OIL SANDS CLAY FINES

Can they be reclaimed as productive, self-sustaining wetlands?

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ABSTRACT

The Clark hot water process currently used for extracting bitumen from the Athabasca oil sands results in large volumes of clay fines containing small amounts of residual bitumen. One possible way of dealing with these fines is to deposit them in abandoned mine pits and cover them with a layer of natural water. Current field trials in a series of 2,000 m^3 pits indicate that a diverse and productive aquatic community can be maintained in the water above these fines. This is due to the properties of the fines and the various processes operating at the fines-water interface. Such water-covered fines would provide suitable habitat for waterfowl.

INTRODUCTION

Syncrude and Suncor, the world's only two commercial oil sands plants, use the Clark caustic-hot water process to extract bitumen from the Athabasca oil sands deposits near Fort McMurray, Alberta, Canada. Processing of a tonne of oil sand results in approximately 0.15 m^3 of mature fines consisting of 30% clay (mainly kaolinite and illite) and a small amount (<1%) of residual bitumen. Currently the two oil sands plants are storing some 200 million m^3 of fines in various tailings ponds and the volume is increasing at about 30 million m^3 per year.

Numerous studies are under way to develop reclamation strategies for these fines. Many of the studies deal with methods for dewatering the fines (i.e. freeze-thaw, evaporation, evapotranspiration, flocculation with chemicals), or else mixing the fines with sand or overburden so as to allow them to be reclaimed as a dry landscape. Another reclamation option, under investigation by Syncrude since 1986 is to deposit the fines in abandoned mine pits and cover them with a layer of natural water.

Because of the rheological properties of these fines and the large density differences between the two layers, the amount of resuspension of the fines into the overlying water column is not considered sufficient to be detrimental to the maintenance of a stable, productive ecosystem in such fines-bottom lakes. Capping fines with water is analogous to land reclamation where barren overburden or tailings sand is capped with a sufficient layer of productive soils to establish a self-sustaining terrestrial community.

Though much work remains to be done, research to date continues to support the concept of capping fines with a water layer. In its 1988 Development and Reclamation Plan, Syncrude proposed to pump mature fines from the tailings pond into the mined-out pit. Pumping is expected to continue for approximately 20 years. As part of the final reclaimed mine area there will be two fines-bottom lakes having surface dimensions of 3 km x 3 km and containing 60 m of fines capped by 5 m of water (Figure 1). The capping water would be taken from the Beaver Creek Reservoir and is expected to evolve into an aquatic system with a biological productivity and diversity (including fish, waterfowl and furbearers) similar to other natural waterbodies in the region.

This paper reviews the results of the various studies carried out so far and discusses a potential end use for such fines-bottomed lakes.

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Wind Generated Mixing

Resuspension of fines by wind-generated turbulence was examined in a number of flume tests. These have shown that the threshold bed velocity (U_t) for resuspension of fines is 0.04 m/s. Orbital velocities produced by waves were found to be much more effective in disturbing the fines than linear velocities resulting from currents. At constant orbital velocities of 0.06 m/s the fines were being suspended at a rate of 1 kg/hr/m^2, resulting in concentrations of solids of 50 - 100 mg/l within a meter of the fines-water interface.

For a fetch (F) of 4 km and a surface wind speed (U) of 15 m/s, the threshold velocity of 0.04 m/s would occur at a depth of 4.75 m (Figure 2). If fetch and surface velocity are kept constant, then small changes in depth of the capping layer result in significant changes in bed velocity. As shown in Figure 3, increasing the depth from 4 to 5 m results in a 50% reduction in the bed velocity (6 cm/s to 3 cm/s).

Figure 4 shows the relationship between surface wind speed and the depth of water required to obtain the threshold bed velocity of 0.04 m/s. This figure also shows the frequency of storm events with various wind speeds. For a capping layer of 5 m, a storm with sufficient strength to stir up the fines would occur only once every 20 years. If the depth of the capping layer is increased to 5.5 m, it would require a 100-year storm event to disturb the fines.

Release of Interstitial water during sludge consolidation

The fines that will be transferred from the tailings pond into the mined-out pit will have a solids content of 25 - 30% (w/w) and contain less than 100 mg/l bitumen. Additional release of water from the sludge will be very slow and will have a composition similar to that shown in Table 1 (Sludge T_o).

The potential impact of fines interstitial water on the capping layer was investigated using a "worst case" test. Fines with a 30% solids content were placed in a series of plexiglass columns (0.3 m x 0.3 m x 2.5 m) and capped with clean water. The ratio of water to fines was 2:3. In order to increase the rate of fines consolidation and release of interstitial water, a small amount of vibration was applied to each column with an aquarium air pump which was also used to aerate the surface water. The quality of the overlying water was then monitored for 12 months.

As shown in Table 1, the interstitial water released from the fines comprised 29% of the capping water after 12 months. Release of sodium, chloride, sulphate and bicarbonate from the fines led to a 2.4 fold increase in conductivity and a 1.6 fold increase in dissolved solids of the capping water. Dissolved organic carbon did not change but chemical oxygen demand increased 2 - 7 fold. There were also some increase in minor elements (i.e. arsenic, boron), however, the absolute concentration of these is low even in the fines.

Of greatest significance, however, is the fact that the capping water remained non-toxic even though the fines were toxic. Toxicity was measured with the Beckman Microtox Toxicity Meter. In this procedure bioluminescent bacteria are exposed to various concentrations of the test solution for 15 minutes. The presence of toxins results in a reduction in the light output of the bacteria relative to a control culture. Toxicity is expressed in terms of the concentration of the test solution which reduces light output to 50% (EC_{50}) or to 20% (EC_{20}). Fines interstitial water has EC_{50} and EC_{20} values of 30% and 10%, respectively. However, the overlying water had no effect on the light output of the bacteria (EC_{50} and EC_{20} are both 100%).

Construction of Experimental Pits

In light of the positive results from the column study, a decision was made to investigate the concept of fines-bottom lakes in a number of large experimental pits. In June, 1989, seven pits were constructed, each having surface dimensions of 50 m x 10 m and containing 2,000 m^3 of water, water and fines, or only fines (Figures 5 and 6). Pit 1 contains only natural water and serves as a control. Pits 2, 3, 4, and 6 each contain 1,000 m^3 of fines (depth 4 m) and 1,000 m^3 of natural water (depth 3 m).

Table 1: Composition of fines and water used to cap the fines. Changes with time are shown in the composition of the capping water maintained under aerobic conditions by aeration ovr a 12-month period.

	FINES	MILDRED LAKE WATER (CAPPING)*			
VARIABLE	T_0	T_0	$T_{1\ month}$	$T_{6\ months}$	$T_{12\ months}$
pH	8.3	7.9	8.4	8.4	8.5
Conductivity (uS/cm^{-1})	1500	285	340	575	685
Dissolved Oxygen (mg.ℓ^{-1})	<.2	9	8	6	5
Dissolved Solids (mg.ℓ^{-1})	1400	250	250	370	405
Suspended Solids (mg.ℓ^{-1})	30000	29	10	<10	10
Dissolved Organic Carbon (mg C.$^{-1}$)	64	25	16	26	16
Phenols (mg.ℓ^{-1})	0.065	0.003	0.006	0.004	0.003
Cyanide (mg.ℓ^{-1})	0.006	0.001	0.001	0.001	0.001
Chemical Demand Oxygen (mg.ℓ^{-1})	>200	20	48	58	55
Release Water from Sludge** (% of Cap Zone)	-	-	1	20	29
MAJOR IONS					
Cations					
Sodium	450	15	40	106	129
Potassium	11	1.3	2.2	3.4	5.0
Magnesium	4.0	10	9.6	8.8	9.2
Calcium	4.0	38	34	20	16
Anions					
Chloride	130	7.8	13.2	33.6	41.5
Sulphate	4	23	22	22	21
Bicarbonate	940	160	198	280	270
Hardness (mg of $CaCO_3$)	27	135	125	87	78
Ratio Na/Cℓ (meq/meq)	5.3	3.0	4.7	4.9	4.8
Nutrients					
$NO_2^- + NO_3^-$	0.04	0.03	0.02	<0.01	0.31
Ammonia	3.8	0.01	0.20	<.01	0.02
O-PO_4	0.14	0.03	0.02	0.02	0.02
Acute Toxicity					
Microtox					
EC_{50}	30	100	100	100	100
EC_{50}	10	100	100	100	100
Minor Elements (mg.ℓ^{-1})					
As	0.0079	0.0010	0.0018	0.0020	0.0010
B	2.45	0.06	0.16	0.43	-
Cd	<.001	<.001	<.001	0.002	-
Cr	0.016	0.003	0.012	0.007	-
Co	<.001	<.001	0.013	<0.001	-
Cu	0.013	0.012	0.003	0.003	-
Pb	<.002	<.002	0.015	0.015	-
Mo	0.058	<.001	0.017	0.009	-
Ni	0.013	<.001	0.048	<0.001	-
Sr	0.21	0.23	0.24	0.24	-
V	0.023	0.006	0.002	0.001	-

*Ratio of capping layer to fines layer = 2:3.
Capping layer = Mildred Lake Water collected September, 1987.

**Volume of release water from fines as a percent of original volume of capping layer.

Pits 2 and 3 were kept as replicates. Approximately 2 cubic mater of aquatic plants, invertebrates and fish were collected from surrounding water bodies with a seine net and introduced to Pit 4. As well, cattails and other emergent vegetation were dug up from a nearby marsh and replanted in the shallow end of Pit 4. Upon completion, a 1-m broad band of vegetation extended along the entire shallow end of the pit. The objective of these additions was to provide a variety of plants, invertebrates and fish which could be monitored over the ensuing months.

Nutrients were added to Pit 6 in order to boost the overall productivity of the water. This in turn should increase the rate of detritus accumulation at the fines-water interface and accelerate the burial of the fines under a layer of natural sediment. Addition of 500 gm of ammonium phosphate dibasic $(NH_4)_2\ HPO_4$ in August and October, 1989 and in May, June, July, and August, 1990 resulted in a 35-fold increase in chlorophyll and primary productivity as determined by the carbon-14 dark and light bottle technique (Table 2).

Table 2: Chlorophyll a (ug/l) and net primary productivity (mg Carbon/m^2/day) for the fines capping experimental pits July 24, 1990. Primary productivity based on a day length of 15 hours and a euphotic zone of 1.75 m (1% of incipient light).

PIT	CHLOROPHYLL a	NET PRIMARY PRODUCTIVITY
1	1	23 ± 0
3	1	20 ± 0
4	3	47 ± 2
5	3	77 ± 1
6	35	845 ± 149

In Pit 5 the 1,000 m^3 of fines were covered with 1,000 m^3 of water from the tailings pond. Although toxic initially (96-hr trout LC_{50} less than 10%), this water will detoxify within 1 - 2 years to a condition suitable for fish growth (Boerger *et al.* 1986, 1987; MacKinnon and Boerger 1987). Since this water is chemically very similar to fines interstitial water, the development of a diverse and productive community in Pit 5 would clearly demonstrate that release of such water from full-sized (3 km x 3 km x 60 m) fines-bottom pits will have no impact on the overlying layer of natural water.

Pit 7 was filled with 2,000 m^3 of fines. The objective here is to further investigate the rate of release of interstitial water from the fines. The larger volume of fines in this pit compared to Pits 2 - 6 will also allow us to assess if any of the fines processes observed in the other pits are dependent on the volume or depth of the fines. This may have some bearing when the results from the pits are extrapolated to full-sized fines-bottom lakes.

<u>Toxicological Analyses</u>

At no time during the last 12 months did the water in Pits 2, 3, 4, and 6 show any signs of acute toxicity based on the Beckman Microtox Test and the standard 96-hour trout test. Lack of acute toxicity does of course not mean that there are no sublethal or chronic effects. To test this possibility, the waters were tested with three different chronic tests in September, 1989 and January, 1990.

In the *Daphnia* life cycle test, these small crustaceans were kept in water from the various pits and their survival and reproduction monitored for seven days. In all eight tests survival was 100% and the number of young produced was not significantly different from that of control animals.

In a second type of chronic test, algae were grown in the water from Pits 2, 3, 4, and 6. In the September tests growth in water from three of the fines-bottom pits was less than in water from the control pit. However, in the January tests, growth in water from the fines-bottom pits was 10 times better than in the water from the control pit.

In a final chronic test, trout eggs were kept in water from the various pits and their development followed for 19 days. Both the hatching of the eggs and the growth of the young alevins are very sensitive to the presence of pollutants. But, as with the other two tests, the water from the fines-bottom pits showed no indication of any chronic toxicity.

Biotic Development of the Pits

Both the fines and the overlying water contain abundant bacteria (10^3 - 10^5 cells/ml, mostly *Bacillus* and *Pseudomonas* sp.), with some indication of higher numbers at the fines-water interface. Based on uptake studies with C-14 labelled glutamate, the bacteria are also metabolically very active. Previous studies (Foght *et al.* 1985) showed that the bacteria associated with tailings are actively decomposing hydrocarbons.

Carbon-14 dark and light bottle measurements made in July, 1990, have shown that Pit 3, which contains fines capped with natural water, to be as productive as Pit 1, the control (Table 2). Addition of biota to Pit 4 has doubled its productivity, while addition of nutrients to Pit 6 has increased productivity 40-fold. Of particular interest, is that Pit 5, which is capped with tailings pond water, has a productivity 4 times higher than Pit 3 which is capped with natural water.

The abundance of algae floating in the water (phytoplankton) has increased steadily in the fines-bottom pits from the time that they were filled (Table 3). However, they did not exhibit a spring bloom as occurred in the control pit. Aquatic macrophytes (*Sparganum, Typha*) are growing in the shallow areas of all fines-bottom pits.

The pits are presently inhabited by a large number of aquatic invertebrates, especially insects. Emergence of the adults is being measured with box-like emergence traps floating on the water surface. As is true for the hatching of fish eggs, emergence of the aerial adult from the aquatic pupal or nymphal stage is very sensitive to the presence of any pollutants. Nevertheless, emergence of insects from the fine-bottom pits is so far not significantly different from that in the control pit.

Table 3: Abundance (cells x $10^3/\ell$) of phytoplankton in experimental pits with and without clay fines.

DATE	NO FINES	FINES
August 17, 1989	177	23
October 15, 1989	116	108
June 4, 1990	180,216	1,154
June 23, 1990	511,595	12,125
July 9, 1990	26,313	12,983

All the fines-bottom pits are inhabited by fish, primarily sticklebacks, fathead minnows and lake chub. These were quite likely introduced during the pumping of the natural water into the pits. An initial survey completed in mid-August, 1990 showed that the size of the fish is not significantly different from that in the control pit and in other surrounding waterbodies, and that reproduction is occurring in all fines-bottom pits. Mr. Allen Verbeek, Department of Zoology, University of Alberta, is currently examining the survival, growth, reproduction and behaviour of these fish as part of a Master's Thesis.

Future Developments

The above results indicate that a diverse and viable aquatic community of plants, invertebrates, and fish will develop in fines-bottom pits. At the current rate of development, it is expected the biota in the pits will be similar to that in surrounding waterbodies within five years. Furthermore, with each passing year the fines will be covered by a thicker and thicker layer of natural sediment resulting from the death of plants and animals and the influx of sand, silt, and clay.

As a final test, it is planned to introduce pike, walleye, and perch as well as waterfowl into the fines-bottom pits. After a period of time the meat of the fish and waterfowl will be tested for tainting. If tainting is shown to be absent, fines-bottomed lakes could be considered suitable for development as waterfowl nesting and staging areas. Development of waterfowl habitat is currently being actively pursued by government agencies in both Canada and United States under the auspices of the North American Waterfowl Management Plan.

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Figure 1: Proposed configuration of fines-bottom lakes as described in Syncrude's 1988 Development and Reclamation Plan.

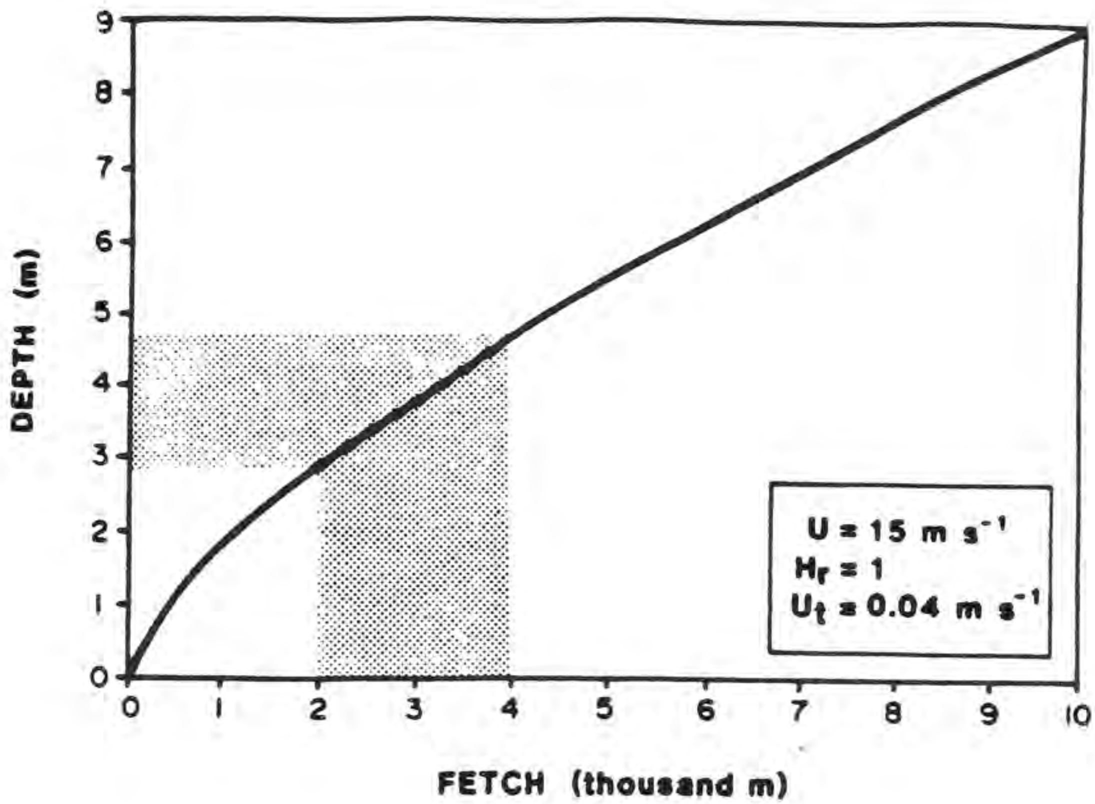

Figure 2: Relationship between fetch and the depth of water at which the wave-induced velocity at the fines interface exceeds the threshold bed velocity (U_t) of 0.04 m/s. Model assumes a surface wind speed (U) of 15 m/s lasting for 4 hours and a wave height ratio (H_r) of 1.

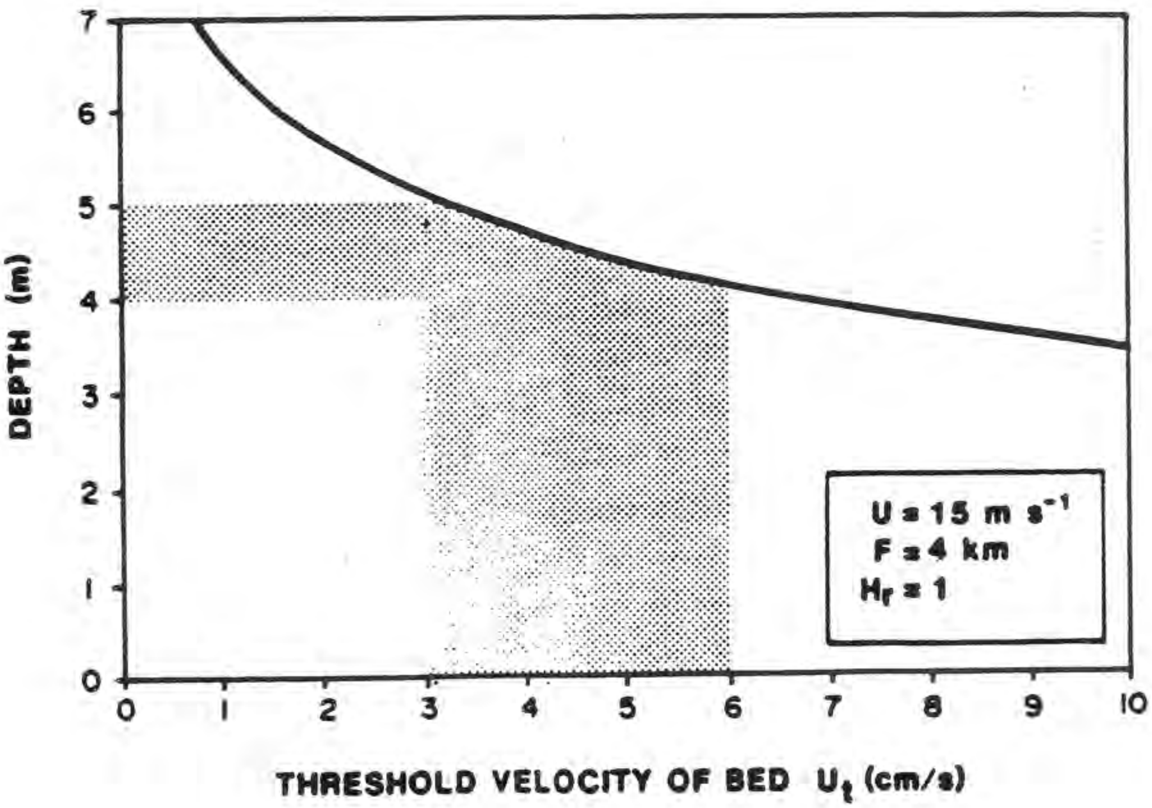

Figure 3: Relationship between threshold bed velocity (U_t) and depth of water for an average surface wind velocity (U = 15 m/s) for a storm of 4 hours duration over a fetch (F) of 4 km. The wave ratio (H_r) of 1 is the ratio of the design wave height to the significant wave height (average wave height if largest one third of waves).

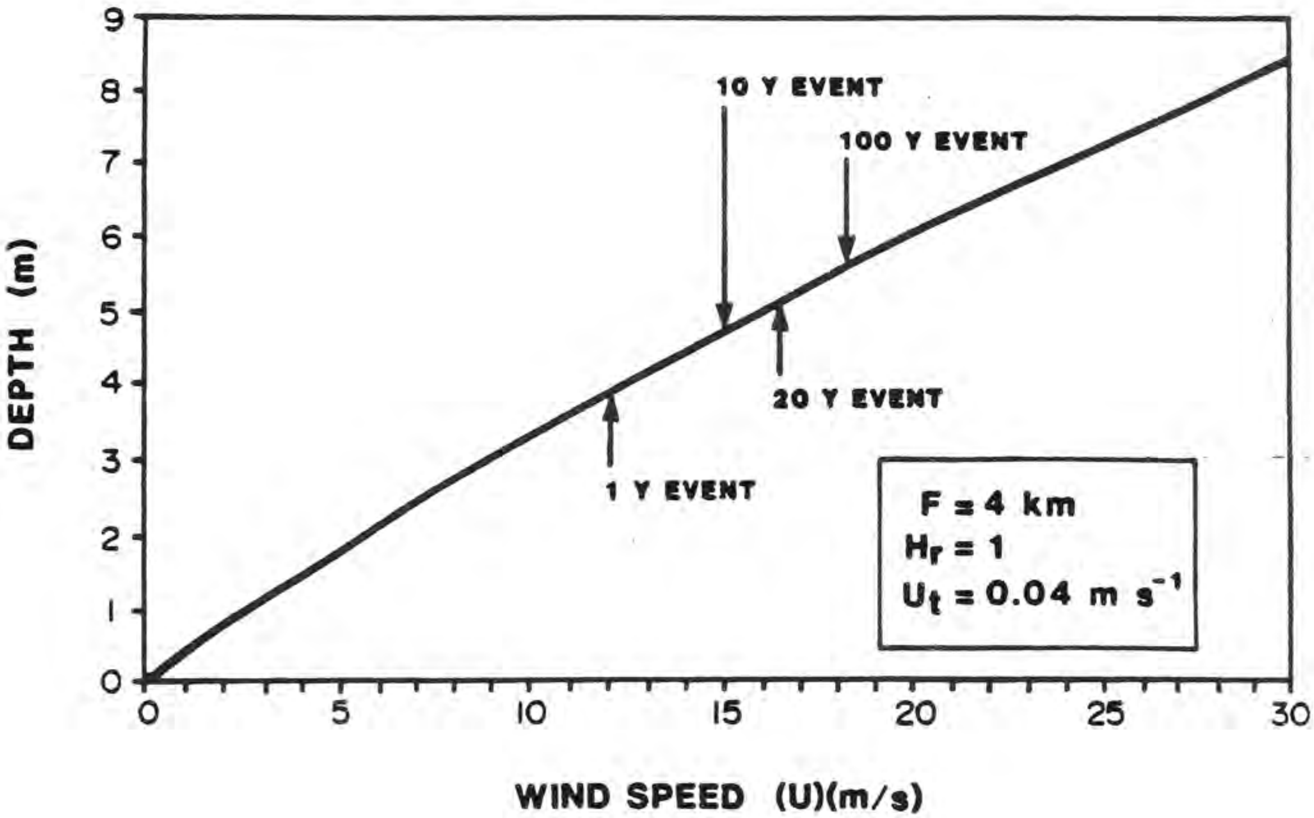

Figure 4: Relationship between surface wind speed (U) and water depth (m) of capping layer required to prevent the bed velocity at the fines interface from exceeding the threshold bed velocity (U_t) of 0.04 $m.s^{-1}$. Model assumes fetch (F) = 4 km, a wave height ratio (H_r) of 1 and storm duration of 4 hours. Shown on the plot are the positions of the 1 in 1, 10, 20, and 100-year storm events.

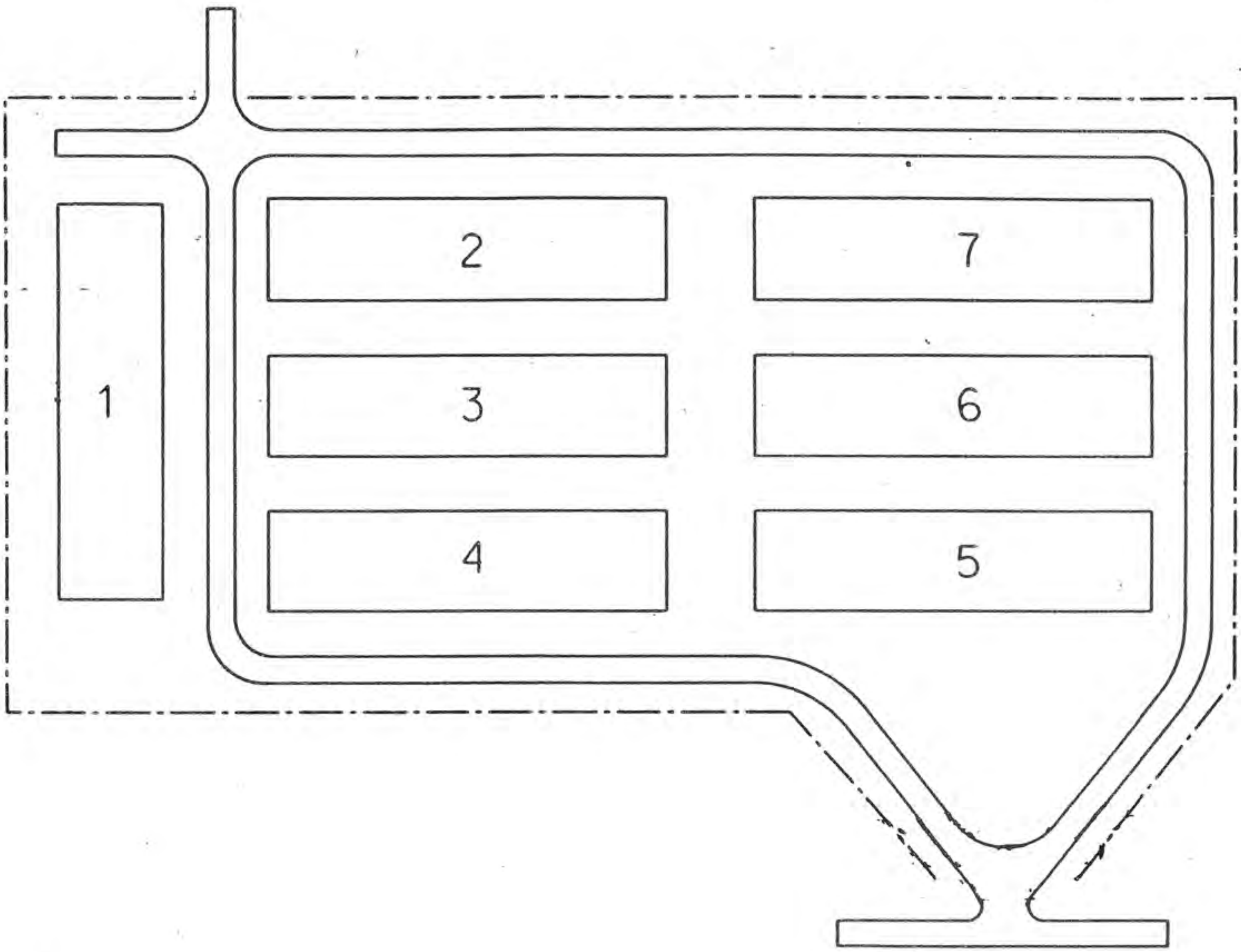

Figure 5: Layout of the fines capping demonstration area. Pit 1 = only natural water (control), Pit 2, 3, 4, and 6 = fines capped with natural water, Pit 5 = fines capped with tailings pond water, and Pit 7 = only fines.

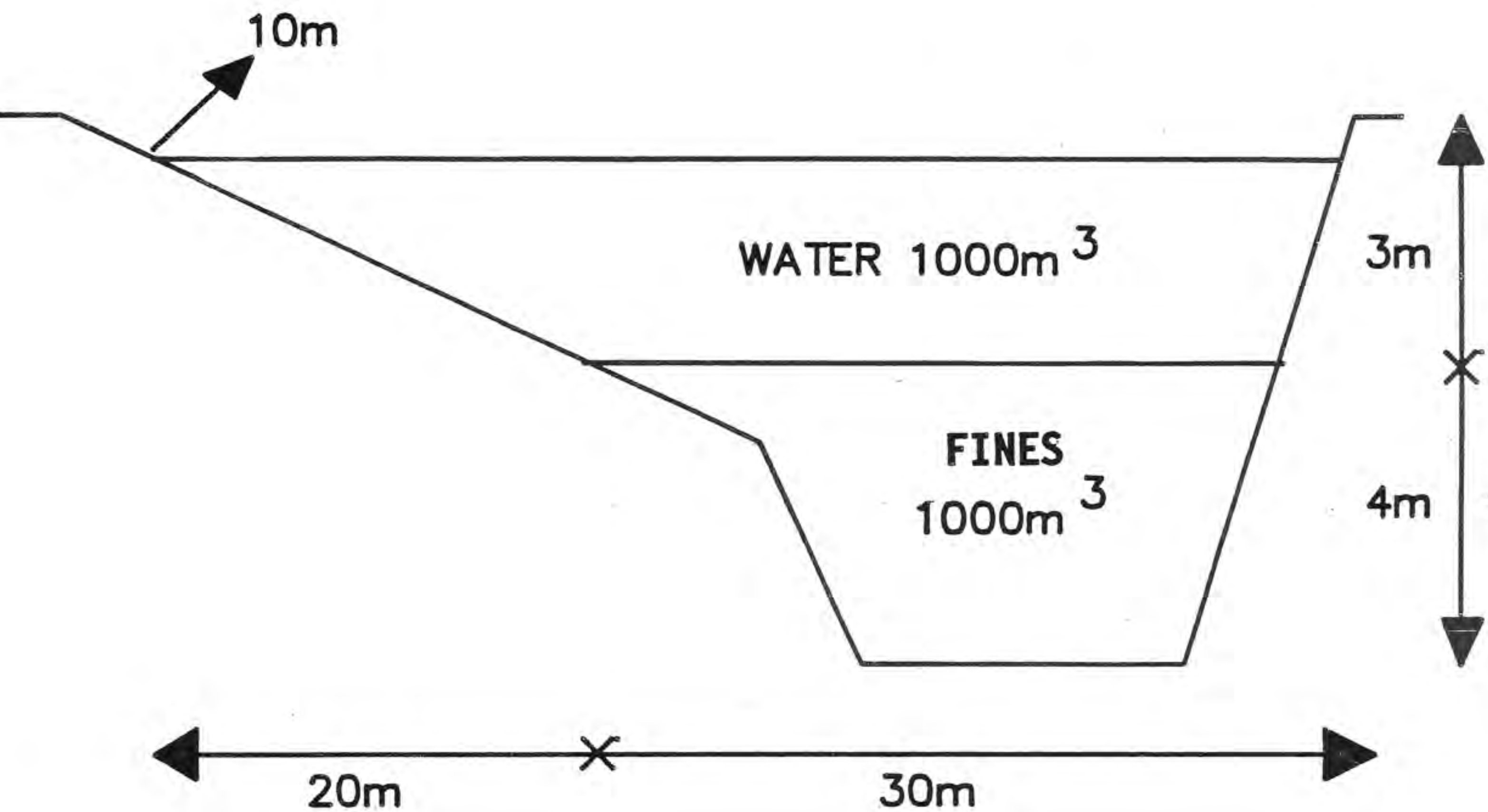

Figure 6: Depth profile of Pits 2 - 6. Pits 1 and 7 have same bottom contours but contain only water (Pit 1) or only clay fines (Pit 7).

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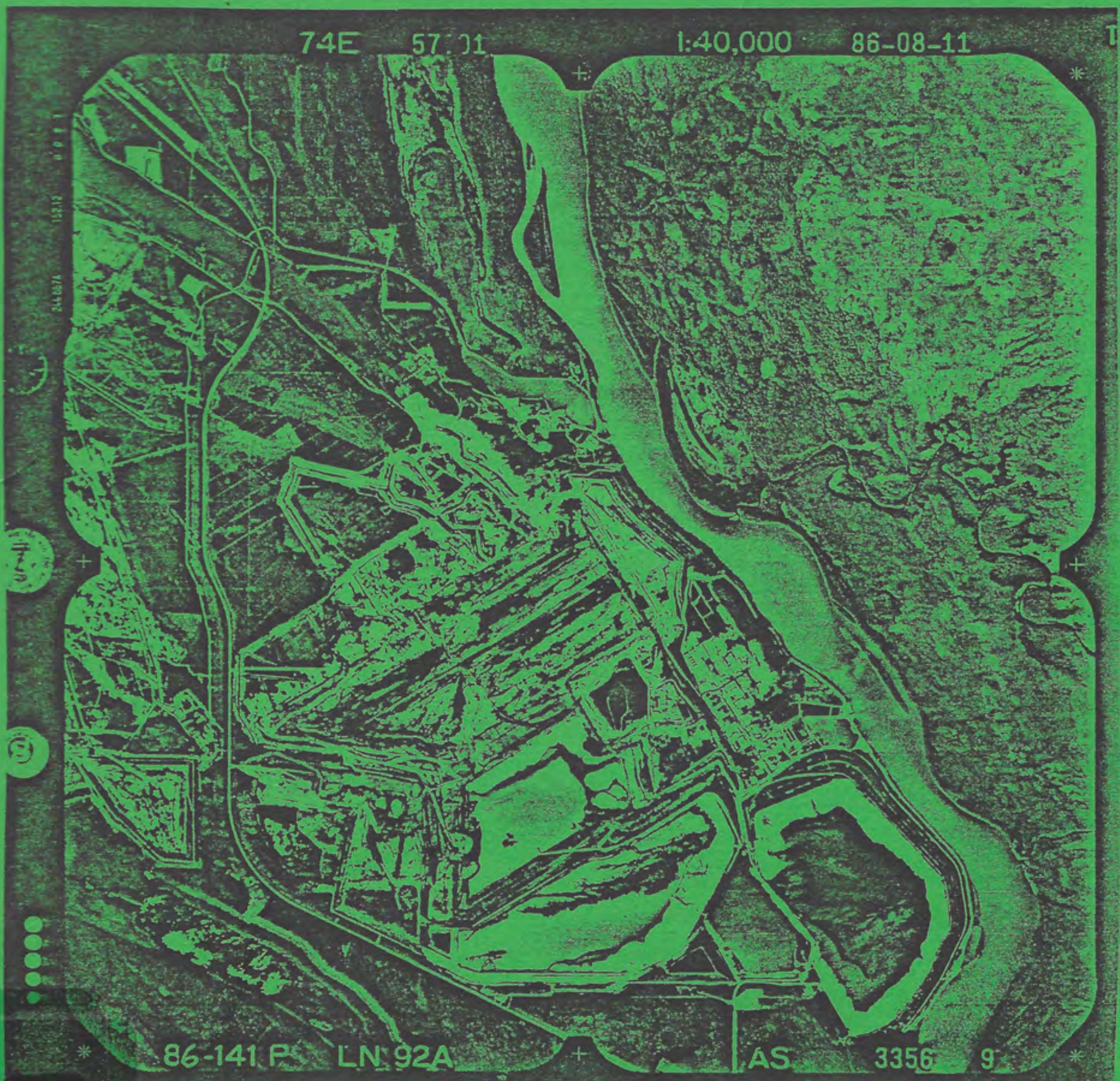

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Front Cover: 1986 airphoto of the Suncor facility, north of Fort McMurray, Alberta.

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DEDICATION

These proceedings are dedicated to the memory of Bruce Runge and Michael Mensforth. These two reclamationists passed away in the fall of 1990 while on the job.

Bruce Runge worked for Western Oilfield Environmental Services Ltd. as Operations Manager and was on his way to conduct a pipeline inspection in the Primrose Lake area when the helicopter he was in crashed on the outskirts of Edmonton. Bruce was 45 years old.

Michael Mensforth worked as a reclamation technologist for Alberta Environment, Land Reclamation Division and was on his way to a site in northern Alberta when he was killed in a freak vehicle accident. Micheal was 35 years old.

The loss of these two specialists is a blow to the small reclamation community of our province. It also points out to the rest of us that ours can be a dangerous profession and that safety is critical in our business.

SPONSORS

The Alberta Chapter of the Canadian Land Reclamation Association would like to thank the following sponsors for making the conference and tour a success:

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