles and swing anchors. However, these controls reduce production rates and increase the volume of water removed, thereby increasing the cost for dewatering/disposal. Clamshells and excavators generate comparatively higher turbidity levels, especially in unconsolidated fine-grained sediment. Sediment spillage occurs as the filled buckets are raised through the water column and swung toward the temporary storage area on shore or to receiving dump trucks.

One of the best options in undrained facilities is the use of silt curtains. These can isolate the area being dredged from the rest of the storage.

A planning option that can minimize sediment resuspension and transport is to schedule the sediment removal maintenance during the driest month in the year (e.g. August) or during winter conditions, when significant rainfall or snowmelt runoff is less likely.

7 Sediment Disposal

Sediment disposal can be a simple task in the project. However, disposal can also be a very expensive task. The best option is one that minimizes costs while adhering to relevant regulations and guidelines. These regulations determine which options are permitted based on sediment contaminant concentrations and the water content.

7.1 Sediment Water Content and Dewatering Considerations

Sediment dewatering or bulking (reducing the percentage of water by adding water-absorbing solid matter) will be necessary when:

- Sediment does not meet the EPA Regulation 347 "slump test" requirements for landfill disposal as solid waste.
- Sediment needs to meet the requirements of other disposal options such as fill and daily landfill cover, etc.;
- Sediment cannot be easily transported without spilling slurry on the road; and/or,
- It is necessary to minimize the weight of sediment to be disposed (de-watering only).

It should be noted that dewatering is not always necessary. For example, if disposed in an open agricultural field with proper spreading, or if disposed in a suitable area with a proper method of transportation to the site as well as sufficient erosion control at the disposal site, dewatering/bulking can be avoided. However, if required, the ease of dewatering will depend upon several factors:

1) Degree of Water Saturation: The higher the water content the more time, cost, and/or effort to dry it or bulk it.

2) Sediment Grain Size Distribution: Typically, the porosity (volume of voids/unit volume of 'bulk' sediment) and therefore the potential water content per unit volume of fine grain sediment (such as silts and clays) is typically higher than equally-compacted course sands and gravel, which have faster percolation rates. Consequently, fine sediment requires more dewatering efforts than course sediment.

3) Available space for spreading and evaporation: Relatively large areas of land are required to spread sediment for air drying and dewatering. As discussed further below, a general rule of thumb for fine sediment is a drying space of 2.5 m^2 / m^3 of sediment, while course sediment requires a drying space of 1 m^2 / m^3 of sediment (Dainty 1998).

4) Available budget: The methods and materials used for dewatering are also affected by budgetary considerations. For example, budget constraints may determine that less efficient, less effective methods be used instead of more expensive, more efficient methods (see ***Appendix G*** for a list of technology descriptions).

Sediment Dewatering-Bulking Methodologies and Case Studies

Methods for 'solidifying' sediment vary both in process and cost. Removal experiences in the City of Nepean (Merivale and Bentley Ponds) explored several alternatives (CG&S 1997). The objective of their work was to identify the most effective method of dewatering through both drying and bulking (see ***Appendix H***). The study concluded that, in their case, mixing with straw was the most effective and least expensive method for reducing water content. Sediment bulking was also used in the City of Mississauga at Lake Aquitaine, where bulking was done with the addition of sawdust.

In contrast, SWMFs in the Town of Markham at the Toogood Pond, in the City of Toronto-Scarborough District at the Bluffers Park facility, and in the Town of Uxbridge at the Lincoln Homes, used the evaporative air drying techniques. Benson and Sill (1991) have theoretically analyzed in detail the method of evaporative drying of dredge material. The evaporation potential from a saturated surface depends on several factors such as net radiation at the surface, wind velocity, air temperature and humidity. The air drying technique can be used effectively for the following spreading criteria (Dainty 1998):

i) Fine sediment requires a drying space of approximately 2.5 m^2/m^3 of sediment. Adequate dewatering levels can be achieved by spreading the sediment to a maximum depth of 425 mm for a drying period of approximately six days (without rain).

ii) Course sediment requires a drying space of approximately 1 m^2/m^3 of sediment. Adequate dewatering can be achieved by spreading the sediment to a maximum depth of 1 m for a drying period of 3 days (without rain).

Sediment removal projects in the City of Kitchener at Victoria Lake and in the City of Waterloo at Silver Lake did not require dewatering. In Kitchener, the sediment was deposited directly into a closed gravel pit. In Waterloo, sediment was spread directly onto an agricultural field.

7.2 Sediment Chemistry Considerations

Sediment chemistry and the regulations and guidelines related to disposal have been discussed in ***Section 5.3*** above. To identify the most suitable disposal option one must consider the cost and the regulatory requirements. From the experience to date the options are:

1) Landfill Disposal

Typically SWMF sediment does not have contaminant levels high enough to be classified as registerable waste, and therefore do not require disposal in a registered landfill site. However, landfill disposal may be necessary based on the test results in accordance with the EPA Regulation 347 Leachate Test and the GCSO criteria. Two of the eight sediment removal and disposal cases investigated (25%) required disposal at a registered landfill facility (non-hazardous). Landfill disposal will be the most expensive option due to tipping fees and the cost of dewatering to meet slump test requirements.

2) Upland Disposal

Land spreading in industrial or commercial areas, residential, or agricultural land is the most common option for disposal, based on the case studies reviewed for this guide. However, the approval requirements for upland disposal are somewhat ambiguous due to the lack of specific disposal criteria and lack of widespread experience with SWMF sediment. The best course of action is to clarify the requirements of the District MOE office. The first step in the process will be to identify the list of contaminants to be included in the bulk analysis test to be compared to the GCSO criteria. Depending on these results, the sediment may be approved for use as agricultural soil supplements, development fill, daily landfill cover, winter road sanding operations, etc.

From experiences in Ontario, there may be other 'wrinkles' in the selection process of a disposal site. In some cases, approvals from other regulatory agencies and additional chemical analysis may be necessary. For example, sediment with constituent concentrations passing the GCSO Table A - Agricultural Criteria may not be approved as a soil supplement if the nutrient levels do not meet the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) requirements. In this case the sediment nutrient levels would need to be analyzed and compared to OMAFRA criteria. Sediment from one of the eight case studies investigated were spread on agricultural lands.

Once the GCSO tests are complete, the use of sediment for construction fill is a viable alternative that does not typically cost anything beyond transportation and possibly, dewatering. The proximity of the disposal area to the SWMF has an impact on the transportation costs. Sediment from two of the eight case studies were used as residential fill.

Daily landfill cover is another option to be considered, which also does not cost anything beyond dewatering and transportation expenses. Sediment from two of the eight case studies were used as daily landfill cover.

Some upland disposal options do not require tipping fees or dewatering costs. For example, in one of the case studies, sediment was transported by sealed trucks to a local closed gravel pit where it was directly deposited without any dewatering.

3) Open Water Disposal

Based strictly on regulation, open water disposal is also an option for sediment disposal. However, SWMF sediment contamination levels are typically well above the Lowest Effect Level (LEL), which would prevent approval for open water disposal. None of the eight sediment removal and disposal case studies utilized the open water disposal option. However, open water disposal would not require tipping fee payments or sediment dewatering costs and as such, is the least expensive disposal option, depending on transportation distances from the SWMF to the disposal site. Unless disposing into facilities such as engineered lagoons, it would be difficult to justify open water as a disposal option on the basis that the objective of storm water treatment is to prevent sediment from reaching receiving water bodies.

7.3 Sediment Remediation

SWMF sediment remediation is usually costly and may not be necessary unless highly contaminated sediment is identified as hazardous wastes. As previously discussed, typical SWMF scenarios would not even be classified as registered waste. However, in cases where the SWMFs have received unusually high contamination levels, the following remediation technologies may be considered (Civil Engineering 1996).

1) A thermal destruction process that heats sediment to evaporate organic compounds. The organic vapors are then destroyed at higher temperatures. Metals remaining in the sediment can then be treated by a separate process.

2) Sediment is heated to destroy the organics and melt the inert sediment. Metals present are immobilized. The material is then pulverized and mixed with cement to yield a blended cement suitable for construction projects.

3) Another thermal destruction process would destroy the organic constituents with intense heat and create a glasslike material with metals immobilized within.

4) Blending immobilized sediment with cement will harden and immobilize metals and organic compounds.

5) Mixing dredged materials with an organic solvent will remove the organics for subsequent treatment and disposal, and is followed by cement stabilization to immobilize metals.

If contaminant recovery is not feasible, pollutants may be extracted and fixed to prevent leaching and release to the environment. Extraction techniques produce sediment that can be used for landfill cover, road or paving sub-base materials, construction backfill, landscaping or composting. The beneficial use of the treated sediment can provide a considerable financial contribution to the overall project.

8 Removal and Disposal Costs

Cost estimating is important for determining single or multiple-project feasibility and for site-specific budgeting prior to tender. Although removal and disposal costs are site specific, a generic approach can be used to estimate the costs. This section compares the costs for each of the eight case studies found in Ontario and presents a method for estimating costs for a generic project. Care should be taken when preparing the cost estimate as the assumptions used in preparing this estimate may not be valid for another site specific case.

8.1 Summary of Costs for Case Studies

The total project cost from each of the eight case studies (refer to ***Appendix D***) was translated into a per m^3 of sediment removed cost for comparison purposes. Costs were also adjusted to 1997 dollars to reflect the increase in construction costs over time. The costs are summarized in ***Table 9***.

Table 9: Summary of Sediment Removal and Disposal Case Studies

Site	Year Cleaned	Removal Method	Dewatering Method	Disposal Method	Cost [1] ($\$/m^3$)
Merivale, Nepean	1997	Mechanical	Bulking	Landfill	124
Bentley, Nepean	1997	Mechanical	Bulking	Landfill	669
Aquitaine, Mississauga	1994	Mechanical	Bulking	Daily Cover	62
Toogood, Markham	1997	Mechanical	Air Dried	Residential	32
Bluffers Park, Scarborough	1995	Mechanical / Hydraulic Dredging	Air Dried	Residential	162
Lincoln, Uxbridge	1994	Mechanical	None	Daily Cover	33
Victoria, Kitchener	1997	Mechanical	Air Dried	Gravel Pit	18
Silver, Waterloo	1997	Mechanical	None	Agricultural	14

Note: [1] Costs are in 1997 dollars based on a construction cost index of 1.6% per annum.

Although the individual item costs (i.e. sediment testing, removal, disposal) for each case study were unavailable, the overall cost per cubic meter (m^3) clearly show that disposing the excavated sediment in a landfill increases the cost significantly. There are also other reasons why the above results should be interpreted with care. For example, at the Bluffers Park Pond project, the use of hydraulic dredging equipment was an experiment and may have contributed to the higher cost of removal. Furthermore, there is a large range in sediment removal costs for the mechanically excavated ponds (non-hazardous material) from $\$14/m^3$ to $\$62/m^3$. This difference in cost could be a result of the bulking method, the transportation costs from each facility to the disposal area, or the amount of restoration done. Therefore, site specific criteria have a significant influence on the final cost.

Refer to ***Appendix D*** for a more detailed summary of each of the eight case studies.

8.2 Method for Estimating SWMF Sediment Removal Costs

Chapter 4 outlined the methods for estimating the quantity of sediment to be removed. Chapters 6 and 7 outlined the process for selecting the proper sediment removal and disposal methods. Once these factors are known, a cost estimate can be prepared for the operation. As an example of what should be considered before preparing the cost estimate, a generic SWMF was chosen with the following characteristics:

- The SWMF is a wetpond with a 50 hectare contributing drainage area from a residential subdivision.
- The SWMF was originally designed for Level 1 protection (i.e. 80% TSS removal).
- The SWMF was built 15 years ago and has never been cleaned.
- The sediment was tested and determined to be non-hazardous, and can be used as construction fill.
- Mechanical excavation was chosen as the appropriate method for sediment removal.
- The pond has no maintenance by-pass so pumping of the storm flow will be necessary in the event of rain events during maintenance.
- The aquatic vegetation will be completely removed and re-instated. There are no opportunities to transplant the material in the vicinity of the SWMF.

With the above information and the original design drawings for the SWMF, a cost estimate can be prepared, based on the individual activities to be performed. Care should be taken when preparing the estimate to ensure that the unit rates selected are reasonable. It is suggested that a contractor familiar with SWMF sediment removal operations be consulted in the preparation of the cost estimate. For the above generic SWMF, a present value unit cost of **$65/m^3** of sediment was estimated. The detailed breakdown of the individual activities upon which the estimate was based is given in ***Appendix I***.

Cost estimates for SWMF sediment removal can also be used by municipalities as a tool for planning future capital budgets. In the above example, if the sediment removal cost is $65/m^3, then the future value of this cost, based on 2% per annum (construction cost index), is $87/m^3. Alternatively, if money were set aside on a yearly basis, based on 5% per annum, then the yearly cost would be about $4/m^3, which over 15 years is a nominal contribution of $60/m^3. Therefore, if money were set aside for SWMF maintenance either at the beginning of the SWMF's service life or on a yearly basis, then the per m^3 cost would be less than it would be without allocating money for the operation until maintenance was required.

SECTION IV. CONCLUSIONS AND RECOMMENDATIONS

9 Conclusions

1) Current regulations require the use of SWMFs. They provide a very useful function and their need for maintenance is a logical consequence of their effectiveness. It is important that owners clearly know the design criteria, as it will affect maintenance requirements.

2) Maintenance timing can be forecasted using literature values for loading and removal rates or through field measurements. Field measurements will provide more accurate estimates and will provide information to refine the site-specific loading and removal estimates. This was shown by the variable accumulation rates found between different SWMFs case studies.

3) Sediment chemistry generally varies according to land use types, with residential land uses having a tendency for lower pollutant concentrations than commercial and industrial land uses. Most SWMF sediment contaminant levels are not high enough to require landfill disposal. However, sediment must be tested and compared with Regulation 347-Leachate Test and the *Guidelines For Use At Contaminated Sites In Ontario* (GCSO),

4) Under the GCSO, although sediment may be clean enough to be spread as construction fill, they may be restricted to placement below vegetative root zones due to elevated chloride levels, typical of SWMF sediment.

5) There are a variety of mechanical and hydraulic dredging technologies available. The choice of technology for a given site will depend on factors such as site accessibility, volume to be removed, options to by-pass inflow runoff, and in-situ sediment drying potential, equipment availability, costs, and scheduling.

6) In cases where sediment resuspension and downstream transport is a concern, a silt screen can be considered to separate the area being dredged from the rest of the storage. Another planning option that can minimize sediment resuspension and transport is to schedule the sediment removal maintenance during driest month in the year (e.g. August) or during winter conditions, when significant rainfall or snowmelt runoff is less likely.

7) The methods to decrease the sediment water saturation include evaporative drying and/or bulking with other solid material. Fine sediment requires a drying space of approximately 2.5 m^2/m^3 of sediment. Adequate dewatering levels can be achieved by spreading the sediment to a maximum depth of 425 mm for a drying period of approximately six days (without rain). Course sediment requires a drying space of approximately 1 m^2/m^3 of sediment. Adequate dewatering can be achieved by spreading the sediment to a maximum depth of 1 meter for a drying period of 3 days (without rain).

8) Disposal destinations include registered hazardous or non-hazardous landfills, landfill daily cover, land spreading in industrial or commercial areas, residential, and agricultural land. Disposal in landfill, though expensive, will be required if the sediment contains high contaminant concentrations when compared with the Leachate Test and/or the GCSO. Of the eight case studies, destinations of the removed sediment included two to registered landfills, two as residential fill, two as daily landfill cover, one to a gravel pit, and one was spread in agricultural fields.

9) Sediment removal and disposal costs can vary substantially depending upon the site conditions that are unique to each SWMF.

10 Recommendations

The following section provides recommendations for a successful SWMF sediment removal operation and gives suggestions for SWMF design features that help maintenance operations.

1) No information was found during the course of the study regarding sediment accumulation rates in facilities designed under the *MOE Storm Water Management Planning and Design Manual* (SWMP). This information would be very useful to provide better estimates of when sediment removal from newer and numerous facilities will be required. A field monitoring program of several facilities servicing single land uses or mixed land uses should be started and the sediment accumulation rates recorded from the time of assumption.

2) A well planned and coordinated sediment maintenance operation cannot be over emphasized. Owners should include a comprehensive inventory of all SWMFs and determine the approximate maintenance intervals. In some cases, depending on the permanent pool storage provided, this interval may be several decades.

3) SWMF sediment volumes should be measured routinely to account for an increase or decrease in accumulation rates caused by watershed land use changes. Routine inspections should also include spot checks of sediment chemistry to detect unusual increases in contaminant levels and/or the presence of hazardous substances caused by illegal discharges. Early detection and prevention of impending toxicity problems will avoid the necessity for costly site clean-ups.

4) A sediment chemistry analysis parameter list should be derived to include those parameters that approach or exceed agricultural, residential, commercial and industrial sediment disposal criteria. The necessity for more detailed analysis can be determined based upon the results of the site inspection and sediment analysis. Consultation with regulatory agencies should be done early in the process as well as during each stage (refer to ***Drawings 1-5*** for flow chart summary).

5) Sediment removal budgets should be created considering that costs can vary significantly depending upon the unique conditions of each site. Preparatory data collection and site inspections provide the knowledge base that is essential to the development of successful and cost efficient SWMF sediment removal projects. During the owner's initial sediment removal experiences with some facilities, an allowance for a significant contingency item should be considered in the budget (e.g. 20-40% of total cost). Experiences with highly contaminated sediment in Nepean, Ontario, suggest that operators should be prepared for a significant increase in cost above their estimates if high contamination is found.

6) Although operators may have an initial tendency to consider mechanical excavating and dredging for SWMF sediment removal, the use of alternative dredging equipment should be considered. Alternative dredging equipment may be better suited for SWMF sediment removal, particularly if it will be used repeatedly in several locations. An economic analysis of different alternatives is highly recommended during the overall planning stage using up-to-date cost estimates and detailed scheduling.

7) The following SWMF design features should be reviewed for feasibility of implementation in future SWMF designs:

i) Allowance for Permanent Pool Drainage

In many cases, permanent pool volumes in SWMF are provided below the outlet invert elevation. This is especially true in facilities located in valley-lands or table lands with limited flexibility in regards to the outlet invert elevation. However, with new designs, there might be opportunities to place a maintenance outlet at the bottom of the facility providing positive drainage from the permanent pool. To avoid sediment clogging of the maintenance outlet, a riser structure design could be considered.

ii) Maintenance Access Road

A maintenance access road allows vehicles to gain access to the SWMF. The slope of the access route should be reviewed to ensure it is conducive to maintenance vehicles. Access to inlet and outlet structures, flow splitters and by-pass manholes/chambers is also important. Access to an outlet structure for a pond can be provided by placing the outlet in a chamber on the embankment.

iii) Maintenance By-pass System

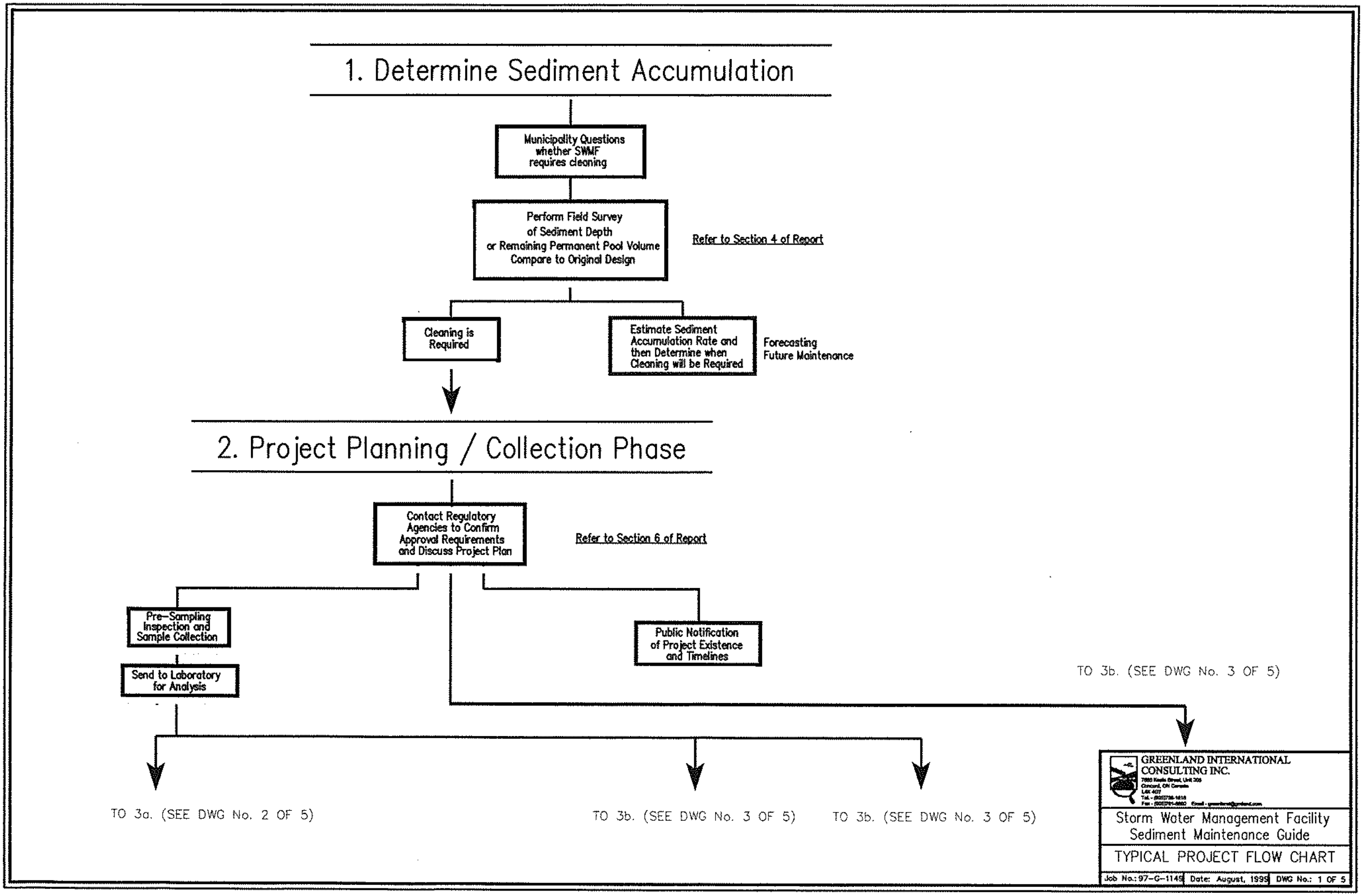
If possible, a storm water by-pass pipe and sluice gate at the inlet should be used to re-route incoming water during sediment removal activities.

iv) Over-sizing SWMF Storage

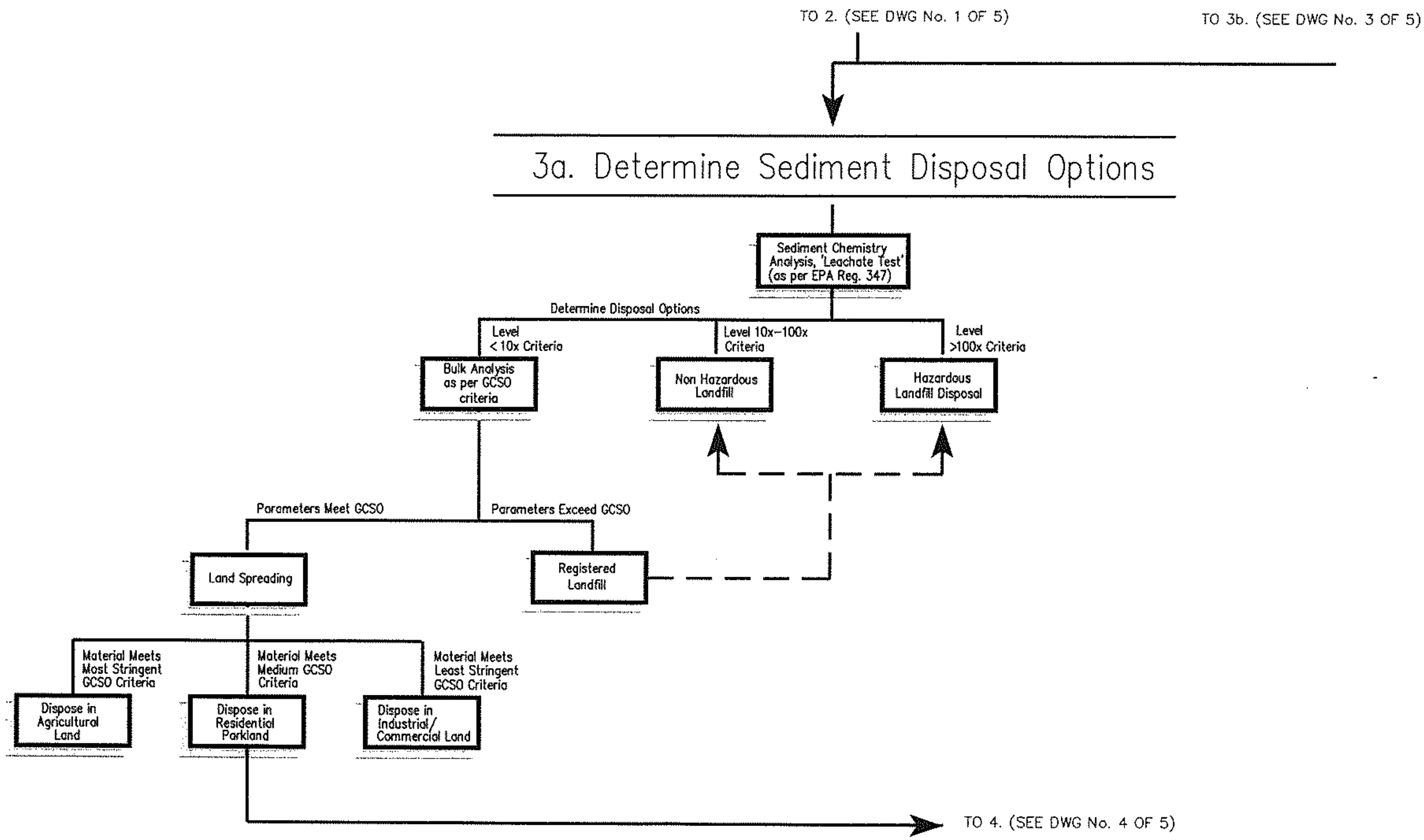
SWMF over-sizing will enhance water quality improvement efficiency while reducing required sediment removal frequencies.

v) On-site Sediment Storage Areas

Sediment dewatering and disposal costs can be reduced if temporary on-site storage areas are provided to allow the sediment to dry before transporting to the off-site disposal area.



1. Determine Sediment Accumulation
Municipality Questions whether SWMF requires cleaning
Perform Field Survey of Sediment Depth or Remaining Permanent Pool Volume Compare to Original Design
Refer to Section 4 of Report
Cleaning is Required
Estimate Sediment Accumulation Rate and then Determine when Cleaning will be Required
Forecasting Future Maintenance
2. Project Planning / Collection Phase
Contact Regulatory Agencies to Confirm Approval Requirements and Discuss Project Plan
Refer to Section 6 of Report
Pre-Sampling Inspection and Sample Collection
Send to Laboratory for Analysis
Public Notification of Project Existence and Timelines
TO 3b. (SEE DWG No. 3 OF 5)
TO 3a. (SEE DWG No. 2 OF 5)
TO 3b. (SEE DWG No. 3 OF 5)
TO 3b. (SEE DWG No. 3 OF 5)
GREENLAND INTERNATIONAL CONSULTING INC.
Storm Water Management Facility Sediment Maintenance Guide
TYPICAL PROJECT FLOW CHART
Job No.: 97-G-1145
Date: August, 1999
DWG No.: 1 OF 5



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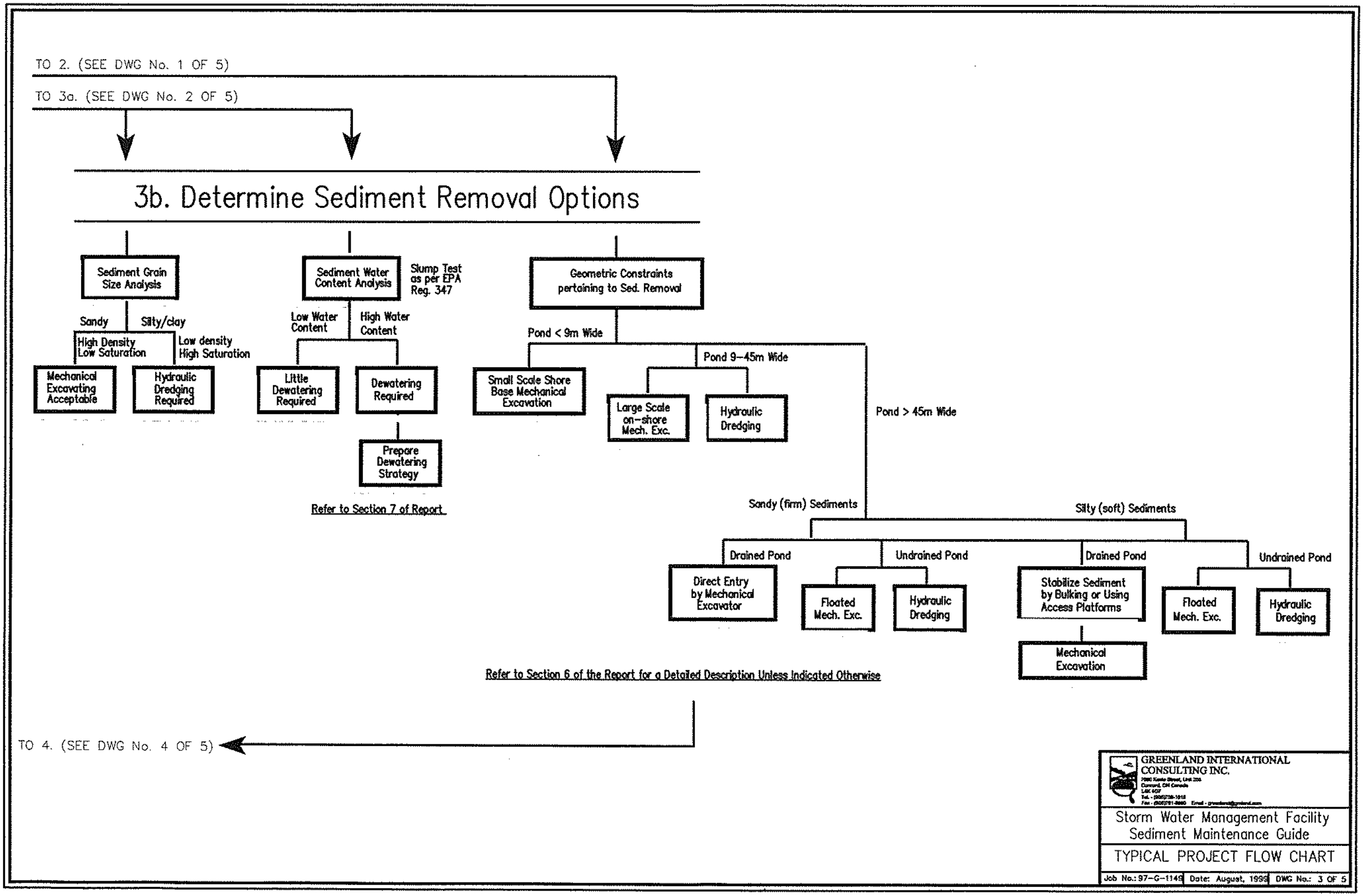
Storm Water Management Facility
Sediment Maintenance Guide

TYPICAL PROJECT FLOW CHART

Job No.: 97-G-1149 | Date: August, 1999 | DWG No.: 2 OF 5


TO 2. (SEE DWG No. 1 OF 5)
TO 3a. (SEE DWG No. 2 OF 5)
3b. Determine Sediment Removal Options
Sediment Grain Size Analysis
Sandy
Silty/clay
High Density Low Saturation
Low density High Saturation
Mechanical Excavating Acceptable
Hydraulic Dredging Required
Sediment Water Content Analysis
Slump Test as per EPA Reg. 347
Low Water Content
High Water Content
Little Dewatering Required
Dewatering Required
Prepare Dewatering Strategy
Refer to Section 7 of Report
Geometric Constraints pertaining to Sed. Removal
Pond < 9m Wide
Pond 9–45m Wide
Pond > 45m Wide
Small Scale Shore Base Mechanical Excavation
Large Scale on-shore Mech. Exc.
Hydraulic Dredging
Sandy (firm) Sediments
Silty (soft) Sediments
Drained Pond
Undrained Pond
Direct Entry by Mechanical Excavator
Floated Mech. Exc.
Hydraulic Dredging
Drained Pond
Undrained Pond
Stabilize Sediment by Bulking or Using Access Platforms
Mechanical Excavation
Floated Mech. Exc.
Hydraulic Dredging
Refer to Section 6 of the Report for a Detailed Description Unless Indicated Otherwise
TO 4. (SEE DWG No. 4 OF 5)
GREENLAND INTERNATIONAL CONSULTING INC.
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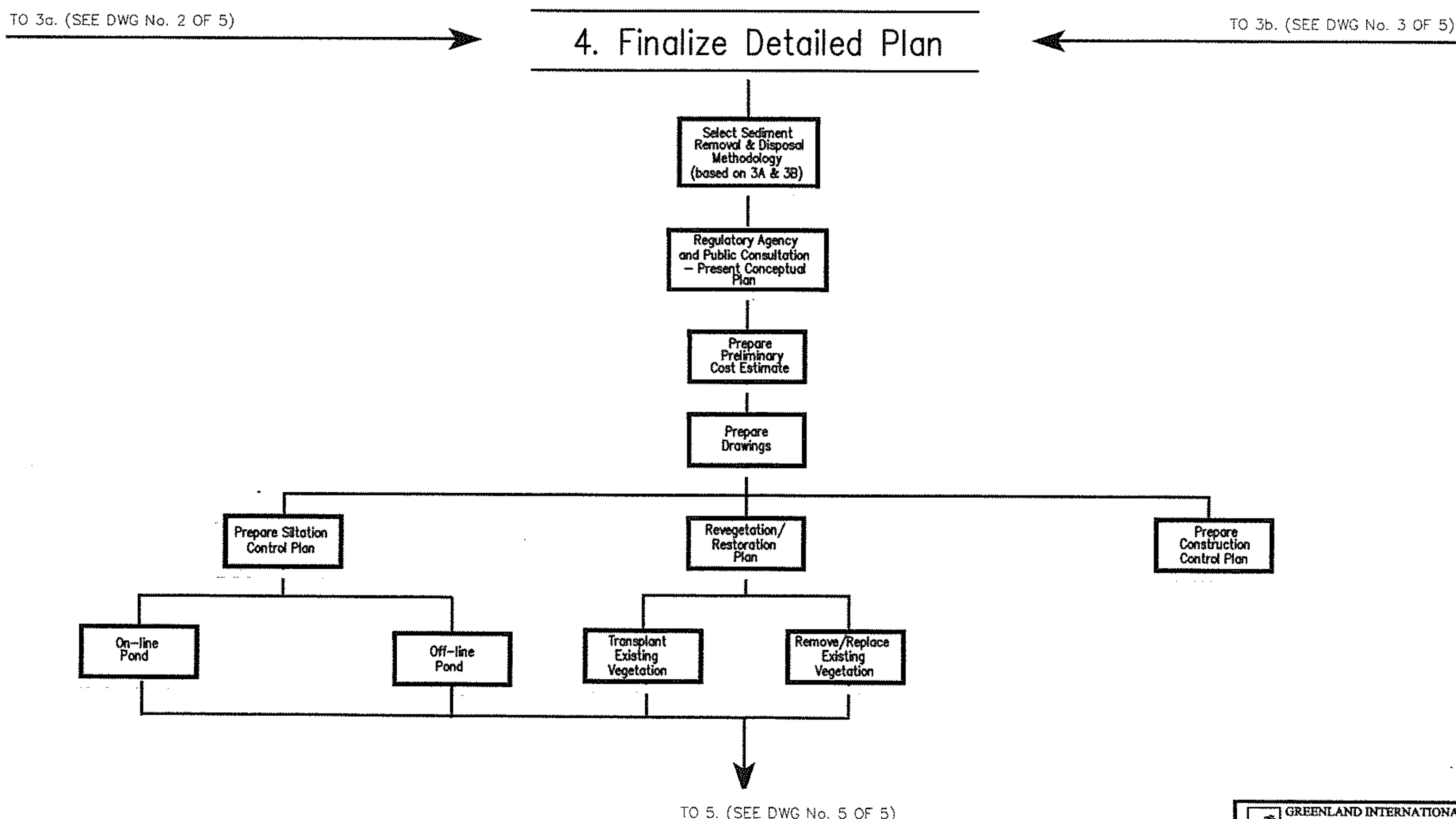
Sediment Maintenance Guide
TYPICAL PROJECT FLOW CHART
Job No.: 97-G-1149
Date: August, 1999
DWG No.: 3 OF 5



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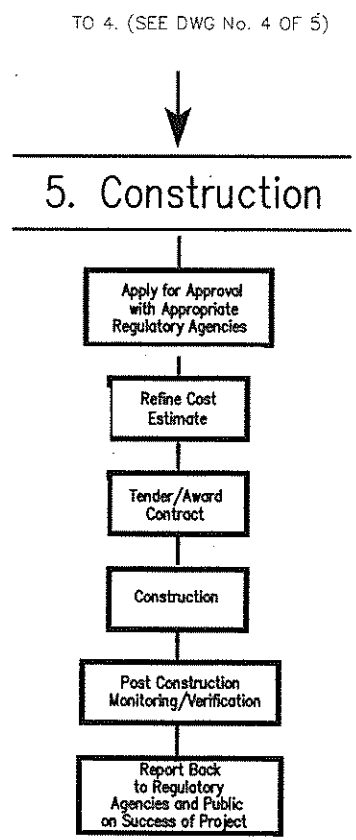
Storm Water Management Facility
Sediment Maintenance Guide

TYPICAL PROJECT FLOW CHART

Job No.: 97-G-1149 | Date: August, 1999 | DWG No.: 4 OF 5



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Storm Water Management Facility Sediment Maintenance Guide

TYPICAL PROJECT FLOW CHART

Job No.: 97-G-1149 | Date: August, 1999 | DWG No.: 5 OF 5

11 Bibliography

Bannerman, R. Baun, K. Bohn, M. Hughes, P.e. Graczyk, D.A. *Evaluation of urban nonpoint source pollution management in Milwaukee County, Wisconsin.* PB 84-114164, U.S. Environmental Protection Agency, Chicago, Ill. 1983.

Benson, R. and Sill, B. *Evaporative Drying of Dredge Material.* Journal of Waterway, Port, Coastal, and Ocean Engineering. Vol 117, No. 3, May/June, 1991.

Booth, D.B. *Stream-channel incision following drainage basin urbanization.* Water Resources Bulletin. Vol. 26 pp. 407-417. 1990.

CH2M Gore & Storrie Limited. *Sediment dewatering pilot study: Merivale Stormwater Management Facility, City of Nepean.* Prepared for the Corporation of the City of Nepean. 1996.

CH2M Gore & Storrie Limited. *Sediment characterization and review of SWMFs , City of Nepean.* Prepared for the Corporation of the City of Nepean. 1997.

Civil Engineering. *Under Way: Decontamination Pilots for Dredge Material.* American Society of Civil Engineering. November, 1996.

Cushing, Bradford S. *Falling short of the mark: the limits of dredging as a feasible technology for contaminated sediment removal.* Water Environment and Technology. , pp 61-66. June, 1998.

Dainty, Bill. *Personal communication.* Aquafor Beech Ltd.. 1998.

Duncan, G.A. and G.g. LaHaie. *Size analysis procedures used in the sedimentology laboratory*, NWRI, Burlington, Ontario. 1979.

Hall, K.J. and B.C. Anderson. *The toxicity and chemical composition of urban stormwater runoff.* Canadian Journal of Civil Enginering. 15:980-106. 1988.

Jaagumagi, R. and D. Persaud. *Sediment assessment: a guide to study design, sampling and laboratory analysis.* Ontario Ministry of Environment and Energy. 1993.

Lawrence, A.I., J. Marsalek, J.B. Ellis & B. Urbonas. *Stormwater detention & BMPs.* Journal of Hydraulic Research, Vol. 34, No.6, 00 799-813. 1997.

Marsalek, J and G.A. Larkin. *Sustainability of stormwater ponds: addressing the sediment issues.* Presented at the February 1998 Stormwater/CSO Technology Transfer Conference, Toronto. 1998.

Marsalek, J., W.E. Watt, B.C. Anderson and C. Jaskot. *Physical and chemical characteristics of sediments from a stormwater management pond.* 1997.

Mayer, T. J. Marsalek and E. Delos Reyes. *Nutrients and metal contamination status of urban stormwater ponds.* Lake and Reserv. Manage. Vol. 12, No. 3, pp 348-363. 1996.

Ministry of Environment. *The Proposed Policy for Management of Excess Soil, Rock and Like Materials.* Ontario Ministry of Environment, 1992.

Ministry of Environment and Energy. *Guideline for use at contaminated sites in Ontario.* Ontario Ministry of Environment. Queen's Printer for Ontario, PIBS 3161E01, ISBN 0-7778-4052-9. 1996, revised February 1997.

Ministry of Environment and Energy. *An integrated approach to the evaluation and management of contaminated sediments.* Ontario Ministry of Environment. Queens Printer for Ontario, PIBS 3349E, ISBN 0-7778-3845-1. 1996.

Ministry of Environment and Energy. *Stormwater management practices planning and design manual.* Ontario Ministry of Environment, 1994a.

Ministry of Environment and Energy. *Evaluating construction activities impacting on water resources: Part III - Handbook for dredging and dredged material disposal in Ontario* - Section A: legislation, policies, sediment classification & disposal; Section B: dredging, transport and monitoring; Section C: sediment sampling and laboratory analysis. Queens Printer for Ontario, PIBS 1711, E02, E02 & E03, ISBN 0-7729-4183-1. 1994b.

Ministry of Environment and Energy. *Dredged Material Sediment Sampling & Analysis Handbook.* Ontario Ministry of Environment, 1994c.

Ministry of Environment. *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario.* Ontario Ministry of Environment, 1992.

Municipal Engineers Association. *Class Environmental Assessment for Municipal Water and Wastewater Projects.* Municipal Engineers Association, June, 1993.

ONeil, J.E. *Pollution from urban land use in the Grand and Saugeen watersheds.* Ontario Ministry of Environment. 1979.

Paragon Engineering Limited. *Sedimentation Control Study for Victoria Lake.* Paragon Engineering Limited. 1993

Persaud, D., R. Jaagumagi and A. Hayton. *Guidelines for the protection and management of aquatic sediment quality in Ontario.* Ontario Ministry of Environment and Energy. 1993.

Pitt, Robert, Richard Field, Melinda Lalor and Michael Brown. May/June *Urban stormwater toxic pollutants: assessment, sources and treatability.* Water Environment Research, Vol. 67, No. 3, pp. 260-275. 1995.

Priore, William, Edward Cichon. *Sediment Management.* Water Environment & Technology, pp. 45-49. October 1996.

Schueler, W. Summer. *Pollutant dynamics of pond muck.* Watershed Protection Techniques, Vol. 1, No. 2, pp 39-46. A Publication of the Center for Watershed Protection. 1994.

Schueler, T.R. *Controlling urban runoff: a practical manual for planning and designing urban BMPs.* Washington Metropolitan Water Resources Planning Board, Washington, DC. 1987.

Shaheen, D.G. *Contributions of urban roadway usage to water pollution.* 600/2-75-004. U.S. EPA. Washington D.C. 1975.

Sutherland, Roger C. & Seth L. Jelen. *Contrary to conventional wisdom: studies show sweeping has beneficial impact on stormwater quality.* APWA Reporter, pp 8,9,23. November 1996.

US EPA. *Results of the Nationwide Urban Runoff Program.* U.S. EPA., Washington, D.C., PB 84-185-552. 1983.

Whipple, W. *Removal of urban stormwater constituents by an on-stream pond.* Journal of Environmental Planning and Management. Vol. 40 pp 5-18. 1979.

Yousef, Y.A., T. Hvitved-Jacobsen, M.P. Wanielista and R.D. Tolbert. *Nutrient transformation in retention/detention ponds receiving highway runoff.* Journal of the Water Pollution Control Federation Vol. 58: 838-844. 1986.

Yousef, Y.A., L.Y. Lin, J.V. Sloat and K.Y. Kaye. *Final Report Submitted to FDOT (FL-ER-47-91).* Tallahassee, Florida, 1991

APPENDIX A
Sediment Removal and Disposal Preliminary Questionnaire

STORM WATER MANAGEMENT FACILITY MAINTENANCE
SEDIMENT REMOVAL AND DISPOSAL QUESTIONNAIRE ✓

Contact name:	______________________	Position:	______________________
Organization:	______________________	e-mail:	______________________
Phone #:	______________________	Fax #:	______________________

Mailing address: ____
____

NOTES / INSTRUCTIONS

1) The following questionnaire is tailored to the unique SWM maintenance status of your jurisdiction:

- ✏ Please complete Sections A and D.
- ✏ Complete Section B *only if* your jurisdiction *currently has* a completed and/or active SWM facility (sediment) maintenance program(s).
- ✏ Complete Section C *only if* your jurisdiction *does not have* a completed and/or active SWM facility (sediment) maintenance program(s).

2) "*Maintenance*" refers to: accumulated sediment depth measurement, removal, disposal and quality analysis. (May also include vegetation removal and disposal -- Please elaborate on this or any other maintenance issues in the final comment section of this questionnaire.)

3) "*Completed and active*" maintenance programs refers to those SWM facilities that have already been maintained and/or are scheduled for maintenance in the near future (e.g. this year).

SECTION A: Existing SWM Facilities and (Sediment) Maintenance Programs

CRITERIA	RESPONSE
1. Number of SWM facilities currently operating within your jurisdiction.	#: ________
2. Number & age range of SWM facilities designed for water quality control.	#: ________ Age Range: ____-____ yrs
3. Does your jurisdiction currently have a completed or active facility (sediment) maintenance program? *Note:* • *If YES, proceed to → Section B (Completed/Active Programs)* • *If NO, skip ahead to → Section C (Inactive Programs)*	YES ☐ NO ☐

SECTION B: Completed/Active SWM Facility (Sediment)Maintenance Programs

QUESTION	RESPONSE
1. How many facilities have been actively maintained within your jurisdiction?	#: ____________
2. List the components of your maintenance program. • *Note: Please feel free to elaborate on the attached comment sheet.*	- Sediment depth measurement ☐ - Sediment quality analysis ☐ - Sediment removal ☐ - Sediment disposal ☐ - Other ____________
3. Would your organization be interested in contributing existing monitoring/ maintenance results and experiences toward the future development of a practical SWM Facility (Sediment) Maintenance Manual? • *Note: - If YES, you will be personally contacted for further information. It would be appreciated if you could please forward any related documents to the Greenland address as listed on the attached comment sheet.* *- Now skip ahead to → SECTION D (Recommendations)*	YES ☐ NO ☐

SECTION C: Inactive Existing and Planned SWM Sediment Maintenance Programs

QUESTION	RESPONSE
1. Which factors have contributed to the absence of a completed and/or active maintenance program within your jurisdiction? • *Note: Please feel free to elaborate on the attached comment sheet.*	- New facility (1-3 yrs old) ☐ - Satisfactory treatment efficiency ☐ - Insufficient guidance/expertise ☐ - Insufficient funding/staff ☐ - Other____________
2. Does your jurisdiction have an existing formal SWM Facility (sediment) maintenance plan for future implementation? • *Note: - If YES, move on to → QUESTION 3.* *- If NO, skip ahead to → SECTION D (Future Needs & Recommendations)*	YES ☐ NO ☐
3. Which criteria were used for the maintenance program design? • *Note: Please feel free to elaborate on the attached comment sheet.*	- BMP manual ☐ - In-house design ☐ - Other____________
4. Estimate when future maintenance activities will begin within your jurisdiction.	1 yr ☐ 5 yrs ☐ 10 yrs ☐ 25 yrs ☐ Other____________

SECTION D: Recommendations

QUESTION
1. Please list topics that you would include in a SWM Sediment Maintenance Manual. ____________________ ____________________

COMMENT SHEET

- Please discuss any other storm water management facility maintenance issues (e.g., vegetation damage caused by maintenance activities, excess vegetation growth/removal, debris removal, etc.).

- Feel free to offer any other comments or suggestions regarding the maintenance issues addressed in this questionnaire.

Thank you for your time and effort!

* *In the interests of efficiency, we would appreciate if you would forward the completed questionnaire to the Greenland Engineering fax number, (905) 761-8880, by June 19, 1998. If this is not possible, the completed questionnaire may be forward to the address below:*

Greenland Engineering
7880 Keele Street, Unit 205, Concord, Ontario, L4K-4G7
Tel. (905) 738-1818
Attention: Francine Kelly-Hooper (ext. 25), e-mail: fkelly@grnland.com

APPENDIX B

Summary of Preliminary Quesionnaire Results

PRELIMINARY QUESTIONNAIRE RESULTS

- # of questionnaires sent ....89 (sent to all Ontario municipalities with populations of greater than 8,000)
- # of questionnaires received 27 (30%)
- # of municipalities with storm water quality facilities 19/26
- # of existing storm water quality facilities 155
- Average age of existing storm water quality facilities.................................. 5 years
- Age range of existing storm water quality facilities ....1-23 years
- # of active/completed sediment .monitoring/maintenance programs 5

Questionnaire Comments/Suggestions
(Ranked in order of most to least mentioned)

1) Sediment <u>disposal</u> options and costs .... ✔✔✔✔✔✔✔✔✔✔ (10)
2) How to evaluate sediment quality for <u>disposal</u> approvals .... ✔✔✔✔✔✔✔ (7)
3) Available sediment dredging technologies .... ✔✔✔✔✔✔✔ (7)
4) Sediment <u>dredging</u> costs .... ✔✔✔✔✔✔ (6)
5) Applicable sediment <u>disposal</u> legislation .... ✔✔✔✔✔ (5)
6) How to determine <u>when to dredge</u> .... ✔✔✔✔✔ (5)
7) How to determine necessary <u>dredging frequencies</u> .... ✔✔✔✔✔ (5)

8) How to determine sediment toxicity and loading rates .... ✔ (1)
9) Effectiveness and efficiencies of existing dredging technologies .... ✔ (1)
10) Compare the maintenance costs and removal efficiencies of various SWM facility types .... ✔ (1)
11) Required storage volumes (construction and steady state) .... ✔ (1)
12) Transportation limitations .... ✔ (1)
13) Efficiency graphs (sediment accumulation and vegetative uptake capacity overtime per size and type of drainage area .... ✔ (1)
14) Re-establishment of shoreline vegetation .... ✔ (1)
15) Vegetation control .... ✔ (1)
16) Vegetation disposal .... ✔ (1)
17) Debris removal.................................. ✔ (1)
18) Fencing requirements .... ✔ (1)
19) Typical maintenance problems and suggested remedies .... ✔ (1)
20) Suggestions for improved pond designs .... ✔ (1)
22) Water quality retrofit suggestions .... ✔ (1)
22) Construction activity nuisance impacts to surrounding neighborhoods .... ✔ (1)

APPENDIX C

Sediment Removal and Disposal Detailed Case Study
Questionnaire

STORM WATER MANAGEMENT FACILITY MAINTENANCE

SEDIMENT REMOVAL AND DISPOSAL

DETAILED CASE STUDY REPORT

- August 1998 -

1.0 GENERAL INFORMATION

1.1 *SWM facility name*:

1.2 *Relevant sediment management project report(s):*

____

____

1.3 Municipality, contact name and phone number:

____

____

1.4 Project consultant, office location, contact name and phone number:

____

____

2.0 SWM FACILITY DESCRIPTION

2.1 Facility type:

wetpond with sediment forebay ❑ wetland with sediment forebay ❑

other ❑ ____________________________________

2.2 Year facility was constructed:

____

2.3 Facility size and storage capacity:

____

2.4 Design objectives:

Water quality ☐ Water quantity ☐ Recreation ☐

Other ☐

2.5 Online ☐ Offline ☐

2.6 Size of drainage area (ha):

____

2.7 Watershed land use type:

%Residential ____ %Commercial ____ %Industrial ____

%Recreational ____ %Rural ____ %Agricultural ____

3.0 PRELIMINARY INVESTIGATION

3.1 Sediment depth measurement methodology:

____

____

____

3.2 Depth of sediment at time of measurement:

____

3.3 Results of sediment grain size analysis:

____

____

3.4 Results of sediment water content analysis:

3.5 Sediment quality analysis criteria:

MOE Regulation 309 ☐ MOE's *Guidelines for Decommissioning and Clean Up of Sites in Ontario* ☐

MOE's Sediment Quality Guidelines ☐ Municipal Sewer Use By-law ☐

Other ☐

3.6 Sediment criteria exceedences:

4.0 SEDIMENT REMOVAL

4.1 Date(s) of previous sediment removal activities:

4.2 Reason for sediment removal:

Reduced storage capacity ☐ Reduced treatment efficiency ☐ Routine maintenance ☐

Other ☐

4.3 Sediment removal approval requirements:

4.4 Time of year and duration of sediment removal project:

4.5 Sediment removal equipment:

Dredge ☐ Clamshell Digger ☐ Back-hoe ☐ Bull Dozer ☐

Other ☐

4.6 Volume of sediment removed:

4.7 Estimated increase in storage capacity:

4.8 Sediment removal costs:

4.9 Sediment removal problems/solutions:

5.0 DEWATERING

5.1 Dewatering methodology

5.2 Duration of dewatering process

5.3 Dewatering costs

5.4 Dewatering problems/solutions

6.0 SEDIMENT DISPOSAL

6.1 Disposal approval requirements:

6.2 Disposal options/restrictions

6.3 Disposal costs

6.4 Disposal problems/solutions

7.0 VEGETATION

7.1 Were any vegetation protection measures implemented prior to the sediment removal activities?

7.2 What vegetation losses occurred due to the sediment removal activities?

7.3 Was a re-planting program implemented upon completion of the sediment removal activities?

7.4 Costs of the vegetation management program?

8.0 BUDGET

8.1 Planned budget for the project:

Sediment analysis = $
Sediment removal = $
Sediment dewatering = $
Sediment transportation to disposal site = $
Sediment disposal = $

TOTAL COSTS = $

8.2 Final costs upon completion of the project:

Sediment analysis = $
Sediment removal = $
Sediment dewatering = $
Sediment transportation to disposal site = $
Sediment disposal = $

TOTAL COSTS = $

9.0 GENERAL DISCUSSION

9.1 Did the completed project adhere to the pre-designed plan?

9.2 Which project components/experiences would be recommended for other sediment removal projects?

9.3 Which project components/experiences would not be recommended for other sediment removal projects?

9.4 How could the project have been made more efficient?

9.5 Recommended SWM facility design features to assist in future sediment removal activities?

9.6 General comments and/or recommendations

APPENDIX D

Summary of Detailed Sediment Removal and Disposal Case Study Questionnaire Results

Table D SWMF Sediment Removal and Disposal Case Studies

SWMF Name	Facility Age & Type	Maintenance Project Date & Description	Facility Size	Watershed Area & Land Use
Case Study #1 *(Industrial)* - Merivale Gardens Pond Nepean, ONT.	Built in 1984 (No prior clean-outs) - Offline wetpond without sediment forebay	- 1997 - Pumped drainage of facility - Wetpond sediment dewatering removal, and disposal	Wetpond - surface area = 0.709 ha - permanent pool volume = 19.200 m^3 - approx. dimensions = 40m x 105m	305 ha Industrial/ Residential/ Parkland
Case Study #2 *(Industrial)* - Bentley Pond Nepean, ONT.	Built in 1982 (No prior clean-outs) - Offline wetpond without sediment forebay	- 1997 - Pumped drainage of facility - Wetpond sediment dewatering removal, and disposal	Wetpond - surface area = 0.12 ha - permanent pool volume = 1,671 m^3 - approx. dimensions = 412m x 412m	20 ha Industrial
Case Study #3 *(Residential)* - Lake Aquitaine Mississauga, ONT.	Built in 1977 (No prior clean-outs) - Online wetpond with sediment forebay	- 1994 - Gravity drainage of facility - Forebay sediment removal, dewatering and disposal	Forebay - surface area = 0.38 ha - permanent pool volume = 29,000 m^3 - approx. dimensions = 40m x 105m	107 ha Residential/ Parkland
Case Study #4 *(Residential)* - Toogood Pond Markham, ONT.	Built in 1981 (No prior clean-outs) - Online wetpond with sediment forebay	- July 1997 - undrained forebay sediment removal de-watering and disposal	Forebay - surface area = 2 ha - permanent pool volume = 29,000 m^3 - approx. dimensions = 220m x 120m	Residential/ Parkland
Case Study #5 *(Residential)* - Bluffer's Park Pond Scarborough, ONT.	Built in 1973 - Offline wetpond with sediment forebay	- May 1995 - Sediment was removed from the undrained facility and subsequently dewatered and disposed of	Wetpond + Forebay - surface area = 2 ha - permanent pool volume = 35,000 m^3 - approx. dimensions = 150m x 150m	Residential/ Parkland
Case Study #6 *(Residential)* - Lincoln Homes Pond Uxbridge, ONT.	Built in 1989 (No prior clean-outs) - Offline wetpond without forebay	- 1994 - Gravity drainage of facility - Wetpond sediment removal and disposal	Wetpond - surface area = 0.12 ha - permanent pool volume = 400 m^3 - approx. dimensions = 20m x 30m + 20m x 30m	11 ha Residential
Case Study #7 *(Residential)* - Victoria Lake Kitchener, ONT.	Built in 1896 (Last clean-out in 1975) - Online wetpond without forebay	- 1997 - Gravity drainage of facility - Wetpond sediment removal and disposal	Wetpond - surface area = - approx. dimensions =	1500 ha Residential/ Parkland/ Rural
Case Study #8 *(Residential)* - Silver Lake Waterloo, ONT.	Built in 1805 (Last clean-out in 1970) - Online wetpond without sediment forebay	- 1997 - Gravity drainage of facility - Wetpond sediment removal and disposal	Wetpond - surface area = 3 ha - permanent pool volume = 36,000 m^3 - approx. dimensions = 100m x 300m	5,200 ha Residential/ Agricultural

SWMF Name	Facility Drainage Methodology	Sediment Grain Size Analysis	Yearly Sediment Accumulation Rate	%Reduction of Permanent Pool Storage Volume	Depth & Volume Of Sediment Removed
Case Study #1 *(Industrial)* - Merivale Gardens Pond Nepean, ONT.	- Permanent pool was Pumped to a storm sewer - Contaminated sediment seepage was pumped to a sanitary sewer	- 80% silty clay - 20% sand	24 mm/yr	12%	Average depth = 0.32m Maximum depth = 0.54m Total Volume = 2,300m^3
Case Study #2 *(Industrial)* - Bentley Pond Nepean, ONT.	- Permanent pool was pumped to a storm sewer - Contaminated sediment seepage was pumped to a sanitary sewer	- 78% silty clay - 22% sand	13 mm/yr	21%	Average depth = 0.2m Maximum depth = 0.5m Total Volume = 345m^3
Case Study #3 *(Residential)* - Lake Aquitaine Mississauga, ONT.	Slow gravity drainage with filter fabric at outlet to reduce sediment migration	- 75% silt - 25% sand - heavily saturated	70 mm/yr	20%	Average depth = 1.5m Total Volume = 2,550m^3
Case Study #4 *(Residential)* - Toogood Pond Markham, ONT.	Facility was not drained	- 60% sand - 40% silt	98 mm/yr	19%	Average depth = 1.5m Total Volume = 5,500m^3
Case Study #5 *(Residential)* - Bluffers Park Pond Scarborough, ONT.	Facility was not drained	- 75% silt - 25% sand	250 mm/yr	20%	Average depth = 0.35m Total Volume = 7,000m^3
Case Study #6 *(Residential)* - Lincoln Homes Pond Uxbridge, ONT.	Slow gravity drainage remaining water was pumped into a filter cloth weir and allowed to infiltrate into the ground	- 53% silt - 29% sand - 18% clay	150 mm/yr	50%	Average depth = 0.5-1m Total Volume = 387m^3
Case Study #7 *(Residential)* - Victoria Lake Kitchener, ONT.	Slow gravity drainage with silt fencing and rock check dam at outlet to prevent sediment migration	Primarily dark silty material with traces of plant matter	37 mm/yr	No data	Average depth = 0.83m Maximum depth = 2.5m Total Volume = 23,900m^3
Case Study #8 *(Residential)* - Silver Lake Waterloo, ONT.	Slow gravity drainage with filter fabric at outlet to reduce sediment migration	Primarily a dark silty material with traces of organic plant matter	56 mm/yr	66%	Average depth = 1.5m Maximum depth = 2.9m Total Volume = 27,000m^3

SWMF Name	Sediment Removal Methodology/ Equipment	Sediment Dewatering Methodology	Permits & Approval Requirements	Disposal Criteria Exceedences
Case Study #1 *(Industrial)* - Merivale Gardens Pond Nepean, ONT.	Drained basin was stabilized by added straw and then removed by a wide track in-situ dozer and an on-shore backhoe and loaded into dump trucks	Sediment was mixed with straw prior to removal by an in-situ dozer and on-shore back hoe	[1]MOEE criteria 1, 2, 3,4 &5 [2]Grand River CA work permit [2]RMOC regulations #1 & 2	[1]MOEE #2 -hydrocarbons (gas & diesel) [1]MOEE #3 LEL -Total Cr,Cu,Pb, Ni,Zn [1]MOEE #3 -Cu [4]RMOC #1 -TSS [4]RMOC #2 -TSS,Cu
Case Study #2 *(Industrial)* - Bentley Pond Nepean, ONT.	Drained basin was stabilized by added straw and then removed by a wide track in-situ dozer and an on-shore backhoe and loaded into dump trucks	Sediment was mixed with straw prior to removal by an in-situ dozer and on-shore back hoe	[1]MOEE criteria 1, 2,3,4 &5 [2]Grand River CA work permit [2]RMOC regulations #1 & 2	[1]MOEE #2 -hydrocarbons (gas & diesel) [1]MOEE #3 LEL -Total Cr,Cu,Pb, Ni,Zn [1]MOEE #3 -Cu,Fe,Ni [4]RMOC #1 -TSS [4]RMOC #2 -TSS,Cu,Zn
Case Study #3 *(Residential)* - Lake Aquitaine Mississauga, ONT.	Drained basin was excavated by an in-situ dozer and an on-shore back hoe	Sediment was mixed with clean fill and sawdust	[1]MOEE approval criteria 1 & 2 [2] Credit Valley CA Permit	[1]MOEE #2 -Electrical cond., Sodium Absorption Ratio [1]MOEE #3 LEL -Cd,Total Cr,Cu, Pb, Ni, Zn
Case Study #4 *(Residential)* - Toogood Pond Markham,ONT.	Long reach back hoe floated on a barge	Spread on land and air dried	[1]MOEE approval criteria #3 [2] Toronto and Region CA Work Permit	Data Unavailable
Case Study #5 *(Residential)* - Bluffers Park Pond Scarborough, ONT.	Combination of a hydraulic dredge and long reach back hoe floated on a barge	Spread on land and air dried	[1]MOEE approval criteria #3 [2] Toronto and Region CA work permit [2] MNR work permit	[1]MOEE #3 LEL -TKN,Total Cr, Cu, Pb, Ni, Zn
Case Study #6 *(Residential)* - Lincoln Homes Pond Uxbridge, ONT.	Drained basin was excavated by an in-situ wide track back hoe, and directly loaded into dump trucks for disposal	Sediment was not dewatered. It was directly loaded and transported in sealed dump trucks	Site specific MOEE recommendations	Data Unavailable
Case Study #7 *(Residential)* - Victoria Lake Kitchener, ONT.	Gravel was laid in the drained basin prior to a small wide track dozer excavating and pushing the sediment to within the range of an onshore backhoe which loaded the sediment into dump trucks	Sediment was stockpiled offsite for several days before it was disposed	[1]MOEE approval criteria 1&3 [2] Grand River CA work permit [3] MNR fisheries permit	[2]MOEE #2 -Electrical cond., [1]MOEE #3 LEL -TKN,Total Cr, Cu, Pb, Ni, Zn
Case Study #8 *(Residential)* - Silver Lake Waterloo, ONT.	Wooden boards were laid on the sediment to allow access for a small dozer which pushed the sediment to within the range of an onshore backhoe which loaded the sediment into dump trucks	Sediment was not dewatered. It was directly loaded into sealed dump trucks to be taken to the disposal site	[1]MOEE approval criteria 1&3 [2] Grand River CA permit [3] MNR permit [4] OMAF soil fertility recommendations	[1]MOEE #3 LEL -TKN,Total P, Total Cr,Cu, Pb, Ni, Zn

SWMF Name	Waste Disposal Classification	Approved Disposal Option	Public Consultation	Total Project Costs (including cost break-downs where available)
Case Study #1 *(Industrial)* - Merivale Gardens Pond Nepean, ONT.	Non-hazardous, registerable waste	Disposed at a Registered landfilled	YES - Project notices were delivered to neighboring industrial operators	TOTAL COST @ $124/m^3$ = $287,000 INCLUDING: *Sediment removal & disposal = $199,000 *Site remediation = $ 48,500
Case Study #2 *(Industrial)* - Bentley Pond Nepean, ONT.	Non-hazardous, registerable waste	Disposed at a Registered landfilled	YES - Project notices were delivered to neighboring industrial operators	TOTAL COST @ $669/m^3$ = $231,000 INCLUDING: *Sediment removal & disposal = $143,000 *Site remediation = $ 48,500
Case Study #3 *(Residential)* - Lake Aquitaine Mississauga, ONT.	Non-hazardous, registerable waste	Daily cover at the Brittania Sanitary Landfill Site	YES - public notices	TOTAL COST @ $62/m^3$ = $149,782 INCLUDING: *Sediment dewatering = $40,000 *Sediment disposal = $ 0 (free)
Case Study #4 *(Residential)* - Toogood Pond Markham,ONT.	Non-hazardous, registerable waste	Used as backfill for the construction of a toboggan hill	YES - Public announcements	TOTAL COST @ $32/m^3$ = $175,000 INCLUDING: *Sediment dewatering = $ 0 (free) *Sediment disposal = $ 0 (free)
Case Study #5 *(Residential)* - Bluffers Park Pond Scarborough, ONT.	Non-hazardous, registerable waste	Used as backfill several land development projects	YES - Public announcements	TOTAL COST @ $162/m^3$ = $1,100,000 INCLUDING: *Sediment dewatering = $ 0 (free) *Sediment disposal = $ 0 (free)
Case Study #6 *(Residential)* - Lincoln Homes Pond Uxbridge, ONT.	Non-hazardous, registerable waste	Landfilled by the Town of Uxbridge	YES - Public notices and information sessions	TOTAL COST @ $33/m^3$ = $12,100 INCLUDING: *Sediment analysis = $ 0 (free) *Sediment removal = $8,300 *basin dewatering = $1,100 *transportation = $2,700 *disposal = $ 0 (free)
Case Study #7 *(Residential)* - Victoria Lake Kitchener, ONT.	Non-hazardous, registerable waste	Disposed at a closed gravel pit located within the City of Kitchener boundaries	YES - Public notices and information sessions	TOTAL COST @ $18/m^3$ = $439,672 INCLUDING: *Sediment analysis & consulting fees = $32,000 *Sediment removal = $202,160 *Site remediation = $49,165
Case Study #8 *(Residential)* - Silver Lake Waterloo, ONT.	Non-hazardous, registerable waste	Spread on a topsoil deficient cash crop agricultural field	YES - Public notices and information sessions	TOTAL COST @ $14/m^3$ = $381,000

FOOTNOTES (applicable to page 3)

[1] MOEE (Ministry of Environment and Energy)

Criteria #1 - Guidelines for Decommissioning and Clean Up of Sites in Ontario, bulk sediment analysis criteria (replaced by Criteria #2)

Criteria #2 - Guidelines for the Clean Up of Contaminated Sites in Ontario, bulk sediment analysis Criteria (Table B: surface soil and groundwater criteria for residential/parkland. industrial/commercial land use for a nonpotable groundwater condition).

Criteria #3 - Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, (LEL – Lowest Effect Level & SEL-Severe Effect Level).

Criteria #4 - Provincial Water Quality Objectives

[2] CA (Conservation Authority)

- Drainage and/or sediment removal from on-line SWM facilities requires a Conservation Authority permit under the Fill, Construction and Alteration to Waterways Regulation.

[3] MNR (Ministry of Natural Resources)

- The MNR regulates fisheries concerns regarding pond drainage and construction impacts and mitigation measures related to in-pond and downstream fish populations and impact mitigation measures.

[4] RMOC (Regional Municipality of Ottawa-Carleton)

- Regulation #1 – RMOC Sanitary Sewer Regulations
- Regulation #2 – RMOC Storm Sewer Regulations

[5] OMAF (Ontario Ministry of Agriculture and Food)

- OMAF requires that any soil/sediment supplements to agricultural fields adhere to minimum soil fertility levels.

APPENDIX E

Exceedences of the MOE Guidelines for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Lake Aquitaine Residential (3 samples)		Bluffers Park Residential (4 samples)		Silver Lake Residential (5 samples)	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range	Mean	Range
pH		*	*	*	7.57	7.1 - 7.8	7.73	7.5 - 7.87	--	--
EC	mS/cm	0.7	0.7	1.4	2.27[1-3]	1.2 - 3.2[1-3]	0.29	0.23 - 0.44	--	--
SAR		5.0	5.0	12.0	48.67[1-3]	15 - 81[1-3]	0.36	0.29 - 0.44	--	--
Chloride	ug/g	*	*	*	--	--	--	--	--	--
CONVENTIONALS										
Free Cyanide	ug/g	100	100	100	--	--	--	--	0.0048	0.0014-0.0073
TOC	%	*	*	*	--	--	--	--	4.5	2.5-5.9
TKN	ug/g	*	*	*	--	--	437.5	250 - 710	900	300-1400
TKN	%	*	*	*	--	--	--	--	--	--
NO2	ug/g	*	*	*	--	--	--	--	--	--
NO3	ug/g	*	*	*	--	--	--	--	--	--
Total P	ug/g	*	*	*	--	--	--	--	750	470-940
Oil and Grease (total)	ug/g	*	*	*	--	--	2505	720 - 3900	3.5	3.7-5.2
Oil and Grease (mineral)	ug/g	*	*	*	--	--	--	--	--	--
Oil and Grease (non-mineral)	ug/g	*	*	*	--	--	--	--	--	--
Oil & Grease	%	*	*	*	0.49	0.43 - 0.58	--	--	--	--
METALS										
Aluminum (Al)	ug/g	*	*	*	--	--	--	--	9364	800-17200
Antimony (Sb)	ug/g	13	13	44	--	--	<0.5	<0.5	--	--
Arsenic (As)	ug/g	25	25	50	5.0	4.0 - 5.5	1.68	1.4 - 1.8	2	1.5-2.9
Barium (Ba)	ug/g	1000	1000	2000	--	--	61.75	28 - 97	18	7-83
Beryllium (Be)	ug/g	1.2	1.2	1.2	--	--	<1.0	<1.0	<MDL	<MDL-0.57
Cadmium (Cd)	ug/g	4	12	12	1.67	1.0 - 2.0	<0.2	<0.2	0.2	0.1-0.3

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Victoria Lake Residential (5 samples)		Lake Wabukayne Residential (4 samples)		G1 Residential (1 sample)	G4 Residential (1 sample)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range		
pH		*	*	*	8.2	7.9-8.3	7.81	7.73 - 7.87	--	--
EC	mS/cm	0.7	0.7	1.4	0.46	0.26-0.82[1&2]	2.83[1-3]	1.71 - 3.57[1-3]	--	--
SAR		5.0	5.0	12.0	1.63	0.78-2.32	16.96[1-3]	10.15 - 19.89[1-3]	--	--
Chloride	ug/g	*	*	*	--	--	--	--	--	--
CONVENTIONALS										
Free Cyanide	ug/g	100	100	100	--	--	<0.02	<0.02	--	--
TOC	%	*	*	*	--	--	--	--	1.9	2.4
TKN	ug/g	*	*	*	952	620-1230	--	--	1000	1660
TKN	%	*	*	*	--	--	--	--	--	--
NO2	ug/g	*	*	*	--	--	--	--	--	--
NO3	ug/g	*	*	*	--	--	--	--	0.15	0.08
Total P	ug/g	*	*	*	690	630-730	--	--	717	809
Oil and Grease (total)	ug/g	*	*	*	1034	590-1710	--	--	--	--
Oil and Grease (mineral)	ug/g	*	*	*	--	--	--	--	--	--
Oil and Grease (non-mineral)	ug/g	*	*	*	--	--	--	--	--	--
Oil & Grease	%	*	*	*	--	--	--	--	1.53	1.67
METALS										
Aluminum (Al)	ug/g	*	*	*	--	--	--	--	10400	8840
Antimony (Sb)	ug/g	13	13	44	<0.2	<0.2	0.55	0.5 - 0.6	--	--
Arsenic (As)	ug/g	25	25	50	3.06	1.9-4.0	4.80	4.00 - 6.10	4.11	3.34
Barium (Ba)	ug/g	1000	1000	2000	48.28	23.5-70.4	81	63 - 102	--	--
Beryllium (Be)	ug/g	1.2	1.2	1.2	0.47	0.31-0.60	0.68	0.5 - 0.9	--	--
Cadmium (Cd)	ug/g	4	12	12	0.4	0.3-0.5	0.89	0.6 - 1.3	0.421	0.180

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			T4 Residential (1 sample)	Kingston Pond Commercial (5 samples)		G8 Commercial (1 sample)	T1 Commercial (1 sample)	Hunt Club Commercial/Industrial (16 Samples)	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]		Mean	Range			Mean	Range
pH		*	*	*	--	--	--	--	--	--	--
EC	mS/cm	0.7	0.7	1.4	--	--	--	--	--	--	--
SAR		5.0	5.0	12.0	--	--	--	--	--	--	--
Chloride	ug/g	*	*	*	--	--	--	--	--	--	--
CONVENTIONALS											
Free Cyanide	ug/g	100	100	100	--	--	--	--	--	--	--
TOC	%	*	*	*	0.84	--	--	4.03	2.19	--	--
TKN	ug/g	*	*	*	457	--	--	1770	1800	--	--
TKN	%	*	*	*		--	--	--	--	--	--
NO2	ug/g	*	*	*	<0.50	--	--	--	0.58	--	--
NO3	ug/g	*	*	*	0.42	--	--	0.15	1.36	--	--
Total P	ug/g	*	*	*	963	--	--	813	752	--	--
Oil and Grease (total)	ug/g	*	*	*	--	--	--	--	--	--	--
Oil and Grease (mineral)	ug/g	*	*	*	--	--	--	--	--	--	--
Oil and Grease (non-mineral)	ug/g	*	*	*	--	--	--	--	--	--	--
Oil & Grease	%	*	*	*	--	--	--	5.56	--	--	--
METALS											
Aluminum (Al)	ug/g	*	*	*	6840	--	--	14600	19600	--	--
Antimony (Sb)	ug/g	13	13	44	--	--	--	--	--	--	--
Arsenic (As)	ug/g	25	25	50	2.25	2	2-2	6.69	4.02	--	--
Barium (Ba)	ug/g	1000	1000	2000	--	--	--	--	--	--	--
Beryllium (Be)	ug/g	1.2	1.2	1.2	--	--	--	--	--	--	--
Cadmium (Cd)	ug/g	4	12	12	0.021	1.2	0.7-1.4	1.12	<0.111	2.38	1.5 - 3.2

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO Agric.[1]	GCSO Res./Park.[2]	GCSO Ind./Com[3]	G6 Ind./Comm. (1 sample)	Bentley Industrial (5 samples) Mean	Bentley Industrial (5 samples) Range	Merivale Gardens Industrial (5 samples) Mean	Merivale Gardens Industrial (5 samples) Range	Smith Industrial (13 samples) Mean
pH		*	*	*	--	8.0	7.7-8.7	7.9	7.8-7.9	--
EC	mS/cm	0.7	0.7	1.4	--	1.28[1&2]	0.68-3.47[1-3]	0.78[1&2]	0.26-1.23[1&2]	--
SAR		5.0	5.0	12.0	--	1.37	0.72-2.57	1.52	1.13-1.90	--
Chloride	ug/g	•	•	•	--	--	--	--	--	--
CONVENTIONALS										
Free Cyanide	ug/g	100	100	100	--	--	--	--	--	--
TOC	%	*	*	*	2.4	--	--	--	--	--
TKN	ug/g	*	*	*	1540	--	--	--	--	--
TKN	%	*	*	*	--	0.11	0.09-0.15	0.14	0.10-0.17	--
NO2	ug/g	*	*	*	--	--	--	--	--	--
NO3	ug/g	*	*	*	--	--	--	--	--	--
Total P	ug/g	*	*	*	808	--	--	--	--	--
Oil and Grease (total)	ug/g	*	*	*	--	--	--	--	--	--
Oil and Grease (mineral)	ug/g	*	*	*	--	2.0	0.8-3.2	3.2	1.0-8.8	--
Oil and Grease (non-mineral)	ug/g	*	*	*	--	--	--	--	--	--
Oil & Grease	%	*	*	*	2.04	0.25	0.04-0.57	--	--	--
METALS										
Aluminum (Al)	ug/g	*	*	*	14400	--	--	--	--	--
Antimony (Sb)	ug/g	13	13	44	--	<1	<1	<1	<1	--
Arsenic (As)	ug/g	25	25	50	6.17	2	2-3	3	3-4	--
Barium (Ba)	ug/g	1000	1000	2000	--	162	152-169	174	152-192	--
Beryllium (Be)	ug/g	1.2	1.2	1.2	--	<1	<1	<1	<1	--
Cadmium (Cd)	ug/g	4	12	12	0.664	1	<1-3	1.8	1-2	6.22[1]

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			G5	T3	Rouge
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Industrial (1 sample)	Industrial (1 sample)	Highway (10 samples) Mean
pH		*	*	*	--	--	--
EC	mS/cm	0.7	0.7	1.4	--	--	2.9[1,3]
SAR		5.0	5.0	12.0	--	--	--
Chloride	ug/g	*	*	*	--	--	1626
CONVENTIONALS							
Free Cyanide	ug/g	100	100	100	--	--	--
TOC	%	*	*	*	2.7	3.62	--
TKN	ug/g	*	*	*	1870	1420	--
TKN	%	*	*	*	--		--
NO2	ug/g	*	*	*	--	<0.50	--
NO3	ug/g	*	*	*	--	0.91	--
Total P	ug/g	*	*	*	928	3510	--
Oil and Grease (total)	ug/g	*	*	*	--	--	--
Oil and Grease (mineral)	ug/g	*	*	*	--	--	--
Oil and Grease (non-mineral)	ug/g	*	*	*	--	--	--
Oil & Grease	%	*	*	*	1.96	--	--
METALS							
Aluminum (Al)	ug/g	*	*	*	16000	21500	--
Antimony (Sb)	ug/g	13	13	44	--	--	--
Arsenic (As)	ug/g	25	25	50	6.5	4.1	--
Barium (Ba)	ug/g	1000	1000	2000	--	--	--
Beryllium (Be)	ug/g	1.2	1.2	1.2	--	--	--
Cadmium (Cd)	ug/g	4	12	12	0.577	0.588	1.04

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Lake Aquitaine Residential (3 samples)		Bluffers Park Residential (4 samples)		Silver Lake Residential (5 samples)	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range	Mean	Range
Chromium (Cr) (VI)	ug/g	10	10	10	<0.5	<0.5	<0.1	<0.1	--	--
Chromium (Cr) (Total)	ug/g	1000	1000	1000	29	20 - 36	21.75	12-28	16.9	11-32
Cobalt (Co)	ug/g	50	50	100	9.67	8.0 - 11.0	6	7 - 10	6.6	<MDL-10
Copper (Cu)	ug/g	200	300	300	58.33	40 - 68	23.75	14 - 39	33.8	2.8-49.6
Iron (Fe)	ug/g	*	*	*	--	--	--	--	13910	1950-22000
Iron (Fe)	% dw	*	*	*	--	--	--	--	0.5	0.2-2.0
Lead (Pb)	ug/g	200	200	1000	120	110 - 130	27.25	16 - 47	41	25-50
Mercury (Hg)	ug/g	200	10	10	0.17	0.15 - 0.18	0.03	0.01 - 0.04	0.03	0.02-0.04
Manganese (Mn)	ug/g	*	*	*	--	--	--	--	527	66-855
Molybdenum (Mo)	ug/g	200	40	40	<2	<2	<1	<1	--	--
Nickel (Ni)	ug/g	200	200	200	26	25 - 27	15.25	10 - 20	20.7	12-27
Selenium (Se)	ug/g	200	10	10	<0.2	<0.2	<0.5	<0.5	--	--
Silver (Ag)	ug/g	200	25	50	<1	<1	<0.5	<0.5	--	--
Sodium (Na)	ug/g	200	*	*	--	--	--	--	436	110-780
Strontium (Sr)	ug/g	200	*	*	--	--	--	--	98	21-137
Vanadium (V)	ug/g	200	250	250	--	--	26	17 - 31	--	--
Zinc (Zn)	ug/g	800	800	800	256.67	190 - 290	71.75	47 - 120	144	23.0-228.0
PURGEABLE HYDROCARBONS										
Benzene	ug/g	0.24	25	25	--	--	--	--	--	--
Toluene	ug/g	2.1	150	150	--	--	--	--	--	--
Ethylbenzene	ug/g	0.28	500	1000	--	--	--	--	--	--
Xylenes	ug/g	25	210	210	--	--	--	--	--	--
EXTRACTABLE HYDROCARBONS										
Petroleum Hydrocarbons (gas	ug/g	100	1000	2000	--	--	--	--	--	--
Petroleum Hydrocarbons (hea	ug/g	1000	1000	5000	--	--	--	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Victoria Lake Residential (5 samples)		Lake Wabukayne Residential (4 samples)		G1 Residential (1 sample)	G4 Residential (1 sample)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range		
Chromium (Cr) (VI)	ug/g	10	10	10	<1	<1	<1	<1	--	--
Chromium (Cr) (Total)	ug/g	1000	1000	1000	34.14	27.6-39.9	28.5	25 - 32	12.8	10.1
Cobalt (Co)	ug/g	50	50	100	<2	<2	8	7.0 - 10.0	--	--
Copper (Cu)	ug/g	200	300	300	35.54	26.9-43.0	54.25	47 - 60	--	--
Iron (Fe)	ug/g	*	*	*	16400	10800-21900	--	--	--	--
Iron (Fe)	% dw	*	*	*	--	--	--	--	--	--
Lead (Pb)	ug/g	200	200	1000	39.6	32-45	68	63 - 72	23.5	27
Mercury (Hg)	ug/g	200	10	10	0.057	0.049-0.070	0.08	0.07 - 0.09	0.053	.047
Manganese (Mn)	ug/g	*	*	*	--	--	--	--	--	--
Molybdenum (Mo)	ug/g	200	40	40	<3	<3	<3	<3	--	--
Nickel (Ni)	ug/g	200	200	200	13.4	10-17	22	19 - 27	8.07	6.26
Selenium (Se)	ug/g	200	10	10	<0.2	<0.2	0.2	0.2	--	--
Silver (Ag)	ug/g	200	25	50	<0.2	<0.2	<1	<1	--	--
Sodium (Na)	ug/g	200	*	*	--	--	--	--	--	--
Strontium (Sr)	ug/g	200	*	*	--	--	--	--	--	--
Vanadium (V)	ug/g	200	250	250	20.22	16.8-23.3	26	22 - 32	--	--
Zinc (Zn)	ug/g	800	800	800	104.1	97.7-148.0	318.75	267 - 374	136	167
PURGEABLE HYDROCARBONS										
Benzene	ug/g	0.24	25	25	--	--	--	--	--	--
Toluene	ug/g	2.1	150	150	--	--	--	--	--	--
Ethylbenzene	ug/g	0.28	500	1000	--	--	--	--	--	--
Xylenes	ug/g	25	210	210	--	--	--	--	--	--
EXTRACTABLE HYDROCARBONS										
Petroleum Hydrocarbons (gas	ug/g	100	1000	2000	--	--	--	--	--	--
Petroleum Hydrocarbons (hea	ug/g	1000	1000	5000	--	--	3862.5[1&2]	3580 - 4600[1&2]	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			T4 Residential (1 sample)	Kingston Pond Commercial (5 samples)		G8 Commercial (1 sample)	T1 Commercial (1 sample)	Hunt Club Commercial/Industrial (16 Samples)	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]		Mean	Range			Mean	Range
Chromium (Cr) (VI)	ug/g	10	10	10	--	--	--	--	--	61[1-3]	57 - 68[1-3]
Chromium (Cr) (Total)	ug/g	1000	1000	1000	7.04	110.4	66-128	21.6	17.3	--	--
Cobalt (Co)	ug/g	50	50	100	--	--	--	--	--	13	9.0 - 16.0
Copper (Cu)	ug/g	200	300	300	10.8	87.6	20-80	52.4	23.9	141	120 - 165
Iron (Fe)	ug/g	*	*	*	--	--	--	--	--	2.18	1.6 - 2.9
Iron (Fe)	% dw	*	*	*	--	2.98	2.62-3.15	--	--	--	--
Lead (Pb)	ug/g	200	200	1000	2.35	125.2	39-158	62.7	8.98	158	130 - 204
Mercury (Hg)	ug/g	200	10	10	0.027	0.05	0.019-0.067	.081	0.058	--	--
Manganese (Mn)	ug/g	*	*	*	--	494.8	465-568	--	--	554	450 - 640
Molybdenum (Mo)	ug/g	200	40	40	--	--	--	--	--	3	1.0 - 5.0
Nickel (Ni)	ug/g	200	200	200	4.36	32	24-35	11.9	16.7	38	36 - 44
Selenium (Se)	ug/g	200	10	10	--	--	--	--	--	38[1-3]	31 - 47[1-3]
Silver (Ag)	ug/g	200	25	50	--	--	--	--	--	7.5	0.5 - 12
Sodium (Na)	ug/g	200	*	*	--	--	--	--	--	--	--
Strontium (Sr)	ug/g	200	*	*	--	--	--	--	--	--	--
Vanadium (V)	ug/g	200	250	250	--	--	--	--	--	39	25 - 47
Zinc (Zn)	ug/g	800	800	800	29.1	318.8	113-406	455	65.6	661	585 - 780
PURGEABLE HYDROCARBONS											
Benzene	ug/g	0.24	25	25	--	--	--	--	--	--	--
Toluene	ug/g	2.1	150	150	--	--	--	--	--	--	--
Ethylbenzene	ug/g	0.28	500	1000	--	--	--	--	--	--	--
Xylenes	ug/g	25	210	210	--	--	--	--	--	--	--
EXTRACTABLE HYDROCARBONS											
Petroleum Hydrocarbons (gas	ug/g	100	1000	2000	--	--	--	--	--	--	--
Petroleum Hydrocarbons (hea	ug/g	1000	1000	5000	--	--	--	--	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			G6	Bentley		Merivale Gardens		Smith
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Ind./Comm. (1 sample)	Industrial (5 samples)		Industrial (5 samples)		Industrial (13 samples)
						Mean	Range	Mean	Range	Mean
Chromium (Cr) (VI)	ug/g	10	10	10	--	2	1-3	1	<1-2	--
Chromium (Cr) (Total)	ug/g	1000	1000	1000	15.8	50	35-61	33.5	28-37	55.2
Cobalt (Co)	ug/g	50	50	100	--	12	6-17	10.8	6-17	--
Copper (Cu)	ug/g	200	300	300	38.0	46	38-54	73.5	63-87	215[1]
Iron (Fe)	ug/g	*	*	*	--	--	--	--	--	--
Iron (Fe)	% dw	*	*	*	--	--	--	--	--	--
Lead (Pb)	ug/g	200	200	1000	45.2	67	45-84	108	93-130	265[1&2]
Mercury (Hg)	ug/g	200	10	10	.052	<0.1	<0.1	0.1	<0.1-0.1	--
Manganese (Mn)	ug/g	*	*	*	--	--	--	--	--	13561
Molybdenum (Mo)	ug/g	200	40	40	--	0.2	<1-2	3.7	<1-7[1]	--
Nickel (Ni)	ug/g	200	200	200	10.6	27	19-33	17.5	14-20	49.7
Selenium (Se)	ug/g	200	10	10	--	0.2	<1-2	<1	<1	--
Silver (Ag)	ug/g	200	25	50	--	1	<1-3	2.2	<1-4	--
Sodium (Na)	ug/g	200	*	*	--	--	--	--	--	--
Strontium (Sr)	ug/g	200	*	*	--	--	--	--	--	--
Vanadium (V)	ug/g	200	250	250	--	44	33-52	26.8	20-30	--
Zinc (Zn).	ug/g	800	800	800	368	433	312-653	369.3	340-420	1077[1-3]
PURGEABLE HYDROCARBONS										
Benzene	ug/g	0.24	25	25	--	<0.05	<0.05	<0.05	<0.05	--
Toluene	ug/g	2.1	150	150	--	<0.1	<0.1	<0.1	<0.1	--
Ethylbenzene	ug/g	0.28	500	1000	--	<0.1	<0.1	<0.1	<0.1	--
Xylenes	ug/g	25	210	210	--	<MDL	--	<MDL	--	--
EXTRACTABLE HYDROCARBONS										
Petroleum Hydrocarbons (gas	ug/g	100	1000	2000	--	2810[1-3]	1220-4400[1-3]	5385[1-3]	2540-7700[1-3]	--
Petroleum Hydrocarbons (hea	ug/g	1000	1000	5000	--	--	--	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			G5	T3	Rouge
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Industrial (1 sample)	Industrial (1 sample)	Highway (10 samples)
							Mean
Chromium (Cr) (VI)	ug/g	10	10	10	--	--	--
Chromium (Cr) (Total)	ug/g	1000	1000	1000	14.6	817	30
Cobalt (Co)	ug/g	50	50	100	--	--	--
Copper (Cu)	ug/g	200	300	300	--	63.4	--
Iron (Fe)	ug/g	*	*	*	--	--	17800
Iron (Fe)	% dw	*	*	*	--	--	--
Lead (Pb)	ug/g	200	200	1000	42.4	24	55
Mercury (Hg)	ug/g	200	10	10	.054	0.042	--
Manganese (Mn)	ug/g	*	*	*	--	--	--
Molybdenum (Mo)	ug/g	200	40	40	--	--	--
Nickel (Ni)	ug/g	200	200	200	11.1	14.7	16.5
Selenium (Se)	ug/g	200	10	10	--	--	--
Silver (Ag)	ug/g	200	25	50	--	--	--
Sodium (Na)	ug/g	200	*	*	--	--	--
Strontium (Sr)	ug/g	200	*	*	--	--	--
Vanadium (V)	ug/g	200	250	250	--	--	--
Zinc (Zn)	ug/g	800	800	800	345	.262	243
PURGEABLE HYDROCARBONS							
Benzene	ug/g	0.24	25	25	--	--	--
Toluene	ug/g	2.1	150	150	--	--	--
Ethylbenzene	ug/g	0.28	500	1000	--	--	--
Xylenes	ug/g	25	210	210	--	--	--
EXTRACTABLE HYDROCARBONS							
Petroleum Hydrocarbons (gas	ug/g	100	1000	2000	--	--	--
Petroleum Hydrocarbons (hea	ug/g	1000	1000	5000	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO Agric.[1]	GCSO Res./Park.[2]	GCSO Ind./Com[3]	Lake Aquitaine Residential (3 samples) Mean	Lake Aquitaine Range	Bluffers Park Residential (4 samples) Mean	Bluffers Park Range	Silver Lake Residential (5 samples) Mean	Silver Lake Range
POLYCYCLIC AROMATICS										
Acenaphthene	ug/g	15	1000	1300	--	--	--	--	0.022	0.016-0.028
Acenaphthylene	ug/g	100	100	840	--	--	--	--	0.005	0.003-0.006
Anthracene	ug/g	28	28	28	--	--	--	--	0.108	0.07-0.15
Benzo(a)anthracene	ug/g	6.6	40	40	--	--	--	--	0.405	0.215-0.594
Benzo(a)pyrene	ug/g	1.2	1.2	1.9	--	--	--	--	0.45	0.274-0.625
Benzo(b)fluoranthene	ug/g	1.2	12	18	--	--	--	--	1.02	0.328-1.71
Benzo(k)fluoranthene		1.2	12	18			--	--		
Benzo(ghi)perylene	ug/g	1.2	40	40	--	--	--	--	--	--
Chrysene	ug/g	1.2	12	17	--	--	--	--	--	--
Dibenzo(a,h)anthracene	ug/g	1.2	1.2	1.9	--	--	--	--	--	--
Fluoranthene	ug/g	1.2	40	40	--	--	--	--	1.53	0.91-2.16
Fluorene	ug/g	1.2	340	340	--	--	--	--	0.035	0.025-0.045
Indeno(123-c,d)pyrene	ug/g	1.2	12	19	--	--	--	--	--	--
Naphthalene	ug/g	1.2	4.6	4.6	--	--	--	--	0.005	0.004-0.006
Phenanthrene	ug/g	1.2	40	40	--	--	--	--	0.588	0.382-0.793
Pyrene	ug/g	1.2	250	250	--	--	--	--	1.134	0.688-1.600
PCBs (total)	ug/g	0.5	5.0	25	--	--	<0.03	<0.03	--	--
Alpha BHC	ug/g	*	*	*	--	--	--	--	--	--
Hexachlorobenzene	ug/g	0.46	0.46	0.76	--	--	--	--	--	--
Gamma BHC	ug/g	*	*	*	--	--	--	--	--	--
Heptachlor	ug/g	0.12	0.12	0.15	--	--	--	--	--	--
Aldrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
Epoxide	ug/g	*	*	*	--	--	--	--	--	--
Gamma Chlordane	ug/g	*	*	*	--	--	--	--	--	--
Alpha Endosulfan	ug/g	*	*	*	--	--	--	--	--	--
Alpha Chlordane	ug/g	*	*	*	--	--	--	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Victoria Lake Residential (5 samples)		Lake Wabukayne Residential (4 samples)		G1 Residential (1 sample)	G4 Residential (1 sample)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range		
POLYCYCLIC AROMATICS										
Acenaphthene	ug/g	15	1000	1300	--	--	--	--	0.01	0.03
Acenaphthylene	ug/g	100	100	840	--	--	--	--	--	0.01
Anthracene	ug/g	28	28	28	--	--	--	--	0.04	0.06
Benzo(a)anthracene	ug/g	6.6	40	40	--	--	--	--	0.2	0.6
Benzo(a)pyrene	ug/g	1.2	1.2	1.9	--	--	--	--	--	--
Benzo(b)fluoranthene	ug/g	1.2	12	18	--	--	--	--	0.45	1.52
Benzo(k)fluoranthene		1.2	12	18	--	--			0.15	0.51
Benzo(ghi)perylene	ug/g	1.2	40	40	--	--	--	--	0.24	0.84
Chrysene	ug/g	1.2	12	17	--	--	--	--	0.38	1.27
Dibenzo(a,h)anthracene	ug/g	1.2	1.2	1.9	--	--	--	--	0.06	0.171
Fluoranthene	ug/g	1.2	40	40	--	--	--	--	0.69	2.12
Fluorene	ug/g	1.2	340	340	--	--	--	--	0.02	0.04
Indeno(123-c,d)pyrene	ug/g	1.2	12	19	--	--	--	--	0.18	0.73
Naphthalene	ug/g	1.2	4.6	4.6	--	--	--	--	0.03	0.05
Phenanthrene	ug/g	1.2	40	40	--	--	--	--	0.32	0.7
Pyrene	ug/g	1.2	250	250	--	--	--	--	0.54	1.64
PCBs (total)	ug/g	0.5	5.0	25	<0.01	<0.01	--	--	0.152	0.119
Alpha BHC	ug/g	*	*	*	--	--	--	--	--	0.0041
Hexachlorobenzene	ug/g	0.46	0.46	0.76	--	--	--	--	--	--
Gamma BHC	ug/g	*	*	*	--	--	--	--	--	--
Heptachlor	ug/g	0.12	0.12	0.15	--	--	--	--	--	--
Aldrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	0.0024
Epoxide	ug/g	*	*	*	--	--	--	--	--	--
Gamma Chlordane	ug/g	*	*	*	--	--	--	--	--	--
Alpha Endosulfan	ug/g	*	*	*	--	--	--	--	--	--
Alpha Chlordane	ug/g	*	*	*	--	--	--	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			T4	Kingston Pond		G8	T1	Hunt Club	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Residential (1 sample)	Commercial (5 samples)		Commercial (1 sample)	Commercial (1 sample)	Commercial/Industrial (16 Samples)	
						Mean	Range			Mean	Range
POLYCYCLIC AROMATICS											
Acenaphthene	ug/g	15	1000	1300	<0.234	--	--	0.06	<0.234	--	--
Acenaphthylene	ug/g	100	100	840	0.01	--	--	0.03	<0.182	--	--
Anthracene	ug/g	28	28	28	<0.182	--	--	0.15	0.01	--	--
Benzo(a)anthracene	ug/g	6.6	40	40	0.09	--	--	1.12	0.04	--	--
Benzo(a)pyrene	ug/g	1.2	1.2	1.9	0.04	--	--	1.5[1&2]	0.02	--	--
Benzo(b)fluoranthene	ug/g	1.2	12	18	0.23	--	--	2.89	0.05	--	--
Benzo(k)fluoranthene		1.2	12	18	0.05			1.02	0.02	--	--
Benzo(ghi)perylene	ug/g	1.2	40	40	0.02	--	--	1.58	0.04	--	--
Chrysene	ug/g	1.2	12	17	0.10	--	--	2.58	0.05	--	--
Dibenzo(a,h)anthracene	ug/g	1.2	1.2	1.9	0.03	--	--	0.33	0.03	--	--
Fluoranthene	ug/g	1.2	40	40	0.16	--	--	4.87	0.05	--	--
Fluorene	ug/g	1.2	340	340	0.02	--	--	0.13	0.02	--	--
Indeno(123-c,d)pyrene	ug/g	1.2	12	19	0.06	--	--	1.39	0.03	--	--
Naphthalene	ug/g	1.2	4.6	4.6	0.03	--	--	0.07	0.03	--	--
Phenanthrene	ug/g	1.2	40	40	--	--	--	1.6	--	--	--
Pyrene	ug/g	1.2	250	250	--	--	--	2.98	--	--	--
PCBs (total)	ug/g	0.5	5.0	25	0.27	--	--	0.365	0.49	--	--
Alpha BHC	ug/g	*	*	*	0.004	--	--	--	0.003	--	--
Hexachlorobenzene	ug/g	0.46	0.46	0.76	<0.001	--	--	--	<0.001	--	--
Gamma BHC	ug/g	*	*	*	<0.001	--	--	--	<0.001	--	--
Heptachlor	ug/g	0.12	0.12	0.15	<0.005	--	--	--	<0.005	--	--
Aldrin	ug/g	0.05	0.05	0.05	<0.001	--	--	--	<0.001	--	--
Epoxide	ug/g	*	*	*	<0.001	--	--	--	<0.001	--	--
Gamma Chlordane	ug/g	*	*	*	0.0025	--	--	--	<0.001	--	--
Alpha Endosulfan	ug/g	*	*	*	<0.001	--	--	--	<0.001	--	--
Alpha Chlordane	ug/g	*	*	*	0.001	--	--	--	<0.001	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO Agric.[1]	GCSO Res./Park.[2]	GCSO Ind./Com[3]	G6 Ind./Comm. (1 sample)	Bentley Industrial (5 samples) Mean	Bentley Industrial (5 samples) Range	Merivale Gardens Industrial (5 samples) Mean	Merivale Gardens Industrial (5 samples) Range	Smith Industrial (13 samples) Mean
POLYCYCLIC AROMATICS										
Acenaphthene	ug/g	15	1000	1300	0.01	--	--	--	--	--
Acenaphthylene	ug/g	100	100	840	0.01	<0.1	<0.1	<0.1	<0.1	--
Anthracene	ug/g	28	28	28	0.02	0.07	<0.1-0.2	<0.1	<0.1	--
Benzo(a)anthracene	ug/g	6.6	40	40	0.14	<0.1	<0.1	<0.1	<0.1	--
Benzo(a)pyrene	ug/g	1.2	1.2	1.9	0.21	<0.1	<0.1	<0.1	<0.1	--
Benzo(b)fluoranthene	ug/g	1.2	12	18	0.39	<0.1	<0.1	<0.1	<0.1	--
Benzo(k)fluoranthene		1.2	12	18	0.14	<0.1	<0.1	<0.1	<0.1	--
Benzo(ghi)perylene	ug/g	1.2	40	40	0.27	<0.1	<0.1	<0.1	<0.1	--
Chrysene	ug/g	1.2	12	17	0.35	<0.1	<0.1	<0.1	<0.1	--
Dibenzo(a,h)anthracene	ug/g	1.2	1.2	1.9	0.06	<0.1	<0.1	<0.1	<0.1	--
Fluoranthene	ug/g	1.2	40	40	0.52	<0.1	<0.1	<0.1	<0.1	--
Fluorene	ug/g	1.2	340	340	0.02	<0.1	<0.1	<0.1	<0.1	--
Indeno(123-c,d)pyrene	ug/g	1.2	12	19	0.18	0.07	<0.1-0.2	<0.1	<0.1	--
Naphthalene	ug/g	1.2	4.6	4.6	0.06	<0.1	<0.1	<0.1	<0.1	--
Phenanthrene	ug/g	1.2	40	40	0.18	<0.1	<0.1	<0.1	<0.1	--
Pyrene	ug/g	1.2	250	250	0.43	0.2	<0.1-0.7	<0.1	<0.1	--
PCBs (total)	ug/g	0.5	5.0	25	0.217	0.06	<0.05-0.2[+A06]	<0.1	<0.1	--
Alpha BHC	ug/g	*	*	*	--	--	--	--	--	--
Hexachlorobenzene	ug/g	0.46	0.46	0.76	--	--	--	--	--	--
Gamma BHC	ug/g	*	*	*	--	--	--	--	--	--
Heptachlor	ug/g	0.12	0.12	0.15	--	--	--	--	--	--
Aldrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
Epoxide	ug/g	*	*	*	--	--	--	--	--	--
Gamma Chlordane	ug/g	*	*	*	--	--	--	--	--	--
Alpha Endosulfan	ug/g	*	*	*	--	--	--	--	--	--
Alpha Chlordane	ug/g	*	*	*	--	--	--	--	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			G5 Industrial (1 sample)	T3 Industrial (1 sample)	Rouge Highway (10 samples)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]			Mean
POLYCYCLIC AROMATICS							
Acenaphthene	ug/g	15	1000	1300	0.01	<0.234	--
Acenaphthylene	ug/g	100	100	840	0.01	<0.182	--
Anthracene	ug/g	28	28	28	0.02	<0.182	--
Benzo(a)anthracene	ug/g	6.6	40	40	0.21	0.1	--
Benzo(a)pyrene	ug/g	1.2	1.2	1.9	--	0.14	--
Benzo(b)fluoranthene	ug/g	1.2	12	18	0.59	0.24	--
Benzo(k)fluoranthene		1.2	12	18	0.2	0.04	--
Benzo(ghi)perylene	ug/g	1.2	40	40	0.33	0.18	--
Chrysene	ug/g	1.2	12	17	0.55	0.24	--
Dibenzo(a,h)anthracene	ug/g	1.2	1.2	1.9	0.07	0.09	--
Fluoranthene	ug/g	1.2	40	40	0.8	0.18	--
Fluorene	ug/g	1.2	340	340	0.02	0.09	--
Indeno(123-c,d)pyrene	ug/g	1.2	12	19	0.29	0.08	--
Naphthalene	ug/g	1.2	4.6	4.6	0.04	0.1	--
Phenanthrene	ug/g	1.2	40	40	0.24	--	--
Pyrene	ug/g	1.2	250	250	0.62	--	--
PCBs (total)	ug/g	0.5	5.0	25	0.186	0.789[1]	--
Alpha BHC	ug/g	*	*	*	--	<0.001	--
Hexachlorobenzene	ug/g	0.46	0.46	0.76	--	<0.001	--
Gamma BHC	ug/g	*	*	*	--	0.0037	--
Heptachlor	ug/g	0.12	0.12	0.15	--	<0.005	--
Aldrin	ug/g	0.05	0.05	0.05	--	<0.001	--
Epoxide	ug/g	*	*	*	--	<0.001	--
Gamma Chlordane	ug/g	*	*	*	--	<0.001	--
Alpha Endosulfan	ug/g	*	*	*	--	0.0009	--
Alpha Chlordane	ug/g	*	*	*	--	0.001	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Lake Aquitaine Residential (3 samples)		Bluffers Park Residential (4 samples)		Silver Lake Residential (5 samples)	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range	Mean	Range
Total Chlordane	ug/g	0.29	0.29	0.29	--	--	--	--	--	--
Dieldrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
P,P-DDE	ug/g	1.6	1.6	2.4	--	--	--	--	--	--
Endrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
Beta Endosulfan	ug/g	*	*	*	--	--	--	--	--	--
Total Endosulfan	ug/g	0.18	0.18	0.18	--	--	--	--	--	--
O,P-DDT	ug/g	*	*	*	--	--	--	--	--	--
P,P-DDT	ug/g	*	*	*	--	--	--	--	--	--
Total DDT	ug/g	1.6	1.6	2.0	--	--	--	--	--	--
Methoxychlor	ug/g	4.0	4.0	4.0	--	--	--	--	--	--
Mirex	ug/g	*	*	*	--	--	--	--	--	--
O&G hexane	ug/g	*	*	*	--	--	--	--	--	--
Grain Size Analysis		NA	NA	NA	75% Si, 25% Sa		--	--	Visual inspection: silt	

GCSO - Guideline for use at Contaminated Sites in Ontario, Table B: Surface Soil and Groundwater Criteria for residential/parkland, industrial/commercial land use for a non-potable groundwater condition

150[1,3] - SWMF contaminant concentration exceeded the GCSO agricultural, residential/parkland and commercial/industrial criteria

< - Less than Method Detection Limit

-- - No Data

* - No Criteria

Si - Silt

Cl - Clay

Sa - Sand

N/A - Not Applicable

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			Victoria Lake Residential (5 samples)		Lake Wabukayne Residential (4 samples)		G1 Residential (1 sample)	G4 Residential (1 sample)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]	Mean	Range	Mean	Range		
Total Chlordane	ug/g	0.29	0.29	0.29	--	--	--	--	--	--
Dieldrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
P,P-DDE	ug/g	1.6	1.6	2.4	--	--	--	--	--	--
Endrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
Beta Endosulfan	ug/g	*	*	*	--	--	--	--	--	--
Total Endosulfan	ug/g	0.18	0.18	0.18	--	--	--	--	--	--
O,P-DDT	ug/g	*	*	*	--	--	--	--	--	--
P,P-DDT	ug/g	*	*	*	--	--	--	--	--	--
Total DDT	ug/g	1.6	1.6	2.0	--	--	--	--	--	--
Methoxychlor	ug/g	4.0	4.0	4.0	--	--	--	--	--	--
Mirex	ug/g	*	*	*	--	--	--	--	--	--
O&G hexane	ug/g	*	*	*	--	--	--	--	--	--
Grain Size Analysis		NA	NA	NA	Visual inspection: silt		83% SiCl, 17%Sa		84%SaSi,16%	59%SaCl,31%

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			T4 Residential (1 sample)	Kingston Pond Commercial (5 samples)		G8 Commercial (1 sample)	T1 Commercial (1 sample)	Hunt Club Commercial/Industrial (16 Samples)	
		Agric.[1]	Res./Park.[2]	Ind./Com[3]		Mean	Range			Mean	Range
Total Chlordane	ug/g	0.29	0.29	0.29	--	--	--	--	--	--	--
Dieldrin	ug/g	0.05	0.05	0.05	<0.005	--	--	--	<0.005	--	--
P,P-DDE	ug/g	1.6	1.6	2.4	<0.001	--	--	--	0.0004	--	--
Endrin	ug/g	0.05	0.05	0.05	<0.005	--	--	--	<0.005	--	--
Beta Endosulfan	ug/g	*	*	*	<0.001	--	--	--	<0.001	--	--
Total Endosulfan	ug/g	0.18	0.18	0.18	--	--	--	--	--	--	--
O,P-DDT	ug/g	*	*	*	<0.005	--	--	--	<0.005	--	--
P,P-DDT	ug/g	*	*	*	<0.005	--	--	--	0.0017	--	--
Total DDT	ug/g	1.6	1.6	2.0	--	--	--	--	--	--	--
Methoxychlor	ug/g	4.0	4.0	4.0	<0.01	--	--	--	0.0059	--	--
Mirex	ug/g	*	*	*	<0.005	--	--	--	<0.005	--	--
O&G hexane	ug/g	*	*	*	0.69	--	--	--	710	--	--
Grain Size Analysis		NA	NA	NA	2%SaSi, 8%C	95%ClSi,5%Sa		95%SiCl,5%	9%ClSi,21%S	--	--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			G6 Ind./Comm. (1 sample)	Bentley Industrial (5 samples)		Merivale Gardens Industrial (5 samples)		Smith Industrial (13 samples)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]		Mean	Range	Mean	Range	Mean
Total Chlordane	ug/g	0.29	0.29	0.29	--	--	--	--	--	--
Dieldrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
P,P-DDE	ug/g	1.6	1.6	2.4	--	--	--	--	--	--
Endrin	ug/g	0.05	0.05	0.05	--	--	--	--	--	--
Beta Endosulfan	ug/g	*	*	*	--	--	--	--	--	--
Total Endosulfan	ug/g	0.18	0.18	0.18	--	--	--	--	--	--
O,P-DDT	ug/g	*	*	*	--	--	--	--	--	--
P,P-DDT	ug/g	*	*	*	--	--	--	--	--	--
Total DDT	ug/g	1.6	1.6	2.0	--	--	--	--	--	--
Methoxychlor	ug/g	4.0	4.0	4.0	--	--	--	--	--	--
Mirex	ug/g	*	*	*	--	--	--	--	--	--
O&G hexane	ug/g	*	*	*	--	--	--	--	--	--
Grain Size Analysis		NA	NA	NA	99%SiCl,1%	70%SiCl, 30%Sa		80%SiCl, 20%Sa		--

Table E: Exceedences of the MOEE Guideline for Use at Contaminated Sites in Ontario (GCSO) by SWMFs Located in Various Land Use Catchment Areas

PARAMETER	UNITS	GCSO			G5 Industrial (1 sample)	T3 Industrial (1 sample)	Rouge Highway (10 samples)
		Agric.[1]	Res./Park.[2]	Ind./Com[3]			Mean
Total Chlordane	ug/g	0.29	0.29	0.29	--	--	--
Dieldrin	ug/g	0.05	0.05	0.05	--	<0.005	--
P,P-DDE	ug/g	1.6	1.6	2.4	--	<0.001	--
Endrin	ug/g	0.05	0.05	0.05	--	0.0019	--
Beta Endosulfan	ug/g	*	*	*	--	<0.001	--
Total Endosulfan	ug/g	0.18	0.18	0.18	--	--	--
O,P-DDT	ug/g	*	*	*	--	<0.005	--
P,P-DDT	ug/g	*	*	*	--	<0.005	--
Total DDT	ug/g	1.6	1.6	2.0	--	--	--
Methoxychlor	ug/g	4.0	4.0	4.0	--	<0.01	--
Mirex	ug/g	*	*	*	--	<0.005	--
O&G hexane	ug/g	*	*	*	--	13.2	--
Grain Size Analysis		NA	NA	NA	99%SiCl,1%Sa	92%SiCl,8%	--

APPENDIX F
Sample Laboratory Test Costs

Organic Chemistry Parameters

Parameter	Matrix	Cost Per Sample
Volatile Organic Compounds (VOCs) EPA624 purge & trap GC/MS, methanol extract of soil	Water Soil Air Tube*	$135.00 $140.00 $155.00
Low-level VOCs, direct soil purge To meet MOE 1997 Guidelines – Tables A, B, and F	Soil-DP	$155.00
Base/Neutral and Acid Extractables (EPA625)	Water Soil	$350.00 $360.00
Base/Neutral Extractables Only, GC/MS	Water Soil	$250.00 $275.00
Acid Extractables Only, GC/MS	Water Soil	$225.00 $250.00
Trihalomethanes, GC/MS	Water	$ 90.00
Dissolved Methane, GC/FID	Water	$ 72.00
Polychlorinated Biphenyls (PCBs), GC/ECD	Water Soil Wipes, Oil	$ 75.00 $ 85.00 $ 60.00
Polynuclear Aromatic Hydrocarbons (PAHs)	Water Soil	$155.00 $160.00
Organochlorine Pesticides & PCBs, GC/ECD	Water Soil	$140.00 $165.00
Phenoxyacid Herbicides, GC/ECD	Water Soil	$120.00 $130.00
Organophosphorus Pesticides, GC/MS	Water Soil	$155.00 $165.00
Triazine Herbicides, GC/MS	Water Soil	$145.00 $155.00
Chlorinated Phenols, GC/MS	Water Soil	$200.00 $250.00
Formaldehyde (colourimetric)	Water Soil	$ 50.00 $ 65.00
Glycols, GC/FID	Water Soil	$ 50.00 $ 65.00

Refer to pages 14 and 15 for routine parameter lists.

* Price per sample is for analysis of the air tube "front end". Analysis of the "back end" is charged at 50% the cost of the front.

Petroleum Hydrocarbons

Accutest Laboratories is accredited through the SCC for the analysis of soil and water for petroleum hydrocarbons (gas/diesel/heavy oils) and volatile organic compounds.

Parameter	Matrix	Cost Per Sample
BTEX Methanol Extract -Purge & trap GC/MS Direct Soil Purge GC/MS – to meet MOE Table F**	Water Soil Soil-DP Air Tube*	$ 75.00 $ 75.00 $ 90.00 $ 90.00
Petroleum Hydrocarbons (gas/diesel) TPH (gas/diesel), GC/FID	Water Soil Air Tube*	$ 75.00 $ 75.00 $ 90.00
Petroleum Hydrocarbons (heavy oils) (Mineral Oil & Grease), gravimetric	Water Soil	$ 35.00 $ 35.00
BTEX + TPH (gas/diesel)	Water Soil	$125.00 $125.00
BTEX + TPH (g/d) + TPH (heavy oil)	Water Soil	$155.00 $155.00
Product Characterization GC/FID	Water Soil Fuel	$ 85.00 $ 85.00 $ 80.00
Petroleum Hydrocarbons (C10 to C50) Québec Guidelines (GC/FID)	Water Soil	$ 75.00 $ 75.00

* Price per sample is for analysis of the air tube "front end". Analysis of the "back end" is charged at 50% the cost of the front.
** Direct purge is the MOE approved method for analysis of low level volatiles in soil.

Landfill Requirements - Reg. 347 for Petroleum Contamination

Parameters	Package Price
Gasoline Contamination: • Flashpoint/TPH on soil with Pb on Leachate	$140.00 Includes leachate preparation
Diesel/Middle Distillate Contamination: • Flashpoint/TPH on soil	$90.00
Waste Oil Contamination: • TPH on soil with Cd, Cr, Pb, and PCBs on leachate	$160.00 Includes leachate preparation
Unknown Petroleum Contamination: • Flashpoint/TPH on soil + Cd, Cr, Pb, and PCBs on leachate	$200.00 Includes leachate preparation

Reg. 347 – Schedule IV Parameters

Physical Tests and Extraction

Parameter	Cost Per Sample
Ignitability (Flashpoint)	$ 50.00
Slump Test	$ 60.00
Leachate Preparation	$ 55.00

Analysis of Schedule IV Inorganics

Parameters		Package Price
• Arsenic • Barium • Boron • Cadmium • Chromium • Cyanide • Fluoride	• Lead • Mercury • Nitrate • Nitrite • Selenium • Silver	$170.00 Includes leachate preparation

If required, add Uranium analysis to the above package for $25.00 per sample.

*Analysis of Schedule IV Organics**

Parameters		Package Price
• 2,4,5-TP • 2,4-D • Aldrin & Dieldrin • Carbaryl • Chlordane • DDT • Diazinon • Endrin	• Heptachlor & Hept. Epoxide • Lindane • Methoxychlor • Methyl Parathion • PCBs • Parathion • Toxaphene • Trihalomethanes	$480.00 Includes leachate preparation

Complete Schedule IV

Parameters	Package Price
Leachate Preparation, Listed Inorganics inc. U, and Organics*	$595.00

* Excluding NTA

Soil Decommissioning Inorganics for 1997 MOE Guidelines

Parameters		Package Price
• Antimony • Arsenic • Barium • Beryllium • Boron (hot water extractable) • Cadmium • Chromium (total) • Chromium (VI) • Cobalt • Copper • Cyanide (free)	• Lead • Mercury • Molybdenum • Nickel • pH, Conductivity • Selenium • Silver • Sodium Absorption Ratio • Thallium • Vanadium • Zinc	$130.00

Metals Only: $98.00/sample

Groundwater Inorganics for 1997 MOE Guidelines – Tables A or B

Parameters		Package Price
• Antimony • Arsenic • Barium • Beryllium • Boron • Cadmium • Chromium (total) • Chromium (VI) • Cobalt • Copper • Cyanide (free)	• Lead • Mercury • Molybdenum • Nickel • Sodium • Selenium • Silver • Thallium • Vanadium • Zinc • Nitrate, Nitrite	$120.00

Metals Only: $80.00/sample

APPENDIX G
SEDTEC Report: Removal Technology (Short List)

SEDTEC Report: Removal Technology (Short List)

Great Lakes 2000 Cleanup Fund
Le Fonds D'Assainissement Des Grands Lacs 2000
10/5/98

Technology Name	Country of Origin	Development Stage	Removal Rate (m^3/hr)	Average Cost (US$/$m^3$)
American Mechanical Dredge, Floating Clamshell Dredge	Germany	Commercial	235	$4.50
Aquamec Ltd., Watermaster	Finland	Commercial	55	$1.90
Aquarius Systems, Amphibious Excavator	USA	Commercial	20	
Aquatics Unlimited, Aquamog	USA	Commercial	55	$4.00
Aztec Development Co., JET-SPRAY Thin-layer Dradged Material	USA	Commercial	100	$4.50
Baggermaatschappij Boskalis B.V., Horizontal Closing Environmental Grab	The Netherlands	Commercial		
Bean Technical Excavation Corp., SONACAVOR w/ Slurry Process	USA	Commercial	75	$21.00
Bedrock Resources Inc., REACT Dredging System	Canada	Bench Scale		$15.00
Cable Arm (Canada) Inc., Cable Arm Clamshell Bucket	USA	Commercial	300	$7.00
Conbar International, Environmental Dredger	England	Commercial	150	$5.00
Consolidated Dewatering Inc., Dewatering	Canada	Commercial	45	$200.00
CP Environmental Inc., Non-Resuspension of Solids	USA	Commercial	300	$3.50
Dosco Klein Baggerwerken B.V., Scraper Dredge	The Netherlands	Commercial		
Dredging International, Scoop Dredge BRABO	Belgium	Pilot Scale		$3.50
Dredging Specialists, Hydraulic Dredges	USA	Commercial	275	$8.00
Dredging Supply Company, Barracuda/Piranha/Shark	USA	Commercial		
Eagle Iron Works, Swintek Dredge Ladder	USA	Commercial		
Ellicott International, Mudcat	USA	Commercial	15	$15.00
Eriksson Sediment Systems Inc., Method for Marine Sediment Removal	Canada	Pilot Scale	40	$200.00
HAM, Visor Grab	The Netherlands	Commercial	50	$77.00
Harbour Development, Dredges	Canada	Commercial		
Honma Corporation, No. 1 Water Refresher (High Density Dredging)	Japan	Commercial	60	$25.00
Honma Corporation, Water Refresher HD-110	Japan	Full Scale Demo	50	$26.00
IHC Holland N.V., Environmental Dredger	The Netherlands	Full Scale Demo		
Innovative Material Systems Inc., Versi-Dredge (Incomplete)	USA	Commercial		
LWT Inc., Liquid Waste Technology Inc., Pit Hog Dredges	USA	Commercial	285	$27.00
Nautilus Dredging and Docks, STUMP	USA	Commercial	130	$7.60
Normrock Industries Inc., Amphibex	Canada	Commercial	40	$14.00
Penta-Ocean, Pneumatic Type Sand Pressurized Feeding Ship	Japan	Commercial	800	
Penta-Ocean, SWAN Method	Japan	Commercial	150	$25.00
Pneuma s.r.1/IME Ltd., Underwater Dredging Pump	Italy	Full Scale Demo		
Pneuma, Hydraulic Dredge	Italy	Commercial	25	$28.00
Pressair International Corp., Airlift Systems	Germany	Commercial	300	
Rinkai Construction Co. Ltd., Pulse Air Type High Density Sludge	Japan	Commercial	100	$10.00
Rinkai Construction Co. Ltd., Screw Conveyor Type Mud Collector	Japan	Full Scale Demo	50	$10.00
Saeki Kensetsu Kogyo Co. Ltd., No. 1 Mud Cleaner	Japan	Commercial	50	
Saeki Kensetsu Kogyo Co. Ltd., Screw-Feeder-Type Air-Pressuring	Japan	Commercial	600	
Saeki Kensetsu Kogyo Co. Ltd., Tank Type Air Pressurizing Method	Japan	Commercial	60	$30.00
Sanexen, Vacuum Clam Dredge	Canada	Full Scale Demo	6	$50.00
Sevenson Environmental, Hydraulic Cutter	USA	Commercial		
Soli-Flo, Eddy Pump Technology	USA	Commercial	230	
SRS Crisafulli, Rotomite 180P	USA	Full Scale Demo	175	$0.50
Toa Corporation, High-Density Sludge Transport System Method	Japan	Commercial	600	$20.00
Toa Corporation, IRIS Method	Japan	Commercial	90	$32.50
Toa Corporation, No. 7 Clean-up Dredger	Japan	Commercial	100	$28.00
Toyo Construction, Floating Pier Reclamation Method	Japan	Commercial	800	$20.00
Toyo Construction, Oozer-Pump Dredging Method	Japan	Commercial		$40.00
Wakachiku Construction, "No. 2 Clean Sweeper"	Japan	Full Scale Demo		$35.00
Wartsila Scraping Dredger	Finland	Commercial	150	
Youngsman, Weed and Sedimentation Removal	USA	Commercial		

All Data retrieved from Environment Canada's SEDTEC CD-ROM dated 1996

APPENDIX H

Two Pilot Studies for CH2M Gore & Storrie

SEDIMENT DEWATERING PILOT STUDY
MERIVALE STORMWATER MANAGEMENT FACILITY
CITY OF NEPEAN

Prepared for:

Corporation of the City of Nepean

Prepared by:

CG&S
CH2M GORE & STORRIE LIMITED
Ottawa, Ontario

December 1996

EXECUTIVE SUMMARY

CH2M Gore & Storrie (CG&S) was retained by the City of Nepean to carry out a pilot study to evaluate various scenarios to minimize the volume of sediment sludge to be removed from the Merivale Stormwater Management Facility (MSMF). Preliminary studies have indicated that the sediment accumulated in the MSMF is contaminated with elevated levels of hydrocarbon compounds which exceeds the Ministry of Environment and Energy (MOEE) 1996 Decommissioning Guidelines for contaminated soil in industrial sites.

The various scenarios examined to minimize the volume of sediment sludge are as follows :

- Additions of conventional coagulants such as Alum and Ferric Chloride to the MSMF sediments
- Additions of synthetic coagulant-flocculant agents to the sediments
- Dewatering the sediments by mechanical centrifugation
- Dewatering the sediments using freezing-thawing technique

The sediment volume reductions was compared to the control sediment samples which were allowed to settle under gravitational forces.

The results of the pilot study can be summarized as follows:

- The additions of conventional and synthetic coagulant-flocculant agents provided supernatant which has total suspended solids (TSS) concentration less than 300 mg/l which meets the Regional Municipality of Ottawa-Carleton (RMOC) By-Law criteria to the discharge of liquid in the sanitary sewers

- Based on the nature of sediment accumulated at MSMF, which is primarily inorganic minerals, control samples achieved similar results to those sediment samples treated with conventional and synthetic coagulant-flocculant agents

- Control samples (no chemical treatment, i.e. sediment settled under the gravitational forces), were considered to be the most appropriate for MSMF, due to the reduction in sludge volume caused by the lack of chemical additions.

- Freezing-thawing of the sediments with and without chemical additions produced clear supernatant

- Centrifugation of conditioned sediment (sediment with high dosage of coagulant-flocculant) produced solid capture in the dewatered sludge of over 99% of the initial concentration in the sediment matrix. However, considering the increase in sediment volume form the additions of the conditioning agents, the performance of a centrifugation was considered minimal due to the high cost of the chemical agents.

The highly mineralized nature of the sediment is probably the major reason for the poor performance of the dewatering procedures. **As such it was concluded that gravity settling is the most appropriate way of dealing with the sediment dewatering at MSMF.**

Sediment Dewatering Study

R.L. Droste and J. Zheng

November 8, 1996

INTRODUCTION

This study was designed to evaluate various scenarios to minimize the volume of sediment sludge to be removed from a stormwater pond containing sediment contaminated with hydrocarbons and possibly other hazardous substances. The pond will be drained and there are a number of possible options for processing the sediment.

The pond will be drained to a local sewer. Preliminary studies have indicated that the upper layers of sediment may be easily disturbed if the pond is drained causing total suspended solids (TSS) concentrations to rise to concentrations higher than 300 mg/L which exceeds the bylaw for discharge into a sewer. Addition of coagulation-flocculation agents to the pond is a primary consideration to remove the maximum amount of water from the pond and minimize the volume of sediment for further processing and transport. The most practical method to add coagulation agents to the pond is to discharge them from the rear of a boat to take advantage of mixing from the propeller.

It may be feasible to process the pond sediment in the pond by segregating a part of the pond with a berm and pumping all sediment into the area after it is drained. Or the sludge may be pumped to a temporary site in the proximity of the pond for drying or freeze-thaw conditions. Freeze-thaw conditioning/dewatering is a natural option for further reducing the volume of sludge before disposal or further processing. Another alternative is to pump the sediment to trucks for transport to a dewatering facility. The final option is to use a portable mechanical dewatering device for onsite processing. Mechanical dewatering options either onsite or at a permanent sludge processing facility include centrifugation and vacuum dewatering.

Pumping the sediment provides an opportunity to add conditioning agents and thoroughly mix them with the sediment. Conditioning agents are often the same chemicals used for coagulation and flocculation; however, they are added at much higher doses to dewater sludge. Conditioning agents may also be added directly to the sediment if a bucket loader is used to remove the sediment from the pond. In this case the sediment would be transported to an offsite dewatering facility and the sediment and conditioning agent would be further mixed during transportation.

A series of lab studies were designed to assess all possible disposal options for chemical and physico-chemical water removal from the sediment. The flow chart in Fig. 1 outlines the possible flow paths.

All analyses described in this report were conducted according to *Standard Methods* (AWWA, 1992) unless otherwise indicated.

SEDIMENT AND SUPERNATANT QUALITY

Six pond locations were sampled for sediment; two near the pond inlet, two in the center, and two near the outlet end. At a sampling section, one sample was taken at a distance of one third of the pond width and the other at a distance of two thirds of the pond width. Also a few buckets of pond water were collected for use in the tests. The sediment samples and pond water were stored at room temperature throughout these exercises since the pond is at ambient temperature. The buckets were covered to prevent evaporation.

A preliminary characterization of the sediment at the six locations was performed. A 500 mL aliquot of sediment was added to a 1 L beaker and it was filled with pond water. Any sticks or other gross material were removed from the sediment. The samples were settled for various periods after which supernatant and sediment quality were analyzed.

Tables 1 and 2 present the characteristics of the supernatant and sediment without any chemical or other treatment beyond quiescent settling. The data in these tables do not exhibit variation that is atypical of sediment samples. For samples take at any location in the pond the sediment mineral content was 90% or higher.

In the following phases of the tests mixed sediment samples from the various locations were used.

	I	II	III	IV	V	VI
1			↗→ →	■ →		
2			↗→ →	Centrifuge →		
3			↗→ →	Vac. Dew. →		Disposal
4	■	Drain Pond			↗→ ■	
5			↘→ →	F/T	→ Centrifuge	
6					↘→ Vac. Dew.	
7			↗→ →	■ →		
8			↗→ →	Centrifuge →		
9			↗→ →	Vac. Dew. →		Disposal
10	Add coag.	Drain Pond			↗→ ■	
11			↘→ →	F/T	→ Centrifuge	
12					↘→ Vac. Dew.	
13				↗→ Centrifuge →		
14				↗→ Vac. Dew. →		
15	Add coag.	Drain Pond	Add cond.		↗→ ■	Disposal
16				↘→ F/T	→ Centrifuge	
17					↘→ Vac. Dew.	
18			↗→ →	Centrifuge →		
19			↗→ →	Vac. Dew. →		
20	Add cond.	Drain Pond			↗→ ■	Disposal
21			↘→ →	F/T	→ Centrifuge	
22					↘→ Vac. Dew.	

Figure 1. Flow chart of disposal options. ■ - do nothing; Add coag. - add coagulant; Add cond. - add conditioner; Vac. Dew. - vacuum dewatering; F/T - freeze-thaw

Table 1 Supernatant quality of raw samples

	Supernatant					Filtrate		
Settling time (h)	18		38.5			38.5		
Sample No.*	TSS mg/L	VSS mg/L	TSS mg/L	VSS mg/L	BOD_5 mg/L	COD mg/L	Alkalinity mg/L as $CaCO_3$	pH
GW 1-1	142	94	62	56	25	116	200	6.76
GW 1-2	178	116	68	60	18	108	175	6.96
GW 2-1	314	176	102	82	19	139	250	7.17
GW 2-2	410	172	106	82	22	132	200	7.18
GW 3-1	86	86	46	46	26	178	188	7.42
GW 3-2	88	82	40	40	27	23	200	7.37
Ave.	203	121	71	61	23	116	202	7.14

* Samples 1, 2, and 3 were taken at the inlet, center , and outlet locations, respectively. The second number indicates the side of the pond standing at the inlet and looking toward the outlet; 1- righthand side; 2- lefthand side.

Table 2 Sediment quality after settling for 38.5 h

Sample No.*	TSS g/L	VSS g/L	VSS/TSS %	s.g. kg/L
GW 1-1	787	48.3	6.1	1.40
GW 1-2	454	40.8	9.0	1.28
GW 2-1	699	52.4	7.5	1.35
GW 2-2	410	38.9	9.5	1.24
GW 3-1	322	31.9	9.9	1.15
GW 3-2	317	32.0	10.1	1.10
Ave.	498	40.7	8.7	1.25

* Samples 1, 2, and 3 were taken at the inlet, center , and outlet locations, respectively. The second number indicates the side of the pond standing at the inlet and looking toward the outlet; 1- righthand side; 2- lefthand side.

JAR TEST ANALYSES

Clarification of pond water-sediment samples was examined with jar tests. Coagulating agents may be added to the pond to maximize the removal of suspended solids which will allow the maximum amount of water to be drained from the pond and minimize the volume of sediment to be further processed.

Dewatering the sediment may be enhanced with the addition of dewatering agents. The dewatering agents may be added to the pond and mixed where they will affect clarification and precipitate that collects on the sediment. If the dewatering agents were added in this manner they would be further mixed with the sediment when it is pumped from the pond. The jar test were used to determine supernatant quality for both coagulating doses and dewatering doses of agents.

The other alternative for addition of dewatering agents is to add them directly to the settled and drained sediment. This alternative is evaluated in a later section.

A 300 mL sediment aliquot was placed in a 1 L jar and the volume was made up to 1 L with the addition of pond water (Fig. 2). Various agents were added to the samples (Fig. 2). The samples were mixed for 15 to 20 s (Fig. 3) and followed by quiescent settling (Fig. 4). Clarification progress was monitored. Supernatant turbidities were analyzed for all samples and in addition TSS analyses were performed on the samples that exhibited the best clarification.

Synthetic coagulant-flocculant agents were used in addition to conventional coagulants of alum and $FeCl_3$. The synthetic agents were supplied by Polypure, Inc[1]. The five samples of primary coagulants (cationic polymers) were designated E-185 - E-187, E-189, and E-190 by the manufacturer. The three samples of flocculants (high molecular weight anionic polymers) were designated E-146, E-147P, and E-184 by the manufacturer. These agents were recommended by the manufacturer after describing the field conditions for the Merivale pond.

These agents were added according to the manufacturer's guidelines. The solution pH should be in the range of 6.5-8.0 and no alkalinity requirement was specified. The pond water pH as shown in Table 1 was satisfactory. The primary coagulants were diluted to a 5% working solution and dosed at an amount that was approximately 10% by weight of the suspended solids in the supernatant. Supernatant solids were assumed to be near 200 mg/L. This is the approximate average quality of supernatant after settling 18 h (see Table 1) and is the most conservative value.

The specific gravities (s.g.s) of the concentrated polymer solutions were assumed to be 1.0 (per the manufacturer, although the solutions were more dense than water). After dosing, the coagulants were mixed

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[1] Polypure, Inc., 5930 Soutel Dr., Jacksonville, FL 32219; Tel: 904-765-3568.

for 15 to 20 s. The flocculant solutions were diluted to 0.1 to 0.2% to make a working solution and added at an amount that was 5-10% of the coagulant dose by weight. Again it was assumed that the densities of the flocculant solutions were 1.0 even though the viscous solutions were more dense. However density differences of 50% would not cause doses that were outside of the recommended ranges. After addition of the flocculant the solution was again mixed for 15-20 s before commencing a quiescent settling period. A large number of coagulant and flocculant combinations were tested but not all combinations were examined.

Based on the manufacturer's recommendations approximately 20 mg/L of coagulant polymer were added followed by flocculant doses in the range of 1-2 mg/L.

The key for the commercial coagulant and flocculant descriptors is given in Table 3. This key is used in all following tables in this report. The costs of the coagulating agents are $US 0.44-0.55/kg and the costs of the flocculants are $US 1.54/kg. The minimum purchase is 208 L (55 US gal). The bulk density of these types of solutions is typically in the range of 110-140 g/100 mL (Droste, 1997).

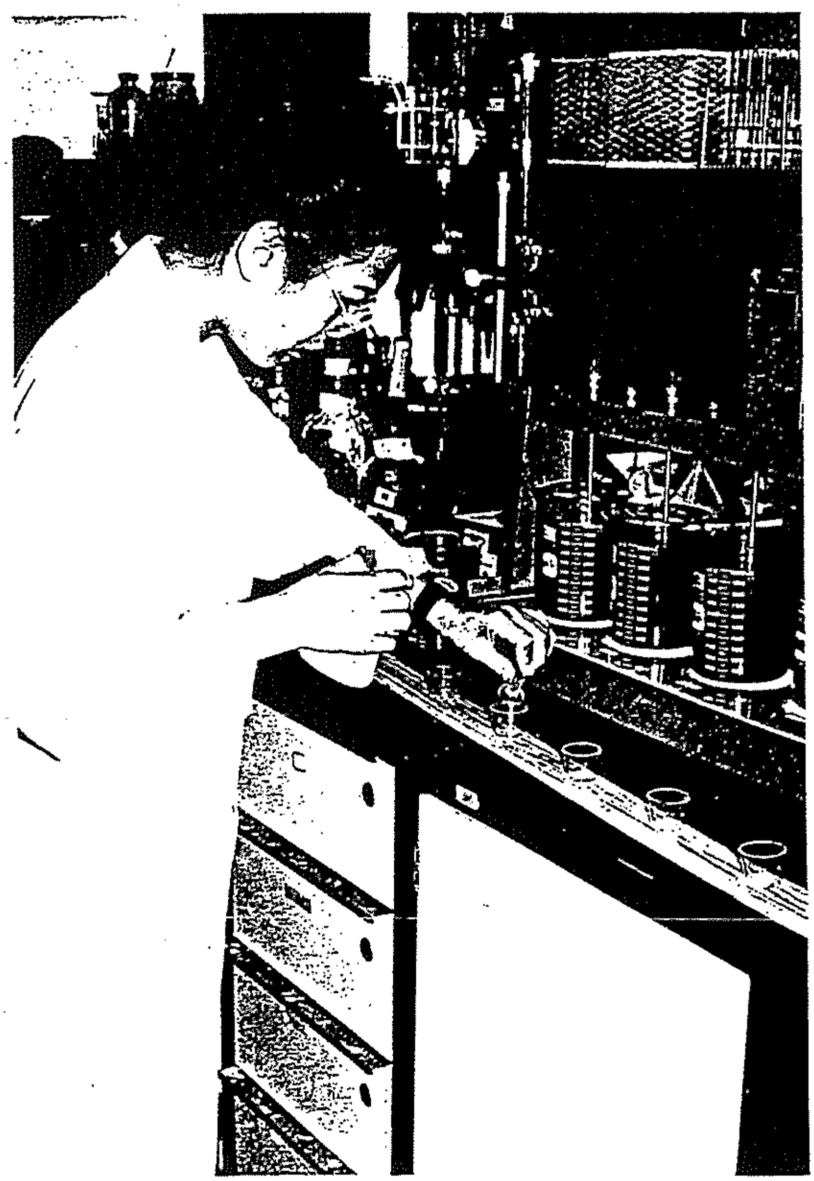

Figure 2. Freshly prepared sediment-pond water samples in the jar test apparatus. The technician is preparing the doses of agents to be added at the same time to all beakers.

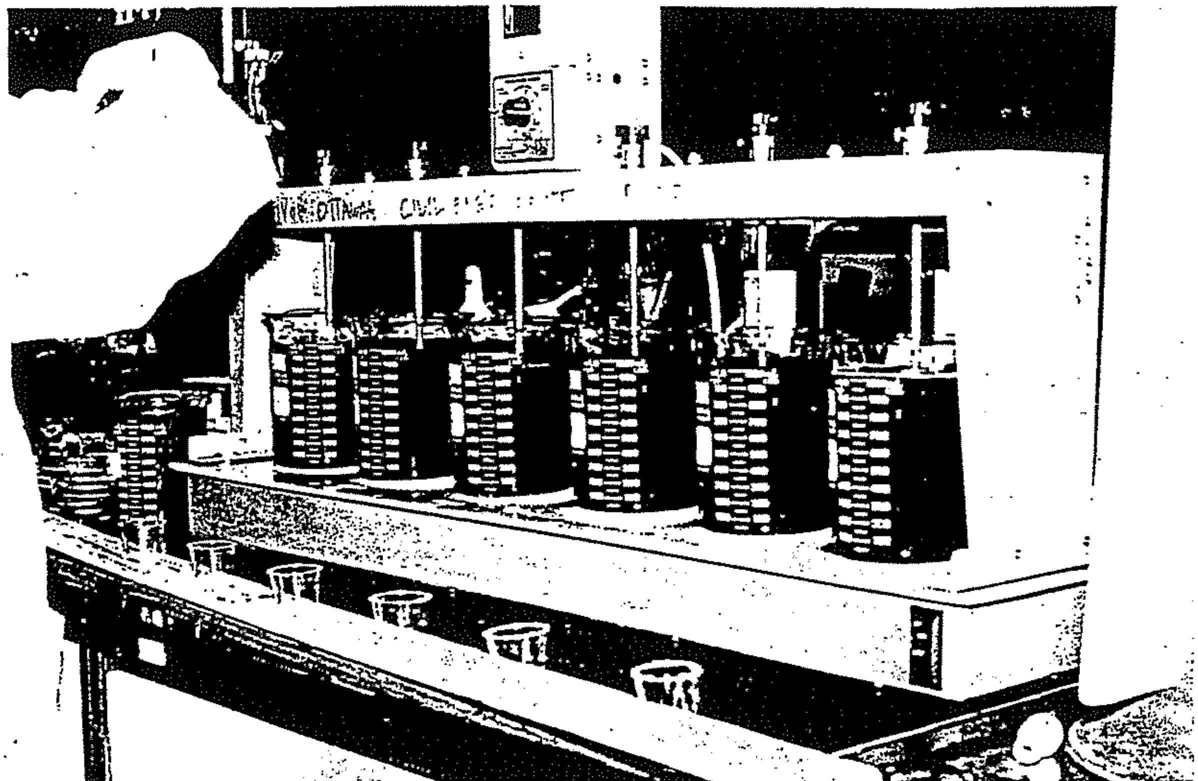

Figure 3. Mixing the agents and the sediment and pond water samples.

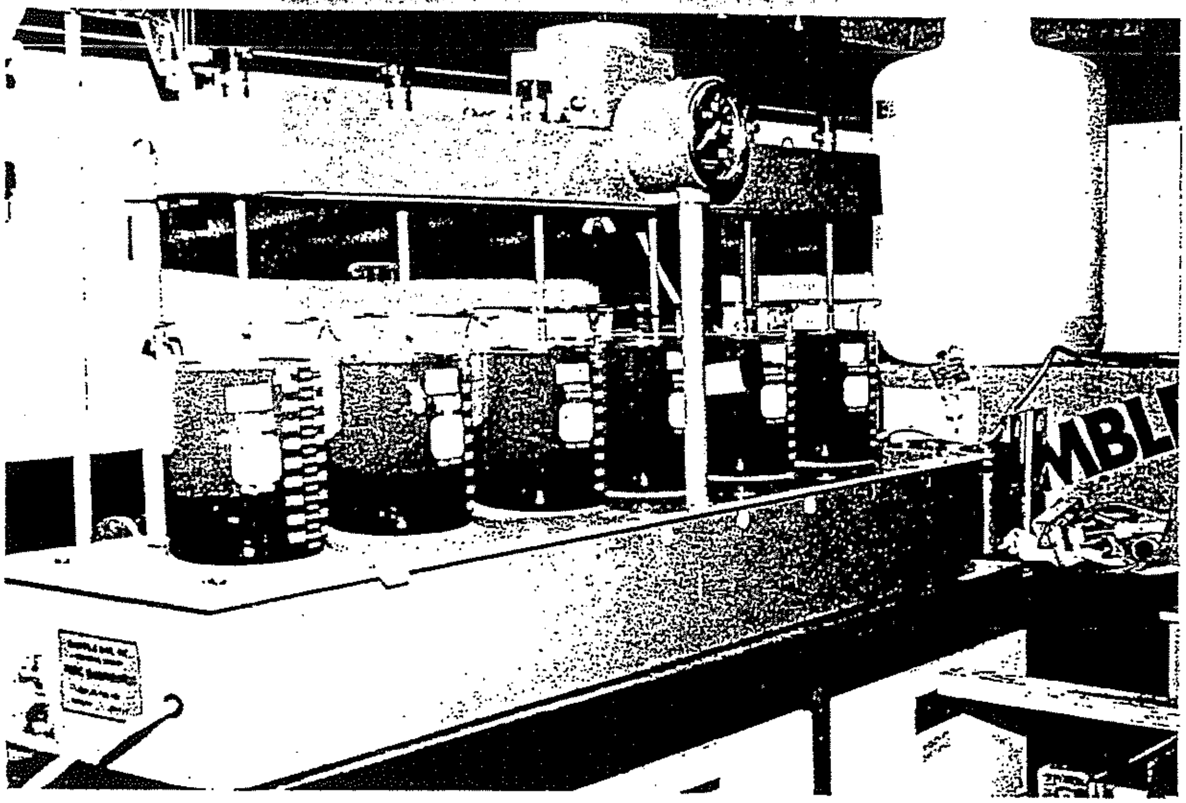

Figure 4. Clarification progress after settling for a period of time.

Table 3 Synthetic coagulant and flocculant key

Coagulant		Flocculant	
Manufacturer's code	Designation	Manufacturer's code	Designation
E-185	C-1	E-146	F-1
E-186	C-2	E-147P	F-2
E-187	C-3	E-184	F-3
E-189	C-4		
E-190	C-5		

Supernatant quality and other information after settling for 24 h are given in Table 4 below. Data taken at times before 24 h are given in Appendix A.

Table 4 Supernatant and sediment quality after settling 24 h

						Comment
	Control					
Dose (mg/L)	0	0				
Sediment Vol. (mL)	250	250				
Turbidity	154	163				
	$FeCl_3$					
Dose (mg/L)	20	40	60	80	100	
Sediment Vol. (mL)	250	260	280	280	280	
Turbidity	96	66	65	53	55	
	Alum					
Dose (mg/L)	20	40	60	80	100	Settled more
Sediment Vol. (mL)	290	250	280	290	290	quickly than
Turbidity	141	88	41	22.1	31.5	$FeCl_3$
	$FeCl_3$					
Dose (kg/Mg*)	20	40	60			Supernatant had a red
Sediment Vol. (mL)	400	490	510			color and
Turbidity	47.5	70.0	85.0			iron oxide
Dose (kg/Mg)	2	4	6			skin
Sediment Vol. (mL)	375	370	410			Red
Turbidity	47.5	70.0	85.0			supernatant
	$FeCl_3$/Lime					
Dose (kg/Mg)	20/75	40/75	60/75			Supernatant
Sediment Vol. (mL)	600	670	620			had a red
Turbidity	7.5	15.0	2.3			color and
Dose (kg/Mg)	2.0/75	4.0/75	6.0/75			thick iron
Sediment Vol. (mL)	530	575	600			oxide skin.
Turbidity	0.7	1.3	2.3			Upper layer of sludge was very light

Table 4 cont'd.

	Alum						Supernatant
Dose (kg/Mg)	20	40	60				had a red color
Sediment Vol. (mL)	440	530	530				and skin.
Turbidity	30	41	25				Settled quickly;
Dose (kg/Mg)	2	4	6				firm floc;
Sediment Vol. (mL)	280	300	350				reddish-brown
Turbidity	48	58	65				color
	Alum/Lime						
Dose (kg/Mg)	20/75	40/75	60/75				No color but
Sediment Vol. (mL)	550	710	580				thick skin
Turbidity	0.7	3.5	4.0				
Dose (kg/Mg)	2.0/75	4.0/75	6.0/75				Upper layer of
Sediment Vol. (mL)	500	530	500				sediment very
							light
Turbidity	0.6	1.2	< 1.0				
	Synthetic Coagulant/Flocculant**						
	C-1/F-1	**C-1/F-2**	**C-1/F-3**	**C-2/F-1**	**C-2/F-2**	**C-2/F-3**	
Sed. Vol. (mL)	400	400	400	450	400	425	For all
Turbidity	11	18.2	23.5	11.5	30	40	synthetic agent
TSS (mg/L)	n.d.	14	26	n.d.	14	26	combinations
	C-3/F-1	**C-3/F-2**	**C-4/F-1**	**C-4/F-2**	**C-5/F-1**	**C-5/F-2**	settling was
Sed. Vol. (mL)	390	375	370	470	375	400	rapid(within 1-
Turbidity	14.5	30.5	12.2	27.6	6	7.5	2 h) compared
TSS (mg/L)	10	n.d.	26	10	8	8	to inorganic
							agents; large
							granules

* Dose in kg/Mg is based on kg/Mg of dry solids.

** Dose for all agents was 10%/1% as described in the text

Except for the synthetic agents, the other coagulation doses were arbitrarily chosen. The doses for conditioning agents above 10 kg/Mg dry solids (dewatering doses) spanned typical ranges given in the literature (Metcalf & Eddy, 1991; USEPA, 1987). Because of poor performance of conditioning agents in the normal dose range, a lower series of doses from 2 to 6 kg/Mg was also tested.

From the results in Table 4, the synthetic coagulant-flocculants were clearly superior to their inorganic counterparts. Not only was the supernatant clear but the clarification was rapid, occurring in two hours or less. Also the flocculated granules were large and not easily disturbed.

Alum at doses of 80-100 mg/L produced the best clarification of the inorganic agents. Addition of inorganic agents at doses that are used for dewatering sludges was problematic for clarification. A crust generally formed at the top of the liquid (Figs. 5 and 6) and the quality of the overlying water was decreased. The low conditioning doses provided results that were fair in most cases.

There is no benefit to adding conditioning (dewatering) doses of agents to the pond with overlying water. High concentrations of these agents must be added directly to the sediment and thoroughly mixed.

The TSS of the supernatant and s.g. of sediment treated with agents that produced better clarification results were measured. Results are given in Table 5.

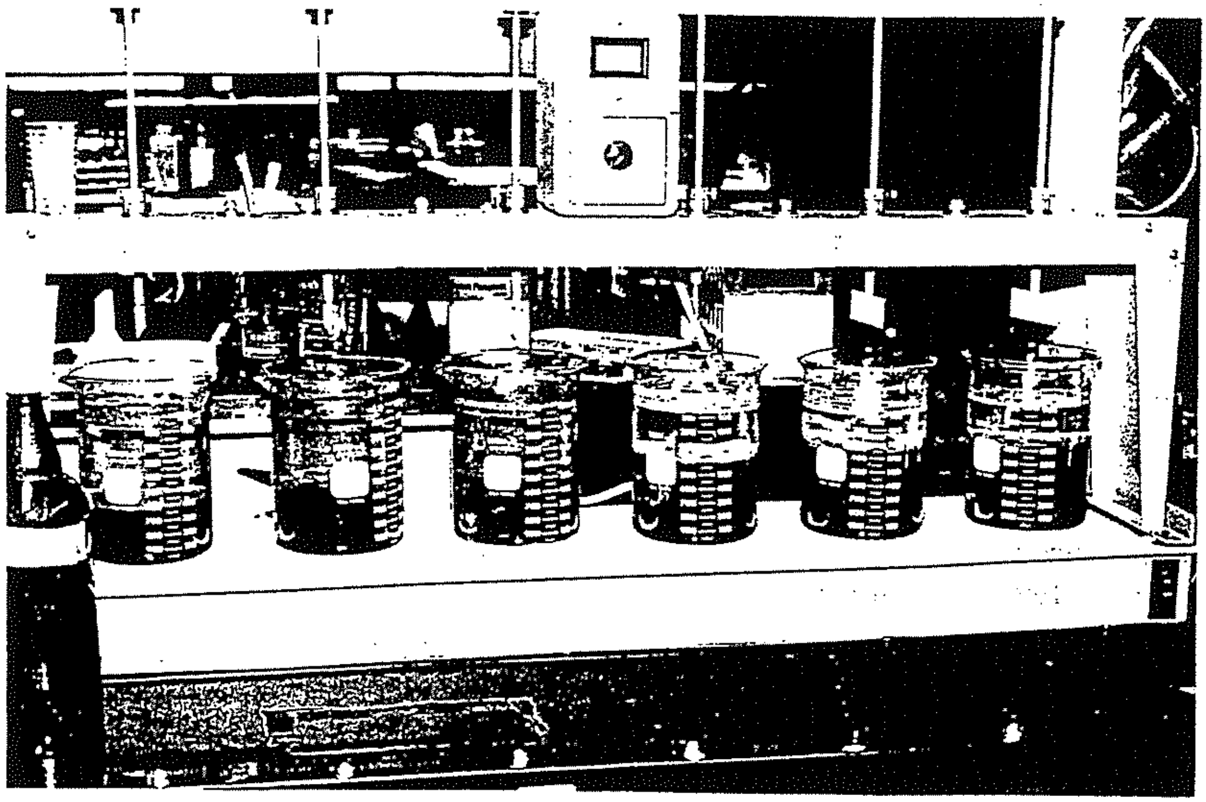

Figure 5. Supernatant after settling and addition of iron salt (the left three beakers) at dewatering doses and synthetic coagulant (the right three beakers).

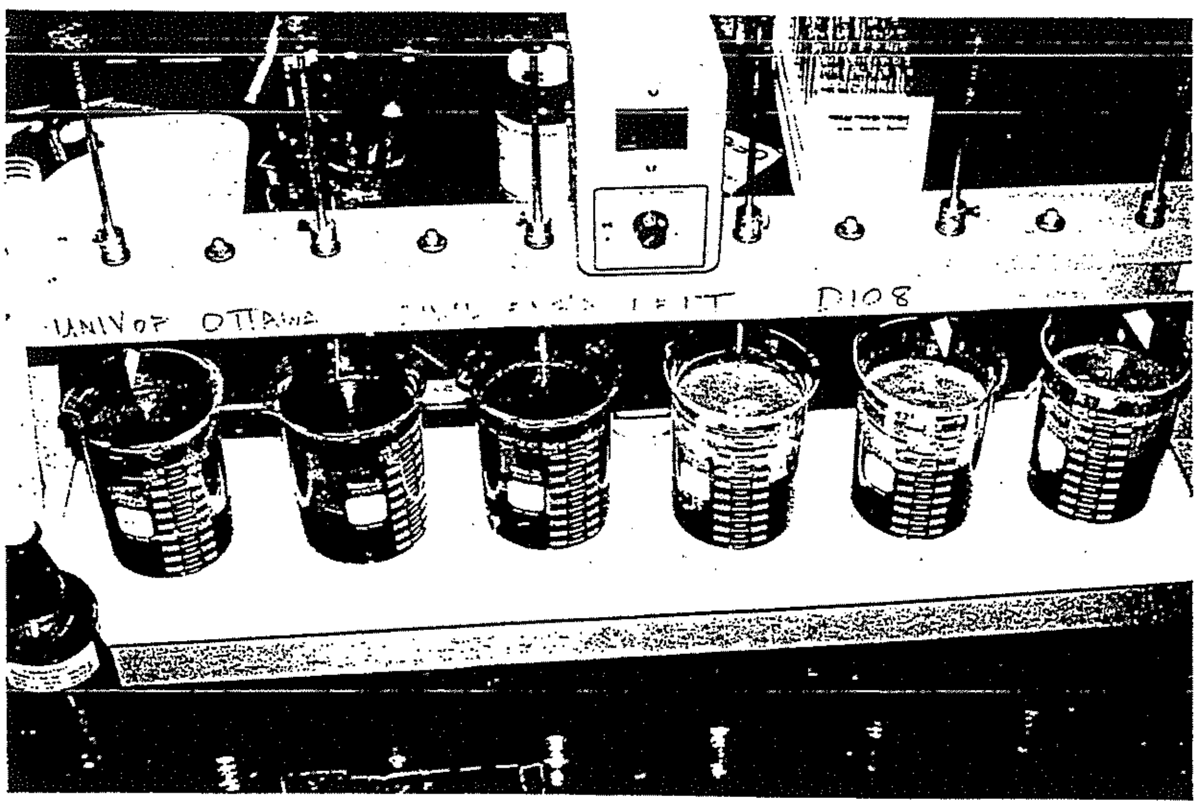

Figure 6. Top view of crust on beakers (the left three) treated with dewatering doses iron salts.

Table 5 Supernatant and sediment characteristics after settling 24 h

		Supernatant		Sediment	
	Dose	Turbidity	TSS	s.g.	TSS
Agent	mg/L	-	mg/L	-	g/L
Control	-		86	1.22	410
	-		82	1.29	454
Alum	80	21	34	1.25	
	100	32	44	1.23	
	2 kg/Mg			1.27	608
Alum/Lime	2/75 kg/Mg			1.12	509
$FeCl_3$	80	53	34	1.23	
	100	55	30	1.68	
	2 kg/Mg			1.27	572
$FeCl_3$/Lime	2/75 kg/Mg			1.11	501
Synthetic polymers	10%/1%	All < 40	All < 26	*	*

* Not measured but these values should be near average values determined for low doses of inorganic agents and the control.

DEWATERING STUDIES

Sediment was subjected to centrifugation and a freeze-thaw cycle to evaluate its dewaterability. Also the specific resistances of sediments were measured. The effects of chemical agents on the dewatering approaches were also evaluated.

Sediment Dewaterability without Freeze-Thaw

The dewaterability of sediment treated with agents that produced better clarification results was evaluated with centrifugation and analyses of specific resistance. For coagulants added at doses that were optimal for clarification the procedure was to add the coagulants to 500 mL sediment aliquots with 500 mL of pond water at doses given in the previous section. Mixing was applied for 15-20 s after addition of the reagents and the samples were allowed to settle for 24 h. Supernatant was drained from the settled samples and analyses were begun.

Since the previous series of tests had shown that addition of agents at dewatering doses to sediment with overlying water produces unsatisfactory results for clarification, dewatering doses (dewatering doses are specified in kg/Mg in Tables 4 and 5; coagulation doses are specified in mg/L), were applied to a sediment sample only (i.e., only a 500 mL sediment sample was used without adding any pond water). The agents were added to the sediment and mixed for 15-20 s. The sediment was allowed to remain quiescent for 24 h and any supernatant was drained before analyses commenced.

The TSS content of the sediment was measured. A 70 mL aliquot of sediment was centrifuged for 20 min at 1 000 g. The relative force is in an intermediate range for commercial centrifuges (Metcalf & Eddy, 1991) and the time was arbitrarily chosen. The volume of centrate and its TSS content were measured after centrifugation.

The specific resistance test was conducted on the sediment according to the procedures outlined in USEPA (1987). The diameter of the Büchner funnel was 9.3 cm and the vacuum was 381 mm Hg (Figs. 7 and 8). A viscosity of 1.002×10^{-3} N-s/m at 20°C (room temperature) was used in the calculation which is based on the following equation.

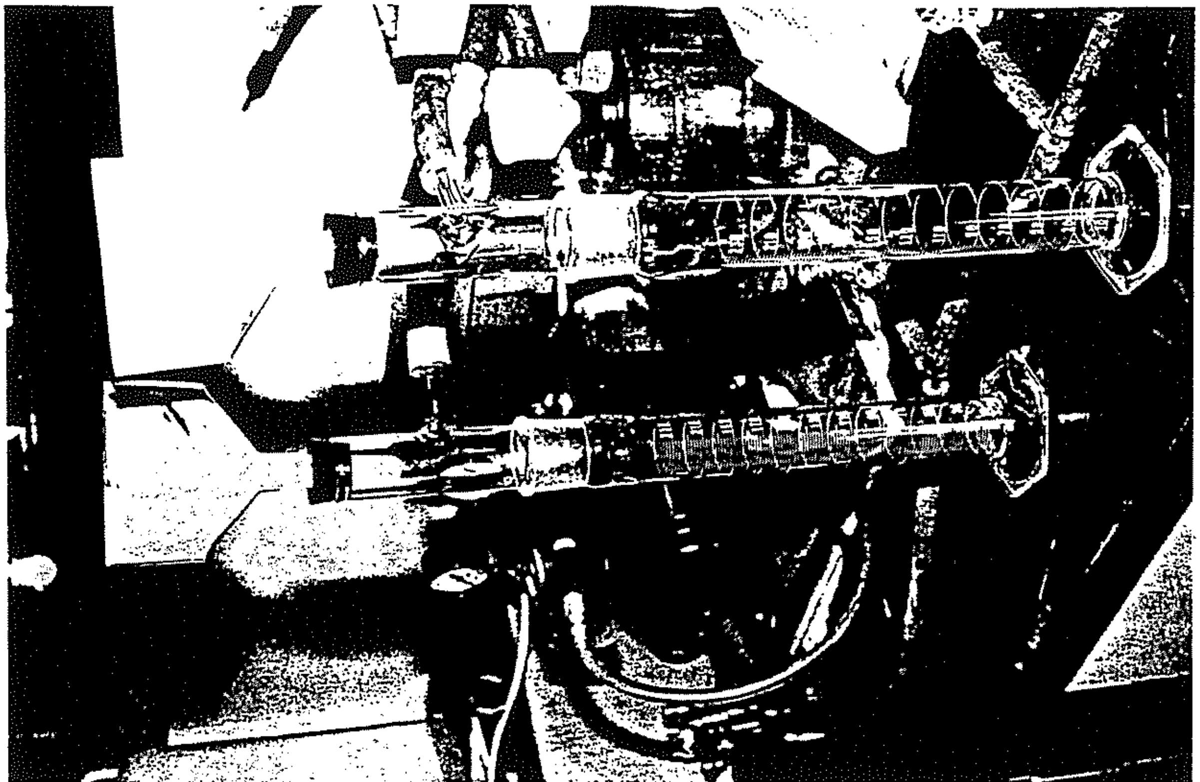

Figure 7. Dewatering apparatus connected to vacuum pump.

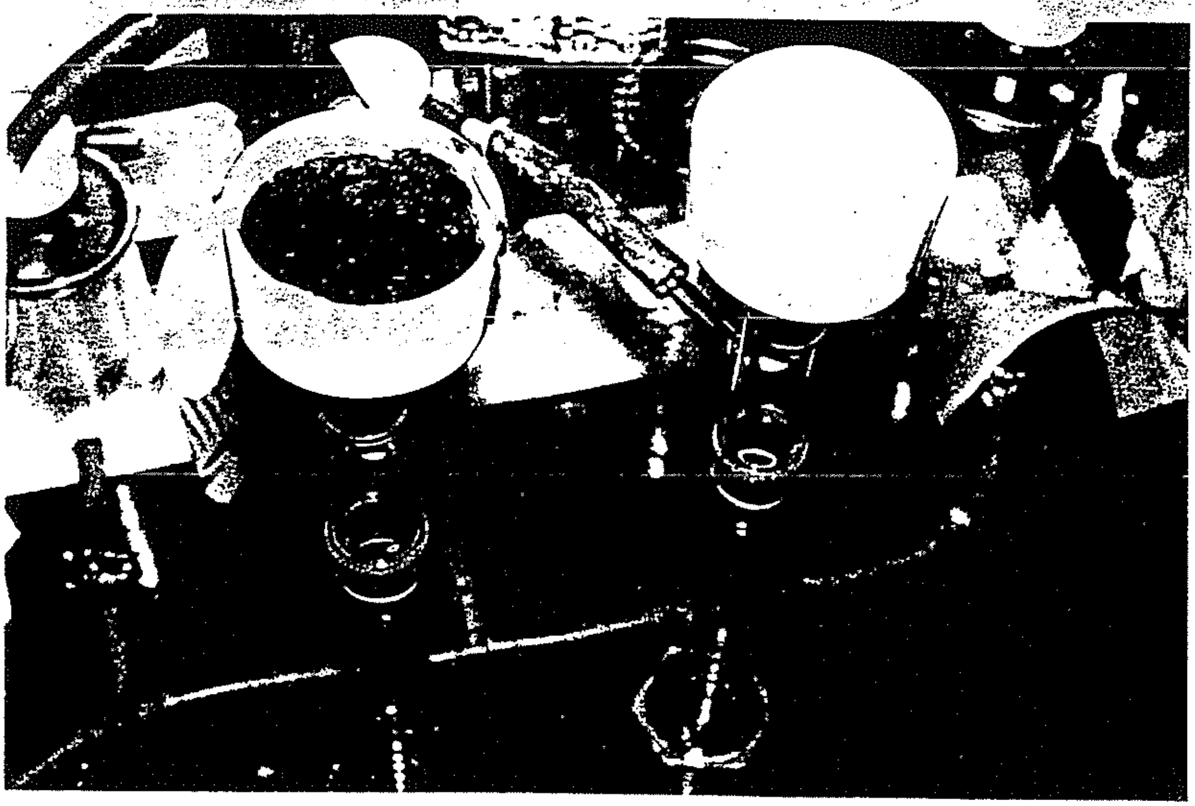

Figure 8. Dewatering apparatus with sediment added to the left unit.

$$r_{wc} = \frac{2\Delta P A^2}{\mu w} m$$

where

r_{wc} is specific resistance
P is the vacuum pressure
A is the area of the filter
μ is viscosity of the filtrate
w is mass of cake solids per unit volume of filtrate (Fig. 9)
m is the slope of a plot of t/V versus V (t is time and V is volume of filtrate collected)

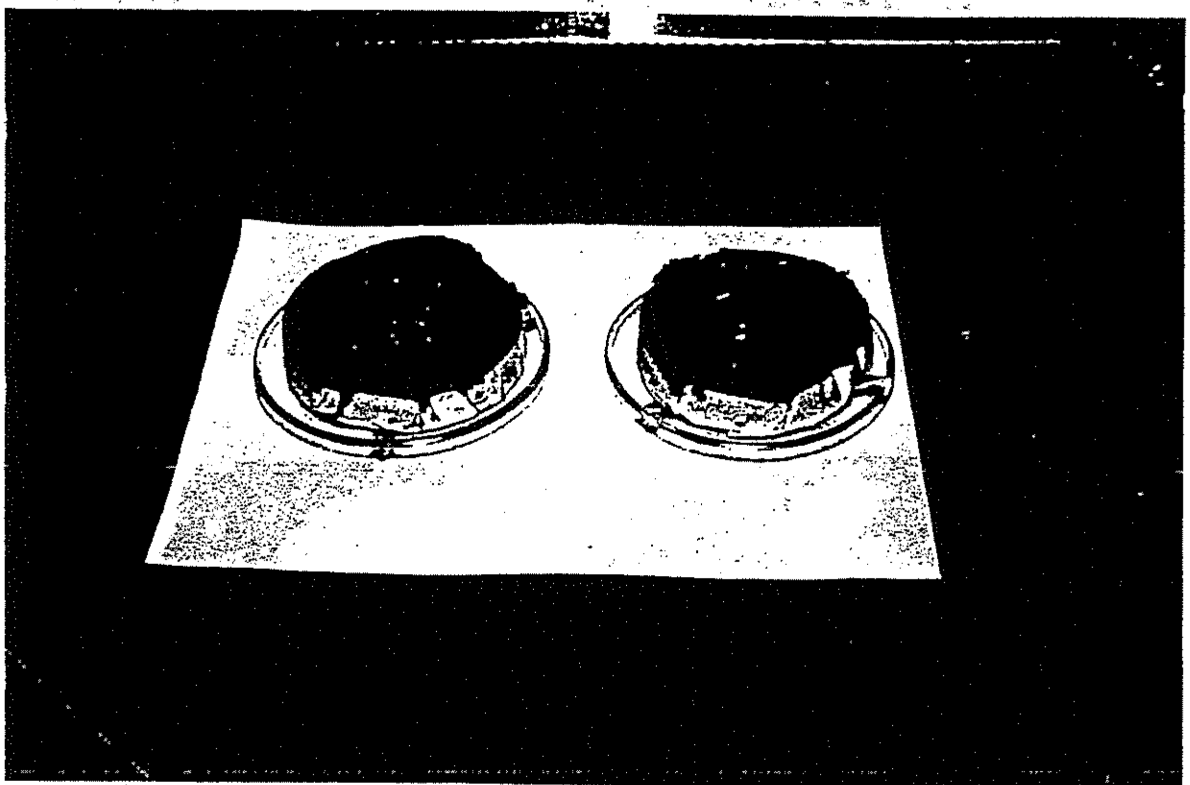

Figure 9. Cake removed from specific resistance apparatus.

Table 6 lists the results of the analyses. Even though a significant number of samples were processed in this study, it would still be classified as a limited evaluation. Therefore results must be interpreted with caution given the variable nature of sediment and associated analytical techniques. See the Discussion section for an analysis of overall volume reductions. The capture of solids was very high as shown in the example below but the quality of the supernatant was well above 300 mg/L in all cases. This would cause an additional treatment of the centrate.

The solids capture by centrifugation was greater than 99% for all cases even though supernatant TSS ranged from 1324 to 4481 mg/L and initial TSS of the sediment samples ranged from 426 to 797 g/L. An example calculation of solids capture by centrifugation follows.

The data for an $FeCl_3$/lime dose of 4/75 kg/Mg will be used because this dose gives the worst solids capture results.

The mass of solids in the 70 mL sample was:

M = 426 g/L × 0.070 L = 29.8 g

The mass of solids in the supernatant was

S = (4203/1000 g/L) 0.030 L = 0.13 g

The percent solids lost in the supernatant was

SL = (0.13/29.8) × 100 = 0.42%

The percent solids capture was

C = 100 − 0.42 = 99.6%

The specific resistance data are variable but the $FeCl_3$/lime combinations produced the lowest values. Vacuum dewatering is not known to be any more efficient than centrifugation. It is likely that the filtrate from vacuum filtration will not be below 300 mg/L.

Table 6 Dewatering characteristics of sediment treated with various agents

			Centrifugation			
Agent	Dose*	Initial TSS* g/L	Vol. of centrate removed mL	Removal %	Centrate TSS mg/L	Specific resistance m/kg × 10^{-12}
Control	-	797	15.2	21.7	1950	1.09
C-1/F-1	10%/1%	745	19.4	27.7	2670	3.36
C-2/F-1	10%/1%	506	20.5	29.3	1605	0.378
C-5/F-1	10%/1%	620	24.6	35.1	890	1.07
C-5/F-2	10%/1%	614	18.6	26.5	1543	0.521
$FeCl_3$	80 mg/L	722	17.6	25.1	1324	1.60
$FeCl_3$	100 mg/L	542	17.0	24.3	1224	0.529
Alum	80 mg/L	749	16.2	23.1	2747	0.932
Alum	100 mg/L	756	16.1	23.0	3410	0.714
$FeCl_3$	20 kg/Mg	765	20.6	29.4	4481	0.540
$FeCl_3$/Lime	20/75 kg/Mg	499	27.2	38.9	2188	0.150
$FeCl_3$/Lime	4/75 kg/Mg	426	30.0	42.9	4203	0.189
Alum	20 kg/Mg	508	28.4	40.6	2584	0.640
Alum/Lime	20/75 kg/Mg	646	21.2	30.3	3288	0.443
Alum/Lime	4/75 kg/Mg	426	30.0	42.9	3282	0.369

*TSS was measured after settling for 24 h.

**Doses are described in the previous section.

Freeze-Thaw Dewaterability

The procedures for adding the chemical agents is as described in the previous section. After the sediment had settled for 24 h, the samples were frozen solid for three days at temperatures of −20°C or lower (Fig. 10). The samples were then thawed for three days (Fig. 11). The volume of supernatant was drained and measured. Supernatant TSS concentrations were not measured but visually, the supernatants were very clear after freeze-thawing. The sediment TSS was measured. A 70 mL aliquot of the drained sediment was centrifuged at 1 000 g for 20 min. The centrate volume and TSS were measured. Results are reported in Table 7.

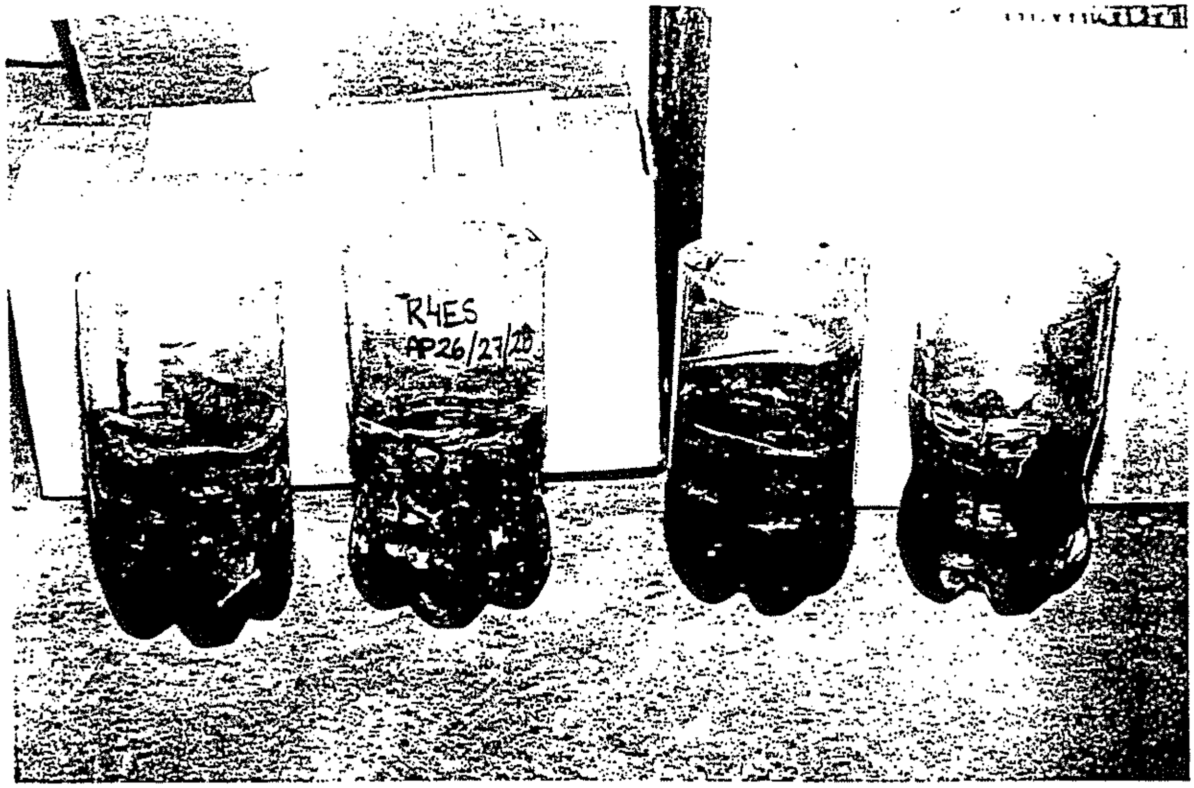

Figure 10. Frozen sediment samples.

Figure 11. Thawed samples.

The data in Tables 6 and 7 show that the volume of the sediment increased after the addition of chemical agents. In Table 6 the lower concentrations of sediment are indicative of a higher water content of sediment; in Table 7 the volumes of sediment after treatment were recorded. In general higher doses of chemical agents increased the volume of sediment more than lower doses. These changes in volume make it more difficult to assess the efficacy of treatment directly from the raw data. The analyses of the results is in the Discussion section.

Freeze-thaw results will probably translate most reliably to field performance. Mechanical dewatering devices experience scale effects. The dimensionless numbers that may be useful for scaling them have not been correlated. In particular, centrifuge results obtained in the laboratory are likely to be the best performance that can be expected.

For centrifugation of the freeze-thaw and drained sediment the percent of solids captured was again above 99% for all agents. Also, although centrate TSS levels were lower than levels observed for non-freeze-thaw treated sediment, they were generally above 300 mg/L.

The specific resistance data were generally consistent among the control and the sediment that had received insignificant chemical doses (i.e., coagulation doses). The lowest specific resistances were recorded for the low $FeCl_3$/lime dose (4/75 kg/Mg) and the alum or alum/lime conditioning doses.

Table 7 Dewatering characteristics of sediment treated with various agents and freeze-thawed

Agent	Dose*	Initial vol. mL	Vol. removed mL	Rem %	Sediment TSS (after thaw) g/L	Centrifuge Vol. removed mL	Centrifuge Rem %	Centrifuge Centrate TSS mg/L	Specific resistance m/kg × 10^{-12}
Control	-	500	29	5.8	866	17.0	24.3	466	0.271
C-1/F-1	10%/1%	570	57	10.0	830	19.0	27.1	195	0.269
C-2/F-1	10%/1%	580	62	10.7	787	19.2	27.4	271	0.277
C-5/F-1	10%/1%	600	76	12.7	839	16.6	23.7	247	0.218
C-5/F-2	10%/1%	570	33	5.8	870	16.4	23.4	396	0.251
$FeCl_3$	80 mg/L	500	17	3.4	921	15.8	22.6	595	0.385
$FeCl_3$	100 mg/L	500	14	2.8	888	16.0	22.9	688	0.436
Alum	80 mg/L	520	37	7.1	897	17.0	24.3	459	0.357
Alum	100 mg/L	600	32	5.3	875	15.8	22.6	494	0.359
$FeCl_3$	20 kg/Mg	660	120	18.2	772	19.4	27.7	531	0.119
$FeCl_3$	60 kg/Mg	670	97	14.4	-	-	-	-	-
$FeCl_3$/Lime	20/75 kg/Mg	780	177	22.7	662	22.2	31.7	279	0.311
$FeCl_3$/Lime	4/75 kg/Mg	780	235	30.1	625	20.0	28.6	345	0.062
Alum	20 kg/Mg	610	80	13.1	915	13.6	19.4	397	0.180
Alum/Lime	20/75 kg/Mg	700	170	24.3	585	21.4	30.6	617	0.068
Alum/Lime	4/75 kg/Mg	820	215	26.2	579	23.2	33.1	720	0.140

*Doses are described in the previous section.

DISCUSSION

The data on clarification from the jar test results were ranked according to the volume of sediment remaining after addition of an agent and the quality of the supernatant. See Table B.1 in Appendix B. Since sediment volume is the primary concern of this investigation, it was weighted more highly than supernatant turbidity. All samples had supernatant TSS concentrations below the 300 mg/L limit after settling 24 h; which relegated this to a secondary consideration.

In Table B.1 the control samples (i.e., no chemical addition) were among the three highest ranked treatment methods because they did not increase the volume of sediment. Inorganic agents at low doses were also among the better performers. Lower doses of chemical agents have smaller effects than larger doses on the sediment matrix and volume.

The results in Table 6 were analyzed in a similar manner in Table B.2. The volume of settled sediment after chemical treatment was taken into consideration to determine the total volume reduction achievable with centrifugation following chemical treatment. Again the control fared well along with samples that received lower doses of inorganic agents.

Finally results from freeze-thaw and freeze-thaw followed by centrifugation were analyzed in Table B.3. The control achieved the best results with agents applied at low doses also grouped among the best performers.

CONCLUSIONS

Comparing data for sediment with no or low amounts of chemicals added for TSS or s.g. shows a fair degree of variability which illustrates the difficulty in conducting tests on sediment. The variable nature of sediment also requires extensive sampling along with testing to confirm results. This highlights the need for caution in interpreting results.

For efficient clarification, the synthetic coagulant/flocculant agents were clearly superior. The settled granules are less likely to be disturbed as supernatant is drained allowing maximum drainage of the pond. Furthermore the rapidity with which these agents act would allow the draining operation to be carried out with certainty and minimal disturbance from unexpected inclement weather or other problems that may occur with time lapses.

From analysis of results on the ultimate volume that must be disposed, no chemical treatment appears to provide the least sediment for disposal regardless of the dewatering approach that is applied. Low doses of chemical agents give results nearer the performance of the control than higher doses.

Although the supernatant solids were not measured in freeze-thaw dewatering tests, visual observation of the supernatant make it the best choice for dewatering if any dewatering is to be considered. Mechanical dewatering will produce a reject water that has a suspended solids content well above 300 mg/L. The reject water will have to be treated again if it is to be disposed of in the local sewer. Conditioning agents for mechanical dewatering increase the volume of sediment with little net gain in overall volume reduction. Centrifugation, in the favorable conditions of the laboratory, produced solids capture over 99% but considering the change in sediment volume from conditioning agents that improve the performance of a centrifuge the gains were minimal or nonexistent notwithstanding the costs of the chemical agents.The highly mineralized nature of the sediment is probably the major reason for the poor performance of the dewatering procedures.

REFERENCES

AWWA (1992), *Standard Methods for the Examination of Water and Wastewater*, 18th ed., American Water Works Association, Denver, CO.

Droste, R.L. (1997), *Theory and Practice of Water and Wastewater Treatment*, J. Wiley & Sons, Toronto.

Metcalf & Eddy (1991), *Wastewater Engineering: Treatment, Disposal, and Reuse*, 3rd ed., G. Tchobanoglous and F.L. Burton, eds., McGraw-Hill, Toronto.

USEPA (1987), *Dewatering Municipal Wastewater Sludges*, United States Environmental Protection Agency, Washington, DC.

APPENDIX A

JAR TEST RESULTS

Table A.1

		FeCl$_3$ Dose (mg/L)					
time	Observation	0	20	40	60	80	100
2 min	General	sediment surfaces about 900 mL at the beginning of settling					
15 min	Sed. Vol. (mL)*	400	400	400	460	500	480
	Turbidity**	supernatants not clear					
30 min	Sed. Vol. (mL)	350	350	350	400	410	400
	Turbidity	supernatants not clear					clearer
1.0 h	Sed. Vol. (mL)	300	300	320	350	350	350
	Turbidity	supernatants not clear				clearer	
4.0 h	Sed. Vol. (mL)	270	270	280	290	300	300
	Turbidity	533	430	425	386	400	332
24.0 h	Sed. Vol. (mL)	250	250	260	280	280	280
	Turbidity	154	96	66	65	53	55
	pH	7.15	7.10	7.10	7.15	7.10	7.10

* Sediment volume (mL) in the beaker.
** Turbidity of the supernatant.

Table A.2

time	Observation	Alum Dose (mg/L)					
		0	20	40	60	80	100
2 min	General	470	520	440	450	480	550
		settle faster than with $FeCl_3$, supernatants not clear					
15 min	Sed. Vol. (mL)	360	400	350	370	380	430
	Turbidity	supernatants the same				clearer	
30 min	Sed. Vol. (mL)	310	350	300	320	340	360
	Turbidity	supernatants the same			clearer with higher dose		
1.0 h	Sed. Vol. (mL)	300	340	300	310	330	350
	Turbidity	supernatants the same			clearer with higher dose		
4.0 h	Sed. Vol. (mL)	270	300	270	290	300	300
	Turbidity	499	324		323	188	178
18.0 h	Sed. Vol. (mL)	250	290	250	280	290	290
	Turbidity	222	190	123	50	28	40
24.0 h	Sed. Vol. (mL)	250	290	250	280	290	290
	Turbidity	163	141	88	41	22.1	31.5
	pH	7.10	7.00	7.00	6.95	7.00	7.00

Table A.3

$FeCl_3$							
Settling Time	Observation	$FeCl_3$ Dose (kg/Mg)			$FeCl_3$/Lime Dose (kg/Mg)		
		20	40	60	20/75	40/75	60/75
15 min		settles fast	settles fast	bubbles		supernatant very clear, slow settling	
4.0 h	Sed. Vol. (mL)	430	510	585	610	675	650
	Turbidity	33.5	23.5	27.1	1.4	12.0	34.2
24.0 h	Sed. Vol. (mL)	400	490	510	600	670	620
	Turbidity	47.5	70.0	85.0	7.5	15.0	2.3
	Color	red supernatant, red skin			red supernatant, thick red skin		
	pH	5.45	5.75	5.45	12.00	11.75	11.40
	Sediment	one color, granules fine			5-10 mL gray color top layer 350-450 mL dark gray middle layer 300 mL black bottom layer		

Table A.4

Alum							
Time	Observation	Alum Dose (kg/Mg)			Alum/Lime Dose (kg/Mg)		
		20	40	60	20/75	40/75	60/75
15 min		settles fast				supernatant very clear, settles fast	
4.0 h	Sed. Vol. (mL)	450	550	550	550	730	610
	Turbidity	30.2	41.0	25.1	1.6	20.0	7.0
24.0 h	Sed. Vol. (mL)	440	530	530	550	710	580
	Turbidity	65.0	31.0	50.0	0.7	3.5	4.0
	Color	reddish brown, with skin			no color, thick skin on the top		
	pH	5.90	5.65	5.65	11.75	11.05	9.15
	Sediment	one color, granules fine			5-10 mL gray color top layer 350-450 mL dark gray middle layer 300 mL black layer at bottom		

Table A.5

$FeCl_3$							
Time	Observation	$FeCl_3$ Dose (kg/Mg)			$FeCl_3$/Lime Dose (kg/Mg)		
		2	4	6	2.0/75	4.0/75	6.0/75
15 min		settles fast				supernatant very clear, settles fast	
4.0 h	Sed. Vol. (mL)	400	380	430	540	590	625
	Turbidity	199.7	140.0	115.0	4.5	6.8	5.0
24.0 h	Sed. Vol. (mL)	375	370	410	530	575	600
	Turbidity	47.5	70.0	85.0	0.7	1.3	2.3
	Color	red			no		
	pH	7.40	7.00	6.90	11.65	11.65	11.65
	Sediment	firm			upper layer (100 mL) very light		

Table A.6

Alum							
Time	Observation	Alum Dose (kg/Mg)			Alum/Lime Dose (kg/Mg)		
		2	4	6	2.0/75	4.0/75	6.0/75
15 min		settles fast				supernatant very clear, settles fast	
4.0 h	Sed. Vol. (mL)	300	350	380	500	540	500
	Turbidity	28.1	29.5	17.7	5.0	4.5	2.1
24.0 h	Sed. Vol. (mL)	280	300	350	500	530	500
	Turbidity	48.0	58.0	65.0	0.6	1.2	< 1.0
	Color	no	reddish brown		no		
	pH	8.35	7.40	7.00	11.85	12.00	12.00
	Sediment	firm			upper layer (100 mL) very light		

Table A.7

time	Observation	C-1/F-1	C-1/F-2	C-1/F-3	C-2/F-1	C-2/F-2	C-2/F-3
0	Settling	Settles very fast compared to $FeCl_3$ or Alum					
	Turbidity	low					lowest
24 h	Sed. Vol. (mL)	400	400	400	450	400	425
	Turbidity	11	18.2	23.5	11.5	30	40
	TSS (mg/L)	n.d.	14	26	n.d.	14	26
	pH	7.4	7.45	7.55	7.35	7.5	7.55
	Sediment	granules larger than with $FeCl_3$ or Alum, not easily disturbed					
	Sed. TSS (g/L)	588			526		
	Sediment s.g.	1.27			1.27		

Table A.8

time	Observation	C-3/F-1	C-3/F-2	C-4/F-1	C-4/F-2	C-5/F-1	C-5/F-2
0	Settling	Settles very fast compared to $FeCl_3$ or Alum					
	Turbidity	low					
24 h	Sed. Vol. (mL)	390	375	370	470	375	400
	Turbidity	14.5	30.5	12.2	27.6	6	7.5
	TSS (mg/L)	10	n.d.	26	10	8	8
	pH	7.45	7.35	7.45	7.45	7.55	7.55
	Sediment	granules larger than with $FeCl_3$ or Alum, not easily disturbed					
	Sed. TSS (g/L)		622			624	
	Sediment s.g.		1.28			1.31	

APPENDIX B

CLARIFICATION AND DEWATERING RANKINGS

NOTES ON TABLE B.1

Table B.1 ranks the clarification performance of all agents used in the study. Data contained in Appendix and tables in the report are reproduced in the first five columns. The raw sediment volume was 300 mL. The lowest sediment volume attained after settling 24 h was 250 mL. All samples were first ranked according to the sediment volume attained after settling for 24 h. The difference between that volume and 300 mL was recorded in column 6; parentheses indicate that the volume was larger than 300 mL. Column 7 contains the percent change in sediment volume. The ratio of final volume to 300 mL is contained in column 8. The values in column were the primary ranking criterion from lowest to highest. When two or more sediment samples had the same change in volume, the samples were arbitrarily sequentially ranked in column 14 (second column from the right).

The second ranking criterion was the turbidity of the supernatant given in column 11. The samples ranks were assigned in column 13.

Weighting factors of 1 and 3 were used to multiply the ranks in columns 13 and 14, respectively, which were then summed to give the total sample rating in column 15.

Table B.1 Clarification ranking

Raw Pond Water Volume	700	mL
Raw Sediment Volume	300	mL

Agent	Dosing			Sediment						Supernatant		Ranking)		
	Coagulant	Flocculant	Units	Vol.	Volume Reduction		*Vol. Ratio Final:Raw*	s.g.	TSS	Turbidity	TSS	Clarif.	Sed. Vol.	Total
				(mL)	(mL)	(%)		(-)	(g/L)	(NTU)	(mg/L)	1.0	3.0	
Control - 1	0	0	mg/L	250	50	17	0.83	1.22	410	154	86	47	1	50
$FeCl_3$ - 1	20	0	mg/L	250	50	17	0.83			96		45	3	54
Control - 2	0	0	mg/L	250	50	17	0.83	1.29	454	163	82	48	2	54
Alum - 2	40		mg/L	250	50	17	0.83			88		44	4	56
$FeCl_3$ - 2	40	0	mg/L	260	40	13	0.87			66		39	5	54
Alum - 6	2	75	kg/Mg DS	280	20	7	0.93	1.27	608	48	?	32	6	50
Alum - 3	60		mg/L	280	20	7	0.93			41		30	7	51
$FeCl_3$ - 4	80	0	mg/L	280	20	7	0.93	1.23		53	34	34	9	61
$FeCl_3$ - 3	60	0	mg/L	280	20	7	0.93			65		38	8	62
$FeCl_3$ - 5	100	0	mg/L	280	20	7	0.93	1.68		55	30	35	10	65
Alum - 4	80		mg/L	290	10	3	0.97	1.25	?	22	34	20	12	56
Alum - 5	100		mg/L	290	10	3	0.97	1.23	?	32	44	27	13	66
Alum - 1	20		mg/L	290	10	3	0.97			141		46	11	79
Alum - 7	4	75	kg/Mg DS	300	0	0	1.00			58		36	14	78
Alum - 8	6	75	kg/Mg DS	350	(50)	(17)	1.17			65		37	15	82
C-4/F-1	10	1	mg/L	370	(70)	(23)	1.23			12	26	16	17	67
$FeCl_3$ - 7	4	0	kg/Mg DS	370	(70)	(23)	1.23			70		40	16	88
C-5/F-1	10	1	mg/L	375	(75)	(25)	1.25			6	8	11	19	68
$FeCl_3$ - 6	2	0	kg/Mg DS	375	(75)	(25)	1.25	1.27	572	48		31	18	85
C-3/F-2	10	1	mg/L	375	(75)	(25)	1.25			31	0	26	20	86
C-3/F-1	10	1	mg/L	390	(90)	(30)	1.30			15	10	18	21	81
C-5/F-2	10	1	mg/L	400	(100)	(33)	1.33			8	8	13	23	82
C-1/F-1	10	1	mg/L	400	(100)	(33)	1.33			11	0	14	24	85
C-1/F-2	10	1	mg/L	400	(100)	(33)	1.33			19	14	19	25	94
C-1/F-3	10	1	mg/L	400	(100)	(33)	1.33			24	26	21	26	99
$FeCl_3$ - 9	20	0	kg/Mg DS	400	(100)	(33)	1.33			48		33	22	99
C-2/F-2	10	1	mg/L	400	(100)	(33)	1.33			30	14	25	27	106
$FeCl_3$ - 8	6	0	kg/Mg DS	410	(110)	(37)	1.37			85		42	28	126
C-2/F-3	10	1	mg/L	425	(125)	(42)	1.42			40	26	28	29	115
Alum - 9	20	75	kg/Mg DS	440	(140)	(47)	1.47			30		24	30	114
C-2/F-1	10	1	mg/L	450	(150)	(50)	1.50			12	0	15	31	108
C-4/F-2	10	1	mg/L	470	(170)	(57)	1.57			28	10	23	32	119
$FeCl_3$ - 10	40	0	kg/Mg DS	490	(190)	(63)	1.63			70		41	33	140
Alum/Lime - 1	2	75	kg/Mg DS	500	(200)	(67)	1.67	1.12	509	1	?	2	34	104
Alum/Lime - 3	6	75	kg/Mg DS	500	(200)	(67)	1.67			1		5	35	110
$FeCl_3$ - 11	60	0	kg/Mg DS	510	(210)	(70)	1.70			85		43	36	151
$FeCl_3$/Lime - 1	2	75	kg/Mg DS	530	(230)	(77)	1.77	1.11	501	1		1	37	112
Alum/Lime - 2	4	75	kg/Mg DS	530	(230)	(77)	1.77			1		4	38	118
Alum - 11	60	75	kg/Mg DS	530	(230)	(77)	1.77			25		22	40	142
Alum - 10	40	75	kg/Mg DS	530	(230)	(77)	1.77			41		29	39	146
Alum/Lime - 4	20	75	kg/Mg DS	550	(250)	(83)	1.83			1		6	41	129
$FeCl_3$/Lime - 2	4	75	kg/Mg DS	575	(275)	(92)	1.92			1		3	42	129
Alum/Lime - 6	60	75	kg/Mg DS	580	(280)	(93)	1.93			4		10	43	139
$FeCl_3$/Lime - 3	6	75	kg/Mg DS	600	(300)	(100)	2.00			2		7	44	139
$FeCl_3$/Lime - 4	20	75	kg/Mg DS	600	(300)	(100)	2.00			8		12	45	147
$FeCl_3$/Lime - 6	60	75	kg/Mg DS	620	(320)	(107)	2.07			2		8	46	146
$FeCl_3$/Lime - 5	40	75	kg/Mg DS	670	(370)	(123)	2.23			15		17	47	158
Alum/Lime - 5	40	75	kg/Mg DS	710	(410)	(137)	2.37			4		9	48	153

Table B.2 Centrifuged conditioned settled sludge ranking

Control TSS = 797 mg/L

			Sample contents	Settled sediment		Centrifuging results (based on 70 mL sample of settled sediment)			
			Raw sediment / water	TSS[1]	*Vol. factor[2] (TSSctl / TSSx)*	Vol. centrate removed		*Net Vol. ratio Final:Raw[3]*	Supernatant TSS
Agent	Dose	Units	(mL)	(g/L)		(mL)	(%)		(mg/L)
$FeCl_3$	20	kg/Mg	500/0	765	*1.04*	20.6	29.4%	*0.74*	4481
C-1/F-1	10/1	mg/L	500/700	745	*1.07*	19.4	27.7%	*0.77*	2670
Control	NT		500/700	797	*1.00*	15.2	21.7%	*0.78*	1950
Alum	100	mg/L	500/700	756	*1.05*	16.1	23.0%	*0.81*	3410
Alum	80	mg/L	500/700	749	*1.06*	16.2	23.1%	*0.82*	2747
$FeCl_3$	80	mg/L	500/700	722	*1.10*	17.6	25.1%	*0.83*	1324
C-5/F-1	10/1	mg/L	500/700	620	*1.29*	24.6	35.1%	*0.83*	890
Alum/Lime	20/75	kg/Mg	500/0	646	*1.23*	21.2	30.3%	*0.86*	3288
Alum	20	kg/Mg	500/0	508	*1.57*	28.4	40.6%	*0.93*	2584
C-5/F-2	10/1	mg/L	500/700	614	*1.30*	18.6	26.6%	*0.95*	1543
$FeCl_3$/Lime	20/75	kg/Mg	500/0	499	*1.60*	27.2	38.9%	*0.98*	2188
$FeCl_3$/Lime	4/75	kg/Mg	500/0	426	*1.87*	30.0	42.9%	*1.07*	4203
Alum/Lime	4/75	kg/Mg	500/0	426	*1.87*	30.0	42.9%	*1.07*	3282
$FeCl_3$	100	mg/L	500/700	542	*1.47*	17.0	24.3%	*1.11*	1224
C-2/F-1	10/1	mg/L	500/700	506	*1.58*	20.5	29.3%	*1.11*	1605

Notes:

1. Data are from Table 6 for samples settled 24 h.
2. The vol. factor is the ratio of control TSS after settling to sample TSS after settling.
3. ratio final:initial volume = vol. factor x (100 – %centrate removal)/100. The samples were ranked based on this parameter.

Table B.3 Freeze-thawed and centrifuged ranking

Control Vol. = 500 mL

			Settled sediment		Freeze/thaw results					Centrifuging results (based on 70 mL sample of freeze/thawed sediment)			
			Volume[1]	*Vol. factor[2] (Vctl / Vx)*	Volume of supernatant removed from *settled sediment*		*Net ratio Final:Raw Vol.[3]*	Resulting sediment TSS	Vol. centrate removed		*Net Vol. ratio Final:Raw[4]*	Supernatant TSS
Item	Dose	Units	(mL)		(mL)	%		(g/L)	(mL)	(%)		(mg/L)
Control	NT		500	*1.00*	29	5.8	*0.94*	866	17.0	24.3	*0.71*	466
Alum	80	mg/L	520	*1.04*	37	7.1	*0.97*	897	17.0	24.3	*0.73*	459
Alum/Lime		kg/Mg	700	*1.40*	170	24.3	*1.06*	585	21.4	30.6	*0.74*	617
C-1/F-1	10/1	mg/L	570	*1.14*	57	10.0	*1.03*	830	19.0	27.1	*0.75*	195
$FeCl_3$	80	mg/L	500	*1.00*	17	3.4	*0.97*	921	15.8	22.6	*0.75*	595
$FeCl_3$	100	mg/L	500	*1.00*	14	2.8	*0.97*	888	16.0	22.9	*0.75*	688
C-2/F-1	10/1	mg/L	580	*1.16*	62	10.7	*1.04*	787	19.2	27.4	*0.75*	271
$FeCl_3$/Lime		kg/Mg	780	*1.56*	235	30.1	*1.09*	625	20.0	28.6	*0.78*	345
$FeCl_3$		kg/Mg	660	*1.32*	120	18.2	*1.08*	772	19.4	27.7	*0.78*	531
C-5/F-1	10/1	mg/L	600	*1.20*	76	12.7	*1.05*	839	16.6	23.7	*0.80*	247
Alum/Lime		kg/Mg	820	*1.64*	215	26.2	*1.21*	579	23.2	33.1	*0.81*	720
C-5/F-2	10/1	mg/L	570	*1.14*	33	5.8	*1.07*	870	16.4	23.4	*0.82*	396
$FeCl_3$/Lime		kg/Mg	780	*1.56*	177	22.7	*1.21*	662	22.2	31.7	*0.82*	279
Alum		kg/Mg	610	*1.22*	80	13.1	*1.06*	915	13.6	19.4	*0.85*	397
Alum	100	mg/L	600	*1.20*	32	5.3	*1.14*	875	15.8	22.6	*0.88*	494
$FeCl_3$		kg/Mg	670	*1.34*	97	14.5	*1.15*					

Notes

1. Data are taken from Table 7 after 24 h settling period following addition of agents.
2. Assumes that all samples consisted of 500 ml of raw sediment prior to addition of agent.
3. Net ratio final:raw volume = (settled volume – volume removed)/500.
4. Net ratio final:raw volume = ratio final:raw$_{\text{freeze/thaw}}$ (100 – %centrate removal/100. Samples are ranked on this ratio.

The following article was included in CH2M Gore & Storrie Limited's quarterly newsletter. It provides a concise summary of the Sediment Dewatering Pilot Study at the Merivale Stormwater Management Facility, City of Napean.

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Stormwater Pond Comes Clean

Prepared for:

Prepared by:

CG&S

CH2M Gore & Storrie Limited

Ottawa, Ontario

March 1998

Introduction

The discovery of petroleum-contaminated sediment in a stormwater pond meant that an otherwise routine cleanout job required careful preparation and planning. Project constraints such as the need to protect the receiving stream; reroute stormwater; collect and dispose of contaminated sediment and water all contributed o the challenge.

Background

The project began in the spring of 1996 when the City of Nepean, Ontario retained CH2M Gore and Storrie Ltd. (CG&S) to survey six Stormwater Management Facilities (SMFs). The goal was to measure the amount of sediment accumulated in stormwater retention ponds and establish plans for cleanout. The survey undertaken that summer discovered petroleum-contaminated sediment in two ponds - Merivale Gardens SMF and Bentley SMF. CG&S was given the task of preparing cleanout plans. This article describes the cleanout of Merivale Gardens SMF.

The Merivale Gardens SMF catchment includes industrial, residential and parkland areas (Table 1). The Rideau River, upstream of a public beach, is the ultimate receiver of the discharge. The survey determined that 12% of the design storage of the pond, which comprised 35% of the permanent pool volume, was occupied by sediment which had accumulated since the pond began operating in 1984. The presence of contamination made the facility a priority for cleanout. At the time of the project, the source of the contamination was undetermined. The municipalities are currently investigating the problem.

Although the discovery of contamination was cause for concern, the SMF had in fact accomplished precisely what it had been designed to do - intercept pollution and thereby protect the receiving body of water.

Table 1. Merivale Gardens SMF

Year built:	1984
Catchment area:	305 ha industrial, residential & parkland
Discharge receiver	Rideau River
Configuration:	long oval (approx. 40x150m)
Operational mode:	continuous flow through with permanent wet pool, orifice plate outlet control
Bottom construction:	1 m crushed stone
Permanent pool area:	0.709 ha
volume:	6,600 m^3
Design storage volume:	19,200 m^3
Sediment accumulation:	2,300 m^3 (2,875 te) as of spring 1996
	i.e. 12% design vol. or 35% permanent pool vol.
Contamination in sediment:	7,000 µg TPH[1]/g

[1] TPH = Total Petroleum Hydrocarbons

Constraints shape the plan

As the logistical details of the project were worked out, the need to satisfy the following constraints shaped the plan:

- The receiving stream, the Rideau River, had to be protected. The SMF was required to remain in full operation during swimming season from May 15 to September 15, therefore no summer work was permitted.
- Pond dewatering would require pumping (the SMF had no low level drain).
- Any discharge to the SMF outlet had to meet storm sewer water quality limits.
- Seepage (groundwater infiltration) from the contaminated sediment could not be discharged to the storm sewer.
- Contamination of the sediment necessitated landfilling, but the raw sediment was too wet to be acceptable.
- A tight site. The SMF was located in an Ontario Hydro corridor on land leased to the City. Because of the contamination, work would be confined to the leased property.

Thorough preparation was essential for success. Particular attention was paid to sediment handling, as described below.

Homework

Lab Testing. The water content of the sediment was problematic. Excess volume and weight would increase handling costs and tipping fees. Raw, wet sediment cannot be landfilled. The City supported laboratory work to find optimal sediment handling methods.

A first series of tests to minimize water content showed that gravity settling alone was as effective as chemical, mechanical or physical dewatering methods.

A second testing series examined methods to meet the solid waste criterion for landfilling of <150 mm of slump. Raw sediment (slump 240 mm) was separately tested by mixing with sand, woodchips, sawdust and oat straw. Straw was most effective. A ratio of only 1.5% straw:sediment by weight passed the slump test. Air-drying of the sediment was also investigated and ruled out due to long drying time, the extra handling required, lack of a suitable staging area and risk of inclement weather.

Groundwater Monitoring. Six groundwater monitoring wells installed around the pond showed that no contamination was present offsite. The pond was below the local water table, infiltration would be expected during the remediation work.

Field Trial. The City undertook a field trial to experiment with pumping and sediment bulking. A videotape of the trial was made available to contractors during bidding.

Geotechnical. Soil penetration tests were carried out to confirm that the pond bottom would support heavy equipment.

After considering the constraints and reviewing the results of the preparatory work, CG&S developed a formal Remediation Plan which consisted of the following main steps:

- Bypassing stormwater around the pond using dikes and pumps
- Pumping out the permanent pool to the storm sewer
- Pumping of sediment seepage to the sanitary sewer
- Excavation and mixing of contaminated sediment with straw in situ on the pond bottom
- Transportation of the bulked mixture to a landfill for disposal
- Restoration work

The Remediation Plan also included recommendations on health and safety when working with petroleum hydrocarbons.

Weather was one factor beyond anyone's control. Pumping capacity would be sufficient to bypass base inflow or a small rainstorm, but pumping a moderately sized storm would be impossible. The contractor would have to demobilize and wait for the storm to subside. Therefore the contract tender included a provisional item for the cost of two rain delays.

The job

It was important that contractors understood the special nature of the job. An information package, site tour, Remediation Plan and videotape of the field trial were available for contractors' review. Seven firms, pre-screened on the basis of contamination experience, submitted bids and the contract was awarded to Tarcon Ltd. of Gloucester, Ontario. Contract specifications were performance-based which allowed flexibility for the contractor. Agreements for sediment disposal at the landfill were the responsibility of the contractor.

Work began on September 29, 1997 after waiting out rainy weather. Figure 1 shows the site plan. Inflow to the pond was bypassed by diking the main inlet and pumping to the outlet storm sewer. The smaller, secondary ditch inlet was also diked and pumped to the main inlet. Two-thirds of the water in the pond (~4,600 m^3) were then pumped to the storm sewer. To prevent contaminated sediment from reaching the river, the final third (~2,000 m^3) was pumped to the sanitary sewer system, for which permission had been obtained from the Regional Municipality of Ottawa-Carleton (RMOC). The RMOC had requested that pumping to the sanitary system use a containment system to prevent overland spills. Tarcon used a simple but effective system of flexible hose contained in sections of corrugated plastic pipe connected with split couplings.

After pond dewatering, drainage of the sediment was improved by excavating a trench down the middle of the pond and bulldozing sediment to higher areas on the side slopes. An average of about 700 m^3/d of groundwater seepage was continuously pumped from the pond sump to the sanitary sewer. A geotextile barrier was placed around the dewatering pump to minimize entrainment of suspended sediment. Daily samples of the discharge were analyzed for total suspended solids (TSS), total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene and xylenes (BTEX). No TPH or BTEX was detected and TSS levels were below the bylaw limit of 350 mg/L for all but two of fifteen samples. In contrast to seepage pumping, bypass pumping of stormwater was needed only during the first few days since the weather remained dry until the end of the job.

Excavation and bulking of the sediment started on October 2 once the pond was dewatered. As part of the contractor's health and safety plan, organic vapour analyses of the air in the working area were compared to background levels once excavation work began. Work was able to proceed without special respiratory equipment.

The contractor initially experimented using automobile shredder fluff as an alternate bulking material, but it failed to meet the slump requirement. As predicted, oat straw performed well, however soybean straw was later used because it was cheaper and more readily available, even though it required a higher percentage to meet the slump. With the exception of experimenting with the alternate bulking material, work methods closely followed the Remediation Plan.

One bulldozer and two excavators were used to excavate sediment, mix in straw and load trucks for transport to the landfill. The excavators were careful to avoid incorporating gravel from the pond base into the sediment, since this would have greatly increased tipping fees. As work progressed down the pond, a pad of clean gravel was placed for the trucks which prevented the tires from becoming contaminated. The sediment removal phase was completed on October 15, including a Thanksgiving break. A total of 3,127 tonnes of sediment and gravel was removed from the pond, close to the survey estimate of 2,875 tonnes of sediment. About 128 tonnes of straw were used for bulking. To complete the job a layer of clean gravel was spread on the pond bottom, side gabions were repaired and a new gabion-reinforced sump was constructed to assist future cleanout operations.

Conclusions

In summary, an apparently simple project was made challenging by contamination and the constraints involved. Preparatory fieldwork and lab experimentation were vital to develop a sound Remediation Plan. The unique combination of problems was successfully overcome through careful planning.

The project emphasized several important aspects of SMF design:

- SMF design should provide a means for clean out.
- The SMF site should include enough property to accommodate work or staging areas around the facility.
- Ponds should have access for vehicles. The base should be capable of supporting heavy equipment.
- Ponds should ideally be self draining or include sumps to permit easy dewatering.

In the end, Nepean's stormwater facility performed admirably, protecting the Rideau River from pollution; and the clean out project was a success due to careful planning.

CG&S

PILOT STUDY 2
SEDIMENT DRYING/BULKING
MERIVALE STORMWATER MANAGEMENT FACILITY
CITY OF NEPEAN

Prepared for:

Corporation of the City of Nepean

Prepared by:

CG&S
CH2M GORE & STORRIE LIMITED
Ottawa, Ontario

December 1996

PILOT STUDY 2: SEDIMENT DRYING/BULKING

1 Introduction

The second pilot study sought the best method to treat Merivale Gardens SMF sediment in order to meet the slump requirement for landfill disposal. The slump requirement in Ontario is 150 mm or less. The study tested two methods:

- Bulking with straw, woodchips, sawdust and sand.
- Air drying.

2 Bulking Test

2.1 Methodology

The bulking test consisted of measuring the slump of MSMF sediment samples after addition of various amounts of bulking material.

Sediment slump was first measured on raw samples, then a known amount of bulking material was added, mixed, and slump test repeated. At the beginning of each round of mixing/test, the weight of the mixture was measured to accurately determine the ratio of sediment to bulking material. The bulking material addition/slump test procedure was repeated until samples passed the test, that is, had a slump of less than 150 mm.

2.2 Results

Figures 1 through 4 show the results of the bulking tests. Initial slump of the raw sediments varied between 200 and 250 mm. Although all materials eventually bulked the sediment sufficiently to meet the slump, the amount of material varied considerably. In order of least to most: straw < woodchips < sawdust < sand.

Fig. 1: Merivale Gardens SMF Sediment Bulking Test
Straw as Bulking Agent

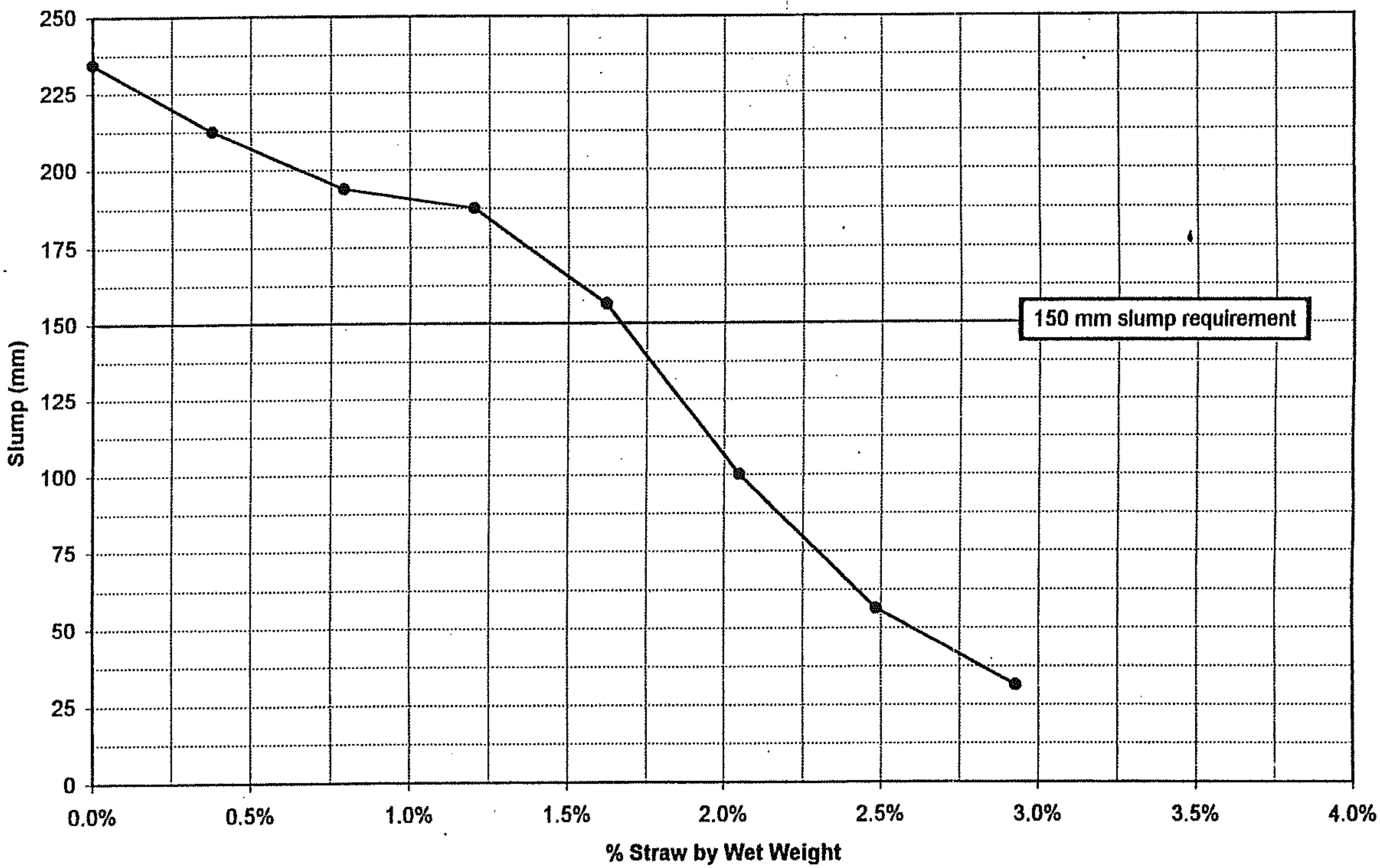


Fig. 2: Merivale Gardens SMF Sediment Bulking Test
Woodchips (*Sanilit Pine Shavings*) as Bulking Agent

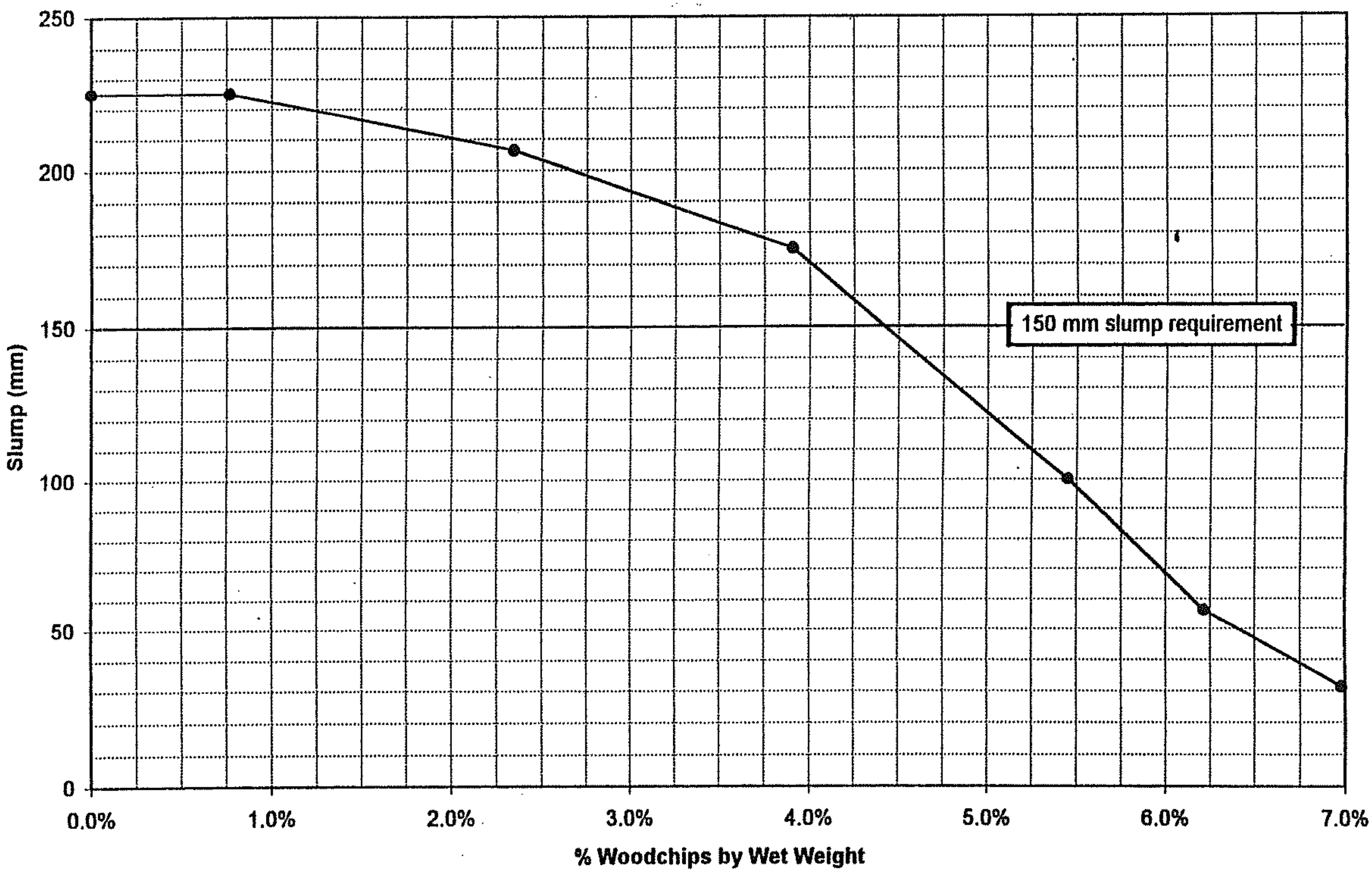


Fig. 3: Merivale Gardens SMF Sediment Bulking Test
Sawdust (*PWI 8-16 Sawdust Bedding*) as Bulking Agent

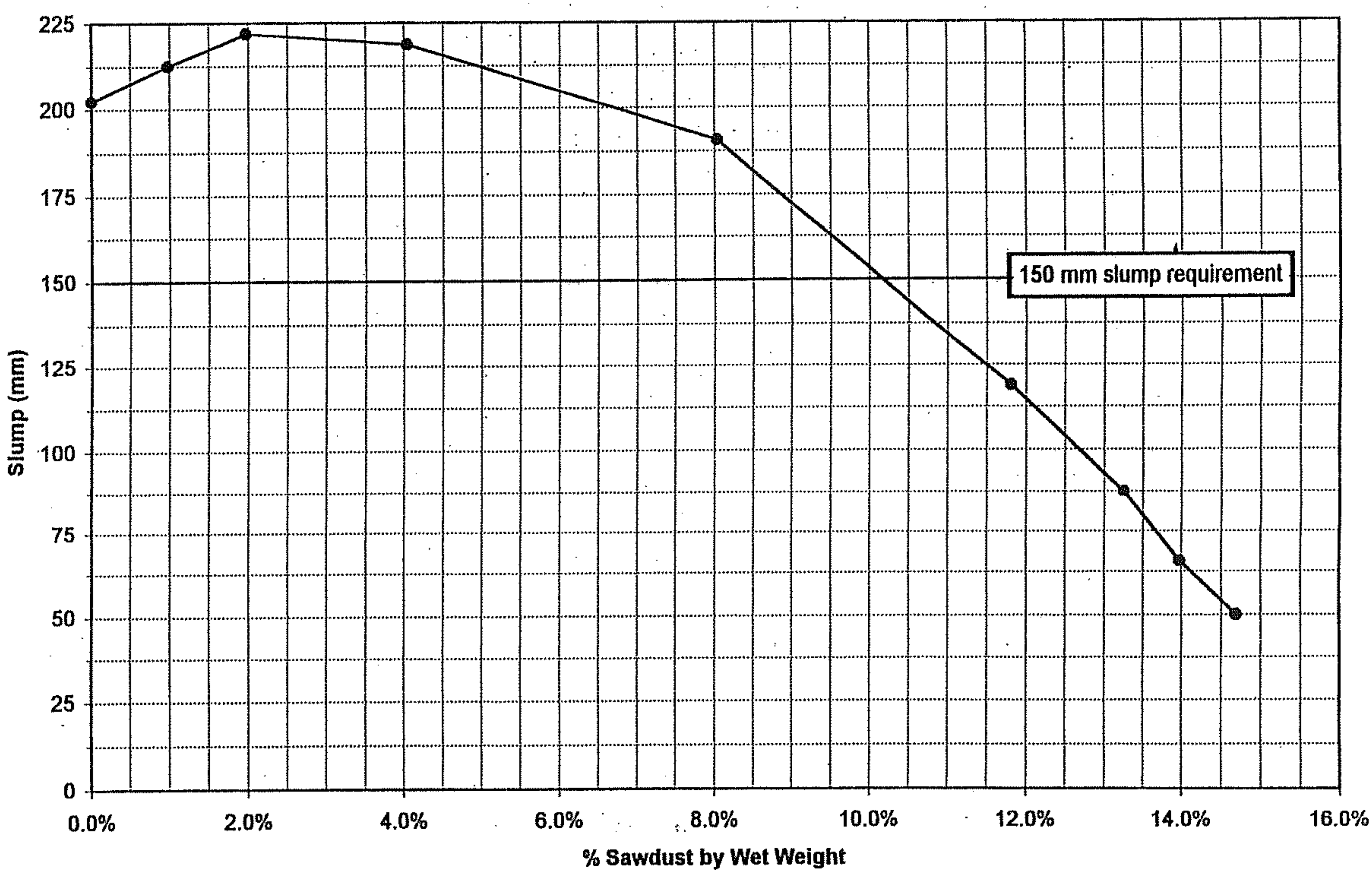
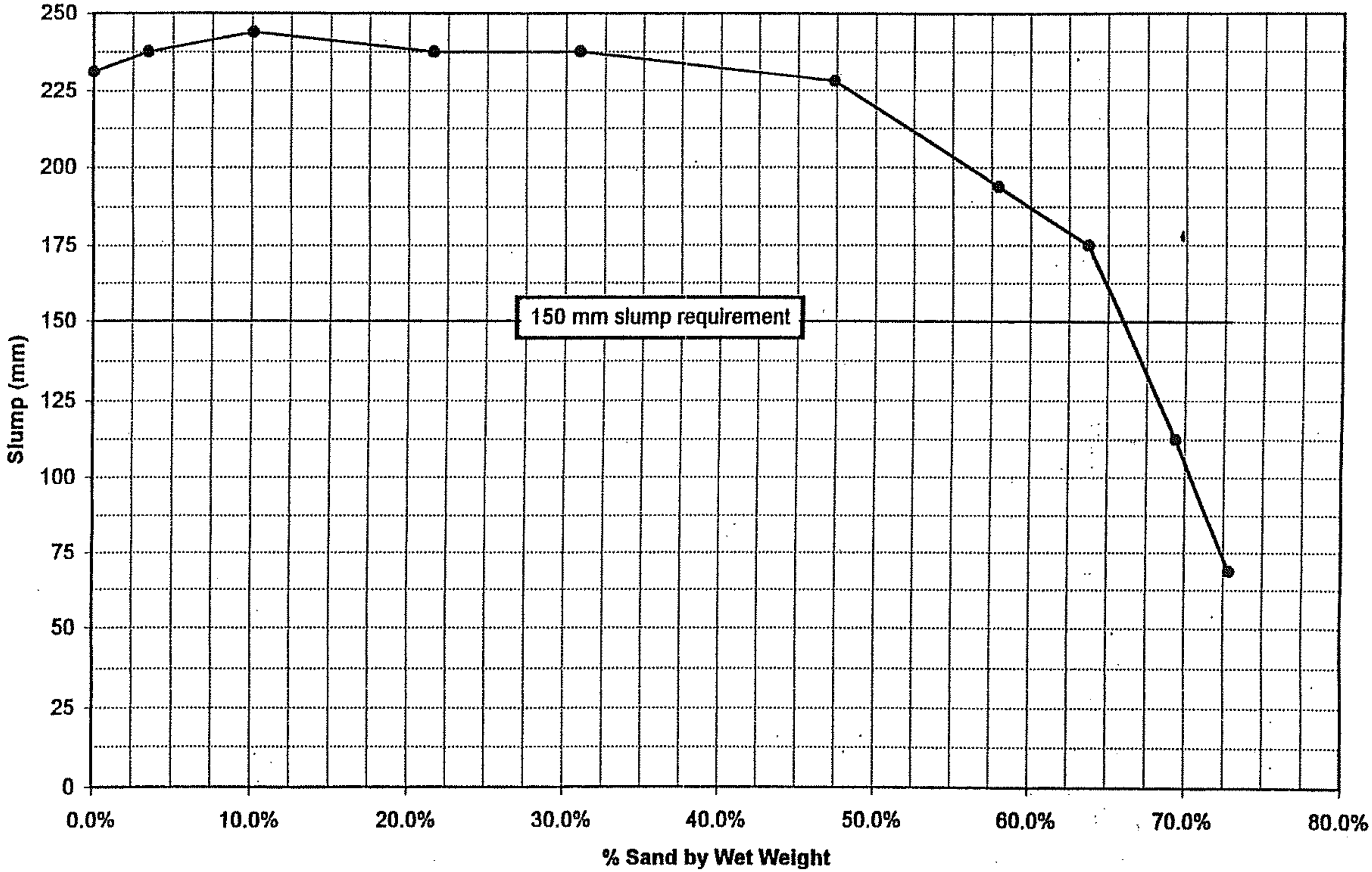


Fig. 4: Merivale Gardens SMF Sediment Bulking Test
Sand as Bulking Agent



The amount of bulking material required to meet the slump is summarized in Table 1. In the case of woodchips and sawdust, commercial products were used, and the brand name is shown in *italics*.

Table 1: Amount of various bulking materials required to meet slump

Material	Amount required to meet 150 mm slump (% of total weight)
Straw	1.5
Woodchips (*Sanilit Pine Shavings*)	4.5
Sawdust (*PWT 8-16 Sawdust Bedding*)	10
Sand	65

Straw was clearly superior, requiring only 1.5 % by weight. When converted to cost of bulking on a per tonne of raw sediment basis (see Table 2), straw is by far the least expensive bulking agent. Note that even if sand was used at no cost, it would have to be added to at least 65% of the total weight and as such would more than double tipping fees for disposal.

TABLE 2:
Merivale Gardens SMF
Pilot Study No. 2
Sediment Drying/Bulking - Material Costs
Proj. No. 111Y-60179

Material purchased 15-Nov-96 from Ritchie Feed and Seed, 1390 Windmill Lane, Ottawa, 741-4430

Material as sold	Cost (incl. GST)	Volume		Weight			Amount required to meet 150 mm slump		
	($)	(m^3)	unit cost ($/$m^3$)	(kg)	unit cost ($/kg)	unit cost ($/te)	% weight	x 1.33 safety factor	**Bulking cost ($/te raw sediment)**
Straw, bale, 35 lb	$4.82			15.9	$0.30	$303.14	1.5	2.0	$6.19
Woodchips, *Sanilit Pine Shavings* 3.6 cu. ft., 50 lb	$5.08	0.10	$50.80	22.7	$0.22	$223.79	4.5	6.0	$14.28
PWI 8-16 **Sawdust** *Bedding* 4 cu.ft., 40 lb	$7.49	0.11	$68.09	18.2	$0.41	$411.54	10	13.3	$63.30

NOTE:
The amount of bulking agent required is expressed as a percentage of total weight of the mixture.
Therefore the cost of bulking agent per tonne of *raw sediment* is calculated as:
***BULKING COST** ($/te raw sediment) = [% bulking material / (1-% bulking material)] x unit cost of bulking material ($/te)*

3 *Air Drying Test*

3.1 *Methodology*

The drying test consisted of two procedures.

One experiment, the hydrating test, sought to determine the water content at which MSMF sediment fails the slump test, by measuring the slump as a function of sediment water content. Water was progressively added to dried sediment samples and the slump measured after each water addition.

A second experiment, the drying test, measured the length of time required for wet sediments to dry. In particular, what length of time would be required to meet the moisture content necessary to pass the slump test. Three samples of sediment, varying in thickness from 15 to 30 cm, were air dried. The water content of samples was tested after 1, 5, 7, 11 and 17 days drying time.

3.2 *Results*

The hydrating test results are shown in Figure 5. Although one of the three samples, that from the 22.5 cm drying bed, behaved differently than 15 and 30 cm drying beds, the results clearly showed that sediment slump increased rapidly as moisture content reached 30 to 33%. Using these observations as a guide, a value of 31% moisture content was considered as the target for the drying tests, that is, the point at which dried sediment would pass the slump test.

The drying test results are shown in Figure 6. Once again the 22.5 cm drying bed sample behaved somewhat aberrantly. This sample appeared to reach a plateau of 34% moisture beyond which no further drying occurred. The 15 and 30 cm bed samples required approximately 14 days drying time to reach the target moisture content of 31%.

It should be emphasized that these tests were undertaken in controlled laboratory conditions which are not expected to occur in the field. Given our local climate, it is unlikely that 14 days would pass without some amount of precipitation.

The fact that the required drying time is long, coupled with the observation that some samples may not even reach the desired dryness, led to the conclusion that **air drying would not be an appropriate method of obtaining the required slump.**

4 *Summary*

The following conclusions were reached:

- Straw is the most effective and least expensive bulking material.
- Air drying is not suitable for obtaining the required slump.

Fig. 5: Merivale Gardens SMF Sediment
<u>Hydrating Test</u>

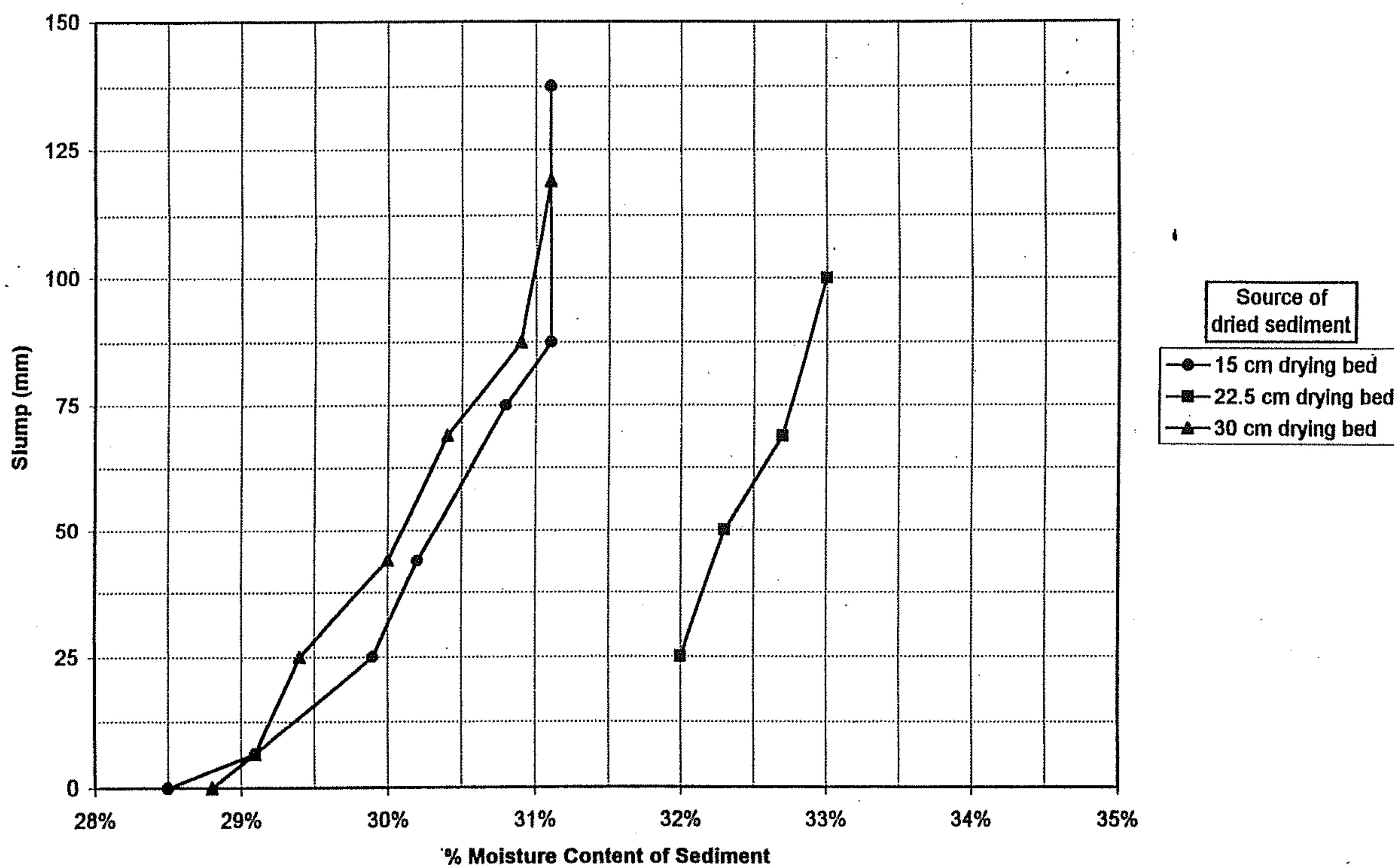


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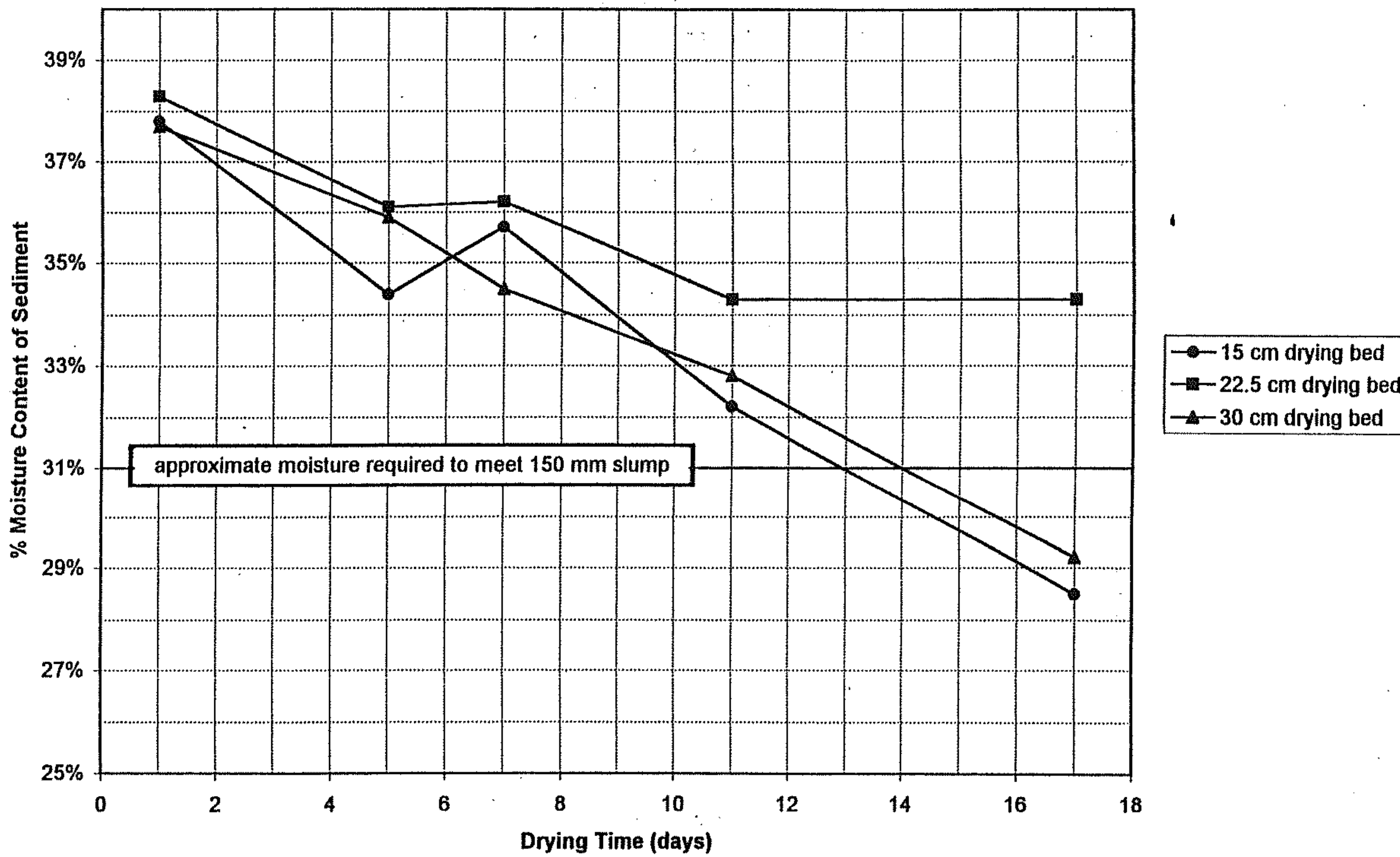
Fig. 6: Merivale Gardens SMF Sediment
Drying Test



APPENDIX I
Example of a Preliminary SWMF Sediment Removal Cost Estimate

Preliminary SWMF Sediment Removal Cost Estimate

Activity	Amount	Unit	Cost per unit	Total Cost ($)	Comments
Siltation Control Fence	125	m	$18.00	$2,250	Fence is on longest side of pond, includes removal
Drain Pond	1	lump	$500.00	$500	
Pumping Storm flows around pond	1	lump	$5,000.00	$5,000	Continuos pumping, 75mm pump.
Soil Sample and Testing	1	lump	$1,000.00	$1,000	Collect and sample
Equipment Setup	1	lump	$2,000.00	$2,000	
Sediment Removal	1150	m^3	$15.00	$17,250	Dry sediment, dozer, excavator, into dump truck, dispose offsite (non-contaminated)
Outlet Structure Restoration	1	lump	$3,000.00	$3,000	Submerged, bottom draw outlet.
Landscape Restoration - topsoil, seed	3700	m^2	$2.00	$7,400	
Landscape Restoration - aquatic veg.	2900	m^2	$5.00	$14,500	4 plugs per m^2 at $1.25 per plug
Access Road Restoration	600	m^2	$15.00	$9,000	Gravel based access road
Miscellaneous Restoration	1	lump	$2,000.00	$2,000	
Post Construction Survey and certify	1	lump	$1,000.00	$1,000	One crew, one day
Sub-total				$64,900	
15% Contingency				$9,735	
TOTAL				**$74,635**	
ROUND TO				**$75,000**	$75,000 of today's money (1999)

Notes:

1. 50 ha residential drainage area
2. SWMF block area = 2.0 ha.
3. SWMF is a wetpond.
4. SWMF surface area = 0.50 ha.
5. 80% TSS removal.
6. SWMF is cleaned after 15 years.
7. Mechanical excavation used.
8. Interest rate is 5% per annum.
9. Construction cost index is 2% per annum.
10. Unit costs should always be verified by a contractor.

Unit cost	\$65 per m^3	Cost today.
Future Cost	\$87 per m^3	Cost in 15 years.
Annuity	\$4.05 per m^3	Annual money you would have to set aside to have future cost in 15 years.
Present Value	\$42 per m^3	Money you would have to set aside today to have future cost in 15 years.