DESIGN PARAMETERS FOR THE BIOLOGICAL SYSTEM COMPONENT OF MINA ESPERANCA SEEPAGE TREATMENT SYSTEM

MINERACAO MORRO VELHO (MMV)

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THE BIOLOGICAL SYSTEM COMPONENT OF
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SUMMARY

The Biological System, shown in Schematics 1 and 2, would provide a total retention time for Mina Esperanca Portal seepage water (flow, 0.74 $L.s^{-1}$) of 125 days, during which water would reside in the ARUM cells for 90 days. **The actual required retention time for treatment of Mina Esperanca Portal seepage water is not known at this time; it may well be less than 125 days, and a smaller system may be adequate. Biological treatability experiments are required to ascertain required retention times.**

The biological treatability experiments must be conducted using low cost or waste organic ARUM Starter materials, rich in organic carbon and nitrogen. Local sources of these materials must be identified, adequate supply guaranteed, and representative samples received before the biological treatability experiments can be performed and interpreted.

The conceptual system would operated as ten (10) sub-systems operating in parallel, fed by a header pond receiving water from the oxidation-settling pond system upstream, and treated water collected by a collector pond.

Good water level control in the ARUM ponds is required for the development and maintenance of a healthy floating Taboa population. This requires the following:

a) Construction of cell floor and walls with low permeability material (clay).

b) Installation of water level control weirs.

c) Source of clean spring water which can be diverted to system in periods of extreme evaporation conditions (existing groundwater-fed stream would be appropriate).

1.0 INTRODUCTION

The Mina Esperanca Portal Seepage is a low flow (0.74 $L.s^{-1}$), but acidic (pH 3.5, oxidizing and acidifying to pH 1.9; acidity 200 to 300 $mg.L^{-1}$), source of somewhat contaminated mine water (moderate dissolved iron and aluminum concentrations; relatively low dissolved manganese, nickel and zinc concentrations).

This mine water presently pools over a small area outside the mine portal where dissolved ferrous iron oxidizes and generated ferric hydroxide precipitates, creating poor aesthetics for the site. Typically, oxidized seepage infiltrates the bottom of the ponded area and re-emerges as a clear seepage (about 2 $mg.L^{-1}$ Fe) some 50 m downstream, joining clean groundwater discharge to form a small stream draining downhill to the Rio das Velhas (see Table 4: Boojum Progress Report: Site Visit, November 18-26, 1997. December 8, 1997).

Water quality data from limited water sampling of this stream (e.g. November 20, 1997), collected just prior to stream crossing the paved highway, indicate that this stream water has a neutral pH and very low dissolved metals concentrations. At the time of sampling, there was little evidence of impact by Mina Esperanca Portal seepage on this stream. In terms of metals loading, the Mina Esperanca Portal seepage is the smallest contributor, compared to Mina Faria and Mina Morro Gloria.

Treatment of the Mina Esperanca Portal seepage has become one major focus of the regulatory agencies, presumably because of the unsightly nature of the Mina Esperanca Portal area and the low pH/measurable dissolved metals concentrations of the mine water, and this focus is not based on the estimated impact on the Rio das Velhas, compared to other mine portal discharges in the area. In response to this demand, MMV has directed Boojum Research Limited to examine the feasibility of designing a treatment system for Mina Esperanca Mine Portal seepage using passive chemical, physical and biological process technology developed by Boojum since 1983 for decommissioning mine operations.

2.0 MAJOR CONSIDERATIONS

2.1 Application of ARUM Process

A microbiologically-based system with the capacity to generate alkalinity will be required for the removal of dissolved metals present in the low pH Esperanca Portal seepage. The Acid Reduction Using Microbiology (**ARUM**) treatment approach, a bacteria-based, anaerobic system developed by Boojum, is suggested (see Schematic 3 for conceptual lay-out of ARUM originally designed for the Makela system, Inco, Sudbury, Ontario, Canada).

2.2 Other Biological Approaches

The aerobic, algae-based **Biological Polishing** system in Buchans, Newfoundland, Canada (examined by V. Ciminelli and W. Chaves) is not considered a suitable approach to Esperanca. This Biological Polishing approach is likely suitable for Mina Faria and Mina Morro Gloria, which generate relatively large flows of more neutral mine effluent water quality.

2.3 Applicability to Other Sites

Since the water chemistry of Mina Esperanca is appreciably different from other mine portal discharges, a single treatment approach and design is not available for all portal discharges considered environmentally significant. The biological system outlined in this document is specific to Mina Esperanca.

2.4 ARUM Process Retention Time

The required retention time in anaerobic treatment cells for removal of metals from the low pH, moderate acidity Esperanca water can only be approximated at this time, since specific biological treatability experiments have not yet been performed on Mina Esperanca seepage. However, for the purposes of this presentation, a retention time of 90 days for water passing through the anaerobic cells alone (not the whole system) will be used as the primary design criterion.

2.5 Maintenance of Anaerobic Conditions

Anaerobic conditions can be maintained in an ARUM treatment cell if:

a) Organic carbon is supplied feeding oxygen-consuming bacteria.

b) A cover is constructed over the cell, preventing wind-generated entrainment of new dissolved oxygen into the pond.

Techniques whereby a floating Cattail (Taboa, *Typha*) population can be established over the ARUM cell have been established (see Plates 1 and 2). This living vegetation cover both prevents wind-driven circulation of the water body and supplies new organic carbon to the oxygen consuming and anaerobic bacteria in the long term.

2.6 Requirement for Biological Treatability Experiments

Biological treatability experiments must be conducted in order to better define the required retention time of water in the biological system. This will require, first, the locating of low cost or waste (free + trucking cost) organic ARUM Starter materials, rich in organic carbon and nitrogen. Local sources of these materials must be identified, adequate supply guaranteed, and representative samples received before the biological treatability experiments can be performed and interpreted.

3.0 DESIGN FEATURES

3.1 Floating Taboa Population Installation

Floating structures constructed from wood/plastic and styrofoam have been tested at several sites in Canada. These structures freely float, supporting the developing Taboa population until it matures and floats on its own. However, for the Esperanca Biological Treatment System, it is suggested, for greater simplicity, that a fixed wooden floor is constructed just below the surface of the ARUM cells for support of the Taboa population. By maintaining constant water levels in the ARUM cell, the Taboa population, when mature (< 5 years) will be fully buoyant, and the wooden structure can decay without concern for system integrity (slow decomposition rates for wood are expected in the anaerobic cells).

3.2 Cell System Layout and Dimensions

If a fixed wooden base for the Taboa population is employed, ARUM cell width will be limited by the length of the main wooden support material readily available. It is assumed that wooden poles (telephone poles?), 8 m long and ~0.3 m in diameter, are available. A wooden lattice (0.05 m wide x 0.01 m thick wood, 0.05 m holes) and a burlap cover would be built over the main support poles. Organic substrate (0.15 m thick) would be placed over the wooden structure to support rooting and development of the Taboa population.

3.3 Parallel Flow System

Using this approach, several long, narrow systems operating in parallel would have to be constructed in order to achieve required retention time and to use the simpler construction method for installing the floating Taboa cover.

3.4 Permeable Berm Design

Permeable Berms (Schematics 1 and 2; B, E, H and J), composed of non-acid reactive (silicate) gravel (>0.01 m to <0.05 m in diameter), are suggested for filtration of particles and distribution of flow from the Head Pond to ARUM Pond I (C), ARUM Pond II (F), ARUM Pond III (I) and between ARUM Pond III (I) and the Collector Pond (K). This approach proved quite effective in distributing flow over the with and depth of the ARUM ponds in the Makela system, and did not show major signs of plugging over 7 years of operation. This approach to controlling water movement and distribution was devised in order to avoid plugging problems (Taboa litter, sediment) when using buried or underwater pipes or culverts.

3.5 Weir Design

A specific design of weir (see Schematics 1 and 2: D and G) is suggested at the outflow of ARUM Pond I © and the outflow of ARUM Pond II (F). This weir type is designed for:

a) water transport from the ARUM Pond to the Permeable Berms
b) water level control in the ARUM Ponds
c) prevention of re-aeration of ARUM Pond water upon transfer to Permeable Berms.

The design of this weir must be such that anaerobic water leaving the ARUM pond is drawn from a depth of 0.5 m or more. Water passing through the weir should not come in contact with atmospheric oxygen in order to prevent re-aeration of the water. The overflowing water should drain down into the Permeable Berm.

The weir is comprised of a closed rectangular chamber with the upstream opening 0.5 m below the ARUM Pond water level. The weir lip located inside the closed chamber is set at the desired water level of the ARUM Pond. Water overflowing the internal lip drains down and enters the Permeable Berm. Installation of an air-tight access door on the top of the weir structure is suggested for access during periodic cleaning. A small (0.5 cm) breather hole is required in order to prevent buildup of air pressure and stoppage of flow.

3.6 Collection and Diversion of Clean Run-off

Run-off from the berms separating the parallel sub-systems into the Permeable perm and ARUM Ponds will increase flow through the systems and reduce retention time.

In Schematic 2, agricultural perforated plastic drainage pipe (T) is shown running the length of the clay berms separating the parallel Permeable Berm-ARUM Pond sub-systems. By placing this pipe just below the surface in a very shallow depression running the length of the clay separator berms, run-off can be collected and diverted away from the Biological System.

3.7 Identification of Suitable Rooting Material for Taboa Population Installation

In addition to the structure installed over each ARUM Pond for support of the floating Taboa population, comprised of the main cross poles, and wooded lattice and burlap layer, an organic substrate suitable for planting Taboa will be required. Substrates such as soil are not suitable, since soil is heavy and, given its fine composition, will tend to sift through the burlap and wood structure to the pond bottom.

Coarse, fibrous, easily degradable saturated materials such as *Sphagnum* moss is the ideal substrate identified in Canada, but it is very unlikely that this material is readily available in the MMV region.

Alternative materials must be identified and tested. Very rough waste plant material, such as maize or Taboa stalks which readily saturate may be candidates.

3.8 Starter Fertilizer for Enhancement of Taboa Population Establishment

Mina Esperanca seepage is likely nutrient-poor, and plant nutrients will have to be supplied to help the Taboa establish. Normal agricultural fertilizer dissolves quickly and will be lost from the system. In North America, very slow-release specialized fertilizers (Osmocote, Grace Chemicals; Nutricote, Sierra) have been demonstrates as an effective means of providing developing Taboa populations with nutrients with minimal loss to the pond water.

4.0 DESIGN AND CONSTRUCTION SUGGESTIONS

In Table 1, brief descriptions of the major components of Biological System are presented. Suggested water elevations within the Permeable Berms, ARUM Ponds and Collector Pond, all with respect to the Head Pond, are presented.

In Table 2, the approximate dimensions and volumes of the Head, ARUM and Collector Ponds, and the Permeable Berms, are presented. Estimated retention times in each of the components, and the overall system operating as ten parallel sub-systems (125 days) are presented.

Construction of the entire system as suggested may result in excess treatment capacity, and replication of engineering mistakes throughout the system. It is suggested that one sub-system is constructed and operated for at least one year (e.g. Sub-system 1: Schematic 1) before completion of construction of the entire system. Important performance and operating information can be collected in this first year which can be used to both improve the design of the overall system and further define the total size and capacity of the system required to treat Mina Esperanca Seepage.

5.0 BIOLOGICAL TREATABILITY EXPERIMENTS

5.1 Sourcing of Candidate Substrates

Once the construction of an ARUM biological system is complete, initiation of the microbial processes must be performed. The development of the Taboa population can be expected to take at least two years, while the Taboa population itself requires and organic substrate as a rooting medium.

Therefore, the ARUM microbial processes must be initiated by adding a low cost of waste organic substrate which provides the appropriate organic compounds for the bacteria.

During the development of the ARUM Process using the Makela Test Cell System, several substrates rich in organic carbon and nitrogen were testing in the laboratory and field.

Dried potato peelings (potato waste), produced by the potato processing industry, is available in northeastern North America. This material is processed for use as a soil amendment for gardening and agriculture. Dried Potato Waste is the best material identified to date. Waste products from potatoes or other root crops growing in the MMV region are good candidates.

Testing was also performed using dried compressed alfalfa (*Medicago* sp.), a highly nutritive food material for horses, rabbits and guinea pigs. This organic material was found to be so rich that its application was difficult to control, and excess amounts could be added.

Dried milk and cheese processing wastes are reported in the literature to favour ARUM-like microbial community development. Boojum has not directly tested milk processing by-products, but these, if available, are worth a try.

Although materials such as grass, hay, and wood sawdust can work, these materials have limited nutritive value and only slowly decompose.

Municipal sewage is commonly suggested, but it is not recommended since it has relatively poor nutritive value, as well as the drawbacks concerning health risks to humans, livestock and other organisms.

5.2 Testing of Candidate Substrates

The first stage of testing and screening of available organic substrates should be performed in the form of simple laboratory static tests. The second stage should involve scale-up to 1 m^3 or greater outdoor set-ups near the MMV lab instrumented with metred input and output of Mina Esperanca seepage. Following construction of Sub-System 1 of the Biological system, final design parameters can be determined.

The laboratory static tests could be conducted in 20 L plastic containers (0.5 m tall buckets). The bottom 0.1 m (~ 5 L) of the bucket would be filled with the same construction material, e.g., clay as planned for use during construction of the field system. Approximately 15 L of Mina Esperanca seepage water would be added to the bucket and organic substrates (2 L doses) would be added. Control buckets would also be set up.

The buckets would be monitored weekly and water loss to evaporation compensated weekly with addition of distilled water up to the original volume. Weekly monitoring would include initial determinations of pH, conductivity, acidity and dissolved metals. Each week, the primary parameters, temperature, pH, conductivity, redox and acidity (very important) would be measured in the buckets at the surface, middle and bottom of the bucket, taking care not to stir the system or disturb sediments. When measurable changes in these primary parameters are recorded, water samples are sampled for determination of dissolved concentrations of metals, cations and anions.

Table 1: General Design Parameters for Biological System (See Schematics 1 and 2 For Graphical Presentation).

Schematics 1 and 2	**Component**	**Purpose**	Pond Elev. Location	Relative Elevation w.r.t. Inflow, A
	Inflow Pipe	Inflow to Head Pond from Oxidation-Settling System		>0.0 m
A	Head Pond	Distribute Flow to Parallel Systems 1 through 10	$W.L._{A}$	0 .0 m
B	Permeable Berm I	Filter Particles: Distribution of Flow to ARUM Pond I		-0.20 m
C	ARUM Pond I	Acid Reduction Using Microbiology (ARUM)	$W.L._{C}$	-0.25 m
D	Weir and Chute I	ARUM Pond I Water Level Control		-0.25 to - 0.4 m
E	Permeable Berm II	Filter Particles: Distribution of Flow to ARUM Pond II		-0.4 m
F	ARUM Pond II	Acid Reduction Using Microbiology (ARUM)		-0.5 m
G	Weir and Chute II	ARUM Pond II Water Level Control	$W.L._{F}$	-0.5 to - 0.7 m
H	Permeable Berm III	Filter Particles: Distribution of Flow to ARUM Pond III		-0.7 m
I	ARUM Pond III	Acid Reduction Using Microbiology (ARUM)	$W.L._{I}$	-0.75 m
J	Permeable Berm IV	Filter Particles		-0.75 m
K	Collector Pond	Collect All Permeable Berm IV Discharges	$W.L._{K}$	-0.85 m
	System Discharge Weir	ARUM Pond III Water Level Control		> -0.85 m
Schematic 2				
L	Taboa Shoots	Production of Organic Carbon For Long-Term Operation		
M	Organic Substrate+ Burlap + Wooden Lattice	Support of Taboa Plants at ARUM Pond Surface		
N	Wooden Poles (0.3 m diam.)	Support of M until Taboa Achieves its Own Buoyancy		
O	Taboa Roots and Rhizomes	Litter Feeds Sediment Microbial Activity		
P	Open Water	Anoxic Volume for Water Treatment and Particle Settling		
Q	Organic N- and C- Rich Substrate	Starter Medium to Get ARUM Process Going		
R	Construction material (clay)	Water Retention and Control		
S	Gravel (>0.01 to < 0.05 m diam.)	Filter Particles: Distribution of Flow to all ARUM Cell Depths		
T	Agricultural Perforated Plastic Drainage Pipe	Collect and Drain Clean Rainwater Away from Biological System		

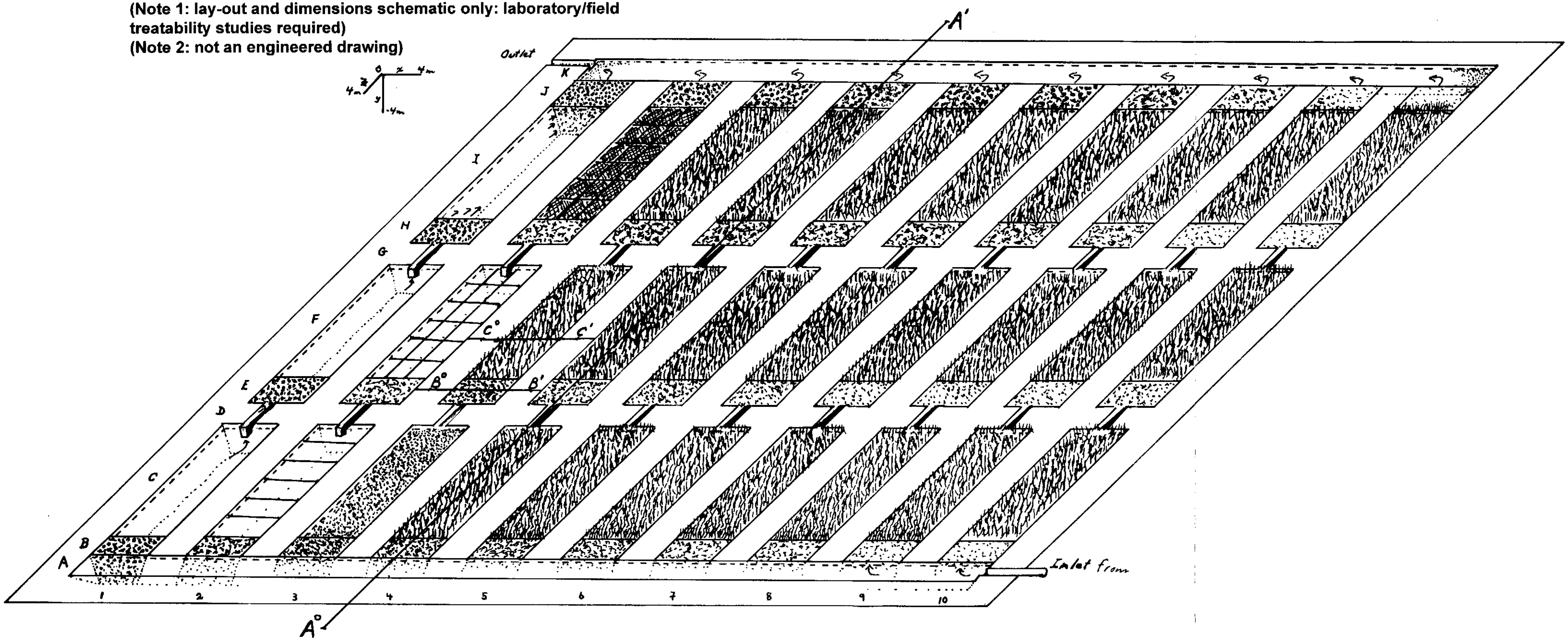
Table 2: Suggested Dimensions of Each Parallel Circuit of Biological System (See Schematics 1 and 2 For Graphical Presentation).

Schematics 1 and 2	Component	Relative Elevation w.r.t. Inflow, A	Approx. Width m top	Approx. Width m bot	Approx. Width m av	Approx. Length m top	Approx. Length m bot	Approx. Length m avg	Approx. Total Depth m	Approx. Max. Water Depth m	Free Board m	Approx. Diameter m	Approx. Volume m^3	Approx. Retention Time [1] d
	Inflow Pipe	>0.0 m										0.4		
A	Head Pond	0 .0 m	4			96			2	1.75	0.25		336	5.3
B	Permeable Berm I	-0.20 m	6	5	5	4	6	5	2	1.75	0.25		44 [2]	6.8
C	ARUM Pond I	-0.25 m	6	4	5	24	20	22	2	1.75	0.25		193 [2]	30
D	Weir and Chute I	-0.25 to - 0.4 m	0.5	0.5		4	4		0.25	0.02	0.23		0.04 [2]	0.006
E	Permeable Berm II	-0.4 m	6	4	5	4	4	4	2	1.75	0.25		35 [2]	5.5
F	ARUM Pond II	-0.5 m	6	4	5	24	20	22	2	1.75	0.25		193 [2]	30
G	Weir and Chute II	-0.5 to - 0.7 m	0.5	0.5		4	4		0.25	0.02	0.23		0.04 [2]	0.006
H	Permeable Berm III	-0.7 m	6	4	5	4	4	4	2	1.75	0.25		35 [2]	5.5
I	ARUM Pond III	-0.75 m	6	4	5	24	20	22	2	1.75	0.25		193 [2]	30
J	Permeable Berm IV	-0.75 m	6	5	5	4	6	5	2	1.75	0.25		44 [2]	6.8
K	Collector Pond	-0.85 m	4			96			2	1.75	0.25		336	5.3
	System Discharge Weir	> -0.85 m	1	1	1	4	4	4	0.25	0.05	0.2			
									Total Retention Time in Biological System					**125 d**

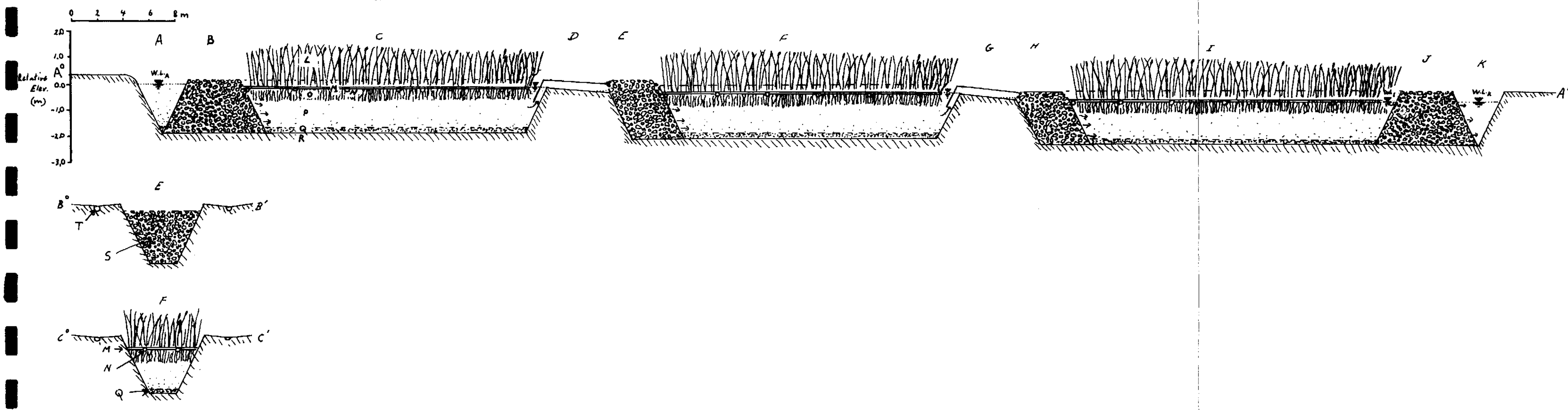
1 Retention Time Estimated at 0.74 $L.s^{-1}$ Flow From Oxidation-Settling System
2 Flow Through Each of the 10 Parallel Systems is 1/10 of Total Flow

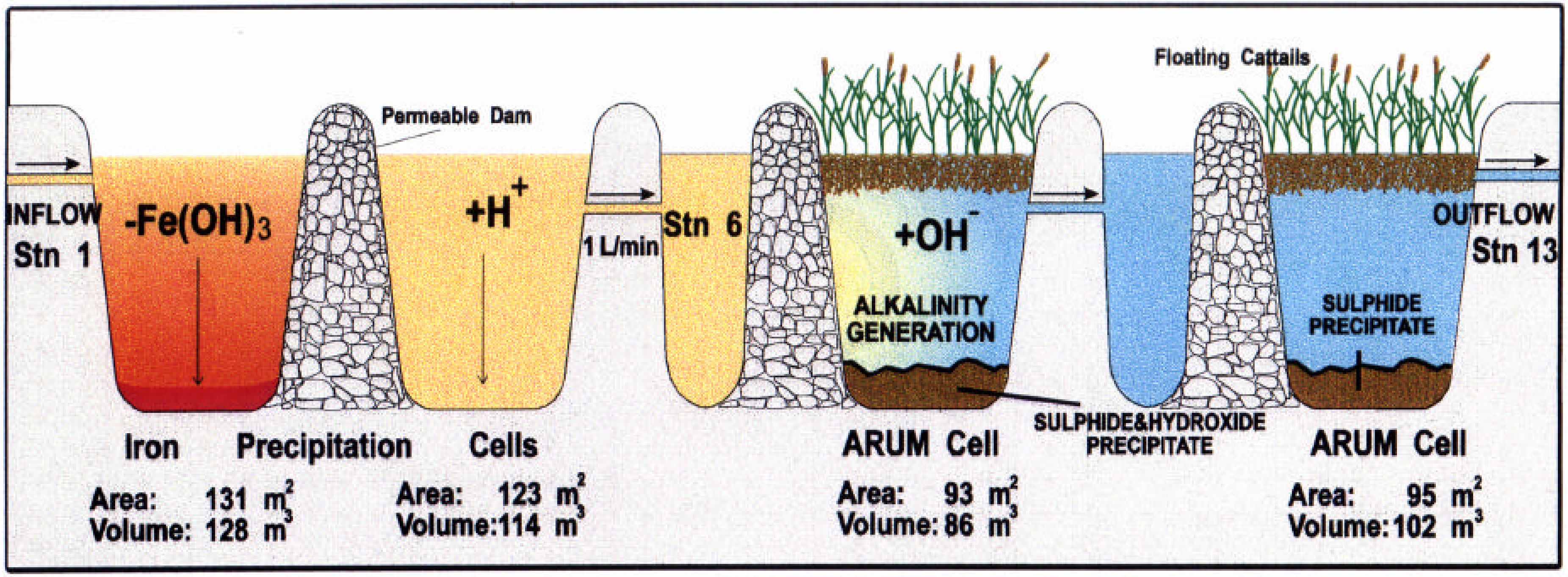
Schematic 1: Schematic Overview of Biological System For Acidic Mina Esperanca Mine Drainage Following Oxidation-Settling System

(Note 1: lay-out and dimensions schematic only: laboratory/field treatability studies required)
(Note 2: not an engineered drawing)



Schematic 2: Schematic of Cross-Sections A° - A', B° - B' and C° - C' from Schematic 1 (Note: not an engineered drawing).





Schematic 3: Original ARUM design for Makela Test Cell System, Inco, Sudbury, Ontario, Canada.

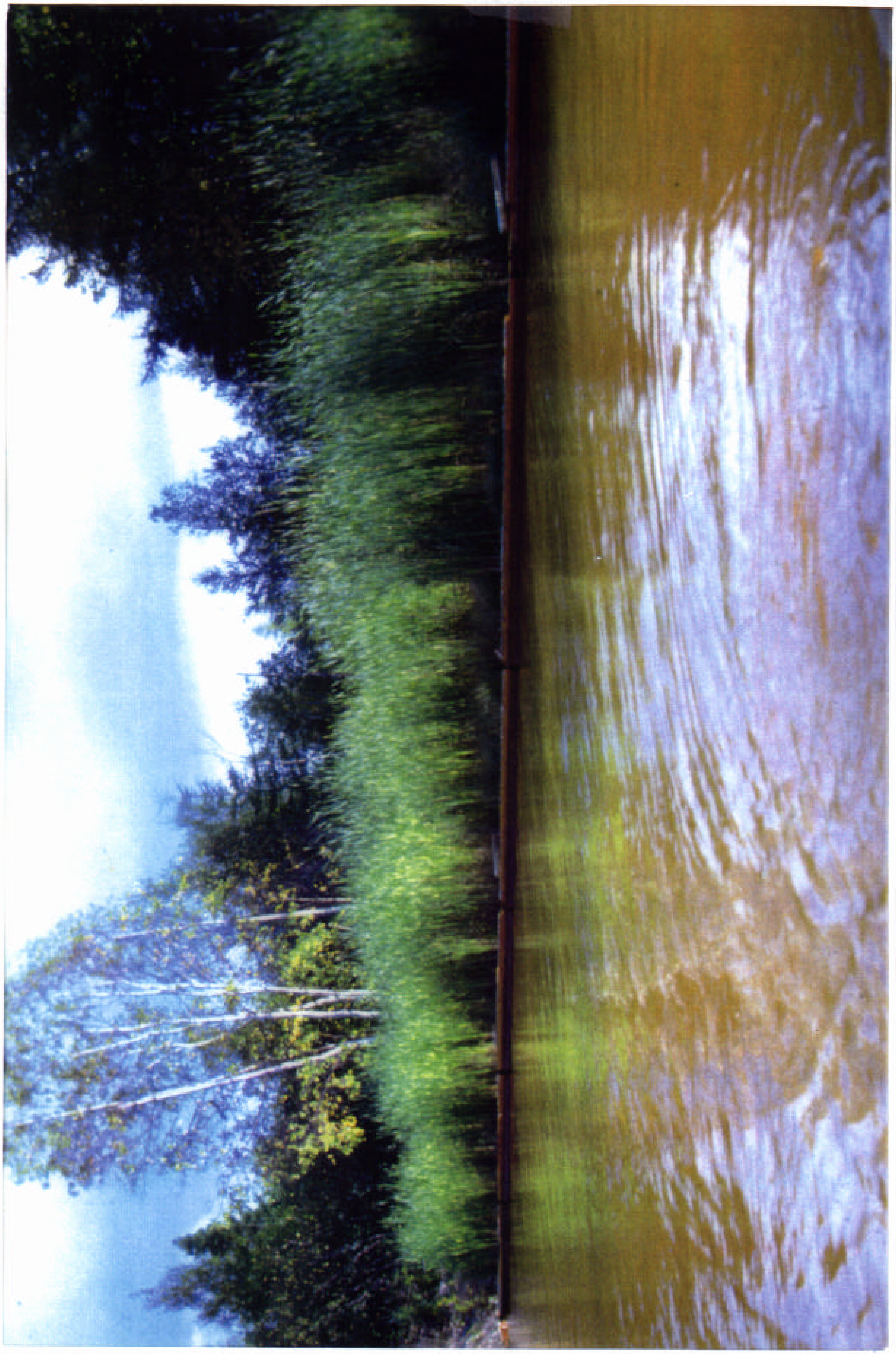


Plate 1: Floating Taboa Population Established over 4 m water depth in a flooded Cu-Zn pit, Buchans, Newfoundland, Canada (1995).

Plate 2: Block of floating Taboa mat (0.35 x 0.35 m) extracted from floating mat population (see Plate 1). Note the large root mass which extends into the water column. Total tape measure length is 2 m for scale.