

METAL TECHNOLOGIES INC.

BENCH-SCALE TREATABILITY STUDY WITH HAMILTON HARBOUR SEDIMENTS

Final Report to:

THE CONTAMINATED SEDIMENT TREATMENT TECHNOLOGY PROGRAM ENVIRONMENT CANADA'S GREAT LAKES CLEANUP FUND

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1.0 EXECUTIVE SUMMARY

A bench scale treatability study was carried out with a sample of Hamilton Harbour Sediment using Tallon's integrated technology for organic and inorganic treatment of soils and sediments.

The untreated harbour sediment was found to exceed parameters for a number of inorganic contaminants including Cd, Pb and Zn as well as for organic contaminants including polyaromatic hydrocarbons.

Due to the high load of organic material in this sediment, total organic carbon > 10%, it was necessary to adapt Tallon's physical/chemical recovery procedures to provide the recovery of an organic rich and metallic rich concentrate from the sediment.

The utilization of primary organic separation with an organic recovery polishing step and closed circuit organic concentrate upgrading, yielded an organic rich by-product representing $\leq 15\%$ of the initial sediment mass and an organic-depleted cleaned sediment with low residual contamination.

The decontaminated sediment, representing approximately 80% of the initial sediment mass met guidelines for on-shore re-use as clean fill. Hydrometallurgical extraction with additional metal recovery by Vitrokele[™] was estimated to be useful in further decontamination of the sediment so as to permit its possible re-use as lake-fill.

The test work permitted the construction of a conceptual flow sheet for full scale pilot confirmation and treatment of this sediment.

Treatment costs with Tallon's technology were estimated at between \$75 and \$100 per ton assuming a sediment mass in excess of 20,000 tonnes was available for treatment and not including disposal/treatment costs for the recovered concentrate.

2.0 INTRODUCTION

The Wastewater Technology Centre (WTC), as part of its mandate related to the evaluation of remediation technologies appropriate to the treatment of contaminated sediments, contracted Tallon Metal Technologies Inc. (Tallon) to complete this bench-scale evaluation of its technologies for the treatment of sediments. It was originally proposed that Tallon would evaluate treatment for a sample of Toronto Harbour sediments but the sample provided was found to be only mildly contaminated and, therefore, it was jointly decided not to proceed to testing with this sample.

A sample of Hamilton Harbour sediment, obtained from near Pier 16 by WTC and known to be rich in both metal and organic contamination, was provided by WTC for testing. This report summarizes the principle findings determined through the bench-scale treatability testing program for the Hamilton Harbour sediment sample. These results have enabled the construction and testing of a process flow sheet aimed at separation and removal of the majority of the organic and inorganic contamination to a by-product concentrate. This approach is shown to be efficient in reducing the mass for organic treatment and enabling further treatment for the extraction and recovery of residual contaminant metals from the organic-depleted "cleaned" sediment. It is recognized that a different treatment approach might be taken for sediments contaminated only with heavy metals.

The test work was performed both in Tallon's laboratory and at Lakefield Research Inc. (Lakefield) under the direction of Tallon.

This report presents a description of the testwork undertaken, analytical results and the interpretation of these results but does not contain specific details of the reagents which are used as part of Tallon's technology. These details are proprietary and are the property of Tallon.

3.0 OBJECTIVES OF THE STUDY

The Hamilton Harbour sediment was known to be enriched with both heavy metal and polyaromatic hydrocarbon (PAH) contamination, therefore limiting any treatment approaches which were exclusively suitable for either organic or metal contaminants. Tallon's technology has been shown to be useful for such mixed contaminant treatment, in the case of soils (ref. 1). Thus, a principle objective of the present study was to assess the potential for Tallon's technology for the combined heavy metal and organic contaminant removal from the Hamilton Harbour sediment. Additional objectives of this study are summarized below:

- 3.1 To determine if a cleaned sediment mass meeting Ontario Ministry of Environment and Energy guidelines for lake-fill or on-shore re-use applications could be obtained through treatment.
- 3.2 To determine what degree of separation of metal and organic contaminants might be achievable for the Hamilton Harbour sediment.

- 3.3 To establish a conceptual flow sheet for the treatment of Hamilton Harbour sediment which could be tested with a continuous pilot treatment plant.
- 3.4 To estimate unit costs for full scale treatment of Hamilton Harbour sediment.

4.0 HAMILTON HARBOUR SEDIMENT CHARACTERIZATION

A 20 kg sample of Hamilton Harbour sediment was obtained from the WTC for the present work. The sample was characterized with respect to particle size distribution and its contained metal and organic contaminants.

The Hamilton Harbour sediment was tar-like in appearance and smell indicating that it contained coal tar (PAH). A sub-sample was conditioned by high speed mixing in water and processed through a series of standard Tyler screens. Yields at each screen size were determined as dry weights and used to construct a size distribution plot, as shown in Figure 1. This size analysis revealed that the sediment was relatively fine in nature with approximately 92% of the total mass of a size less than 100 μ m and 75% of the total mass less than 50 μ m particle size.

Sub-samples of the Hamilton Harbour sediment were used for the determination of pH, moisture content and inorganic contents using MOEE approved procedures. These results are summarized in Table 1 and were examined in relation to sediment quantity guidelines (ref.2).

The Hamilton Harbour sediment was found to be significantly contaminated with heavy metals, exceeding the severe effect limits in the case of Cd, Cr, Fe, Mn, Ni, Pb and Zn. The sediment also exceeded the lowest effect guideline for Cu.

Both Zn and Fe levels in the sediment were high, consistent with the source of this sediment, i.e. near steel making operations.

The analysis for organic contaminants revealed a high content of organic material in the sediment as shown in Table 2. Total organic carbon exceeded 10 % (w/w) for the sediment with total oil and grease exceeding 1% (w/w). The sediment was found to have an elevated PAH content but this was below the severe effect guideline for this sediment (2).



Figure 1. Hamilton Harbour Sediment Size Distribution

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Table 1

ANALYTE	ua/aª	Exceedence ^b
рН	8.0	NA
Total solids	63.2%	NA
Total water	36.8%	NA
Ba	3500	NA
Be	<1°	NA
Ca	81,300	NA
Cd	10	> SE
Co	15	NA
Cr	135	> SE
Cu	55	>LE
Fe	91,300	> SE
La	25	NA
Mg	11,900	NA
Mn	1900	> SE
Мо	90	NA
Na	8800	NA
Nd	< 50°	NA
Ni	80	> SE
Р	1500	NA
Pb	250	> <u>S</u> E
S	4500	NA
Sb	10	NA
Se	< 50°	NA
Sn	20	NA
Te	< 10°	NA
Y	15	NA
Zn	2250	>SE

Inorganic Contents of Hamilton Harbour Sediment

^a Units in μ g/g (ppm) except where noted in % (w/w).

^b Exceedence as per MOEE sediment quantity guidelines:

LE = lowest effect level; SE = severe effect level; NA = not applicable.

 $^{\circ}$ < limit of detection.

ANALYTE	µg/g*	EXCEEDENCE
Total Organic Carbon	10.4%	> SE
Total Oil and Grease	1.2%	>LE
Total Base Neutral Extractables	2268	NA
Total Volatile Organics	1.3	NA
Total PAH	270. (2596)°	>LE
Acenaphthene	<1	NA
Acenaphthylene	4	NA
Anthracene	<1	NA
Benzo(k)fluoranthene	4	NA
Benzo(b)fluoranthene	35	NA
Benzo(a)anthracene	8	NA
Benzo(a)pyrene	15	NA
Benzo(g,h,i)perylene	13	NA
Chrysene	29	NA
Dibenzo(a,h)anthracene	<1	NA
Fluoranthene	28	NA
Fluorene	4	NA
Indeno (1,2,3-cd)pyrene	16	NA
Naphthalene	69	NA
Phenanthrene	20	NA
Pyrene	24	NA

 Table 2

 Organic Contents of Hamilton Harbour Sediment

^a Units in μ g/g (ppm) except where noted in % (w/w).

^b Exceedence as per MOEE sediment quality guidelines:

LE = lowest effect level;

SE = severe effect level normalized to 10% w/w total organic carbon; NA = not applicable.

[°] Value in parentheses in ug/g organic carbon.

5.0 TECHNOLOGY AND TREATMENT APPROACH

5.1 Description of Tallon Technology

Tallon's technology integrates physical metal recovery steps with hydrometallurgical metal recovery and physical-chemical recovery of organics to provide a technology capable of the simultaneous recovery of inorganic contaminants from both soil and sediments.

The technology employs a number of standard mineral processing steps which have been adapted by Tallon. The hydrometallurgical extraction process employs selective heavy metal leaching and recovery using VitrokeleTM technology. The overall process is the subject of a number of patents and patent applications.

Figure 2 shows a fully integrated process flow sheet for the total treatment of soil contaminated with heavy metal and organic contamination as has been applied by Tallon at full demonstration scale (Ref. 1 and Appendix 11.2).

Contaminated feed is scrubbed, classified and treated using a combination of magnetic and gravity separation steps to yield coarse clean products and various recovered coarse metal products.

The partially metal-depleted, classified soil is then subjected to selective organic contaminant recovery. This involves proprietary reagents with conventional flotation equipment (see 5.2 as applied to Hamilton Harbour sediments).

The organic-depleted soil is then subjected, if necessary, to selective heavy metal leaching and VitrokeleTM metal recovery to recover residual heavy metals of a fine and dispersed nature, i.e. metals which were not physically recoverable.

5.2 **Process Considerations for the Hamilton Harbour Sediment**

The relatively fine nature and high organic, oily nature of the Hamilton Harbour sediment dictated the requirement for recovery of organic contamination as a principle treatment step. Consequently, Tallon evaluated the approach of physical/chemical recovery of organic contamination in conjunction with metal recovery steps.

Figure 3 shows the simplified treatment approach taken for the Hamilton Harbour sediment. Size classification would be restricted to the removal of a minor coarse fraction as a preparatory step to organic recovery.

Organic recovery using physical/chemical means involves flotation technology as used routinely in the minerals processing industry but as adapted to organic recovery by Tallon with specialized reagent systems. Figure 4 shows a flotation unit cell. Separation by flotation is achieved on the basis of surface charge characteristics of the particles treated. Particles of low surface charge are more hydrophobic and can be entrained with air bubbles introduced to the particle suspension. The entrained hydrophobic particles report with the froth generated at the surface of the cell and are mechanically harvested (see Ref. 3 for further details).

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Figure 3

Simplified Conceptual Flowsheet for Testing of Hamilton Harbour Sediment





Various chemical additions (activators) can be made to the flotation system so as to create charge differences, enhance charge differences and collect fine hydrophobic particles into aggregates which are more readily separated. Other reagents are added so as to lower surface tension and create a stable frothing system for separation (froth collectors). Both organic-selective and metal-selective flotation separation and recovery possibilities were assessed for the Hamilton Harbour sediment.

6.0 TEST RESULTS

6.1 Preliminary Scoping, Test Series ML-1

Series ML-1 constituted scoping tests, wherein the sample was assessed in relation to treatment by flotation, magnetic separation and gravity separation techniques.

A 1L sample of the sediment sample was subjected to series of staged primary flotation steps using frothed addition only. The purpose of these flotation tests was to determine the relative ease of removing a hydrophobic product, the degree of selectivity of organic separation and the presence of a recovery endpoint. The separated flotation concentrate from each of four staged primary flotation tests was pooled as a primary crude rougher concentrate. The flotation underflow was screened at 20 mesh (0.84 mm) and then subjected to magnetic separation (ref. 3). The non-magnetic product was processed on a Deister gravity table (ref. 3) to yield a table concentrate and a table tailing.

Table 3 summarizes the results from these tests. The results revealed the potential for recovery of in excess of 80% of the total contaminant organics, as represented by total oil/grease, to a concentrate product representing less than 50% of the initial mass. A primary concentrate would be further processed so as to reduce its mass and increase its organic contaminant concentration, i.e. concentrate upgrading (see 6.2).

Sample	% Initial Mass	Total Oil/Grease (ppm)	% Total Oil/Grease
Feed Sediment	100	14,200	100
Pooled Flotation Concentrate	44	27,200	84
+ 20 Mesh	1	ND	NA
Magnetic Concentrate	4	ND	NA
Table Concentrate	3	ND	NA
Table Tailing	48	ND	NA

Table 3Results Summary for Scoping Test Series ML-1

The organic-depleted sediment, post flotation recovery, yielded a significant magneticallyrecovered concentrate and gravity separation concentrate. Both of these had visible high contents of sand.

The +20 mesh product represented a small amount of the total sediment mass and its characteristics were addressed in later tests (see 6.3).

6.2 Organic Concentrate Upgrading, Test Series ML-2

A sediment sample was screened at 14 mesh (1.19 mm) and the screen undersize was used for a series of flotation tests as shown in Figure 5. The primary flotation step was carried out as for test series ML-1 but the primary organic concentrate was then subjected to two stages of cleaning/upgrading to produce a 2° cleaner organic product concentrate as well as 1° and 2° cleaner tails. Cleaner tails would normally be re-routed to the primary flotation stage for re-processing as shown, i.e. in a full operating continuous circuit.

The primary flotation tails were classified by cyclone to remove slimes and the U/F was subjected to a metal scavenger flotation where residual metals in the tails were selectively activated, collected and recovered by flotation into a concentrate. This concentrate was reprocessed in a single scavenger/cleaner stage to yield a scavenger/cleaner concentrate and tails.

Table 4 summarizes the mass distributions and the oil/grease (organic) distributions in the products. The organic recovery circuit was found to account for 78% of the total oil and grease with 43% of this in the 2° cleaner concentrate. This concentrate represented only 7% of the total mass.

These tests confirmed the ability to produce an organic concentrate of relatively low mass but representing a substantial amount of the total contaminant organic load. Note that the cleaner circuit tails (1° and 2°) contained 35% of the total organics in 21% of the total mass. This material would be reprocessed in a continuous treatment circuit. Batch tests do not reveal the final concentrate mass or organic yields but it can be expected that a recovered concentrate representing less than 14% of the initial sediment mass and carrying in excess of 75% of the total organics would be achievable in a continuous treatment circuit.

The fines (slimes) fraction produced from cyclone classification of the sediment slurry after organic recovery was found to contain 14% of the total oil and grease indicating that an additional 8% of the total oil/grease would be in the other circuit products (not assayed in Table 4) i.e. by mass balance difference.

Sample ^ª	% of Initial Mass	Oil/Grease (ppm)	% Total Oil/Grease
Feed Sediment	100	14,200	100
+14 mesh	1	ND	ND
2° Cleaner Concentrate (Organic Product)	7	86,300	43
2° Cleaner Tails	4	45,600	13
1° Cleaner Tails	17	18,500	22
Cyclone O/F Slimes	15	13,000	14
Metal Scavenger Flotation Cleaner Concentrate	2	ND	NA
Metal Scavenger Flotation Cleaner Tails	2	ND	NA
Scavenger Tails	48	ND	NA

Table 4Results Summary for Test Series ML-2

^a As per flow sheet Figure 5

Metal contents were determined for the final metal scavenger tails (presumed decontaminated sediment) and the metal scavenger concentrate recovered in the metal selective flotation. These results were compared to the initial feed sediment metal values as shown in Table 5.

Element	Feed Sediment	Metal Scavenger Concentrate	Metal Scavenger Tails
Ва	400	200	400
Be	<1	<1	<1
Са	81,900	27,700	67,700
Cd	10	7	6
Co	20	20	20
Cr	200	150	90
Cu	60	300	20
Fe	98,500	64,700	81,300
La	< 30	<10	< 10
Mg	12,800	4,800	10,800
Mn	2,100	1,600	1,300
Mo	< 90	<40	<100
Na	9,700	1,400	11,300
Nd	< 50	< 10	< 50
Ni	500	100	50
Р	1,800	1,500	1,100
Pb	300	300	<10
S	4,900	1,020	3,300
Sb	< 20	< 20	< 20
Se	< 50	< 50	< 50
Sn	< 20	< 20	< 20
Те	< 10	< 10	<10
Y	20	< 10	<10
Zn	2,300	1,100	300

Table 5Metal Contents of Circuit Products from Test Series ML-2

These results indicated only a slight enrichment of metals in the scavenger metal concentrate in comparison to the metal scavenger tailings. The greatly reduced metal levels in the metal scavenger tailings (presumed decontaminated sediment product) in comparison to the metal levels in the initial feed sediment indicated that the organic flotation step had recovered the substantial portion of the metal load, i.e. in addition to recovering organics. It therefore appeared that the recovery of organic contaminants from this sediment would also recover contaminant metals (see 6.4).

6.3 Organic Recovery Optimization, Test Series ML-3

This series of tests was performed using a protocol similar to that for test scenes ML-2 (Figure 5) except for the following. The primary recovery of organics in the primary flotation was optimized through the use of organic collectors in addition to the use of frothers.



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Figure 5 Testing Sequence for Test Series ML-2



Additionally, an organic scavenger flotation stage was employed for the tails of the primary flotation, i.e. in place of the cyclone classifier shown in Figure 5. In this stage, organic concentrate which had not been recovered in the primary flotation was recovered through addition of additional organic collector agents and frothed.

A metal scavenger stage was also employed after the organic scavenger stage, i.e. as in Figure 5. Test series ML-2 had indicated that this step was relatively ineffective for metal scavenging but in test series ML-3 this was tested on non-classified organic-deleted sediment slurry.

Table 6 shows the distribution of sediment mass and organics as reflected by total oil/grease for Test Series ML-3. No metal determinations were made for samples in this series, the objective of the tests being to optimize organic recovery and produce a tailings product with low organic load.

Sample	% Initial Mass	Oil/Grease (ppm)	% Total Oil/Grease
Feed sediment	100	10,688	100
+ 14 mesh	1.6	22,445	3.3
2° cleaner concentrate	8.8	41,563	34.3
2° cleaner tailing	13.4	20,020	25.0
1° cleaner tailing	35.2	5,751	18.9
Organic scavenger concentrate	5.8	21,056	11.4
Metallics scavenger concentrate	6.2	9,051	5.2
Final Tailings (product)	29.1	689	1.9

Table 6Results Summary for Test Series ML-3

These results indicated that the utilization of organic collectors during the primary flotation recovery resulted in additional organic recovery. The organic recovery circuit, in total, including the cleaner and scavenger circuits accounted for approximately 90% of the total oil and grease. The cleaner tailings (1° and 2°) and organic scavenger concentrate would be returned to the circuit for upgrading in practice so as to achieve a circulating load in the circuit and an optimized yield of cleaner concentrate (product).

The integration of primary and cleaner circuits can be appreciated in the flow sheet (Figure 1), where a primary and two stage of cleaner flotation are employed. The results indicated the potential to produce a decontaminated sediment with relatively low residual oil and grease. Test series ML-4 (below) explores PAH and metal distribution in this process sequence.

6.4 Mass, PAH and Metal Distribution, Test Series ML-4

Test series ML-4 was a repeat of test ML-3 protocols except that only a single (1°) cleaner stage was utilized for the organic concentrate of the primary flotation stage.

The WTC also witnessed test series ML-4 and obtained circuit samples for their own analyses (see Appendix 11.1 for sample details).

Table 7 summarizes the mass and oil/grease distributions for test series ML-4.

Sample	% Initial Mass	Oil/Grease (ppm)	% Total Oil/Grease
Feed sediment	100	10,208	100
+ 14 mesh	1.6	20,862	3.2
Cleaner concentrate	22.3	26,408	57.2
1° cleaner tailing	29.0	8,480	23.9
Organic scavenger concentrate	2.5	19,360	4.8
Metallics scavenger concentrate	4.7	14,711	6.7
Final Tailings (product)	39.9	1,069	4.1

Table 7Results Summary for Test Series ML-4

The results of Table 7 were in good agreement with those shown in Table 6 in terms of overall recovery of organic contaminant. The +14 mesh material was of a similar mass and organic yield to that shown in Table 6. The yield of organics in the recovery circuit was also similar despite the operation of only a single cleaner stage for series ML-4. Note, total organics in the recovery circuit (2° cleaner concentrate, 2° cleaner tailings and 1° cleaner tailings) for series ML-3 represented 78.2% of the total organic load versus 81.1% in series ML-4 (cleaner concentrate plus 1° cleaner tailings).

The operation of only a single stage of organic product upgrading did result in a higher mass yield for the organic product (22.3%) in the case of series ML-4 as compared to only 8.8% for the organic product after two stages of upgrading in the case of ML-3.

Samples of the feed sediment, organic product (pooled 1° cleaner concentrate and organic scavenger concentrate) and treated sediment (final tailings) were analyzed for metals by ICAP, total oil and grease, total organic carbon, total PAH and individual PAH compounds as shown in Tables 8 and 9. These samples and their analyses were as agreed with the WTC, the WTC also carrying out its own analyses (see Appendix 11.1).

The results of Table 8 and Table 9 indicated a good overall reduction of key target heavy metals (Pb, Zn, Cd) and organic contaminants (PAH's, oil/grease, organic carbons) in the treated sediment versus the raw sediment feed.

Element	ug/g (ppm)		
	Feed Sediment (raw)	Treated Sediment (final tailings)	Organic Product (pooled float product)
Ва	400	400	400
Be	<1	<1	<1
Са	80,700	79,300	78,300
Cd	10	6	20
Со	10	10	10
Cr	70	60	100
Cu	50	40	100
Fe	84,000	67,000	100,200
La	<20	<20	< 20
Mg	11,000	10,900	11,300
Mn	1,600	1300	2100
Mo	< 90	< 90	< 90
Na	7,900	11,200	3300
Nd	< 50	< 50	< 50
Ni	20	15	40
Р Р	1200	1100	1500
Pb	200	<10	600
S	4100	1500	8600
Sb	10	10	10
Se	< 50	< 50	< 50
Sn	40	<20	100
Те	< 10	<10	<10
Y	10	10	10
Zn	2200	600	4900

Table 8Metal Analysis of Circuit Products from Test Series ML-4

Table 9 **Organic Analyses of Circuit Products from Test Series ML-4**

	ug/g*			
ANALYTE	Feed Sediment (raw)	Treated Sediment (final tailings)	Organic Product (pooled float product)	
Total Organic Carbon (%)	10.4	2.9	8.8	
Total Oil and Grease	8443	1069	23,931	
Total PAH's ^b	369	45	1017	
Acenaphthene	4	<1	10	
Acenaphthylene	< 1	<1	< 1	
Anthracene	20	4	98	
Benzo(k)fluoranthene	4	< 1	10	
Benzo(b)fluoranthene	35	3	66	
Benzo(a)anthracene	29	9	141	
Benzo(a)pyrene	15	<1	24	
Benzo(g,h,i)perylene	16	<1	31	
Chrysene	8	2	11	
Dibenzo(a,h)anthracene	<1	<1	<1	
Fluoranthene	<1	<1	<1	
Fluorene	28	6	122	
Indeno (1,2,3-cd)pyrene	13	<1	19	
Naphthalene	69	16	381	
Phenanthrene	4	1	21	
Pyrene	24	5	83	

 $^{\rm a}$ Units in $\mu g/g$ (ppm) except where noted in % (w/w). $^{\rm b}$ Total of 16 listed PAH's

The mass yields and contaminant reduction/ recoveries for specific targets are summarized in Table 10.

The cleaned tailings sediment product representing 40% of the initial raw sediment mass was found to be relatively free of contaminants this containing only 4.1% of the total oil/grease, 4.9% of the total PAH's, <2% of the total Pb and 11% of the total Zn. The tailings were reduced in Cd but still contained 24% of the initial Cd load. Similar reductions in Ni and Fe contents (30% of initial remaining) were obtained for the treated sediment.

The organic product was highly enriched in oil/grease and total PAH's (62% to 74% of initial load) which was recovered in 27% of the total mass. The organic product was also enriched in Pb, Zn, Ni, Cd and S but not in Fe.

 Table 10

 Recoveries/Reductions for Target Contaminants in Circuit Products of Test Series ML-4

	% of Total Contamination in:					
Contaminant	Cleaned Sediment (tailings) (pooled floatation product)		Other Interstage Products			
Mass	40.0	27.0	33.0			
Oil/grease	4.1	62.0	33.9			
Total PAH	4.9	74.0	21.1			
Pb	<u><</u> 2.0	81.0	<u><</u> 17.0			
Zn	10.9	60.1	29.0			
Cd	24.0	54.0	22.0			
Ni	30.0	54.0	16.0			
Fe	32.0	32.0	36.0			
S	14.6	56.6	28.8			

^a Other products eg + 14 mesh and interstage products eg. cleaner tails calculated by difference, see Table 7

The results of test series ML-3 and ML-4 were used to construct a preliminary mass balance, revealing sediment mass and organic contaminant mass distributions as shown in Figure 6. The relative enrichment or depletion of organic contaminant as a function of sediment mass through the treatment steps can be appreciated in Figure 6.

While raw sediment feed is non enriched O/M = 1.0 relative enrichment for organic contaminants is indicated by an O/M > 1.0 and depletion by an O/M < 1.0. The final cleaned sediment with an O/M = 0.09 was relatively depleted for contaminant.

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Figure 6 Mass and Organic Contaminant Distribution During Treatment



Mass=% mass of sediment 0=% mass of oil/grease 0/M=% oil/grease / % mass It is important to note that +14 mesh sediment is relatively rich in organics and on this basis it could be added to other recovered organic concentrates i.e. the clean concentrate and the organic scavenger concentrate. The metal scavenger concentrate was not enriched and therefore this step would not be useful at full scale.

The upgrading of recovered concentrate through the cleaner circuit can be appreciated in Figure 6. The primary rougher concentrate was of relatively high mass and of low enrichment (O/M = 1.5) whereas the primary cleaner concentrate was more highly enriched (O/M = 2.6).

Figure 6 shows only the affects of a single cleaner upgrading of the organic concentrate. The influence of a second cleaner step can be appreciated with the data summarized in Table 11. The progressive mass reductions and enrichments of organic contaminants into the final recovered concentrate can be appreciated. Note that a full scale recovery circuit would likely take the form of that shown in Figure 2, i.e. a primary separation with two interconnected cleaning upgrading steps. A continuous dynamic recovery circuit such as that shown in Figure 2 would achieve the internal recirculation of 1° and 2° cleaner tails as shown with a corresponding increase in final primary tailings (cleaned sediment); expected yield of cleaned sediment of \geq 70% of initial sediment mass.

	Characteristics of Concentrates			
· · · ·	% Total sediment mass	% Total Organic mass	Enrichment Factor	
Primary rougher concentrate	54.4	79.6	1.46	
1° cleaner concentrate	22.3	57.0	2.56	
2° cleaner concentrate	8.8	34.3	3.90	

	Table 11	
Influence	of Cleaner Upgrading Steps on Mass and	
Organic	Yields from Hamilton Harbour Sediment	

7.0 CONCEPTUAL FLOW SHEET FOR PILOT-SCALE OR FULL-SCALE TREATMENT

The results of this bench scale treatability study have permitted the construction of a conceptual flow sheet for the treatment of the Hamilton Harbour sediment as shown in Figure 7. Raw dredged sediment would be fed to the treatment plant as a slurry, e.g. 50% solids in water. The +14 mesh oversize, o/s, would be retained as a contaminant-rich product. The -14 mesh slurry would be processed through a wet-type magnetic separator to remove scrap metal containing a portion of the Fe and heavy metal load of sediment. The metal product MP-1 would be sent off-site, possibly for recycling to the steel industry.



The non-magnetic discharge from MS-1 would be routed to a chemical conditioner where organic collecting and separating agents would be added. The conditioned feed would be processed through organic separators OS-1A and OS-1B, in series. The primary concentrate of organics from OS-1A would be upgraded in OS-2 and OS-3 operating in closed circuit with OS-1A. The tails exiting OS-1A would be conditioned with secondary organic collecting and separating agents for polishing in OS-1B. The polished (scavenger) concentrate of OS-1B would be routed to OS-3 for final upgrading.

The final organic concentrate of OS-3 (approximately 12 - 15% of initial feed) would be added to the +14 mesh product for off-site destruction or disposal.

Contaminant-depleted tailings exiting OS-1B would be thickened to recover process water for recycle and the tails (u/f) would be treated in one of two routes (A or B as shown) depending on the final disposition of the cleaned sediments.

Cleaned sediments (Product A) as depicted in route A represent tailings without treatment beyond the point of organic contaminant recovery, i.e. no hydrometallurgical extraction. The present study has shown that this product sediment representing approximately 80% of the initial feed would meet the MOEE guidelines for on-shore use as fill material.

Route B represents the potential requirement to re-utilize the treated sediment as lake-fill for which additional metal recovery would be necessary to meet MOEE lake-fill guidelines. This would be achieved through the use of a hydrometallurgical leach circuit and counter-current VitrokeleTM adsorption circuit as has been applied to the treatment of soils (Figure 2, reference 1 and appendix 11.2).

This processing has been shown capable of removing >90% of the residual Cd, >60% of the residual Zn and in excess of 50% of the residual Cu, Ni and Pb from feeds to the leach circuit.

On this basis, hydrometallurgical recovery (route B) would be expected to reduce inorganic residual metal contamination to levels meeting lake-fill criteria. This can only be confirmed with a pilot test campaign as part of a further study on the treatment of Hamilton Harbour sediment.

8.0 DISCUSSION

The present bench-scale feasibility study with Tallon's technology has confirmed the potential to provide a flexible treatment approach for both contaminant organics and contaminant inorganics in the Hamilton Harbour sediment.

The high organic and inorganic contaminant loads of this sediment dictate that both contaminant types be dealt with effectively so as to permit re-use of decontaminated sediment in either on-shore or off-shore applications. Thus, any treatment approach suited only to organic or inorganic contaminants would require a secondary approach, i.e. for residual, organic or inorganic contaminants. It is highly likely that two independent treatment processes would be economically unattractive for the above reasons.

Tallon's technology, which has been applied to mixed (organic and inorganic) contamination in the case of soil contaminated with various heavy metals (Pb, Zn, Cd, Cu, Ni) and organics (PAH's oil/grease). The utilization of physical/chemical recovery unit process steps for organic contaminants within a process flow sheet otherwise dedicated to metal recovery has been shown to be potentially useful for sediments carrying mixed contamination. A conceptual process flow sheet as in Figure 7, has been developed and this can now be fully tested and verified in a pilot/demonstration campaign with the Hamilton Harbour sediment.

The potential end-use of decontaminated sediment will dictate the degree of treatment necessary and therefore the overall costs to meet these end-use requirements Thus, re-use of decontaminated sediment for on-shore recycling applications does not require full hydrometallurgical extraction of the sediment.

Based on other commercial-scale and demonstration scale projects where Tallon has applied its technology it can be estimated that overall treatment costs would be in the range of \$75 to \$100 per tonne, assuming in excess of 20,000 tonnes of sediment was available for treatment.

A final cost estimate would require demonstration-scale confirmation, decontaminated sediment end-use option selection and verification of disposal or treatment options for the recovered contaminant concentrate.

9.0 CONCLUSIONS

The present treatability study with Hamilton Harbour sediments has permitted a number of conclusions to be drawn in relation to the treatment requirements of this sediment and the results achievable using Tallon's integrated technology approach.

- 9.1 The Hamilton Harbour sediment contains a high total organic carbon load, high PAH load and high load of heavy metals, this exceeding severe effect limits for a number of parameters, both organic and inorganic.
- 9.2 A treatment approach exclusive to organic or inorganic contaminant removal for the Hamilton Harbour sediment would present process limitations and be less cost effective than an integrated treatment approach.
- 9.3 Tallon's integrated technology for the simultaneous recovery of organic and inorganic contamination, as previously proven successful for contaminated soils, has been shown to have good potential for the treatment of the Hamilton Harbour sediment.
- 9.4 A conceptual treatment process flow sheet is available to confirm Tallon's technology for the treatment of the Hamilton Harbour sediment.

10. REFERENCES

- 1. HALL, D. and B.E. HOLBEIN, 1993. Integrated treatment of heavy metal and organic contaminated industrial soils. 3rd Symposium on Groundwater and Soil Remediation. September, Quebec City, Canada.
- 2. PERSAUD, A., R. JAAGUMAGI and A. HAYTON, 1992. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment and Energy.
- 3. PERRY, R.H. and D. GREEN, 1984. Perry's chemical engineer's handbook. 6th edition. McGraw Hill. Toronto.

11. APPENDICES

11.1 WTC/TALLON SAMPLING/ANALYSES PROTOCOL 21/03/93 (5 pages)

TALLON

METAL TECHNOLOGIES INC.

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	_	DATE: 21/3/93
то:	Craig Wardlow	FAX #: 416-326-8913
FIRM:	WR.	
FROM:	B.Holbein.	# of pages: <u>5</u> .
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Brion Glassford.

110 LEACOCK ROAD POINTE CLAIRE QUEBEC H9R 1H1 Tel: (514) 694 0080 Fax: (514) 694 0084

UNIT 4, 67 WATSON RD S. GUELPH ONTARIO N1H 6H8 Tel: (519) 766 9160 Fax: (519) 766 9170

Re. Bench Run with Craig Woodlaw WTC. Hamilton Bay Feed (14 mesh -> + 14 mesh. t uff Tongler float. -> cleaner flood. --> cleaner com + u/f Float product Scavenger Aud. -> Scavenge un. Hailings (3) Assays. For (D, (2), (3) (as attached., 3 gages as indicated). () = Sediment feed. conterninant groduit. (2) = 3 clean sediments. metho by ICAP. TOG. offgruse. TOC. org. Eurbon PAH total (16 individual). B.Hobe

21/3/93

Details on these levels, and the protocols used in developing the guidelines are provided in section 4 of this document.

The No Effect and Lowest Effect guidelines compare closely with the lowest or no effect levels determined through a review of sediment toxicity bioassays by National Oceanic and Atmospheric Administration (NOAA) (Long and Morgan, 1990). As is discussed in Section 4.4, it is not currently possible to calculate a No Effect value for all parameters. Where this is the case for the metals, an interim value based on the lower of the background or Lowest Effect Levels will be used as a lower practical limit for management decisions. For the organics, the background values in Table 5 define the lower practical limit for management decisions.

Table 1: Provincial Sediment Quality Guidelines for Metals and Nutricats. (values⁴ in ug/g (ppm) dry weight unless otherwise noted)

-			i	
	METALS	No Effect Level	Lowest Effoct Lovel	Sovere Effoct Level
By CAP See the Typle 3.	Arsenic Cadmium Chromium Copper Iron (%) Lead Manganese Mercury Nickel Zinc	• • • • • • • • • • • • • • • • • • •	6 0.6 26 16 2 31 460 0.2 16 120	33 10 110 110 4 250 1100 2 75 820

NUTRIENTS

moc (m)		1 "	10
	•	550	4800
/ TP	-	600	2000
× •••		-	

^a - values less than 10 have been rounded to 1 significant digit. Values greater than 10 have been rounded to two significant digits except for round numbers which romain unchanged (e.g., 400).

"-" - denotes insufficient data/no suitable method.

TOC - Total Organic Carbon TKN - Total Kjeldahl Nitrogen

TP - Total Phosphorus

(June 1992)

3

Table 2: Provincial Sediment Quality Guidelines for Organic Compounds. (values in µg/g (ppm) dry weight unless otherwise noted)

Compound	No Effect Lovel	Lowest Effect Lovel	Severe Effect Level (µg/g organic carbon)*	
		0.007	. 8	
~~ 1d-l-	•	0.002	12	
	-	0.005	10	
BHC	-	0.006	21	
a-BHC	-	0.005	(1)4	
β-BHC	0.0007	(0.003)"		
Y-BHC	0.004	0.007	0	
Chlordane	0.005	0.007	12	
DDT(total)		0.008	71	
on+np-DDT	-	0.008	6	
an DDD	-	0.005	. 19	
DDE	-	0.000	91	
pp-DDC	0,0006	0.002	130	
Dielaria	0.0005	0.003	24	
Endrin	0.01	0.02		
нсв	0,00	· · ·	e e e e e e e e e e e e e e e e e e e	
Heptachlor	0.0003	0.005°	3	
Heporide	-	0.007	130	
Mirex	-	0.07	530	
PCB(total)	0.01	(0.06) ^b	(34) ^e	
PCB 1254	•	0.00	(1 5 0)°	
PCD 1248d	-	(uus)	ີ (ສ) ໌	
PCB LOIS	-	(0.00)-	(24)°	
PCB tulo	•	(0.005)*	(11,000)	
PCB 1260	· •	(2)	(11,000)	
/PAH (total)	· -		the South and the South	

Lowest Billect Lovels and Sovere Billect Lovels are based on the 5th and 95th percentiles respectively of the Sevenning Lovel Consentration (SLC) (nos Section 4.2.4) campt where noted otherwise.

() Denotes tentative guidelines

⁶ - Values less than 10 have been rounded to 1 significant digit. Values greater than 10 have been rounded to 2 significant digits. except for round numbers which romain unchanged.

b . 10% SLC

5 - 90% SLC.

^d - Analysics for PCB Arochlors are not mandatory values specifically requested by MOE.

- Insufficient data to calculate guideling.

• Numbers in this column are to be converted to bulk sodiment values by multiplying by the actual TOC concentration of the rumbers in this column are to be converted to our assiment values by realighting by the section of 10%), e.g. analysis of a sectiment sample gave a PCB value of 30 ppm and a TOC of 5%. The value sectiments (to a maximum of 10%), e.g. analysis of a sectiment sample gave a PCB value of 30 ppm and a TOC of 5%. The value for PCB in the Sovero Biforts column is first converted to a bulk sediment value for a sediment with 5% TOC by multiplying 530 to reason the covers interesting the interesting of a subment verse for a seminant with the form is the compared with x 0.05 = 26.5 ppm as the Severe Effect Level guidelines for that assiment. The measured value of 30 ppm is then compared with this bulk sediment value and is found to exceed the guideline.

PAH (total) is the sum of 16 PAH compounds: Accusphthene, Accusphthylene, Anthracone, Benzo(k)fluorenthene, Benzo(b) fluorene, Benzo(a) enthreecenc, Benzo(a) pyrens, Benzo(g,h,l,) perylene, Chrysene, Dibenzo(a,h,) anthreecene, Fluorenthene, Pluorene, Indeno(1,2,3-od) pyrene, Nephthalene, Pheneathrene and Pyrene.

(June 1992)

Table 3: Additional Parameters.

Parameters carried over from the Open Water Disposal Guidelines.

Oil and Grease	0.15%
J Cvanide	0.1 ppm
Ammonia	100 ppm
/ Cobalt	S0 ppm
Silver	0.5 ppm

Routine testing for these parameters would not be required but may be requested on a case-specific basis.

(June 1992)

SECTION 3

APPLICATION OF THE SEDIMENT QUALITY GUIDELINES

The Provincial Schiment Quality Guidelines (PSQGs) shown in Tables 1 and 2 supersede the Open-Water Disposal Guidelines and will provide the basis for all sediment (or potential lakefill materials to be placed in water) evaluations in Ontario. The guidelines portain mainly to activities within the equatic environment and adherence to them is not to be construed as exemption from the requirements of other guidelines, policies, or regulations of this Ministry or other agencies (e.g., the placement of contaminated sediment at an upland site or facility will be subject to the requirements of the Ministry's Waste Management Regulations). The PSQGs will be used in making decisions on a number of sediment-related issues ranging from prevention of sediment contamination to remedial action for contaminated sediment. lasues to be addressed include, but are not limited to, the following:

- Determination of fill quality for lakefilling associated with shoreline development programs.
- Evaluation of sediment quality.

- Determination of appropriate action with regard to sediment clean-up in areas with historic sediment contamination such as IJC Areas of Concern as well as other areas of potential impact.
- Determination of the suitability of dredged material for open-water disposal.
- Establishing the chemical suitability of substrate material for the restoration of benthic habitat.
- Determination of the appropriate degree of acdiment clean-up as a result of chemical spills or unauthorized discharge.

3.1 THE EVALUATION PROCESS

Initial evaluation of bottom sediment or fill material is conducted by comparing the chemical concentrations of the material to the appropriate parameter values listed in Tables 1 and 2, and where required Tables 4 and 5, based on the conditions described in section 3.1.1. Provincial Sediment Quality Guidelines could not be calculated for the parameters in Table 3. Since these parameters can be of concern in protecting aquatic biological resources, the Open Water Disposal Guidelines will continue to be used though chemical analysis for these parameters will be performed only where specifically requested by MOE.. The Open Water Disposal Guidelines are equivalent to the Lowest Effect Level in terms of management decisions.

3.1.1 General Conditions Governing Evaluation

- (a) Material will be tested by bulk sediment analyses and results reported on a dry weight basis (MOE Analytical Methods (MOE 1983) or MOE approved equivalent analytical procedures to be used).
- (b) For the purposes of sediment or fill quality evaluation, actual analytical results reported by the performing laboratory must be provided. However, in comparing the results with the parameter values in the guidelines the results will be rounded as follows: if the reported value is less than ten, it will be rounded to one significant digit. Values greater than 10 will be rounded to two significant digits. Round numbers remain unchanged.

11.2 DECONTAMINATION OF ATARATIRI SOILS CONTAMINATED WITH HEAVY METALS AND ORGANICS EMPLOYING AN INTEGRATED SOIL DECONTAMINATION PROCESS

🔶 TALLON

METAL TECHNOLOGIES INC.

DECONTAMINATION OF ATARATIRI SOILS CONTAMINATED WITH HEAVY METALS AND ORGANICS EMPLOYING AN INTEGRATED SOIL DECONTAMINATION PROCESS

ABSTRACT

Full demonstration treatment of four bulk samples of contaminated soils from the Ataratiri site in Toronto was completed using an integrated heavy metal/organic contaminant recovery technology.

The excavated soils from the site, prior to treatment, all exceeded the Ontario Ministry of the Environment and Energy (MOEE) industrial guidelines for re-use with respect to a variety of heavy metals (Pb, Cu, Zn etc) and polyaromatic hydrocarbons (PAHs). Treatment was completed in a continuous plant at a treatment rate of one tonne per hour using commercial-size equipment which can be scaled up directly to in excess of 1,000 tonnes per day treatment.

All four treated soils were brought to within MOEE residential or industrial guidelines for all metal and PAH targets, enabling their re-use on the site. Recovered contaminant metal products were of low mass, metal-rich and suitable for off-site recycling in the steel and base metal industries. Recovered organic contaminant product was of low mass, highly enriched in oil/grease and PAH's and was suitable for on-site or off-site treatment using companion destruction technologies.

The technology and results revealed the potential for the full scale cost-effective remediation of the estimated 500,000 tonnes of contaminated Ataratiri soils.

1.0 INTRODUCTION

Past industrial activities and historically less stringent waste management practices have resulted in the contamination of substantial quantities of soil with a variety of contaminants including heavy metals, polyaromatic hydrocarbons, oil and grease and polychlorinated biphenyls.

Industrially contaminated sites are often impacted with both heavy metal and organic contamination which can make separate soil treatment for both contaminant types unattractive due to costs. There are few technologies in use for the treatment of heavy metal impacted soils and the various organic destruction technologies now in use are ineffective for metal contamination.

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Tallon Metal Technologies Inc. (Tallon) recognized that a number of technical and economic advantages could be realized through the integrated treatment of soils containing both heavy metals and organics, wherein recovery was provided for metal contaminants separate from the recovery of organic contaminants. The principle advantages are process flexibility over a wider range of soil and contaminant types, reduced treatment times and reduced treatment costs.

Tallon has developed an integrated technology approach which provides for metal recovery using physical and hydrometallurgical procedures and organic recovery using physical/chemical recovery procedures. These technologies have been used by Tallon in other areas of application, employ standard minerals processing engineering principles, as adapted to soil treatment by Tallon, and are the subject of various patents, patent applications and proprietary know-how, all owned by Tallon.

The technology has been applied at a commercial scale for projects in Canada and has been the subject of various demonstration trials. This paper reports the principle findings in relation to a technology demonstration program involving the treatment of soils from the Ataratiri site in Toronto. This project was carried out with funding support by the Ontario Ministry of the Environment and Energy and Environment Canada under their Demonstration of Environmental Site Remediation Technologies (DESRT) program. This paper summarizes the key findings of this demonstration program which have been reported in full elsewhere (Tallon, 1993 and Hall and Holbein, 1993). The excellent technical support of the staffs at Lakefield Research Inc. and Tallon Metal Technologies Inc. is acknowledged.

2.0 CHARACTERISTICS OF SOILS TREATED

The Ataratiri site encompasses approximately 32 hectares of land near the central business core of Toronto which had been secured for residential/commercial redevelopment by the City of Toronto and the Province of Ontario.

Earlier environmental assessments had revealed that a substantial portion of the site was contaminated with heavy metals, including Pb, Cu, Zn and Cd, and organics, principally polyaromatic hydrocarbons (PAH's) to levels requiring remediation prior to re-development. It has been estimated that a minimum of 500,000 tonnes of soil on the site does not meet the less stringent commercial/industrial usage criteria.

Four bulk samples of soil (35 tonnes each) were obtained from the site on the basis that these represented the expected range of remediation requirements for the entire site in relation to past land usage (foundries, scrap yards, rail lands, coal yards), the presence of various heavy metal and organic contaminants (Pb, Cu, Zn, Ni, Cd, As, oil/grease, PAH's) and the range of contaminant exceedences (above residential to greatly exceeding industrial guidelines; registerable waste soil).

The excavated soil samples were mechanically blended to near homogeneity and used for confirmatory feasibility test work and then for continuous treatment testing in a pilot plant providing treatment at a rate of 1.0 tonne per hour. The complete analysis of the soil samples revealed the nature and extent of the contamination as shown in Table 1. Soil AT-1 was excavated in the vicinity of a former foundry and coal yard near Front and Cherry Streets and it was found to exceed industrial criteria for Cd, Zn, and benzo(b)fluoranthene, as well as exceeding residential criteria for other metals (Pb) and PAH's.

Soil AT-2 was excavated from a former rail yard off Cherry Street and Eastern Avenue and it was found to exceed industrial criteria for Ni and residential criteria for As, Cd and PAH compounds.

Soil AT-3 was excavated from the yard of a former scrap metal operation near Front and Overend Streets and it was found to exceed industrial criteria for Cd, Zn, and benzo(b)fluoranthene, as well as residential criteria for Hg, Pb, As and other PAH's. Oil and grease were elevated in Soil AT-3 but not to levels in excess of guidelines.

Soil AT-4 was excavated from former foundry and transport maintenance yards, near King Street and Eastern Avenue, and it was found to greatly exceed commercial/industrial guidelines for Pb, Cu and Zn. This soil was also found to be a registerable waste, as judged by Ontario Regulation 347 leachate toxicity testing criteria, with respect to its contained Pb (results not shown).

The results of Table 1 confirmed that the four soil types spanned a fairly broad range of remediation requirements with respect to various target heavy metals and PAH contaminants.

TABLE 1

CONTAMINANTS IN ATARATIRI SOILS

	Soil Type (values in ppm)				
Contaminant	AT-1	AT-2	AT-3	AT-4	
Antimony	< 10	<10	< 20	< 20	
Arsenic	*36*	*34*	*32*	*32*_	
Barium	300	400	600	195_	
Beryllium	< 2	<2	< 1.5	< 2.	
Cadmium	**20**	*6*	**9.5**	*7.5*_	
Chromium	300	100	80	150	
Cobalt	25	25	20	30	
Copper	100	150	150	**2000**	
Lead	*800*	250	*650*	**3500**	
Mercury	1	0.6	*1.4*	0.6	
Molybdenum	<u>< 65</u>	< 100	< 95	< 100	
Nickel	65	* * 250 * *	70	**300**	
Selenium	<ld< td=""><td><ld< td=""><td><ld< td=""><td><ld< td=""></ld<></td></ld<></td></ld<></td></ld<>	<ld< td=""><td><ld< td=""><td><ld< td=""></ld<></td></ld<></td></ld<>	<ld< td=""><td><ld< td=""></ld<></td></ld<>	<ld< td=""></ld<>	
Silver	ND	ND	ND	ND	
Vanadium	ND	ND	ND	ND	
Zinc	**7400**	550	**1300**	**2300**	
Oil/Grease	1512	1707	8792	3261	
Benzo(a)anthracene	*5.7*	*1.5*	*4.8*	*2.0*	
Benzo(a)pyrene	*8.0*	*2.5*	*3.8*	*1.5*	
Benzo(b)fluoranthene	**12.3**	*3.0*	**10.8**	*1.3*	
Benzo(k) fluoranthene	< 1.0	<1.0	< 1.0	< 1.0	
Dibenzo (a,h)anthracene	< 1.0	<1.0	< 1.0	< 1.0	
Indeno(1,2,3-c,d)pyrene	*3.0*	< 1.0	*3.0*	<1.0	
Naphthalene	< 1.0	< 1.0	< 1.0	< 1.0	
Pyrene	*12.3*	4.0	*11.6*	5.0	

LD = Limit of Detection

ND = Not Determined

*value * = Exceeds Residential Criteria

value = Exceeds Industrial Criteria

3.0 DESCRIPTION OF INTEGRATED METAL/ORGANIC RECOVERY TECHNOLOGY

The treatment process schematic as employed for the treatment of the four Ataratiri soil types is presented in Figure 1.

It should be noted that the process schematic, as shown, was verified through unit process bench tests using a composite of the four soil types (results not shown, see Tallon, 1993). Figure 1 does not show hydraulic circuits.

The technology has been described in full elsewhere (Tallon, 1993). A simplified description of the treatment process can be made as follows.

Contaminated soil is pre-screened to remove large stone, brick etc., which is generally suitable for return to the site (SP-1). The screened soil is scrubbed in a wet scrubber which comminutes soil aggregates and effects surface cleaning of coarse soil components.

The soil slurry is then subjected to classification steps based on size, magnetic and gravity separations to yield additional clean soil products MP-3/MP-4. The recovered metal products are destined for off-site metal recycling. Soil slurry, free of coarse metal contaminants, is then chemically treated to recover organic contaminant product OP-1 using specialized reagents and physical organic separators.

The organic-depleted soil slurry is then treated in a hydrometallurgical circuit where fine metal contamination is selectively leached to solution and then recovered using VitrokeleTM metal selective adsorbents. Recovered metal product MP-5 is a metal-rich filter cake suited to off-site metal recycling. The slurry, depleted of fine metal contamination, is then washed, dewatered and recombined with the other decontaminated soil products for re-use on the site as clean soil.

4. RESULTS

Continuous treatment testing employing the process flow sheet, as detailed in Figure 1, and a plant capable of treatment throughputs ranging between 0.5 to 1.5 tonnes per hour was completed for a composite of the Ataratiri soils and for each separate soil type. All plant operations were carried out at Lakefield Research Inc.

Sampling for mass balance determinations and product characteristics was carried out during steady state operation. Samples taken for analysis represented time-weighted aliquots from different streams of the treatment circuit. A total of five separate campaigns was completed for the composite soil mixture in order to confirm plant operation. Two separate campaigns were carried out for each of the four individual Ataratiri soil types.

Thickener underflow from TH-1 was stored in 200 L drums for subsequent processing through the metal leaching/ Vitrokele[™] recovery circuit. This hydrometallurgical treatment was carried out continuously, employing re-pulped thickener underflow feed to the leach circuit.

4.1 Recovery of Coarse Heavy Metal Contamination

The recovery of coarse metal contaminant fractions from all four soils was quite effective yielding products of low mass but highly enriched in heavy metals as shown in Table 2 for soil AT-3.

	(ppm)					
Contaminant	Feed Soil	Metal Product MP-1/MP-2	Metal Product MP-3	Metal Product MP-4		
Cd	9.0	10.	30.	10.		
Cu	200.	400.	21,600.	2,400.		
Pb	1,400.	845.	129,000.	14,400.		
Hg	1.4	< 0.3	41.	7.		
Ni	70.	650.	1,800.	1,500.		
Zn	1,300.	950.	91,900.	6,900.		
Fe	5.5%	55.3%	26.4%	37.9%		

Table 2						
Coarse	Metal	Recovery	/ from	Ataratiri	Soil	AT-3

Metal products MP-1 and MP-2 are iron rich (55% Fe) and contain relatively small amounts of base metals, thus making these products useful for recycling in the steel industry.

Metal Products MP-3 and MP-4 are less enriched for Fe but highly enriched for base metals, i.e. compared to MP-1/MP-2 and starting soil. These products are useful for recycling in the base metal industry as smelter flux, due to their high silicon (mineral) contents.

Table 3 summarizes the mass yields for coarse metal products as recovered from each of the Ataratiri soils. The overall mass recovered in these products from each soil was relatively low (1.5 to 3.0% of initial soil weight) but the recovery of these products provided an effective pre-treatment. In terms of metal contamination this pre-treatment was sufficient to yield a recovered soil meeting MOEE guidelines in the case of soils AT-1 and AT-2. Secondary hydrometallurgical treatment was required for soils AT-3 and AT-4 (see below).

Ataratiri Soil	Mass yields (% of initial soil weight) for Metal Products					
	MP-1/MP-2 MP-3 MP-4 Total					
AT-1	2.26	0.50	0.43	3.19		
AT-2	0.64	0.18	0.59	1.41		
AT-3	2.11	0.19	0.77	3.07		
AT-4	1.14	0.38	0.80	2.32		

 Table 3

 Recoveries of Coarse Metal Contaminants from Ataratiri Soils

4.2 Recovery of Organic Contamination

Physical/chemical recovery of organic contaminants after metal recovery proved effective for all four Ataratiri soils. Table 4 summarizes the mass yields and principle organic contaminants in the organic product (OP-1, see Figure 1). These results indicate that the bulk of the initial soil organic contaminants can be recovered to a concentrate of relatively low mass (2 to 7% of initial soil mass). These concentrates are highly enriched in oil/grease and PAH's when compared to the initial soil loads (compare to Table 1).

Table 4Characteristics of Recovered Organic Contaminant Product (OP-1)from Ataratiri Soils

	Concentration (ppm)			
	AT-1	AT-2	AT-3	AT-4
Mass (% of feed soil)	2.13	2.54	6.54	7.41
Total Oil/Grease	22,938	12,240	54,560	32,255
Benzo(a)anthracene	74	19	16	19
Benzo(a)pyrene	111	23	20	1
Benzo(b)fluoranthene	261	39	24	1
Dibenzo(a,h)anthracene	243	26	<1	<1
Indeno(1,2,3-cd)pyrene	596	58	47	87
Pyrene	150	44	51	63

Individual recoveries for oil/grease were in excess of 75% and in the case of individual PAH's up to 95% recovery was obtained. The recovery process for organic contaminants therefore proved to be very valuable for the treatment of the Ataratiri soils.

It should be emphasized that overall decontamination factors for organics would be further improved with normal full scale practice. Here, the coarse soil products would be washed with surfactants to remove surface organics; the released organics would be routed to the organic separator stages for recovery. This was not carried out in the demonstration plant, and thus, figures for organic decontamination are conservative.

The recovered organic product was also relatively free of initial soil metal contamination as shown in Table 5. The organic product representing a mass-reduced concentrated (6% of initial soil weight) carried metal loads similar to the original soil, indicating that these metals were not recovered with the organic contaminants. This selectivity of organic contaminant versus metal contaminant recovery has importance in relation to secondary treatment steps for the recovered organic contaminant product. It is expected that both thermal or biological treatments would provide useful companion technologies for the ultimate destruction of the recovered organic product.

	(ppm)				
Metal	Feed Soil	Metal Product MP-3	Organic Product OP-1		
As	32.	90.	140.		
Cd	9.	30.	<2.		
Cr	70.	200.	100.		
Со	20.	40.	10.		
Cu	200.	21,600.	600.		
Pb	1,400.	129,000.	1,800.		
Hg	1.4	41.	4.0		
Ni	70.	1,800.	600.		
Zn	1,300.	91,900.	1,700.		

Table 5Selectivity of Metal and Organic Contaminant Recovery

4.3 Hydrometallurgical Contaminant Recovery

The organic/contaminant-depleted fine soil slurry was found to carry sufficient fine heavy metal contamination so as to necessitate its hydrometallurgical treatment in the case of soils AT-3 and AT-4. All base metal targets of interest were found to be extractable and recoverable as shown in Table 6 for soil AT-4 (Note feed for Table 6 is TH-1 underflow see Figure 1).

Hydrometallurgical	Recovery of N	letal Contaminant	s from Ataratiri Soil	

Tahla 6

	ppm in Soil Solids				
Stage	Pb	Cu	Cd	Zn	
Feed*	2112	950	4	2535	
Post-Leaching	1070	480		1050	
Post-Vitrokele [™]	898	289	< 1	826	
% Recovery to Metal Product MP-5	57%	70%	>90%	67%	

* Thickener underflow post pre-treatment

Overall recoveries for metals ranged from 60% for Pb to in excess of 90% for Cd, resulting in an additional recovered metal product MP-5 for off-site recycling and a decontaminated soil mass for re-use on the site. The stage-to-stage leaching of target metals in the leach circuit and the stage-to-stage recovery of the target metals in the VitrokeleTM adsorption circuit can be appreciated in Figure 2.

4.4 Overall Metal and Organic Contaminant Recoveries

Ataratiri soils AT-1 and AT-2 were effectively treated to meet MOEE guidelines using coarse metal recovery and organic contaminant recovery as shown in Table 7. These two soils had initially exceeded the MOEE industrial guidelines for various heavy metals and for certain PAH's. The treated soils represented a recovery of approximately 95% of the initial soil mass and these were within industrial guidelines for certain PAH's.

It is virtually certain that a full scale plant would yield recovered soil meeting residential guidelines for both of these soils, i.e. due to additional PAH recovery from coarse soil products during processing, as previously discussed.

Ataratiri soils AT-3 and AT-4 were effectively treated using the fully integrated steps of coarse metal contamination recovery, organic contaminant recovery and hydrometallurgical contaminant recovery as shown in Table 8. Soil AT-3 which had exceeded industrial criteria for Cd, Pb, Zn and Benzo(b)fluoranthene was brought to within residential criteria with 86% of the initial soil mass being recovered for re-use.

Soil AT-4 had been the most contaminated of all four Ataratiri soils with very high levels of Cu, Pb, Ni and Zn. Treatment of the soil with the integrated treatment resulted in 84% of the initial soil mass being recovered for re-use, this meeting industrial criteria and only modestly exceeding residential criteria.

5.0 Perspectives for Full Scale Remediation of Ataratiri

The technology reported herein has been shown capable of the effective treatment of a wide range of remedial requirements and soil types. This range should reflect the overall treatment requirements of the Ataratiri site.

The integrated treatment provided effective coarse heavy metal recovery, organic contaminant recovery and fine heavy metal recovery providing a flexible treatment approach to Ataratiri soils with their mixed contaminant loads. Contaminants were recovered into treatment by-products which were highly enriched in recovered contaminants and suitable for off-site recycling.

The information gained in this demonstration treatment trial with the four Ataratiri soil types has permitted the construction of a full scale remediation model for Ataratiri as shown in Figure 3.

The 500,000 tonnes of Ataratiri soils based on previous assessments and the present study is expected to require treatment as follows. Seventy percent (70%) is expected to require organic treatment due to one or more parameters exceeding residential criteria. Of the total it is estimated that 35% will require full treatment i.e. hydrometallurgical extraction while 100% would require partial treatment for metals.

Assuming the four soil types as tested herein accurately reflect the entire 500,000 tonnes, treatment products as shown in Figure 3 will be obtained.

The 7,500 tonnes of steel (MP-1/MP-2) is expected to be recycled to the steel industry with a modest cash return. The other metal products (MP-3, MP-4, MP-5) are expected to be recycled in the base metal industry on the basis of a net cost for toll refining and transportation. The organic product is expected to be treated with a secondary companion technology, either thermal or biological, at a net cost.

The overall cost components of the full scale remediation of Ataratiri, on the above basis, have been examined (Tallon, 1993 and Hall and Holbein, 1993).

A high potential for soil treatment at costs of approximately \$100 per tonne have been estimated on the above basis.

This demonstration has therefore, confirmed the technical merits of the technology and revealed that treatment of soil with this integrated technology can provide a cost effective and environmentally attractive approach to the remediation of the Ataratiri and other sites.

REFERENCES

- 1. Tallon, 1993. Decontamination of Ataratiri Soils Contaminated with Heavy Metals and Organics: A Demonstration of Tallon Metal Technologies Inc.'s Soil Remediation Technology.; MOEE Project ET173WM Report September 1993
- 2. Hall, Derek and Bruce E. Holbein, 1993. Integrated Treatment of Heavy Metal and Organic Contaminated Industrial Soils.; 3rd Annual Site Remediation Symposium, Quebec City (Environment Canada)

Table 7

Contaminant ^a	Contaminant level ppm			
	Soil AT-1		Soil AT-2	
	Before Treatment	After Treatment	Before Treatment	After Treatment
Arsenic	*36* ^b	< 25	*34*	< 25
Cadmium	**13.5**	2	*5.5*	2
Copper	100	100	*200*	160
Lead	*800*	230	400	265
Nickel	68	40	**238**	70
Zinc	**4026**	360	475	385
Oil/Grease	1512	458	1707	936
Benzo(a)anthracene	*6.4*	*2*	*1.5*	< 1.0
Benzo(a)pyrene	*8.25*	*2*	*2.5*	< 1.0
Benzo(b)fluoranthene	**14.65**	*4*	*3.0*	*2.0*
Dibenzo(a,h)anthracene	**10.0**	*3.0*	< 1.0	< 1.0
Indeno(1,2,3-cd)pyrene	*3.5*	< 1.0	< 1.0	< 1.0
Pyrene	*12.65*	3.0	4.5	1.0
Percentage of soil recovered for re-use on site	01 > industrial	94.6 ² residential	0 ¹ > industrial	96² residential

Overall Treatment Results Summary for Ataratiri Soils AT-1 (Front and Cherry) and AT-2 (Cherry and Eastern)

* Only target values of significance shown.

Soils were analyzed for 24 metals and 16 PAH's.

value exceeds residential guideline
 *value** exceeds industrial guideline
 *ceeds commercial/industrial guidelines.

² Meeting commercial/industrial ≈ meeting residential guidelines^c.

^e Expected with simple detergent wash of coarse products during treatment.

Table 8

Contaminant ^a	Contaminant level ppm			
	Soil AT-3		Soil AT-4	
	Before Treatment	After Treatment	Before Treatment	After Treatment
Arsenic	*32 ^b *	< 25	*32*	20.
Cadmium	**9.25**	2	*7.5*	< 1.7
Copper	175.	120.	2400.	*297.*
Lead	**1025**	480.	**3300.**	*681.*
Mercury	*1.4*	0.6	0.6	0.3
Nickel	70	50.	**400.**	60.
Zinc	**1300.**	481.	**2300.**	768.
Oil/Grease	8792.	2559.	3261.	966.
Benzo(a)anthracene	*4.4*	< 1.0	*2.0*	< 1.0
Benzo(a)pyrene	*4.8*	< 1.0	*1.6*	< 1.0
Benzo(b)fluoranthene	**12.4**	*3.0*	*1.3*	< 1.0
Indeno(1,2,3-cd)pyrene	*1.5*	< 1.0	< 1.0	< 1.0
Pyrene	*12.15*	1.0	5.0	< 1.0
Percentage of soil recovered for re-use on site	0 ¹ > industrial	86² residential	0 ³ 3 4 7 registerable waste	84⁴ industrial

Overall Treatment Results Summary for Ataratiri Soils AT-3 (Front and Overend) and AT-4 (King and Bayview)

* Only target values of significance shown.

Soils were analyzed for 24 metals and 16 PAH's.

^b *value* exceeds residential guideline

value exceeds industrial guideline

¹ Exceeds commercial/industrial guidelines.
 ² Meeting commercial/industrial ≈ meeting residential guidelines^c.

[°] Expected with simple detergent wash of coarse products during treatment.

³ Exceeds industrial guidelines, fails 347 leachate for Pb.

⁴ Meets industrial guidelines