





Management Perspective

The oxygen concentration in the hypolimnion of Hamilton Harbour is below the provincial objective. In summer, fish and many benthic invertebrates are unable to live in the hypolimnion. The harbour sediments contain high concentrations of pollutants from the past; they will continue to consume oxygen and remain a potential source of toxic metals and organic compounds. Computer predictions on the effect of implementation of advanced sewage treatment (e.g., 75% reduction in BOD) indicate that after improved sewage treatment, the oxygen concentration would remain below the provincial objective.

The Ontario Ministry of the Environment recommended that "a medium cost measure" for rehabilitating the harbour is hypolimnetic aeration. The stakeholders of Hamilton Harbour Remedial Action Plan resolved that the current status of the harbour warrants aeration or oxygen bubbling.

Pilot-scale tests indicate that the cost of injecting oxygen into the hypolimnion of Hamilton Harbour is less expensive than other direct treatments such as air bubbling. In Hamilton, the supply of oxygen to the steel mills is large (>3,000 tonnes/d), relative to the harbour's hypolimnetic oxygen demand (20-80 tonnes/d).

In laboratory microcosms, toxic metals were precipitated and made less mobile by oxygenation. Thus, oxidized sediments should be less toxic. In concurrent National Water Research Institute (NWRI) laboratory trials, oxidized sediments were less toxic than untreated sediments to zooplankton, rainbow trout, and mayflies.

PERSPECTIVE DE GESTION

La concentration en oxygène de l'hypolimnion du port de Hamilton est en dessous des objectifs de qualité provinciaux. Durant l'été, le poisson et plusieurs invertébrés benthiques ne peuvent survivre dans l'hypolimnion. Les sédiments du port renferment des accumulations élevées de polluants qui continueront de consommer de l'oxygène et qui demeureront une source potentielle de métaux et de composés organiques toxiques. Des prévisions par ordinateur sur l'effet de l'épuration avancée des eaux usées (entraînant une réduction de 75 % de la DBO) indiquent que, advenant sa mise en oeuvre, la concentration en oxygène demeurera sous le seuil voulu.

Le ministère de l'Environnement de l'Ontario voit en l'aération hypolimnique une mesure abordable pour la réhabilitation du port. Les responsables du Plan d'assainissement du port de Hamilton ont reconnu que l'état actuel des eaux du port nécessite l'aération ou le barbotage d'oxygène.

Des études-pilotes montrent que le coût de l'injection d'oxygène dans l'hypolimnion du port de Hamilton est moindre que celui d'autres traitements directs, tel le barbotage d'air. Dans la ville de Hamilton, l'approvisionnement en oxygène des aciéries est significatif (plus de 3 000 tonnes/jour) relativement à la demande d'oxygène de l'hypolimnion du port (20 à 80 tonnes/jour).

Des études de simulation en laboratoire ont montré que l'oxygénation a pour effet de précipiter et de diminuer la mobilité des métaux toxiques. Ainsi, les sédiments oxygénés devraient être moins toxiques. Lors d'essais concordants à l'Institut national de recherche sur les eaux, les sédiments oxygénés étaient moins toxiques vis-à-vis du zooplancton, de la truite arc-en-ciel et des éphémères que les sédiments non traités. Oxygen Treatment of Hamilton Harbour: a Pilot Scale Test

Dr. Tom Murphy, Lakes Research Branch, National Water Research Institute

Abstract

The oxygen concentration of Hamilton Harbour is below the provincial guidelines. The low oxygen concentration prevents fish from using the hypolimnion, reduces the diversity of benthic fauna, enhances the potential for release of toxic metals and phosphorus from the sediments, and reduces the rate of biodegradation of organic materials.

In two laboratory experiments, oxygen bubbling induced the precipitation of the following percentages of metals: copper (0-49%), iron (45-76%), lead (40-69%), manganese (35-81%), and zinc (73-78%). The precipitation of the metals and the decrease in the concentration of dissolved organic carbon (32%), particulate organic carbon (76%), phosphorus (44%), and particulate nitrogen (78%), resulted in a great improvement in clarity of the water overlying the sediment. Oxygen bubbling of the sediments reduced the extractability of cadmium, copper, lead, and zinc by 50%.

Field trials indicated that oxygen bubbling of Hamilton Harbour at the rate of 40 tonnes/d could reoxygenate the harbour. The efficiency of oxygen injection in water 10 meters deep was approximately 90%. Sediment resuspension was not observed in any field trials. The capital costs of oxygen injection are less than one tenth those of air bubbling and if a pipeline supply of oxygen was used, the operating costs of these two methods would be similar.

ABRÉGÉ

La concentration en oxygène des eaux du port de Hamilton se situe en dessous de la norme provinciale. La faible teneur en oxygène empêche l'utilisation de l'hypolimnion par les poissons, diminue la diversité de la faune benthique, augmente le potentiel de libération de métaux toxiques et de phosphore à partir des sédiments, et inhibe la biodégradation des matières organiques.

Deux séries d'expériences en laboratoire ont permis de démontrer que le barbotage d'oxygène entraînait la précipitation de métaux dans les proportions suivantes : cuivre (0 à 49 %), fer (45 à 76 %), plomb (40 à 69 %), manganèse (35 à 81 %) et zinc (73 à 78 %). La précipitation des métaux, ainsi que l'abaissement de la concentration de carbone organique dissous (32 %), de carbone organique particulaire (76 %), de phosphore (44 %) et d'azote particulaire (78 %), ont entraîné une amélioration significative de la clarté de l'eau couvrant les sédiments. Le barbotage d'oxygène dans les sédiments a réduit de 50 % la capacité d'extraction du cadmium, du cuivre, du plomb et du zinc.

Des essais en grandeur réelle ont indiqué que le barbotage d'oxygène, à un débit de 40 tonnes/jour, permettrait la réoxygénation des eaux du port de Hamilton. L'efficacité de l'injection d'oxygène, à une profondeur de 10 mètres d'eau, était d'environ 90 %. Aucune remise en suspension des sédiments n'a été observée lors des essais sur le terrain. Les coûts en capital de l'injection d'oxygène sont moins du dixième de ceux du barbotage d'air et, si un pipeline devait assurer l'approvisionnement en oxygène, les coûts d'exploitation des deux méthodes seraient du même ordre. 1. Direct Oxygen Treatment of Hamilton Harbour

Hamilton Harbour is a 2150 hectare basin at the extreme western end of Lake Ontario. The harbour receives the treated wastes from about half a million people and many industries including Canada's two largest steel mills. Hamilton Harbour has been identified by the International Joint Commission as one of 17 Canadian Areas of Concern in need of a Remedial Action Plan (RAP).

Although treatment of the source of contaminants is the most important step in a remedial action plan, the rehabilitation of Hamilton Harbour could be expedited by direct treatment. A common observation in many rehabilitation projects is that a reduction in external nutrient loading results in slow recovery of the ecosystem and occasionally, no improvement is measured (Ryding 1985, Bostrom 1984, Sas 1989).

1.1 Oxygen Depletion - Rationale for Direct Treatment

The eutrophication of Hamilton Harbour results in severe oxygen depletion in the hypolimnion. From the onset of stratification in late spring or early summer, the oxygen concentration in the hypolimnion quickly decreases to less than 2.0 mg/L and can be less than 1.0 mg/L for a period of weeks (MOE 1975, 1976, 1977a, 1977b, 1978, 1985; Harris 1976, Polak and Haffner 1978, Piccinin 1977, 1980; Harris et al. 1979, Ng 1981). The oxygen concentration in the epilimnion can occasionally decrease during the summer to approximately 4.0 mg/L. In late fall, the harbour cools, destratifies, and oxidizes.

Cold-water fish cannot survive in Hamilton Harbour during the

summer. Warm-water fish are somewhat restricted in that the low oxygen concentration reduces the supply of benthic food. To establish a diverse benthic community, the oxygen concentration should exceed 5.0 mg/L (MOE 1981). Moreover, low oxygen concentrations in the thermocline would stress warm-water fish.

With 1977 data, Snodgrass and Ng (1985a) found that organic compounds from land were a small component of the oxygen demand of the harbour; ammonia oxidation, algal decay and sediment oxygen demand were the main oxygen consumers. Snodgrass and Ng (1985b) found that 25% of the hypolimnetic oxygen demand was due to biomass decay. The oxidation of ammonia consumes about half of the oxygen in the harbour (Klapwijk and Snodgrass 1982). Fortunately, controls on ammonia discharges have reduced ammonia loadings from 12.0 tonnes/d in 1977 to 7.1 tonnés/d in 1985 (Rodgers et al. 1988). Further reductions in ammonia discharge would effectively decrease oxygen consumption in the harbour.

Removal of ammonia could be accomplished by several methods, but the conversion of ammonia to nitrate (nitrification) is the most common (Boller and Gujer 1986). The nitrification method may be most suitable in that the ratio of nitrogen to phosphorus in the effluent remains high and maintaining this ratio should discourage the growth of blue-green algae (Barica et al. 1980); moreover, bacteria can use the oxidizing potential of nitrate when oxygen concentrations are low.

A model developed by J. Vogt for the Hamilton Harbour RAP (Rodgers et al. 1988) indicates that a 50% reduction of ammonia loadings could result in the oxygen demand in the water column

being matched by the input of oxygen from oxidized Lake Ontario water entering via the shipping canal. After implementation of full-scale sewage nitrification and a delay of several years for the sediments to oxidize, the water column would be oxygenated. Some of the uncertain aspects of this model concern how rapidly the sediments oxidize, and the accuracy of the model.

The present impact of ammonia on the oxygen content of the harbour is best derived by the Snodgrass and Klapwijk model (Snodgrass and Klapwijk 1982, Klapwijk and Snodgrass 1982). They found that:

 approximately 36% of the oxygen was consumed in the hypolimnion, 15% of the oxygen was consumed in the sediments, and 49% was consumed in the epilimnion;

 nitrification consumed about 50% of the total oxygen demand;

3) approximately 19% of the nitrification occurred in the hypolimnion and 28% occurred in the sediment.

In 1985, ammonia discharge to Hamilton Harbour was approximately 7,134 kg/d (Rodgers et al. 1988); thus, nitrification in the hypolimnion would have consumed 7,134 x $(47/100)^{#}$ x 4.33^{*} = 15,754 kg 0₂/d.

* is the % of ammonia oxidized in the hypolimnion and sediments * is the molar coefficient for the oxidation of ammonia to nitrate, i.e., 4.33 mg of oxygen reacts with 1.0 mg of ammonia to form nitrate

Since nitrification consumed about 50% of the oxygen, the total hypolimnetic oxygen demand was about 29.0 tonnes of oxygen per day. This estimate agrees well with the MOE (1975) estimate of a hypolimnetic oxygen demand of 33 tonnes/d.

1.2 Oxidation of Lake Water - Oxygen Injection History

To expedite the recovery process, the harbour water could be directly oxidized by several methods. In general, air bubbling is the most common technique (Lorenzen and Fast 1977, Pastorok et al. 1980), but pure oxygen injection may be more suitable for Hamilton Harbour. Where large volumes of oxygen are needed and where pure oxygen is produced on-site, bubbling with pure oxygen may be more efficient and therefore less expensive than air bubbling (McAuley 1973, Speece et al. 1973, Fast and Lorenzen 1976). Hamilton has two large producers of oxygen near the harbour.

The lower capital costs of oxygen injection and faster oxygen dissolution relative to air are resulting in large uses of oxygen in pulp mill digestion (Hsu and Hsieh 1986) and sewage treatment (i.e., Air Products, Detroit 380 tonnes O_2/d , New Jersey 500 tonnes O_2/d ; Bennett 1980, Toms and Booth 1981, Hollerbach 1985). The lower capital costs for oxygen injection may have important implications to the RAP. A few years after implementing the RAP, the sediments will have less oxygen demand. The reduced oxygen demand will, in turn, reduce the size of equipment needed to inject oxygen or air.

The choice of methods used to inject oxygen appears to be a function of physical limitations (e.g., water depth) and industrial controls (e.g., location of oxygen production, company's experience, and patents). In France, most of the oxygen injection is done with equilibration tanks (L'Air Liquide, Paris). Various other types of oxygen injection pump systems are in use in the Thames River, United Kingdom (Wood et al. 1980), Lake Ghirla in Italy (Bianucci and Bianucci 1979), in West German lakes (Hansen, Berlin, personal communication), and several sites, especially rivers, in the United States (Fast et al. 1975a, Overholtz 1975, Fast 1977). These pump systems dissolve oxygen efficiently in shallow water, but they have higher capital and operating costs than simple diffuser injection systems.

The least expensive type of oxygen injection for deep water is a system with diffusers. The first use of diffusers to dissolve oxygen in water apparently occurred in 1953 in a Georgia river (Speece 1969). The efficiency of oxygen bubbling was 14%. For most treatments, the cost of pure oxygen requires higher efficiency of absorption for oxygen bubbling to be competitive with air bubbling. The efficiency of oxygen dissolution is greater in deeper water. A model of Speece (1969) indicates that a diffuser with 2 mm holes, would dissolve 70% and 80% of the oxygen in water 10 and 20 m deep, respectively.

The pore size of the diffuser is critical. In general, smaller pores produce smaller bubbles. The total oxygen flow from a bubble varies as the square root of the diameter of the bubble up to about 2 mm diameter (Speece 1969). As well as resulting in

more oxygen dissolution, small bubbles avoid nitrogen stripping. When large holes were used in Swiss diffusers, large oxygen bubbles triggered the formation of nitrogen bubbles in the hypolimnion and these bubbles resulted in mixing of the water column of Baldeggersee, a lake with an area of 520 ha.

When the Swiss oxygen injection system was changed to stainless steel diffusers with 20 μ mesh in 1985, the smaller bubbles all dissolved, the lake was oxidized, and destratification did not occur (Marki and Schmid 1983, Stadelmann et al. 1984, Joller et al. 1985). The response prompted managers to initiate treatment of Sempachersee (area of 1900 ha) and Hallwilersee (area of 1020 ha) in 1986. Although the Swiss diffuser design has never been published, pictures of the diffuser grid can be seen on the cover of Wasser, Energie, and Luft, 1987 7/8, or within the issue of 1988 3/4 of the same journal.

Oxygen injection with ceramic diffusers was effective in a reservoir on the Savannah River (U.S.A.); destratification did not occur (Schreiner 1987). Although the project was generally successful, the ceramic diffusers often cracked. The Savannah River project was larger than would be required to oxidize Hamilton Harbour (100 tonnes O_2/d vs. <40 tonnes O_2/d).

In the Hamilton Harbour project, we studied the efficiency of a variety of new diffuser materials, the spacing of diffusers, and the distribution of oxygen in a pilot-scale oxygen injection.

2. <u>Methods</u>

2.1 Laboratory Sediment Assays

In June of 1986, 12 sediment cores were collected from two sites (3, 7, Fig. 1) in the harbour to determine the effect of oxygen treatment on toxic metal solubility. The sediment cores were collected with a Williams light-weight corer and 6.6 cm diameter tubing (Williams and Pashley 1978). The sediment cores were about 50 cm deep and were covered with a metre of lake water. The water columns overlying the sediments of three samples from each site were bubbled slowly (30-50 mL/min) with nitrogen or oxygen in a 15°C incubator for four months; the water volumes were maintained by addition of double distilled water.

At the end of the treatments the water was withdrawn with a large syringe and prepared for elemental analysis (Environment Canada 1979). Samples were acidified with aqua regia (10% final acid concentration), left stationary for 16 h, boiled for 1 h, and filtered through acid washed GF/F filters. Metals were determined by atomic absorption spectrometry (direct aspiration or graphite furnace, Perkin Elmer).

In July of 1988, sediment samples were collected from four sites (2, 5, 6, and 7, Fig. 1) with a mini-Shipek dredge. Samples were either left in Ziploc bags as a control, or bubbled with nitrogen or oxygen at 30-50 mL/m in 10 L reaction vessels at 14°C for six months. At the end of the experiment, the sediments were extracted with distilled water for 16 h on a rotary shaker, centrifuged, and the extracts analyzed for metals.

2.2 Laboratory Testing of Diffuser Materials

Several different diffuser materials were tested in a stainless steel tank that was 1.0 m in diameter and 4.0 m deep. Prior to the experiment, the water was bubbled with nitrogen until the oxygen concentration was approximately 1.0 mg/L. During the oxygen bubbling trials the oxygen concentration in the tank was measured at 1.0 m from the bottom and 1.0 m from the top of the tank. Measurements were made with a YSI model 54 meter every two minutes for the first 10 minutes and every five minutes thereafter until the oxygen concentration reached at least

6.0 mg/L. The oxygen dissolution rates were determined by linear correlation analysis; all r values exceeded 0.99. All experiments were run at room temperature. The gas pressure and flow rates were monitored for each trial. The rate of oxygenation of unaerated water was insignificant for the length of an experiment.

2.3 Pilot-Scale Oxygen Injection

Although the method with the least operating cost of injecting oxygen into Hamilton Harbour would use one of Hamilton's two industrial oxygen pipelines, the extension of a temporary oxygen pipeline through the steel mills appeared to be too big a job for an experiment. The optimal efficiency of oxygen dissolution is in deep water (Speece et al. 1973); thus, the ideal site would be the northwest corner of Stelco; this site is only 100 m from water 20 m deep.

The other method of supplying pure oxygen uses a truck to deliver liquid oxygen to a storage tank. The liquid oxygen is converted into a gas prior to discharge to a hose. No pumps or electricity are required.

2.3.1 Site selection

A tank with a capacity for 8500 m^3 was located upon the City of Hamilton's future waterfront park property (Fig. 1) for three reasons. (1) The city was very supportive. (2) The property is in an area considered by the Department of Fisheries and Oceans as a prime area for fisheries rehabilitation. (3) Other sites had a variety of limitations.

The Burlington side of the harbour consists primarily of residential and recreational property. Access for oxygen injection from a tank to deep water would be a short distance from either Danforth Place or La Salle Park. Road access is poor at Danforth Place. Concerns over losing space at the La Salle pier, safety of an oxygen storage tank in the park, and limited room for a truck to turn around would likely preclude using a storage tank in La Salle Park. The northeast shore of the harbour is far from deep water.

The southeast shore is close to a deep sub-basin (Station 1, Fig. 1) that receives treated sewage from Hamilton. This site has the highest ammonia concentration in the harbour (Barica and Vieira 1988). The water in this sub-basin flows into the main deep basin or out through the shipping canal (Spiegel and Charlton 1989). The QEW highway and a large bird colony block truck access for oxygen delivery to this sub-basin. It could be reached by pipeline from the Dofasco property. Although permission was granted to locate a tank there and it may be possible to use an existing industrial pipeline supply of oxygen, this site has some risk in that the intense shipping might disrupt an oxygen pipeline. A pipeline could be buried by a diver operated water jet, but this action was too large for an experiment.

The Hamilton Harbour Commission property on the industrial south shore at piers 11 and 15 is seldom utilized and may be a prime area for any future oxygen storage tanks. Pier 11 has good road access and short access to deep water. Pier 15 is further from deep water but it is close to Canadian Liquid Air and a pipeline supply of oxygen is possible. The optimal pipeline option would be evaluated best by a consortium including personnel from Dofasco and Stelco. Their existing oxygen pipelines could provide oxygen to the deepest water in Hamilton Harbour (sites 1 and 4, Fig. 1).

2.3.2 Hose

The hose used to deliver oxygen from the storage tank to the diffusers was a reinforced seven ply rubber hose with a 1.91 cm inside diameter. The hose must be cleaned with trichloroethylene, an organic solvent with many safety restrictions; some hose firms are not equipped for handling trichloroethylene. The cleaning is required to remove the grease that is used to assist insertion of

the end fittings. If the grease is not removed, an explosion could occur. The firm with the lowest tender price in 1987 supplied several hoses with fittings with large quantities of grease clearly visible.

In 1986, one hose supplied gas to one diffuser grid. In 1987 three hoses supplied oxygen to three grids. The most suitable anchors were steel bars that are normally used to reinforce concrete. Hoses delivered about one tonne of oxygen per day to the diffusers. Similar flow in the three hoses in 1987 was achieved by using orifice plates with 0.25-cm diameter holes to split the flow. The pressure at the head of the system was 170 PSIG.

2.3.3 Diffuser grids

The grid that was used in 1986 was designed by the gas supplier. The diffuser material, garden soaker hose, was kept a trade secret until after the contract was signed. The 1986 diffuser grid was supported by a frame 2.0 m wide by 19 m long of 5 cm PVC pipe. The frame was made of two subunits that were clamped to a brass manifold which distributed oxygen to the soaker hoses. The length of the diffuser and the hinge effect of the manifold made the apparatus very difficult to install in the lake.

The diffusers for the 1987 trials were chosen after extensive testing by NWRI. Three grids, each 3.65 m wide, were built to support Micropore diffusers. The lengths were 3, 6, and 9 m long. Each grid used a different density of diffusers. The diffusers were either 10, 20, or 30 cm apart. The superstructure was made

of 7.6 cm schedule 40 PVC pipe that was reinforced with 10 gauge wire (Fig. 2). Each grid contained three banks of diffusers (Fig. 3). The gas flow to each bank of diffusers was regulated by an orifice union (Fig. 4). The header for the 1987 diffusers was made of PVC pipe (Fig. 5).

No surface floats were used to mark the location of the diffuser grids. Divers were used to verify that the grids were level, and to retrieve them. Anchors were attached to each teejoint in the PVC pipe with polyethylene rope. The PVC pipe remained full of air and the grids floated 0.5 m above the sediments. Warning markers were placed 100 m from the diffusers and at each marina. Navigation was not restricted but boaters were asked not to anchor near the diffusers.

Measurements of the oxygen concentration were made with YSI meters. Water flow was measured with a Pygmy meter calibrated in the Canada Centre for Inland Waters (CCIW) flume. All measurements of water flow at the injection site were made with the boat tied fore and aft to large anchors (railway wheels); the force of the upwelling water kept the boat firmly in place.

3. <u>Results</u>

3.1 Laboratory Studies

3.1.1 Effect of oxygen treatment on metal solubility and water quality in sediment cores

Oxygen bubbling maintained oxygen concentrations between 6 and 10 mg/L and induced the precipitation of the following percentage of metals: copper (0-49%), iron (45-76%), lead (40-69%), manganese (35-81%), and zinc (73-78%) (triplicate analysis: Table 1 and 2). The two sets of data on metal precipitation reflect the collection of samples 37 days (Table 1) and four months (Table 2) after the start of bubbling. The precipitation of the metals and the decrease in the concentration of dissolved organic carbon (32%), particulate organic carbon (76%), phosphorus (44%), and particulate organic nitrogen (78%), resulted in a substantial improvement in clarity of the water overlying the sediment.

The 6 mg/L increase in dissolved inorganic carbon in the oxidized cores indicates that much of the organic carbon was metabolized by bacteria to carbon dioxide. Most of the carbon dioxide would have escaped; thus, the enhancement in bacterial activity must have been large.

A number of organic contaminants were either precipitated or broken down by the oxygen treatment of the cores from station 3 (Table 3). To limit the number of analyses, water samples from each bubbled core were combined; thus, there is no estimate of variation and these analyses should be considered preliminary.

		Oxygen	Oxygen Treated Cores					
	Ca	Cu	Fe	Mn	Pb	Zn		
	mg/L	μg/L	mg/L	mg/L	µg/L	µg/L		
Station	108	6.1	2.7	2.0	17	280		
3	80	4.8	0.9	1.6	12	180		
	45	3.8	1.6	2.5	12	70		
Station	59	1.8	1.4	1.4	11	50		
7	52	1.4	2.4	1.6	12	50		
	61	1.9	1.4	1.7	12	50		

Table 1 Metals in Oxygen and Nitrogen Treated Cores*

Nitrogen Treated Cores

	Ca	Cu	Fe	Mn	Pb	Zn
<u></u>	mg/L	µg/L	mg/L °	mg/L	µg/L	μq/L
Station	73	7.8	5.9	3.3	24	600
3	98	7.6	5.5	1.9	18	550
	148	2.1	3.9	2.7	16	500
Station	52	5.7	3.0	2.4	17	410
7	83	7.3	2.6	1.8	17	420
	96	8.6	2.6	2.5	17	370

•

* 37 days of treatment.

,				Me	tals					
	Ca	Cr	-	Cu	Fe	ľ	ſn	Pb	Zı	n
	mg/L	μg/	'L	µg∕L	_µq/L	μ	1/L	<u>µd\</u> Γ	μ	g∕L
Oxygen										
Stn 3	52.8	<0.5	5	8.3	116	10	00	5.4	38	В
Stn 7	51.3	. 4	ł	6.3	449	29	90	2.9	2:	1
Nitrogen										
Stn 3	54.3	1.2	1	6.0	612	63	30	10.8	8(6
Stn 7	56.3	8.9)	9.0	1,575	1,32	20	22.5	197	7 .
				Maj	jor Io	ns				
	DIC	DOC	POC	PN	NO ₂	NO3	TKN	P	so ₄ s	SiO ₄
<u> </u>	mg/L	mg/L	mg/L	mg/L	µg∕L_	_µg/L	_µg/L	<u>μg/1</u>	<u>mg/L</u>	mg/I
Oxygen					٥					
Stn 3	17.5	77.0	5.0	0.58	2	127	742	98	41.5	3.3
Stn 7	14.0	89.8	6.5	0.66	27	84	504	175	46.3	4.7
Nitrogen			¢							
Stn 3	9.5	114	22.0	2.41	3	16	679	180	38.5	3.4
Stn 7	10.0	131	24.7	3.40	<1	12	626	303	47.0	5.2

Table 2 Oxygen and Nitrogen Treated Cores*

* Four months following treatment. Each value is a mean of three sediment cores. Symbols: Ca calcium, Cr chromium, Cu copper, Fe iron, Mn manganese, Pb lead, Zn zinc, DIC dissolved inorganic carbon, DOC dissolved organic carbon, POC particulate organic carbon, PN particulate nitrogen, NO₂ nitrite, NO₃ nitrate, TKN total Kjeldahl nitrogen, P total phosphorus, SO₄ sulphate, SiO₄ silica.

Compound (ng/L)	Treatment				
	oxygen	nitrogen			
BDH	<0.4	3.42			
DDE	<0.4	0.79			
Phenanthracene	<50	205			
Pyrene	<50	594			

Table 3 Effect of Oxygen on Organic Contaminants"

Four months of treatment.

The responses of the two sediment core experiments were verified in a sediment bubbling experiment. After oxidation, the extractability of cadmium, copper, lead, and zinc was reduced by 50% (Table 4). Oxidation of the sediments had no consistent significant effect on the extractability of cobalt, iron, mercury, Note that all of the sediments contained high or nickel. concentrations of ammonia and low concentrations of nitrate. Α high concentration of oxygen should have resulted in complete oxidation of ammonia to nitrate. Thus, the rate of oxidation was similar to what could be achieved in surface sediments. The oxidation rate was much higher in oxygen treated sediments than in nitrogen treated sediments as reflected by lower ammonia and higher sulphate concentrations in oxygen treated sediments. Oxygen stimulated ammonia oxidation and inhibited sulphate reduction. It may be significant that stations 5 and 6 were more oxidized (lower ammonia and higher sulphate) and the mercury from these stations was less extractable. It is highly significant that phosphorus was much less extractable from the oxidized sediments.

<u>Station</u>	Cd	Co	Cu	Fe	Hq	Ni	Pb	Zn
	µg/L	_µq/L	µg/L	mg/L	µg/L	µg/L	μq/L	mg/L
2-C	1.6	10.6	64	12.7	0.2	53	96	0.71
$-N_2$	3.6	3.8	166	18.8	0.52	16	224	1.15
-0 ₂	3.0	4.8	93	26.0	0.50	18	183	0.97
5-C	2.4	9. 6	81	7.5	0.16	61	114	1,15
$-N_2$	3.2	3.6	52	11.0	0.28	12	267	2.38
-0 <u>-</u> 2	1.6	3.2	38	18.6	0.14	16	110	0.94
6-C	2.0	14.8	61	9.9	0.18	92	938	0.93
$-N_2$	5.8	6.4	154	20.2	0.52	24	325	2.70
-0 ₂	2.4	5.8	69	22.2	0.28	24	138	1.10
7-C	1.0	2.6	41	3.1	0.56	32	32	0.61
-N ₂	4.2	5.2	113	13.0	0.48	190	189	1.78
-02	2.0	4.8	55	10.5	0.50	77	77	0.77

Table 4 Metals in Oxygen and Nitrogen Treated Sediments

3.2 Laboratory Diffuser Studies

The efficiency of oxygen dissolution was easy to measure in a laboratory tank; with few exceptions, oxygen increased linearly with r values greater than 0.99 (Fig. 6). In a few cases, the solution rate was curvilinear up to 2.0 ppm; in these cases the upper portion of the response was linear and only the upper portion was used for calculations. This calculation results in the most Table 4 continued Major Ions and Nutrients*

<u>Station</u>	DOC	DIC	TKN	NO3	NO2	NH3	Ca	<u> </u>	TP
				μġ/I	μg/	'L			
2-CONT	24.0	32.4	22.8	<18	4	0.06	392	94	0.62
-N ₂	32.8	44.8	26.0	100	104	13.2	49	26	1.32
-0 ₂	18.0	47.6	21.7	86	56	13.8	93	129	0.88
5-CONT	48.8	29.6	11.1	<32	12	0.32	664	1700	0.62
-N ₂	18.8	37.6	15.5	10	50	7.38	48	30	1.32
-0 ₂	21.0	31.4	7.8	2	40	1.85	204	512	0.40
6-cont	28.0	25.0	10.2	213	58	0.44	500	1290	0.71
-N ₂	36.2	38.6	22.3	34	170	8.34	45	24	1.33
-0 ₂	16.8	32.6	18.7	68	86	5.91	119	298	0.78
7-CONT	11.2	31.8	3.0	60	14	0.74	234	486	0.31
-N ₂	15.6	32.2	13.1	114	176	5.39	44	226	1.66
-0 ₂	12.2	35.8	10.5	108	54	4.72	100	143	0.70

* All parameters expressed as mg/L, except where noted.

conservative and reproducible estimate of diffuser efficiency. The pattern of water movement and shape of diffusers varied and may have affected the dissolution of oxygen. Only the initial rate of oxygen injection was variable. The rate of oxygen injection was linear with the stainless steel diffuser when the concentration of oxygen was as high as 32 mg/L; the experiment was terminated prior to an anticipated curvilinear response at higher concentrations.

The efficiency of the diffusers varied greatly (Table 5). In general, three diffusers had a much greater efficiency; Micropore, Porex, and Stainless Steel. At a flow rate of 1.5 cfh (cubic feet an hour) in water 4 m deep, these diffusers only produced fine bubbles and could dissolve 40% of the oxygen. A few diffusers produced a mixture of coarse and fine bubbles and their efficiency was less (Table 5). Some diffusers produced only large bubbles and their efficiency was very poor (Table 5). Some of the products may not have been representative of the manufacturer's Although great care was taken to follow instructions supply. (i.e., prewet the diffusers and seal leaks), these results are inconsistent with the manufacturer's specifications. Small leaks can have a big effect; small leaks in the fittings for the Porex diffuser reduced the efficiency in water 4 m deep (flow 1.5 cfh/ft) from 40% to 26% or 20% in two trials.

Some of the inferior products warrant future consideration. For example, the Tifax product is very inexpensive (\$0.19/m). Tifax dissolved oxygen with a very high efficiency at low flow rates (70% at 0.1 cfh in 4 m of water), but to achieve significant oxygen dissolution with these gas flow rates would require an enormous diffuser. The current product would not likely perform; in laboratory trials it split three times. At moderate flow rates,

Tifax produced large bubbles and its efficiency decreased. The product needs more development. At low to moderate flow rates, gas was emitted from only a small portion of the ceramic and Elastox diffusers.

Table 5 Diffus	ser Efficiencies	in 4.0 m Water	Column, Flow 1.5 cft
Product	Supplier	Comments	Efficiency [#]
Stainless	Linde	fritted	40%
ABS	Micropore		40%
Polyethylene	Porex	20 µ pores	40%
Polyethylene	Aquaresearch		30%
Tifax	Irrigro		278
Air hose	Linde	<1 mm holes	20%
Polyethylene	Linde	1 mm Holes	13%
Ceramic	Linde		88
Elastox	Eimco	large slits	88
Rubber	Canadian Tire	soaker hose	8*
<u>Polyethylene</u>	Linde	2 mm holes	8%

[#]Percent oxygen dissolved

Bubbles emerging from the bottom of the horizontal diffuser tube coalesce before they leave the diffuser. To determine if the circular nature of the diffuser reduced the efficiency, the bottom half of a Porex diffuser was sealed and compared to an unaltered

Porex diffuser of the same length. The unit with the sealed bottom was 4% more efficient. The standard deviation of the efficiency of oxygen dissolution with unaltered Porex was approximately 3% (n=4). The statistical validity of the response was not confirmed; the effect was too modest to warrant sealing the bottom of all the diffusers.

The efficiency of oxygen versus air bubbling was studied with Porex, Micropore, and stainless steel diffusers. To compare an equivalent flow of oxygen in air to pure oxygen, the flow rate of air was increased fivefold. The injection rate of pure oxygen was about twice as efficient as air (Table 6).

O ₂ flow (cfh)	Diffuser	• 0 ₂	Air
0.25	Porex	73	41
1,5	Porex	43	17
1.5	Stainless	40	20
1.5	Micropore	40	23

<u>Table 6 Efficiency of</u>	Air	Versus	Oxygen	Bubbling
------------------------------	-----	--------	--------	----------

The efficiency of oxygen injection is also a function of gas flow. At rates of flow exceeding 2.5 cfh, the efficiency of the Micropore diffuser decreased greatly (Table 7). The results in Table 7 indicate that the Porex diffuser is more efficient at slower gas fluxes; this response could be partly a reflection of the smaller diameter and surface area of the Micropore diffuser (1.3 cm vs. 2.4 cm, 1.85 times less surface area).

Flow (cfh)	Percent of Oxygen	Dissolved (4 m depth)
·	Micropore	Porex
0.25	41	73
0.5	-	72
1.0	40	55
1.5	40	43
2.0	41	43
2.5	41	, ,
3.0	26	-
4.0	- 23	

Table 7 Effect of Flow Rate on Diffuser Efficiency

The efficiency of oxygen injection was directly proportional to the depth of water overlying the diffuser. With both Micropore and Porex diffusers in water 2,3, and 4 m deep, the relationship between the rate of oxygen dissolution and depth was linear. An extrapolation of this relationship to the pilot-scale study where the water depth was 9.0 m indicates that about 90% of the oxygen should dissolve (Fig. 7).

3.3 Pilot-scale Oxygen Bubbling Studies

Several delays prevented the start of 1986 experimental oxygen bubbling until October. Two factors terminated this trial; cold weather and large leaks in the diffusers. When the soaker hose diffusers were retrieved, they were extremely brittle. Apparently the hose quickly oxidized. In spite of the technical

problems, positive observations were made. Water quality was not impaired; therefore, sediments were not resuspended by the rising bubbles (Table 8). No change in the local concentration of oxygen was noted. Large quantities of gas were reaching the surface and generating a large upwelling of bottom water. The water column had mixed prior to this experiment; therefore, it was not possible to use temperature as a guide to distinguish oxidized bottom water from which naturally had surface water a higher oxygen concentration. Speece's (1969) relationship indicating that 70% of the oxygen should have dissolved could not be verified.

The 1987 experiments demonstrated that oxygen injection could be efficiently done. The efficiency of oxygen dissolution was determined by using the water temperature (Fig. 8) as a tracer for water movement, measuring currents and oxygen concentration of the water, and calculating the percent of oxygen injected to oxidize the upwelled water (Table 9). The cool bottom water contained very little oxygen but one pass through the rising bubbles resulted in an increase of oxygen of approximately 2.0 mg/L. The bottom water rose to the surface and produced plumes of treated water with a distinct colour that in calm water were readily visible. The formation of currents by the rising bubbles or natural currents prevented a large increase in oxygen concentration around the injection site.

				М	ajor I	ons		e.		
Depth	æ	SO4	cl	SiO ₂	NH3	NO2	NO3	TN	TP	
<u>Site</u>	<u></u>	mg/L	mg/L	mg/L	_µg/L	µq/I	µg/L	µg∕I	<u>µq∕L</u>	
1 m	0 ₂ *	46.8	52.1	1.86	27	5	2.08	810	49	
11 m	O ₂	48.3	51.1	1.59	8	6	2.14	660	49	
1 m	Cont [#]	47.6	51.4	1.54	6	6	2.11	520	46	
11 m	Cont	47.8	51.2	1.54	8	6	3.13	540	47	
			Metals	6						
Depth	&	Cu	Fe	Mn	Pb	Zn	Ca	Mg	K	Na
<u>Site</u>	- <u></u>	µg/L	μg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L_	mg/L
1 m	0 ₂	24	334	60	2	15	49.5	11.7	4.13	29.3
11 m	0 ₂	3	327	47	2	15	50.4	11.6	3.95	29.3
lm	Cont	2	296	69	2	1 5	49.2	11.0	3.95	28.1
11 m	Cont	2	296	56	1	14	50.0	11.1	3.99	28.5

* O_2 is the diffuser site. *Cont is a control site 0.5 km north of the diffuser.

The rising oxygen produced an air lift pump that upwelled water with a flow from 2,700 L/s to 6,400 L/s with an efficiency of oxygen dissolution from 53 to 92% (Table 9). The smallest grid pumped much less water and was less efficient at dissolving oxygen than the two larger grids. The pattern of water movement was verified with an underwater videocamera. Strong currents moved

Table 8 Water Quality at the Oxygen Injection Site Nov. 10, 1986

into the diffuser near the bottom; no resuspension of the sediments was observed.

Table 9 DI	Huser Gria EII.	ICIENCY		
<u>Raft Size</u>	3m	6m	9m	
%0₂ ^{#0} dissolved	53 54	92	79 92	
<pre>% bottom^{#*} water</pre>	41 40	39	23 40	
Water Flow (L/s)	2,700	5,200	6,400	

[#]The two numbers are each independent measurements.

^aSample calculation for 6-m grid. [(Surface plume O_2 - Bottom O_2) x (proportion bottom water x H₂O flow)] & [(surface plume O_2 control surface O_2) x (proportion surface water x H₂O flow)] /oxygen flow rate

$$[(9.9-3.6)(.385x5,200)] + [(9.9-9.5)x(.615x5,200)]/1.3=.92$$

*Indicates the proportion of bottom water in the surface of the upwelling plume, derived from temperature data assuming simple 2 compartment model (Fig. 8).

The lack of sediment resuspension was verified by the suspended solids data (Table 10). No significant differences were observed between the concentration of particles in the upwelling water and neighboring water.

Sample Location	Date	Concentration
3-m grid	07/28/87	6.9
6-m grid	07/28/87	10.2
9-m grid	07/28/87	9.4
9-m grid	07/28/87	11.3
u-cont	07/28/87	10.0
3-m grid	08/21/87	11.0
6-m grid	08/21/87	12.0
9-m grid	08/21/87	12.0
u-cont	08/21/87	10.4
d-cont	08/21/87	8.4
3-m grid	08/24/87	11.1
6-m grid	08/24/87	6.6
9-m grid	08/24/87	12.6
u-cont	08/24/87	15.0
1-m-c"	08/24/87	8.0
2-m-c	08/24/87	5.3
3-m-c	08/24/87	7.2
4-m-c	08/24/87	4.5
5-m-c	08/24/87	7.0
7-m-c	08/24/87	7.6
8-m-c	08/24/87	10.4

Table 10 Suspended Solids In Hamilton Harbour

*Samples 1 m-8 m-c were collected in the middle of the three diffuser grids. All other samples are surface samples. U-cont and d-cont are the upstream and downstream controls, i.e., surface water samples that were collected with respect to where the wind blew the surface water 100 m from the diffusers.

Generally, the water quality data of the upwelling plume supported the visual observations that sediment resuspension was insignificant (Table 11). The total phosphorus and total nitrogen concentrations of the upwelled water were relatively low. The water quality of the upwelled plumes was different from the

(mq/L)

surrounding surface water, but it was a result of mixing of bottom water not sediment resuspension. Note that six water samples contained unusually high concentrations of either zinc, copper, lead, or manganese. These samples did not contain significantly more suspended solids; thus, these metals were not likely from the sediments. Contamination of the surface samples with small metalrich particles seems to be the most likely explanation of the odd high metal concentration. During these sampling days, black particles from presumably the steel mills, were conspicuous on the water surface.

The thermal budget calculated for stratified water (Fig. 11) indicated that approximately 40% of the surface water in the upwelling plume was bottom water (Table 9). A comparison of this set of calculations to a calculation of percent upwelling on September 10, when thermal stratification was weak, is interesting. On September 10, the difference in water temperature from top to bottom at this site was 0.1°C. By using the sulphate and chloride differences in the bottom water, surface water, and upwelling water on September 10, it appears that approximately 63% (60% chloride budget, 66% sulphate budget) of the surface plume over the 6- and 9-m diffuser grids and 49% of the surface

<u>28</u>

7	α
-	_

Site	SO4	CL	si02	NH3	NO2	NO3	DIC	DOC	TŇ	TP	Chl <u>a</u>
	mg/L	mg/L	mg/C	µg7L	µg7L	µg7L	mg/L	mg/L	mg/L	µg/L	μg/L
07/28/87				<u> </u>							
3-m grid	48.5	47.3	1.07	773	25	1.11	29.2	5.4	2.74		6.4
6-m grid	47.8	53.4	0.52	364	44	1.44	27.3	4.5	2.38		26.2
9-m grid	45.9	51.5	0.6	343	6	1.36	27.1	3.2	2.10		20.3
u-Cont	47.9	57.2	0.15	130	27	1.71	25.9	3.7	2.29		29.4
08/21/87											
3-m grid	46.3	51.7	0.86	789	158	- 3.35	24.7	5.9	4.96	27	14.4
6-m grid	46.1	52.7	1.39	357	26	1.51	25.8	3.4	2.18	20	12.3
9-m grid	46.4	52.8	1.05	288	150	1.41	25.5	3.0	2.02	9	17.6
u-Cont	46.5	53.0	1.23	166	150	1.32	25.8	3.3	1.87	13	28.8
a-cont	46.5	53.4	1.48	193	158	1.37	26.2	3.0	1.96	12	22.4
09/3/:/07											
00/24/0/ Zam anid	/E 0	17 4	0.40	777	4/0	4 70					~~ /
5-m grid	47.0	41.0	1 31	322	149	1.30	25.9	4.3	2.13	13	22.4
0-m grid	28 2	40.7	1.21	244	120	1.20	45 0	2.9	1.65	10	22.0
	20.J	10.4	49.2	234	121	1.10	12.0	2.4	1.79	12	23.0
d cont		47.6	1.17	232	150	1.20	10.4	2.4	1.03	10	17.0
08/26/87											
1-m	44.6	48.1	0.19	219	169	1.12	26.0	3.5	1.78		21.4
2-m				151	166	1.12	16.2	15.0	2.0		20.8
3-m	44.3	48.0	0.14	189	167	1.09	25.8	3.0	1.68		21.4
4-m	44.2	42.9	0.14	198	169	1.09	25.9	3.3	1.74		28.8
5-m	44.8	38.9	0.21	228	178	1.13	26.1	3.4	1.83		18.2
6-m	44.1	47.9	0.17	230	162	1.10	25.7	3.0	1.72		26.2
7-m	44.0	47.9	0.17	209	183	1.10	24.8	3.4	1.79		11.5
8-m	44.0	47.3	0.21	213	177	1.09	25.7	3.0	1,70		28.8
									-		
09/10/87											
1-m	51.3	52.9	0.5	407	236	1.08	24.9	5.8			32.6
2-m	46.4	51.1	80.0	242	252	1.03	24.5	3.7			29.4
3-m	46.7	51.6	0.07	246	219	1.07	24.8	3.7			25.6
4-m	46.5	51.6	0.13	285	219	1.09	24.4	4.1			28.3
2-W	46.1	51.6	0.14	203	200	1.12	23.9	3.5			15.0
0-M	45.0	48.0	0.4	53	65	1.35	25.0	3.3			9.6
8-Ŵ	40.2	44.5	0.72	14	2	1.35	25.3	3.2			17.6
5-m grid	45.4	48.4	0.55	53	6	1.39	25.0	5.4			16.0
o-m grid	42.4	47.4	0.46	27	4	1.37	25.1	3.3			
A-W BLIQ	42.0	47 . Y	U.4	28	- 4	1.42	Z5.0	5.4			15.5

Table 11 Water Quality at the Oxygen Injection Site 1987

*Samples 1 m-8 m were collected in the middle of the three diffuser grids. All other samples are surface samples. U-cont and d-cont are the upstream and downstream controls, i.e., surface water samples that were collected with respect to where the wind blew the surface water 100 m from the diffusers.

÷

Site	Al	Cu	Fe	Mn	Pb	Zn
07/28/87						
3-m grid	8.6	47	23	220	5	2080
6-m grid	7.1	18	17	11	2	406
9-m grid	6.6	12	16	<2	1	110
u-Cont	9.6	11	20	<2	1	119
			20	16	*	01
08/21/87						
3-m grid	24	14	129	8	39	859
6-m grid	10	83	32	4	5	50
9-m grid	8	10	16	2	2	J J J
u-Cont	8	6	16	<2	1	94 94
d-Cont	7	5	14	<2	1	24
	·	U	• •	14	_	~ 20
08/24/87						
3-m grid	5	4	24	13	3	139
6-m grid	5	5	25	3	2	43
9-m grid	4	5	19	3	1	25
u-Cont	5	5	13	<2	2	23
		-		- 4	L	57
08/26/87						
lm	5	-5	12	<2	<1	50
3m	4	4	13	<2	<1	27
4 m	4	4	13 •	<2	1	26
5m	4	5	11	<2	ī	57
6m	4	7	15	<2	<1	29
7m	6	3	16	4	<1	32
8m	4	4	14	4	<1	28
00/10/07				-		20 、
1-	10	_				
1m	13	5	13	5	2	261
2m	10	6	57	3	1	46
3m	18	6	32	3	1	54
4 m	8	4	24	4	1	65
5m	13	4	27	<2	<1	34
6m	6	4	13	<2	1	45
8m	5	3	7	<1	<1	44
3-m grid	4	4	8	3	<1	49
6-m grid	3	2	7	<1	<1	36
9-m gri	5	3	8	<1	<1	39
						÷ =

٠

Table 11 continued - Total Metals*

* 4

 μ g/L of total extractable metals.

<u>30</u>

plume over the 3-m grid (50% sulphate budget, 47% chloride budget), was bottom water. Although the thermal and chemical budget calculations utilize different methods, the differences between upwelling during strong stratification (thermal budget) and upwelling during weak stratification (chemical budget) are significant and reflect the uncoupling of denser cold bottom water in the upwelling water during stratification. Less bottom water reaches the surface during oxygenation of a thermally stratified water column.

The upwelling bottom water produced an interesting response in the bait fish. Emerald shiners concentrated around the diffusers. In the early morning or on cloudy days, at least several hundred fish were visible near the surface. Later in the day, the fish were not visible, but they could be caught within five minutes in small Windermere traps that were lowered to a depth of two metres. The schooling of fish attracted herring gulls and cormorants.

Although the 1987 system performed well, there were two problems. (1) The amount of gas emitted from the Micropore diffusers varied greatly; a few discharged much more gas than others. Since the efficiency of the diffusers decreased with greater gas flow, this variable gas flow may indicate that some diffusers have a lower efficiency. (2) Several of the Micropore diffusers cracked at the joint with the manifold. With the assistance of a large barge and an experienced dive crew, it was relatively easy to retrieve the diffusers and repair them.

<u>31</u>

Moreover, because the site is within view of our building, we were able to choose calm days for repairs.

A small trial was carried out on October 16 in water 20 m deep using the smallest 1987 diffuser. Oxygen was supplied from a barge carrying a small tank of liquid oxygen. Much less gas reached the surface at this depth than in water 10 m deep.

The plume of rising gas and water was much less distinct than at 10 m. In water 10 m deep, the plume rose more or less straight up; in water 20 m deep, the plume wandered horizontally by several metres. It was not possible to calculate the efficiency, but less oxygen reached the surface than occurred with the largest diffuser in water 10 m deep (>90% efficiency).

4. DISCUSSION

4.1 Reduction of Toxicity by Oxygen Bubbling

The hypothesis that at least some of the acute toxicity of Hamilton Harbour sediments is caused by metals is supported by several studies. The harbour sediments are heavily polluted with lead $(320\pm200 \ \mu\text{g/g})$, zinc $(3110\pm2000 \ \mu\text{g/g})$, iron $(68\pm41 \ \text{mg/g})$, and manganese $(1670\pm920 \ \mu\text{g/g})$; moderately to heavily polluted with chromium $(206\pm59 \ \mu\text{g/g})$ and copper $(101\pm59 \ \mu\text{g/g})$; and moderately polluted with nickel $(45\pm19 \ \mu\text{g/g})$; MOE 1977a and MOE 1977b).

Lum and coworkers (McIsaac et al. 1981) found that the most important chemical phase for metals was the iron-manganese oxides. These oxides controlled the solubility of manganese, zinc, and occasionally lead. These elements can be released into solution and their bioavailability and toxicity increase if the water becomes anoxic (Berner 1971).

The observations that oxidized sediments have more extractable calcium and less extractable cadmium, copper, lead, and zinc is consistent with observations by Snitz et al. (1979). They found that the addition of calcium to dredged sediment reduced the release of metals. They proposed that calcium bound colloids into larger aggregates, thus reducing the "solubility" of colloid associated metals. In related unpublished studies at NWRI, it has been observed that calcium hydroxide also reduced the solubility of metals. In other ongoing NWRI studies, it has been observed that many flocculating agents (calcium hydroxide, alum, ferric

chloride) reduce the acute toxicity of sediments. The reduction in toxicity is variable and inconsistent.

The relatively high concentration of polynuclear aromatic hydrocarbons (PAH's, Onuska et al. 1983), PCB's (MOE 1985), oils and grease (Mudroch and Sandilands 1980), and the presence of certain pesticides such as chlordane (MOE 1985), suggests that chronic or sub-lethal toxicity could exist. Ongoing NWRI studies have discovered sediments containing very high concentrations of PAH's and that much of the acute toxicity of the harbour is apparently associated with PAH's. Bacteria can degrade organic contaminants faster with oxygen than in anoxic environments (Renzo 1980) and some PAH's (anthracene and napthalene) can only be degraded by bacteria with oxygen (Bauer and Capone 1985). However, many organic toxins degrade very slowly (Heitkamp and Cerniglia 1987, Rache and Frink 1989) and it would be too optimistic to suggest that oxidation of the harbour sediments would destroy all organic toxins.

4.2 Pilot-Scale Studies

The emerald shiners may have been attracted to the diffusers by either food in the upwelling currents or the oxygen. Since bait fish and avian predators were attracted to the diffusers, predator fish should be attracted as well. This hypothesis should be tested since oxygen bubbling might provide good recreational fishing for the proposed Hamilton Waterfront Park. Perhaps if the diffusers

were matched with a floating brush bundle to provide refuge, etc., fish would congregate in areas where fishermen could catch them.

4.2.1 Design considerations for oxygen iInjection

Although oxygen injection at the future park may be useful, it is not the optimal site to oxidize the harbour. The diffusers should be placed in the deepest water available. Not only is a higher proportion of the oxygen dissolved by injection into deeper water but also the size of the diffuser can be smaller in deep water. The greater hydrostatic pressure in deep water increases the mass of each bubble; therefore, more oxygen can flow through a diffuser in deep water than in shallow water.

If the oxygen injection was done in water 20 m deep, the fine diffusers would produce minimal upwelling of bottom water (Ruane and Vigander 1973), whereas a diffuser with coarse holes would produce more upwelling of bottom water. There is little concern with upwelling in the harbour. In other lakes, the upwelling of bottom water would increase the availability of nutrients and enhance algal growth. Hamilton Harbour has very high concentrations of nutrients and upwelling would not change nutrient availability. Upwelling should be minimized so that the sediments are not warmed; warmer sediments consume more oxygen (Holdren and Armstrong 1980). Bubbling with air rather than pure oxygen would produce much more upwelling and would both warm the sediments and cool the surface water. Cooling the surface water would restrict the potential for recreational swimming.

Results of a Danish oxygen treatment are applicable to Hamilton Harbour. The Danish treatment used simple diffusers with visible holes (<1 mm) in water 30 m deep. The efficiency of oxygen dissolution was 90%, destratification was insignificant, and the sediments remained cool (Lajer 1988). Use of finer diffusers in water 20 m deep should also produce little destratification.

The Danish diffusers were placed on the sediments and the sediments were not resuspended. The Swiss diffusers were placed 20 cm above the sediments and no disruption of the sediments occurred. The NWRI diffusers were located 0.5 m above the sediments and sediment resuspension did not occur. No simple relationship has been developed to predict when air or oxygen bubbling would significantly resuspend sediments.

The risk of sediment resuspension is less with oxygen than with air bubbling because oxygen bubbling requires fewer diffusers. NWRI studies indicate that 50% more oxygen is dissolved with pure oxygen bubbling relative to an air bubbling system with an equivalent flow of oxygen. Thus, for equivalent oxygen dissolution, a 50% smaller diffuser system could be used for oxygen injection relative to air bubbling. Markofsky (1979) compared equal flows of air and oxygen and reported that aeration using oxygen is somewhat less efficient than using air. Systems are designed to provide a specific quantity of oxygen, not air. Thus, to compare costs of bubbling systems a comparison of efficiency at equivalent flows of pure oxygen and oxygen in air is more useful.

The ABS Micropore diffusers appear to be too brittle for use in a project with little maintenance. Polyethylene Porex diffusers would probably require less maintenance. Unlike data in an earlier report (Tennessee Valley Authority 1973), the gas flow was spread evenly over the surface of the Porex diffusers. The Porex diffusers are slightly more expensive per unit surface area than the Micropore diffusers but the Porex diffusers have much thicker and more flexible walls. A full-scale study with Porex diffusers is now operating in Amisk Lake, Alberta (Prepas, et al. 1989).

The 9-m diffuser grid was too large for easy installation and retrieval for repair with our 13-m barge and 8-m launch. The diffusers cannot be placed closer than 20 cm from each other without losing their efficiency; thus, the 3-m grid was too small while the 6-m grid was optimal to emit a tonne/d of oxygen efficiently. The concept of using orifice plates to distribute an equal flow of gas to three subunits worked well; for operations with small boats a grid of two subunits would be manageable. The total area of the harbour sediment that would be covered with diffusers is approximately 600 m², or about the size of one of the dots used in Figure 1 to mark the sample stations. To maximize efficiency, the grids would be separated and the actual area

The small bubbles produced by the Micropore diffuser increased the efficiency of oxygen injection by about 20% relative to diffusers using 2 mm holes (Speece 1969). Extrapolation of our laboratory tests of simple diffusers indicates that high quality

diffusers in water 10 m deep would dissolve as much as 70% more oxygen than would diffusers with large holes.

Retrieval of diffusers for repair or seasonal shutdown must be done soon after the flow of oxygen is stopped. The Micropore diffusers were left in the water for two weeks after the oxygen was turned off and they became fouled with microbial growth. Sodium hypochlorite cleaned off most of the growth but the flow did not return to original rates. No growth problems were noticed while the oxygen was flowing or after disruptions of flow for two days. Daily monitoring of diffusers is recommended.

The hose should have been bought in longer lengths but due to limited time we had to buy hose that was in stock

(30-m lengths). The hose can be made longer but a custom order is required. Moreover, we discovered later that the two hose suppliers had provided non-CGA fittings. The less expensive fittings could not sustain the strains of installation and retrieval for repair. Strain members to transfer the stress to the hose might have prevented leaks at the joints. Two small leaks that were observed in the hose in 1987 were in the joints. This problem was more irritating in 1988; the same hose was used in Dr. Prepas's Amisk Lake project and several joints leaked (Prepas et al. 1989).

4.3 Estimated Cost for Oxygen Treatment of Hamilton Harbour

The degree of sewage treatment determines the amount of oxygen treatment needed to oxidize the harbour; thus, three scales of treatment are considered; 1) no further improvements to the sewage treatment plants, 2) enhanced nitrification of sewage, and 3) enhanced nitrification and dual point iron treatment of sewage to remove nutrients, reduce the algal growth in the harbour, and in turn reduce algal decay by 50% (Rodgers et al. 1988). The following estimate uses Klapwijk and Snodgrass's 1982 model which estimates that 50% of the oxygen demand is from nitrification and 15% is from sediment demand. No cost estimates for treatment of sewage are included here. The costs are an extrapolation of the NWRI study with no adjustments for the normal reduced price of oxygen bought in larger quantities.

Table 12 is presented as a general guide. Oxygen bubbling, especially with a pipeline supply of oxygen, should be less expensive than air bubbling. Where oxygen can be produced on-site or can be delivered by pipeline, the cost of oxygen can be less than half the cost of oxygen delivered by truck (Speece and Malina 1973). A final choice of treatment can only be made after an extensive tendering and review process. Market demand strongly influences the price of oxygen. Moreover, new aeration techniques are being developed and a more cost-effective air bubbling system might be available soon.

A complete assessment would also require an estimate for pipeline construction. Oxygen injection appears to be more costeffective because of the relatively low capital cost of oxygen diffusers relative to the capital cost of air compressors.

However, if the capital cost of extending current oxygen pipelines were large, much of the apparent advantage of using oxygen would disappear.

Oxygen treatment by itself would not completely restore Hamilton Harbour. For example, the deposits of coal tar require dredging or sealing. The treatment of sewage is being improved, however, after use of the best available sewage technology, some direct treatment of the harbour may be desirable. Unpolluted basins often develop temporary anoxia and in Hamilton Harbour the mobility of toxic metals can be enhanced by anoxia. Laboratory studies indicated that oxygen can induce precipitation of copper, iron, lead, phosphorus, and zinc. Oxygen greatly increases the clarity of the water by precipitation reactions and by enhancing bacterial metabolism of organic compounds.

Table 12	Estimated C	<u>Cost to O</u>	<u>kygenate a</u>	<u>l of H</u>	amilton	<u>Harbour</u>		
Treatment	No change	<u>es in STP</u>	Nitrifica	ation	Dual Point			
	Capital	O&M	Capital	O&M	Capital	<u>M</u> &O		
Aeration	4-40 m [#]	205 k ^{##}	2.0-20 m	103 k	1-10 m	52 k		
Oxygen								
Injection [*]	170 k ⁰	360 k [#]	85 k	190 k	857 k	100 k		

* Two quotations for 40 tonnes of oxygen per day to be injected using air bubbling (m=million).

Estimate is for 128 days of operation (k=thousand).

² Costs include 15k for concrete pads, 30k for road improvement, 60k for hoses, and 40k for diffusers (k=thousand).

* System would use simple diffusers to inject 40 tonnes per day of oxygen at 80% efficiency for 128 days in midsummer to midfall.

* This price is a simple extrapolation of the small project in Hamilton Harbour in 1986. Costs are usually less in larger scale. Moreover, the operating costs of using a pipeline would be much less, but the capital cost of a pipeline is unavailable. The estimate assumes that destratification would not be broken and that the oxygen consumption would be 1 mg $L^{-1} d^{-1}$. A more modest oxygen requirement of 29 tonnes of oxygen per day could be derived by using estimates of current rates of hypolimnetic oxygen consumption; however, the higher rate of 40 tonnes/d would ensure that the sediments were oxidized. Acknowledgments

Mrs. Jayne Tollefson of the City of Hamilton solved several problems with the location of the oxygen storage tank. Mr. Henk Don, Mr. Gary Bruce, Mr. Ken Hill, and other staff of the Technical Operations Division of the National Water Research Institute, adapted their schedules several times to build the diffusers on a weekend, repair the diffusers, collect extra samples, etc. Mr. Ian Dunlop helped build the diffusers, collected samples, and did some of the drafting. Mrs. Allyn Abbott, Ms. Shelly McLean, and Mrs. Lucy McArdle did the oxygen bubbling experiments and prepared samples for analysis by the Inland Waters Directorate, Water Quality Laboratory. Dr. Peter Hodson of the Department of Fisheries and Oceans allowed the use of his large tank for calibration of diffusers. Mr. Mark Kirby of Linde Gas Division of Union Carbide gave useful advice and equipment for the testing of the oxygen diffusers. Mr. Kirby also contributed to the design of the 1987 diffusers. Mr. Ken Carter, Mr. Mike Fullam, Mr. Hugh McGowan, and Mr. Constantine Karaynnopoulos, of Linde assisted with the development of this project.

References

- Barica, J., H. Kling, and J. Gibson. 1980. Experimental manipulation of algal bloom composition by nitrogen addition. Can. J. Fish. Aquat. Sci. 37:1175-1183.
- Barica, J. and C. Vieira. 1988. Nitrogen, phosphorus and chlorophyll <u>a</u> regime of Hamilton Harbour. NWRI Contribution No. 88-43.

Bauer, J.E. and D.G. Capone. 1985. Degradation and mineralization of the polycyclic aromatic hydrocarbons anthracene and napthalene in intertidal marine sediments. App. Envir. Micro. 50:81-90.

Bennett, G.F. 1980. Oxygen transfer rates, mechanisms, and applications in biological wastewater treatment. CRC Crit. Rev. Environ. Cont.

Berner, R.A. 1971. Principles of Chemical Sedimentology. McGraw-Hill. New York.

Bianucci, G. and E.R. Bianucci. 1979. Oxygenation of a polluted lake in Northern Italy. Effl. Wat. Treat. 19:117-128.

Boller, M. and W. Gujer. 1986. Nitrification in tertiary trickling filters followed by deep-bed filters. Wat. Res. 20:1363-1373.

Bostrom, B. 1984. Potential mobility of phosphorus in different types of lake sediment. Int. Revue ges. Hydrobiol. 69:457-474.

Environment Canada. 1979. Analytical Methods Manual. Inland Waters Directorate. Water Qual: Branch, Ottawa.

Fast, A.W., W.J. Overholtz, and R.A. Tubb. 1975a. Hypolimnetic oxygenation using liquid oxygen. Water Resour. Res. 11:294-299.

Fast, A.W., V.A. Dorr, and R.J. Rosen. 1975b. A submerged hypolimnetic aerator. Water Resour. Res. 11:287-292.

Fast, A.W. and M.W. Lorenzen. 1976. Synoptic survey of

hypolimnetic aeration. J. Envir. Eng. ASCE 102:1161-1173.

Fast, A.W. 1977. Hyperoxygen concentrations in the hypolimnion produced by injection of liquid oxygen. Water Resour. Res. 13:474-476.

Harris, G.P. 1976. The biological survey of Hamilton Harbour 1975. McMaster University, Dept. Biol., Tech. Rep. No. 1. 1976.

Harris, G.P., B.B. Piccinin, and S. Morgan. 1979. Research in Hamilton Harbour 1978-79. McMaster University Dept. Biol. Tech. Rep. Ser. No.4.

Heitkamp, M.A. and C.E. Cerniglia, 1987. Effects of chemical structure and exposure on the microbial degradation of polycyclic aromatic hydrocarbons in freshwater and estuarine ecosystems. Envir. Tox. Chem. 6:535-546.

Holdren, G.C. and D.E. Armstrong. 1980. Factors affecting phosphorus release from intact lake sediment cores. Envir. Sci. Technol. 14:79-87.

Hollerbach. G.H. 1985. Controlling sulfides in sewage by direct injection of oxygen. Public Works, 82-83, March. Hsu, C.L. and J.S. Hsieh. 1986. Advantages of oxygen vs. air in delignifying pulp. Tappi 69:125-128.

Joller, T.A.R., D. Imboden, and H. Ambuhl. 1985. Untersuchung vertikaler mischungsprozesse mit chemisch physikalischen tracern im hypolimnion des eutrophen Baldeggersees. ADAG Administration and Druck AG, Zurich.

Klapwijk, A. and W.J. Snodgrass. 1982. Lake Oxygen Model 3: Simulation of ammonia, nitrate, and oxygen in Hamilton Harbour (1977-1978). In P.G. Sly (ed.), Sediment/Freshwater Interaction. Dr. W. Junk, The Hague.

Lajer, G. 1988. Restoration of Lake Hald: the oxygen project, Hede-Nielsen, Horsens, Report in Danish.

Lorenzen, M. and A.W. Fast. 1977. A guide to aeration/circulation for lake management. EPA 600/3-77-004.

Marki, E. and M. Schmid. 1983. Der zustand des Hallwilersees. Wasser 4:105-112.

Markofsky, M. 1979. On the reoxygenation efficiency of diffused air aeration. Water Res. 13:1339-1346.

McAuley, W.J. 1973. Production and supply logistics of cryogenically produced oxygen. In R.E. Speece and J. F.

Malina (eds.). Applications of Commercial Oxygen to Water and Wastewater Systems. Center for Research in Water Resources, Austin, Texas.

McIssac, G., R. Karin, J.S. Betteridge, R.R. MacDonald, and K.R. Lum. 1981. The chemical form and potential availability of trace metals in the southwestern part of Hamilton Harbour. Experience 1981 paper.

Mudroch, A. and R.G. Sandilands. 1980. Preliminary report on dredging studies carried out during the period of April 1978 to February 1979. NWRI Report.

Ng, P.S. 1981. Model for the Hypolimnetic Oxygen Deficit in Hamilton Harbour. M.Eng. Thesis. McMaster University Dept. of Chem. Eng. 235pp.

- Ontario Ministry of Environment. 1975. Hamilton Harbour Study 1974.
- Ontario Ministry of Environment. 1976. Hamilton Harbour Study 1975. Technical Report.
- Ontario Ministry of Environment. 1977a. Hamilton Harbour Study 1975.
- Ontario Ministry of Environment. 1977b. Hamilton Harbour Study 1976.
- Ontario Ministry of Environment. 1978. Hamilton Harbour Study 1976.
- Ontario Ministry of Environment. 1981. Hamilton Harbour Study 1977.
- Ontario Ministry of Environment. 1985. Hamilton Harbour Technical Summary and General Management Options.
- Onuska, F.I., A. Mudroch, and K.A. Terry. 1983. Identification and determination of trace organic substances in the sediment cores from the western basin of Lake Ontario. J. Great Lakes Res. 9:169-182.

Overholtz, W.J. 1975. An Ecological Evaluation of Hypolimnetic Oxygenation by the Side Stream Pumping Process on Ottoville Quarry, Ottoville, Ohio. M.Sc. Thesis. Ohio State Univ.

Pastorok, R.A., T.C. Ginn, and M.W. Lorenzen. 1980. Review of aeration/circulation for lake management. In Restoration of Lakes and Inland Seas. EPA 440/5-81-010.

Piccinin, B.B. 1977. The Biological Survey of Hamilton Harbour 1976. McMaster University, Dept. Biol., Tech. Rep. No. 2. 1977.

Piccinin, B.B. 1980. The Biological Survey of Hamilton Harbour 1979. McMaster University, Dept. Biol., Tech. Rep. 1980.

Polak, J. and G.D. Haffner. 1978. Oxygen depletion of Hamilton Harbour. Water Res. 12:205-215.

Prepas, E.E., D.J. Webb, and C.L.K. Robinson. 1989 Injection of oxygen into the north basin of Amisk Lake: final report. University of Alberta Report to Alberta Environment.

Racke, K.D. and C.R. Frink. 1989. Fate of organic contaminants during sewage sludge composting. Bull. Environ. Contam. Toxicol. 42:526-533.

Renzo, D.J. 1980. Biodegradation techniques for industrial organic wastes. Noyes Data Corporation. Park Ridge, New Jersey.

Rodgers, G.K., D. Boyd, V. Cairns, H. Lang, T.P. Murphy, S. Painter, L. Simser, and J. Vogt. 1988. Hamilton Harbour Remedial Action Report - Goals, Problems, and Options.

Ruane, R.J. and S. Vigander. 1973. Oxygenation of turbine discharges from Fort Patrick Henry Dam. In R.E. Speece and .J F. Malina (eds.). Applications of Commercial Oxygen to Water and Wastewater Systems. Center for Research in Water Resources, Austin, Texas.

Ryding, S.O. 1985. Chemical and microbiological processes as regulators of the exchange of substances between sediments and water in shallow eutrophic lakes. Int. Revue ges. Hydrobiol. 70:657-702.

Sas, H. 1989. Lake Restoration by Reduction of Phosphorus Loading: Experiences, Expectations and Future Problems, Dr. W. Junk, The Hague.

Schreiner, S.P. 1987. Evaluation of a prediction method for oxygen injection requirements in Russell Lake. Lake Reserv. Manage. 3:76-84.

Snitz, F.L. W.J. Weber, J.L. Barney, and J.C. Posner. 1979. Effects of calcium and sediment concentrations on the release of metals and nutrients from dredge spoil dispersions. In L.L. Marking and R.A. Kimerle (eds.), Aquatic Toxicology. ASTM STP 667.

Snodgrass, W.J. and Klapwijk. 1982. Lake oxygen model 1: Modelling of sediment water transport of ammonia, nitrate, and oxygen. In P.G. Sly (ed.), Sediment/Freshwater Interaction. Dr. W. Junk, The Hague.

Snodgrass, W.J. and P.S. Ng. 1985a. Biochemical models for the hypolimnetic oxygen depletion in lakes impacted by wastewater discharges. 1. Alternative models. Arch. Hydrobiol. 72:81-109.

- Snodgrass, W.J. and P.S. Ng. 1985b. Biochemical models for the hypolimnetic oxygen depletion in lakes impacted by wastewater discharges. 2. Phytoplankton biomass model. Arch. Hydrobiol. 72:220-236.
- Speece, R.E. 1969. Use of pure oxygen in river and impoundment aeration. Proceedings of 24th Purdue Industrial Waste Conference.
- Speece, R.E., F. Rayyan, and G. Murfee. 1973. Alternative considerations in the oxygenation of reservoir discharges and rivers. In R.E. Speece and J. F. Malina (eds.), Applications of commercial oxygen to water and wastewater systems. Center for Research in Water Resources, Austin, Texas.
- Speece, R.E. and J.F. Malina. 1973. Preface. In R.E. Speece and .J
 F. Malina (eds.), Applications of commercial oxygen to
 water and wastewater systems. Center for Research in Water
 Resources, Austin, Texas.
- Spiegel, R.H. and M.N. Charlton. 1989. Some aspects of the physical limnology of Hamilton Harbour. NWRI Cont. No. 89-08.
- Stadelmann, P., T.A.R. Joller, and D. Imboden. 1984. Die auswirkungen von internen Mabnahmen in Baldeggersee: zwangszirkulation und Sauerstoffbegasung des hypolimnions. Verh. Internat. Verein. Limnol. 22:1052-1065.
- Tennessee Valley Authority, 1973. Evaluation of Porex diffuser, Fort Patrick Henry Discharge Oxygenation Advance Report No.7; Report 24-24.
- Toms, R.G. and M.G. Booth, 1981. The use of oxygen in sewage treatment. pages 2-15. Annual Conference of the Institute of Water Pollution Control, 53 London Road, Maidstone, Kent, ME16 8JH, England.
- Williams, J. D. H. and A. E. Pashley. 1978. Lightweight corer designed for sampling very soft sediments. J. Fish. Res. Board Can. 36:241-46.
- Wood, L.B., P.F. Borrows, and M.R. Whitehead. 1980. Scheme for remedying the effects of storm sewage overflows to the tidal river Thames. Report of Thames River Authority, New River Head, London, EC1R 4TP, England.

List of Figures

- 1. Map of Hamilton Harbour. Sample collection sites (\bullet). Oxygen injection site (γ).
- 2. Diffuser grids used in 1987.
- 3. Diffuser banks used in 1987.
- 4. Further detail of 1987 diffuser bank.
- 5. Detail of 1987 header.
- Oxygen dissolution in a 4 m tank a typical calibration plot.
- 7. Effect of injection depth on efficiency of oxygen dissolution
- Oxygen and temperature of a stratified water column at injection site September 22, 1987.





PARTS LIST

ITEM	QUANTITY	DESCRIPTION								
1	138'	Pipe 3" d SCH 40, PVC								
2	2	Cross 3" d PVC								
3	6	Tee 3" d PVC								
4	4	Elbow 90° 3" d PVC								
5	2001	Support Wire								

DIFFUSER GRIDS USED IN 1987.



ITEM	QUANTITY	DESCRIPTION
1	96'	Pipe 3" d SCH 40, PVC
2	1	Cross 3" d PVC
3	4	Tee 3" d PVC
4	4	Elbow 90° 3" d PVC
5	120'	Support Wire



ITEM	QUANTITY	DESCRIPTION								
1	54 '	Pipe 3" d SCH 40, PVC								
3	2	Tee 3" d PVC								
4	4	Elbow 90° 3" d PVC								
5	40'	Support Wire								



ITEM	QUANTITY	DESCRIPTION								
1	1	Frame (See Figure 2)								
2	6	Connector (See Figure 4)								
3	10	Header (See Figure 5)								
4	1000'	O ₂ Hose, 3/4", 7-Ply								
5	As Req'd	Cable Ties								



FURTHER DETAIL OF 1987 DIFFUSER BANK



ITEM	QUANTITY	DESCRIPTION
1	As Req'd	Oxygen Hose 3/4", 7-Plv
2	9	Clamps, For O. Hose
3	9	Hose Fittings, 3/4"
4	9	Adaptor, Hose Fitting to 3/4" NPT Male, C.S.
5	3	Tee 3/4" NPT x 3/4" NPT Female. C.S.
6	9	Nipple, 3/4" NPT x 3" Long - Steel
7	9	Orifice Union, 3/4" C.S., C/W Orifice Model
8	3	Tee 3/4" NPT, Male, C.S.
10	3	Elbow 3/4" NPT Male, C.S. (90°)
11	3	Elbow 3/4" NPT Female, C.S. (90°)



ITEM	QUANTITY (per header)	QUANTITY (per raft)	DESCRIPTION
1	18	180	End-cap for Micro-Por 9/16" tube
2	18	180	Tube, Micro-Por 9/16" Sintered Plastic
3	18	180	Adaptor, 1/2" NPT to 9/16"
4	8	80	Cross, 3/4" Socket x 1/2" NPT Female PVC
5	8	80	Nipple 3/4" PVC
6	1	10	Tee, 1/2" NPT x 3/4" Socket Female



55

Figure 6



Figure 7

Environment Cenada Library, Burlington 3 9055 1017 0731 2

Æ,			installer Aller			X			19		<u>_</u>	e ne 👰	北北	(i) Ka	<u>^</u>	r 👘		A
	K 🥀	P	N/ 0. F	ATIC 30X	DNA 50	LV 50	VATI Buf	ER RLIN	RES	SEA ON	RC	H IN NTA	ist Ric	1TU) L7	TE R 4	A6		
ð.	Maria	Ì			edigi	Å	-Afe				- 6						÷.	
			τĘ.	n digar	$\neg z$	۶Ē	Ē	nviro	nme	nt	Envi	ronne	eme	ntés	s. Heigh			
	ing singer Program	÷.	: Alfred	n Siliyi			ş	anac				aua		-				÷
din	1. A		4		- Maria			di k	ŃŻ			<u>A</u> NK	a fili	i di ja			No.	
	s is the	rije	Â.			1	\bigcap	<u>س</u> 1	n n	\dot{n}_{l}	J.	ბ ე უ		Mer	Á.			
		Ð.			nije.		Ý	٩IJ	I II(alu	مال	1	Å.			nin - Narati		Maria
	÷.	April	c inffe		÷.							s: Alter					A. S.	
		NS	IΠ		VAT	ION			RE				SU ON	RL 7R	ES 4A	EAL 6	JХ.	藏
Vé.	AN A	્યુક				Maria		a desire	- Alama	Ala	i Stan	e u u			Å.	- Caracia	and and a second se	3

Think Recycling! Pensez à Recycling!