

**3.10. PREDICTION FROM AN AUSTRALIAN
PERSPECTIVE**

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Australian Nuclear Science & Technology Organisation**

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An Australian Perspective on Acid Rock Drainage
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Preamble

The following notes and overheads formed the framework of the presentation made at the Workshop. Rather than write them up as a paper, I feel that the flavour and key points of the address are preserved in this form. I will be happy to expand on any points if the reader cares to contact me.

Introduction

This workshop has come at a particularly opportune time for us at ANSTO as we near the end of a concerted effort to examine Australia's research needs in the field of managing sulphidic mine wastes.

In terms of prediction, we consider a system in two parts:

- (a) primary pollutant generation - oxidation of sulphides, rate controlled by the intrinsic oxidation rate of the material and often by the physical supply of primary reactants;
- (b) secondary generation - transport of pollutants by water and geochemical reactions along the pathway to the impacted environmental system.

These involve principally the disciplines of physics, chemistry and mathematics. Could also add ecological impact as a third part of the whole system, bringing into play the disciplines of biology and risk assessment, but I will not address this in this forum.

We at ANSTO have focused our attention on waste rock dumps.

Our program to develop predictive tools has been intimately bound up with field measurements. It is the field measurements which tell us how the real world behaves and directs us to the dominant processes, mechanisms and features which a model must incorporate and allows us to disregard speculative processes which may sound plausible but which are either not observed or found to be insignificant.

I will take a few moments to provide some background to our work in the field.

Background

Fig 1

We have worked and are working at a large number of sites around the world. These include different types of mines (Cu, Au, U, Fe, C, Ag/Pb/Zn) in a wide range of climatic zones (equatorial, arctic, monsoonal tropics, wet temperate, arid etc.).

Our involvement has covered measurement/quantification, modelling, advice, and reviewing the work of others.

I will now discuss some of the key concepts which we have found apply generally to waste rock dumps and illustrate them with field data.

Fig 2

This is a schematic dump at some time after it has been created. The features are:

- a zone which has completely oxidised and no longer contributes pollutants;
- an oxidising zone where primary and secondary generation are occurring;
- a zone which has yet to oxidise but where secondary generation is occurring.

The behaviour of the dump is both space dependent and time dependent.

The transport of pollutants is by water. The pollutants may end up in groundwater, surface water or runoff.

In the dump as presented, the dominant rate controlling mechanism is the supply of oxygen by diffusion. As a consequence, the primary pollutant generation rate is governed by the oxygen supply rate.

The size of the oxidising region will depend on the oxidation rate of the material and can vary from involving the whole dump at once (if oxidation rates are low) to a very thin region if rates are high. Above a certain value oxidation rates can be considered to be 'infinite' and the overall process is controlled solely by the diffusion coefficient of the material.

Except where all the dump is oxidising, the system is spatially dependent and the primary pollutant generation rate will be time dependent.

Fig 3a and 3b

The significance of different values of intrinsic oxidation rate (IOR) is shown in 3a for a dump with the characteristics set out in 3b.

Field Data

Fig 4

Aitik Mine, arctic Sweden

- diffusion is the gas supply mechanism in all cases
- in probe hole A7, very little oxygen consumption in 18m;
- in probe hole A1, typical profile of 1-D diffusion, material has low IOR and the whole thickness of dump is oxidising;
- in probe holes A8 and A2, there are pods of material with higher IOR embedded in low IOR material, requiring a 2-D description of oxygen transport.

Fig 5

Brukung Mine, South Australia

- top, pods of material with higher oxidation rate embedded in material with lower oxidation rate;
- bottom, variation in oxidation rates with depth.

Fig 6

Mt Lyell Mine, Tasmania

- pods having an IOR of $\sim 10^{-7} \text{ kg(O}_2\text{) m}^{-3} \text{ s}^{-1}$ are seen throughout the dump and are the major source of pollutants;
- note the corresponding evidence of a heat source at the position of the pod.

Fig 7

Gordonstone Coal Mine, Queensland

- co-disposal of rejects and tailings
- oxidation is all occurring in top 25 cm. With time this oxidising layer will move down through the dump.

Fig 8

Mt Lyell Mine

- the size and shape of the dump and the climate are such that that wind-driven advection becomes a significant gas transport mechanism;
- the evidence is that the oxygen profile at depth is time-dependent;
- this is supported by the temperature profiles which indicate significant heating at depth;
- this is a case where the oxidation rate at depth depends on the properties of the material, not on the oxygen supply rate, i.e. is not diffusion limited.

Fig 9

A four year old waste rock dump.

- here we have temperatures as indicators of oxidation;

- at the maximum, the temperatures are some 30°C above ambient, in keeping with other independent measures of oxidation rate which indicate rates $\sim 10^{-7}$ kg(O₂) m⁻³ s⁻¹;
- clearly advection is occurring in region of batters and crest (either wind- or temperature-driven);
- the influence penetrates of the order of 100m into the dump, which is typical for this mechanism;
- note that the bulk of dump may still be diffusion controlled;
- modelling helps to interpret the field observations and quantify the significance of the different gas transport mechanisms on oxidation rates and primary pollutant generation rates.

Prediction

Fig 10

- compare the previous 2-D temperature contours with the output of FIDHELM, ANSTO's finite difference numerical dump model (which was made available through MEND on a limited basis);
- although the modelled dump does not have the same dimensions, the general form of the output matches the field measurements very well;
- this is where we take issue with the concept of 'calibrating' a model. FIDHELM incorporates the physics of gas, heat and water transport. Given that it includes the major transport mechanisms and that the required physical parameters are either known or can be estimated well, there is no 'calibration' necessary - the code models the physical world;
- note the agreement between the shape of the measure and modelled temperature contours near the crest of the dump;
- note the gas discharge near the crest, matching the region where water vapour is observed in the field;
- as an aside, this explains in part why running bio-oxidation heaps is so difficult - although the oxidation rate can be considered to be 'infinite' the problem is to transport oxygen throughout the volume of the heap;
- the model output illustrates the time dependent nature of primary pollutant generation;
- we believe that at ANSTO we are in a good position to predict primary pollutant generation confidently as a function of time and space;

Now consider secondary pollutant generation by referring to the schematic dump shown earlier.

Fig 2

In a dump the time it takes for polluted drainage to appear will depend on a number of factors. There are two routes for polluted water to reach an impacted ecosystem, each with different timescales:-

- (a) surface runoff;
- (b) drainage to groundwater and then to surface waters.

- can consider surface runoff to be immediate, time for it to become acid (assuming SO_4 not a problem) depends on how long it takes for quick-acting acid consuming material to be used up (weeks, months, years). This depends on oxidation rate, sulphur density and density of acid consuming material;
- this lasts for as long as it takes to oxidise the surface layer of the dump or until a cover is applied.

For drainage it is more complex:

- depends on the time for the oxidising layer to 'go acid' and then depends on chemical transport through the lower region (time to consume all quick-acting acid consuming material) and in some circumstances on water transport time;
- in a dump with low oxidation rate, where whole dump is oxidising, it may take a long time to go acid but then the whole dump generates pollutants at once;
- pollutants in drainage will ramp up over the transit time of water through the dump (which may be several years) and may also include the transit time of groundwater from beneath the dump to some surface expression.

So, an important message is that in general the whole system is both space and time dependent and both must be taken into account in describing it. If the spatial dependence is not taken into account then incorrect conclusions are likely to be reached and bad advice will be given to operators.

Research Directions

To move on from here it is our view that there is a need for a physically justifiable (and validated) model of water flow in these heterogeneous, unsaturated systems and also a chemical transport model which incorporates the appropriate rate constants.

These then provide the basis for our research directions - water transport and chemistry.

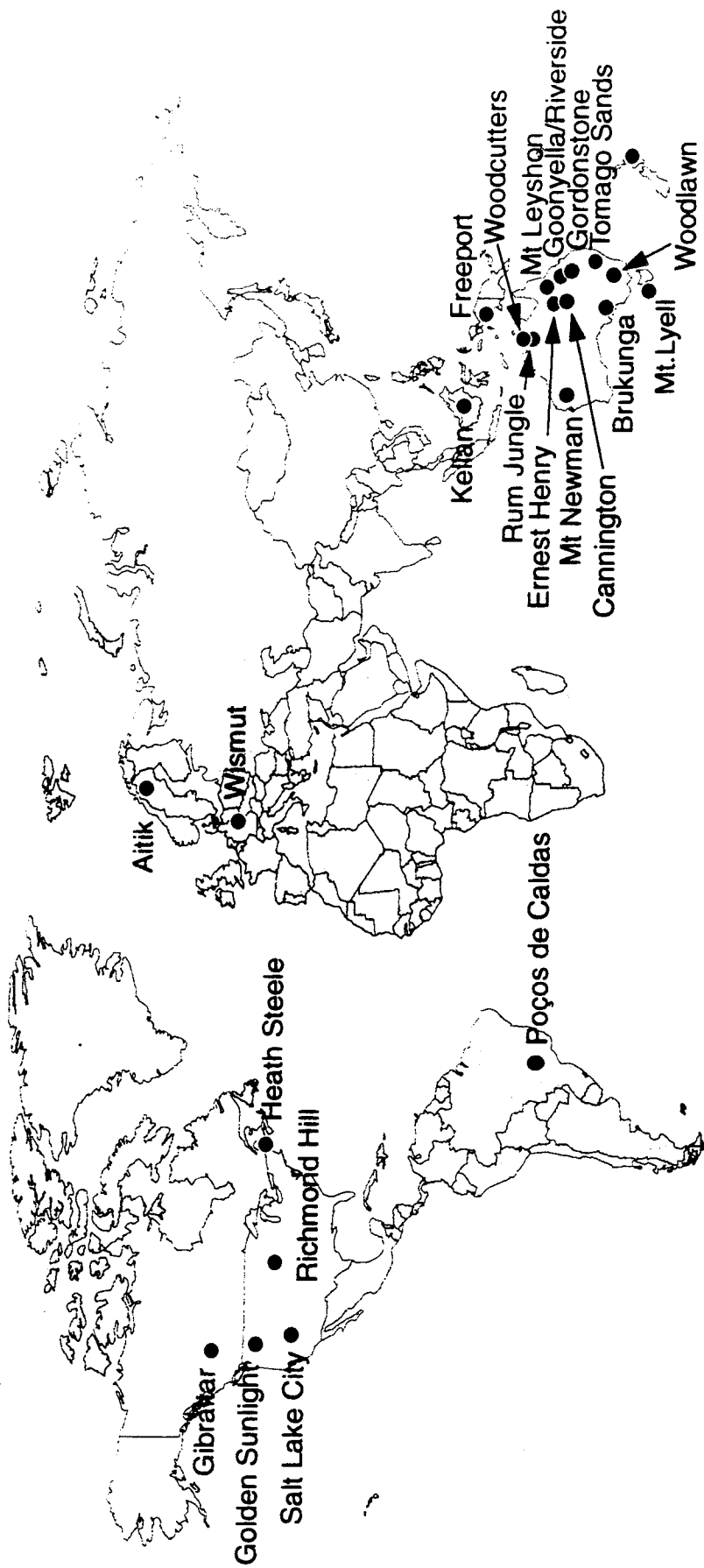
We see the aim as being able to predict the efficacy of management strategies for sulphidic wastes.

Fig 11

- within an overall management scheme, we see that an operator needs to begin assessing options at an early stage;
- on the right of the figure, at the end of the 'Exploration and Early Feasibility' phase, are water treatment options for which you need to be able to predict the chemical composition of drainage in detail;
- for options on the left (which includes covers) it is sufficient to look at the main environmental pollutants and to do the chemistry for these alone;

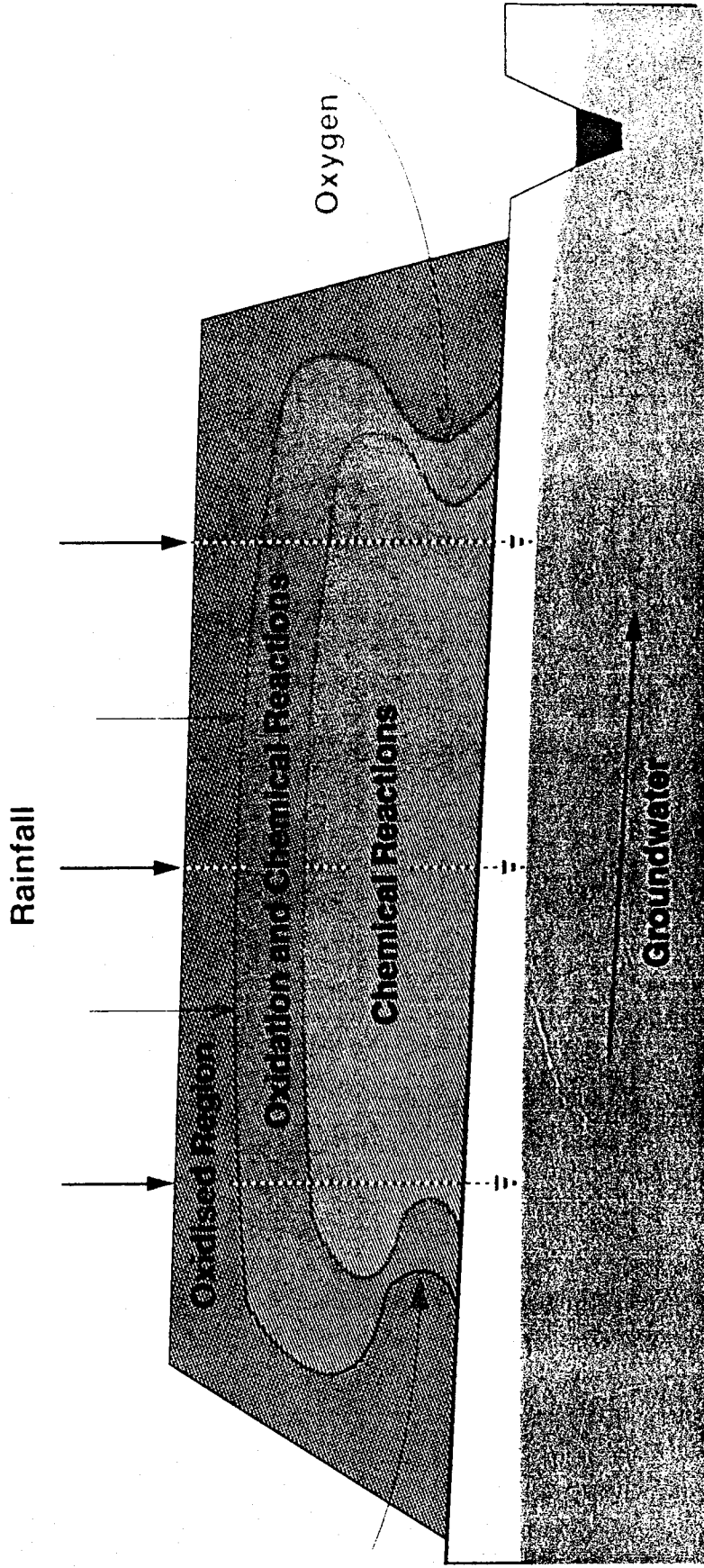
Fig 12

- this is because it is the load (or concentration) versus time and how these compare with environmental limits (L_R) which is required to specify the management strategy. These curves are only needed for the most ecologically significant pollutants.



Location of ANSTO pyrite oxidation work

Figure 1



Ansto

Figure 2

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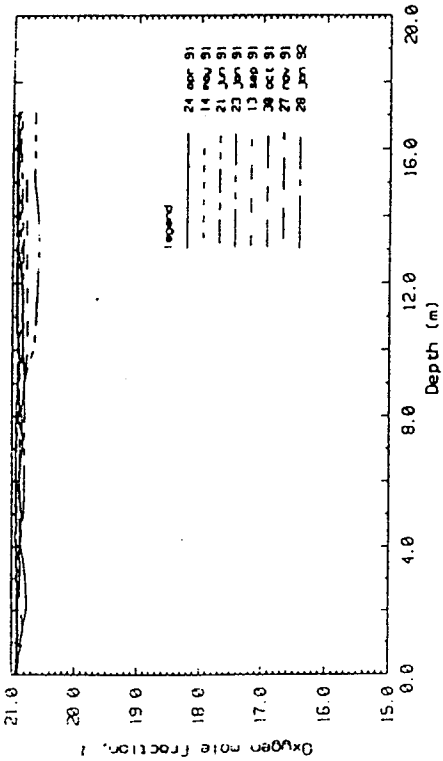
IOR ($\text{kg m}^{-3} \text{s}^{-1}$)	Relevance of Rate	Time to use up pyrite (y)	NOTE 1	Time to use up carbonate	NOTE 2	Time to use up initial pore space oxygen	NOTE 3	Heat generation rate (W m^{-3})	Approx. temp above ambient ($^{\circ}\text{C}$)	Sulphate conc. (mg L^{-1})	NOTE 4	Copper conc. (mg L^{-1})	NOTE 5
10^{-5}	Rate seen for biotic oxidation in laboratory based experiments	0.167	NOTE 1	2.4 d	NOTE 2		NOTE 3	129			NOTE 4		NOTE 5
10^{-6}	Rate needed in biooxidation heap Rate for chemical oxidation	1.67		3.4 w		0.9 d		12.9					
10^{-7}	Effectively infinitely high rate in a waste rock dump	16.7		0.66 y		1.3 w		1.29					
10^{-8}	Typical rate found in waste rock dumps	167		6.57 y		13.1 w		0.129	~ 10	21,600		430	
10^{-9}	Typical low rate found in waste rock dumps	1670		65.7 y		2.52 y		0.013	~ 1	2160		43	
10^{-10}	Rate at which there is a marginal environmental problem	16,700		657 y		25.2 y				216		4.3	
10^{-11}	Probably acceptably low rate	167,000		6,570 y		252 y				22		0.4	

Figure 39

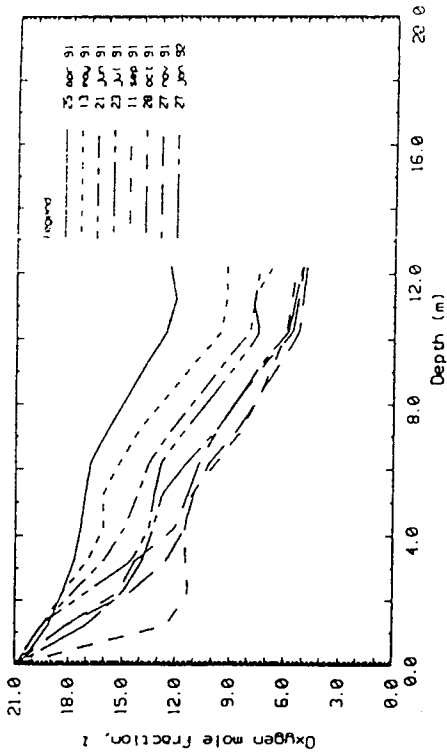
SPECIFICATION OF DUMP

Note 1 -	Bulk density 1500 kg m ⁻³ ; sulphur density as pyrite 30 kg m ⁻³ ; oxidation rate maintained throughout dump
Note 2 -	Calcium carbonate density 3.45 kg m ⁻³ (0.23%)
Note 3 -	Gas filled pore space 0.3; oxygen concentration in air 0.265 kg m ⁻³
Note 4 -	Sulphate assumed conserved; dump height 20m; infiltration 1.59 x 10 ⁻⁸ ms ⁻¹ (0.5 mg ⁻¹)
Note 5 -	Sulphate to copper concentration in drainage 50 : 1

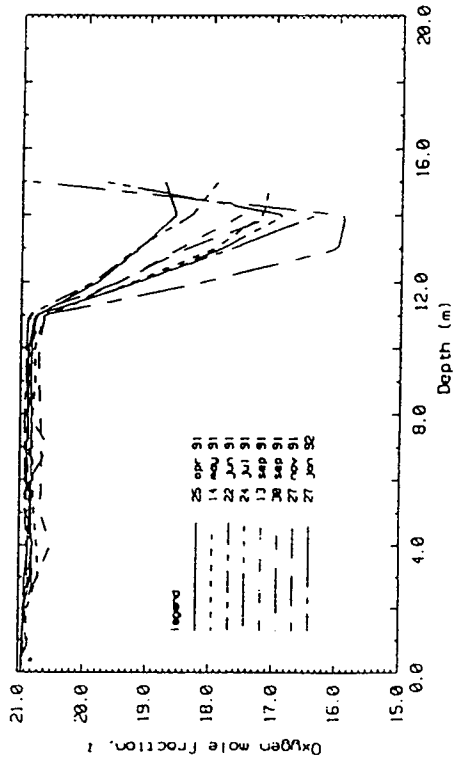
Figure 3b



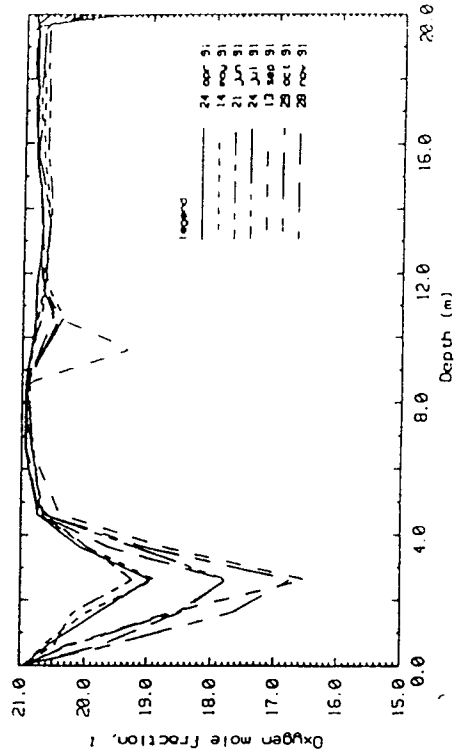
Pore gas oxygen concentration profiles measured at A7.



Pore gas oxygen concentration profiles measured at A1.



Pore gas oxygen concentration profiles measured at A8.



Pore gas oxygen concentration profiles measured at A2.

Figure 4

Figure 5

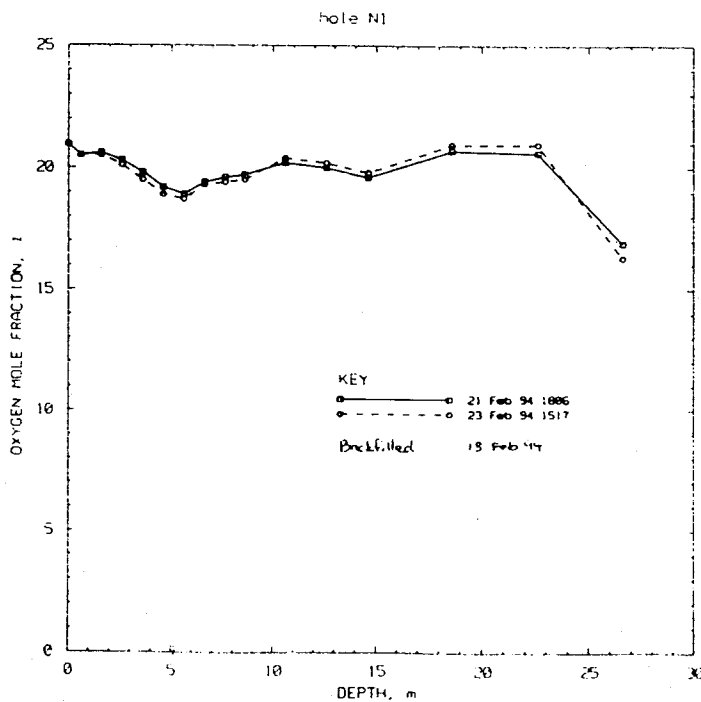
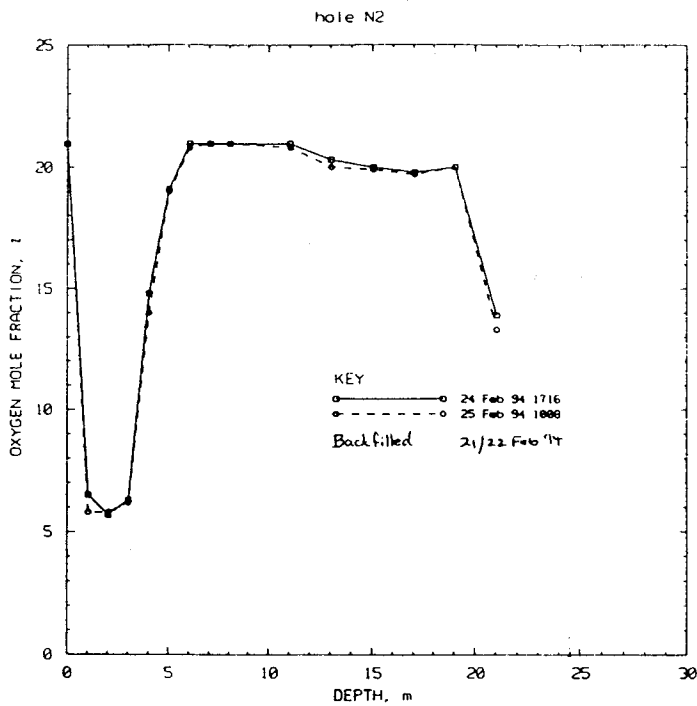


Figure 6

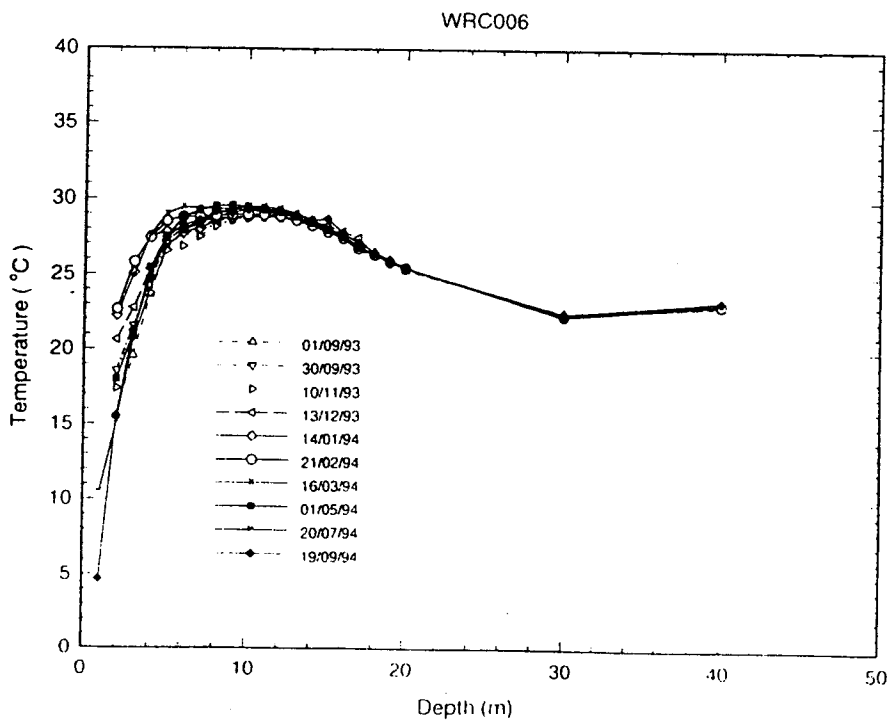
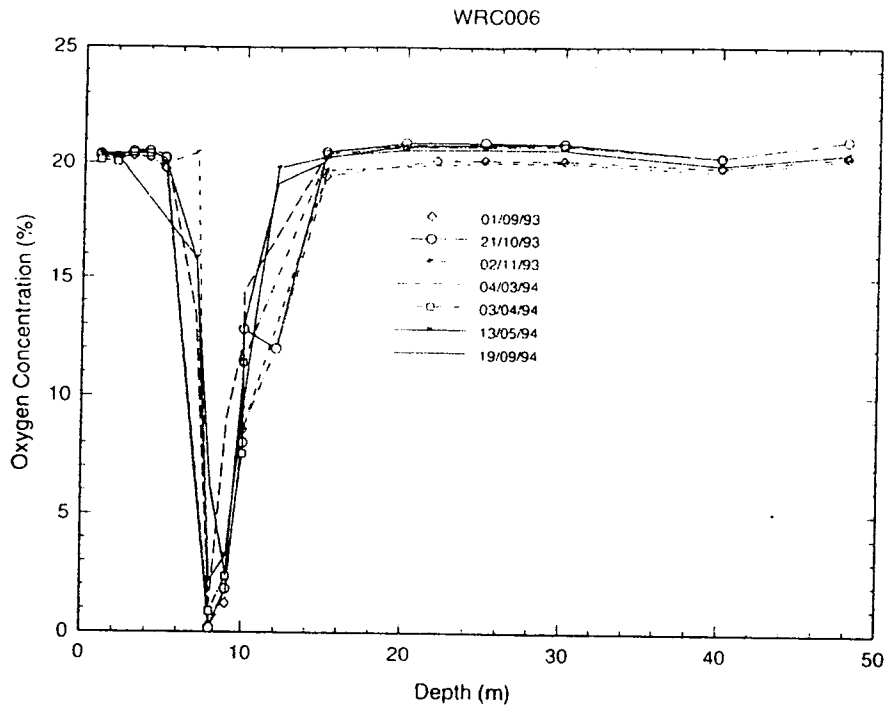


Figure 7

Oxygen Concentration Profile Probe Hole GH04

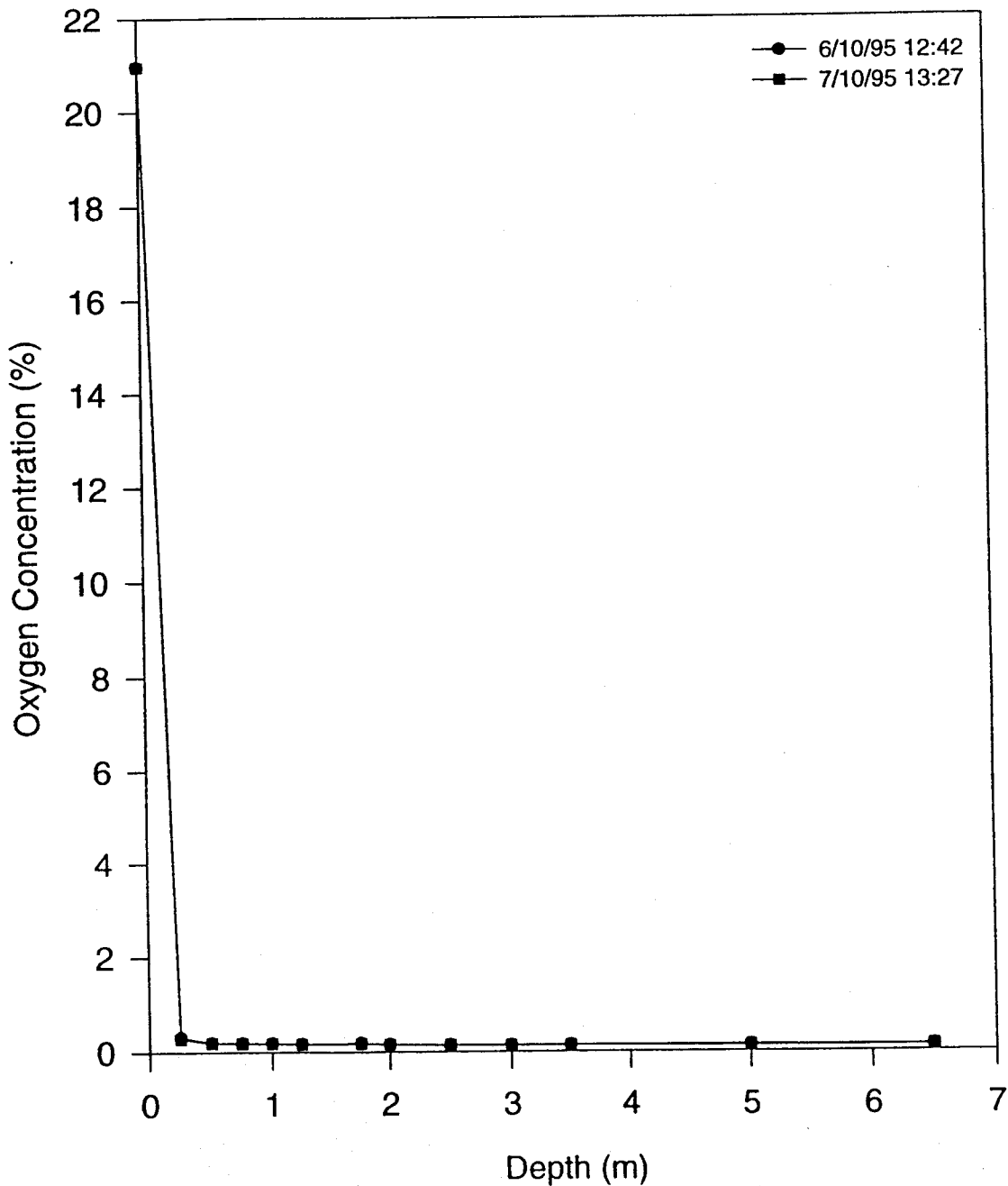
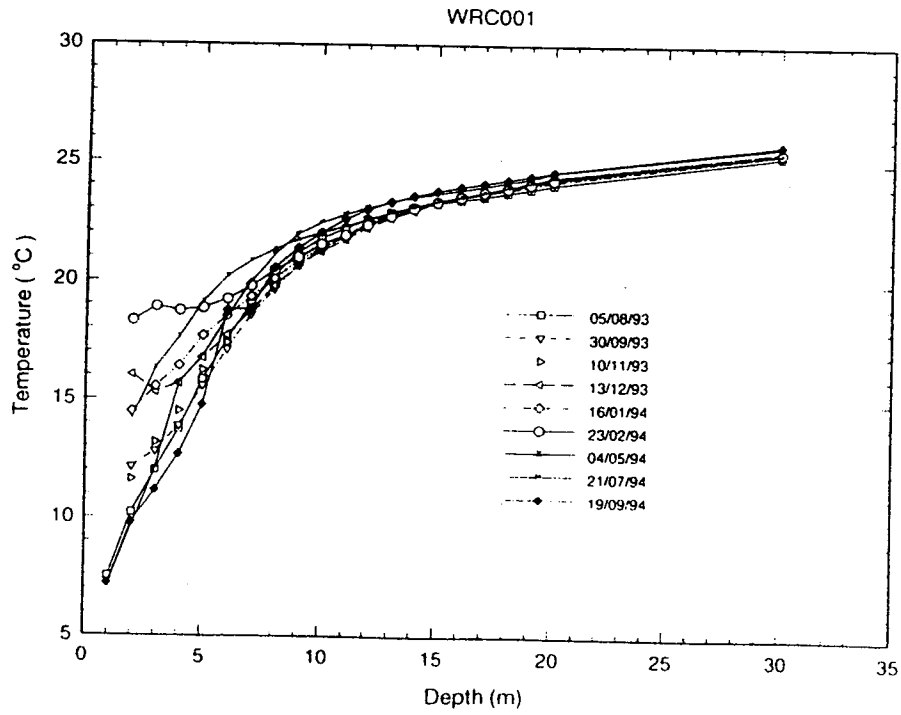
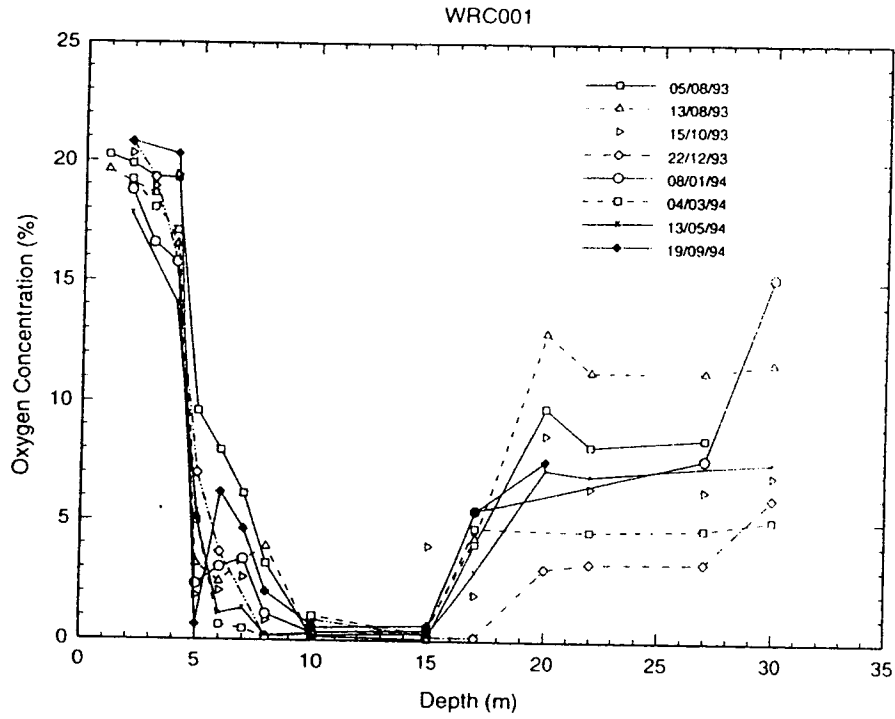


Figure 8



TEMPERATURE CONTOURS (°C) SEPTEMBER

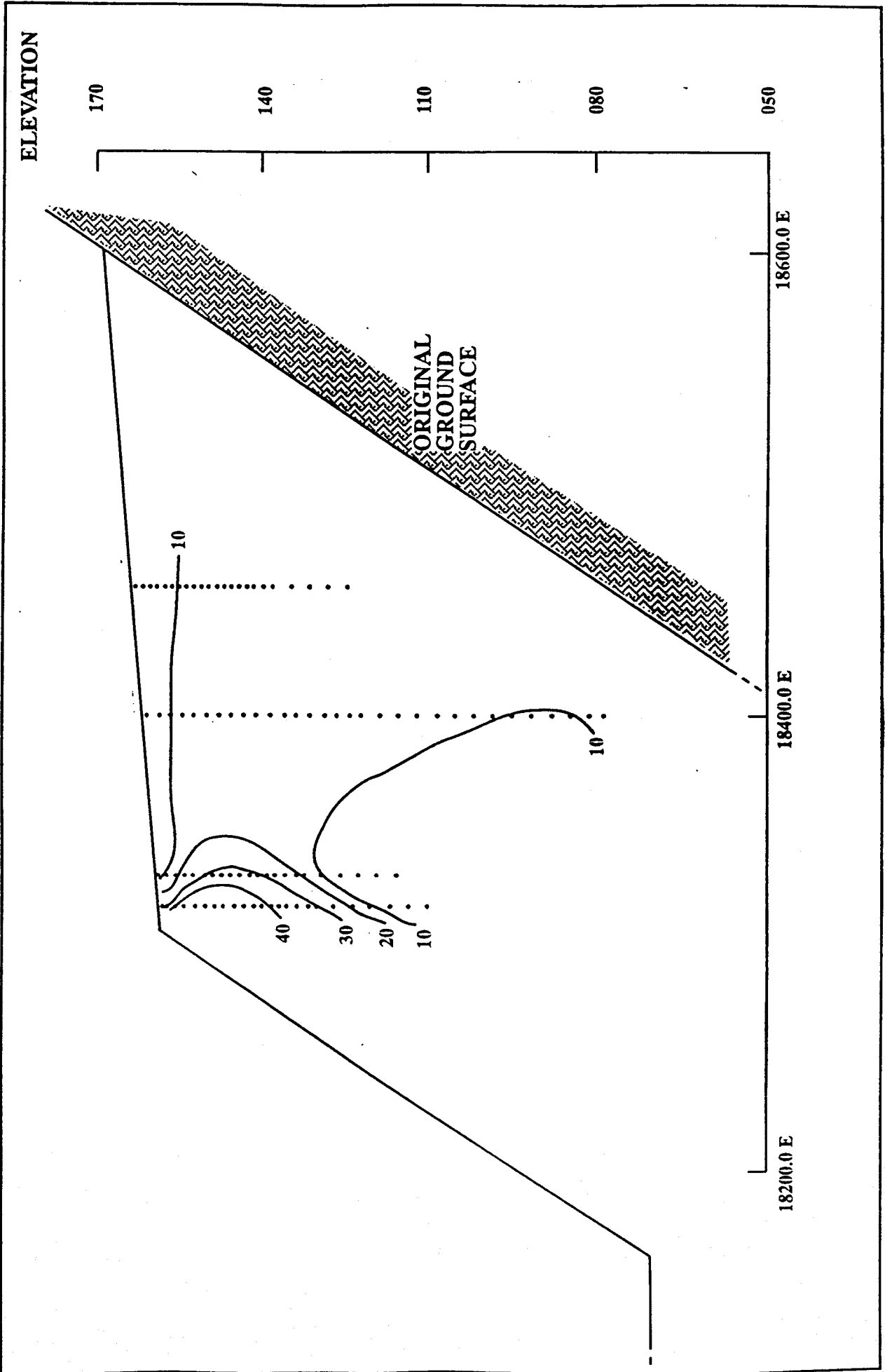
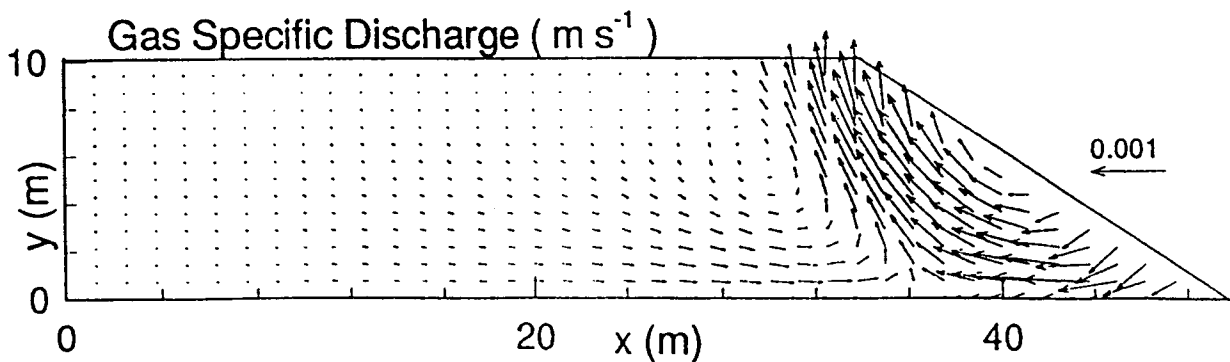
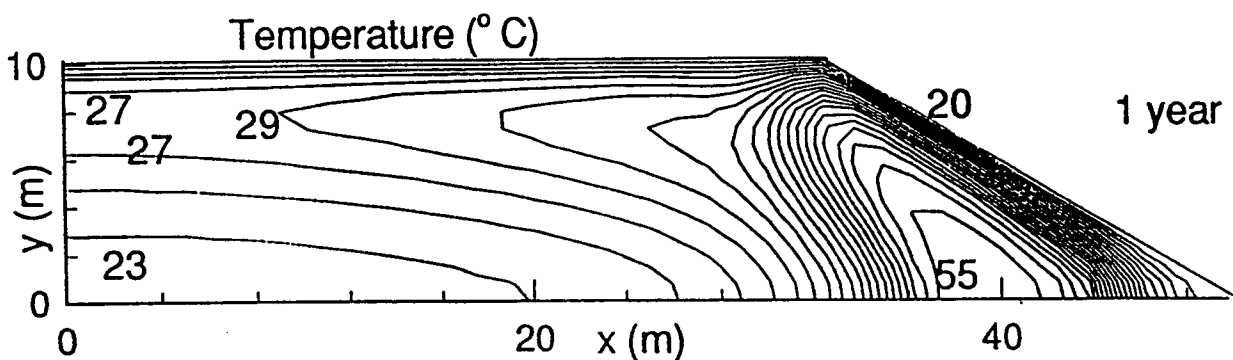
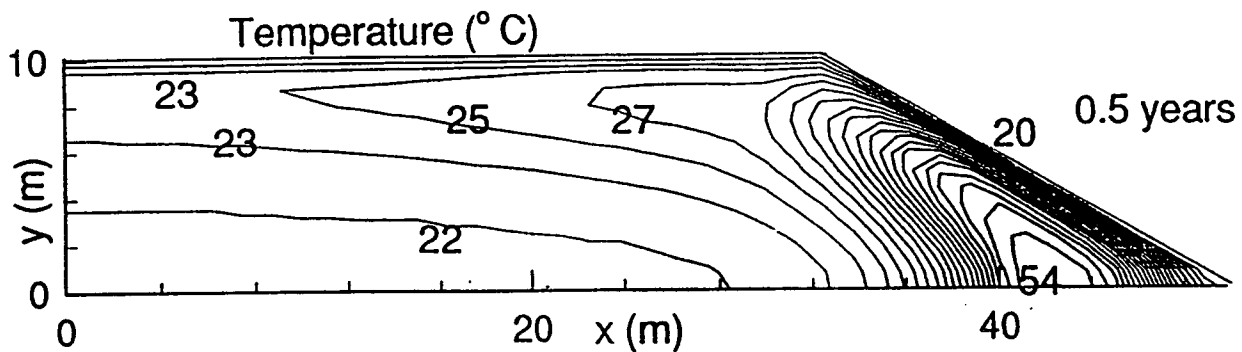
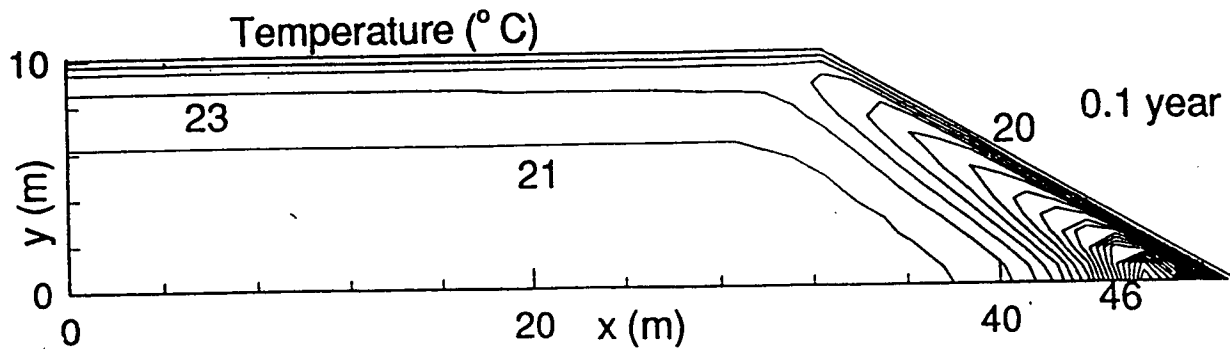


Figure 9

Figure 10



Closed Based Heap

height of heap (m)	half width of heap (m)	Permeability (m^2)	ambient temperature ($^{\circ}\text{C}$)	sulphur density (kg m^{-3})	T_{kill} ($^{\circ}\text{C}$)
10	50	10^{-8}	20	15	60

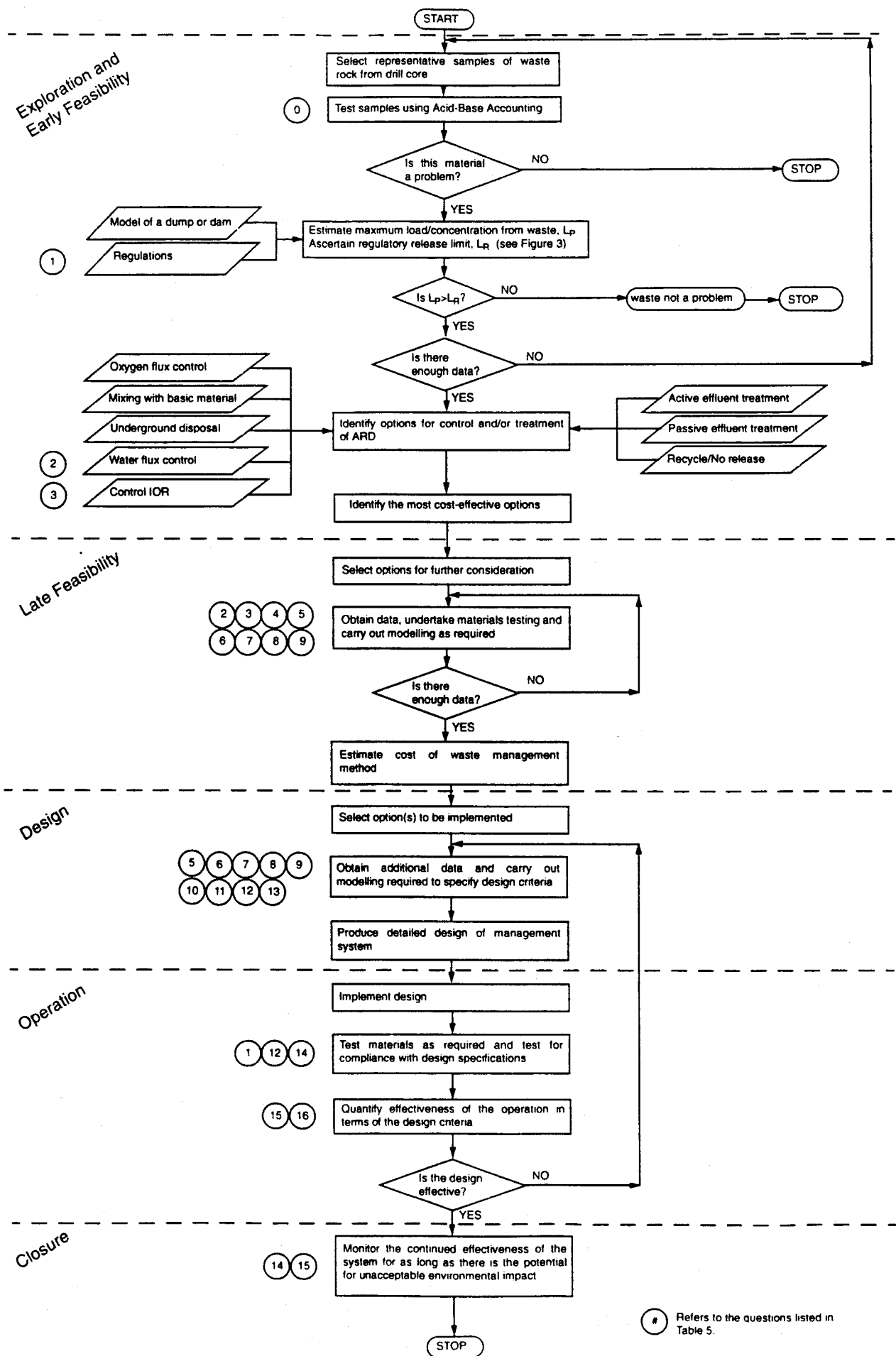
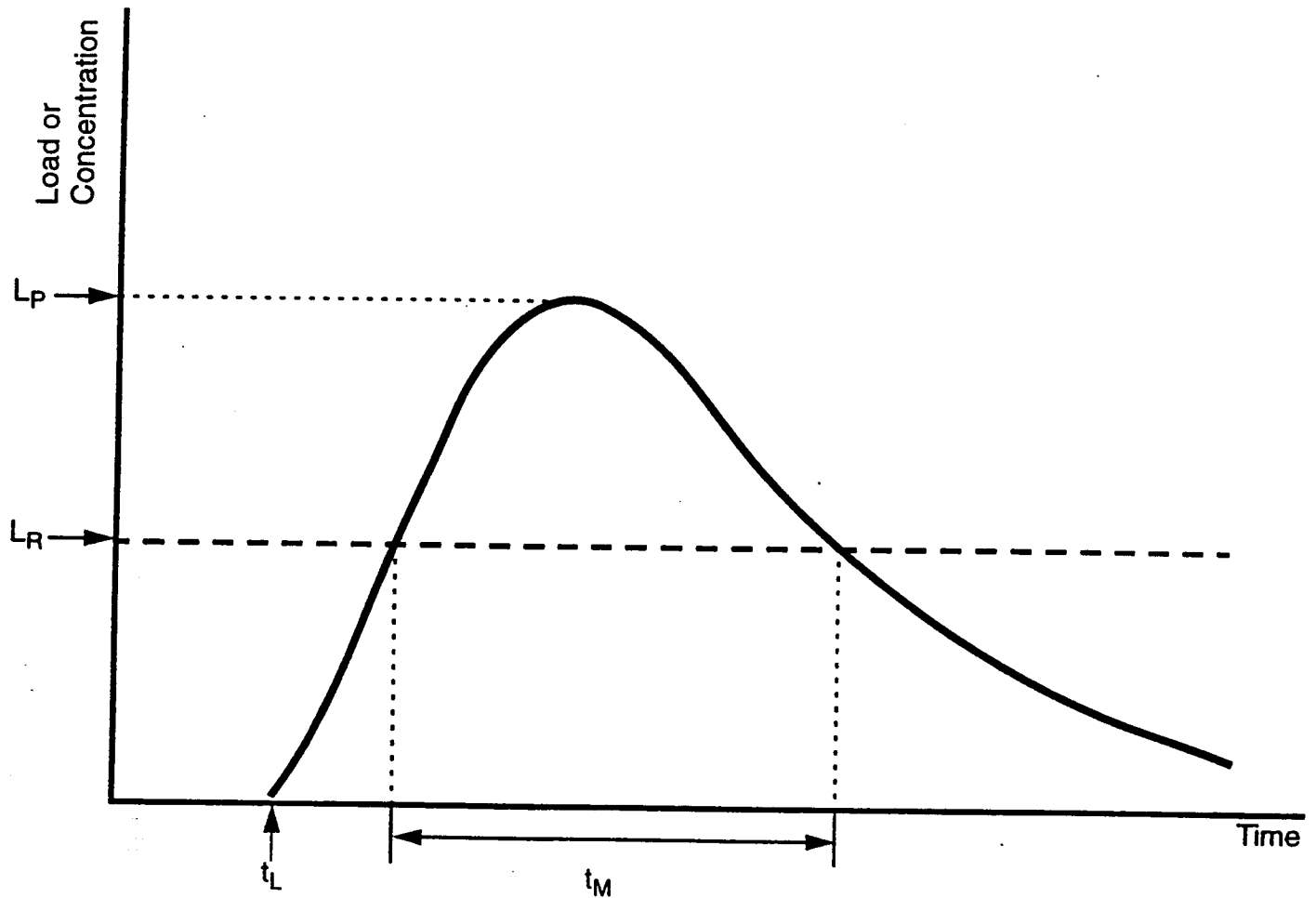


Figure 11 Procedure for managing sulfidic mine wastes

Figure 12. Pollutant Load or Concentration Released from a Pile of Sulfidic Mine Waste as a Function of Time



Glossary of Symbols

- L_P Peak load or concentration of pollutants in drainage from the pile.
- L_R Environmentally acceptable load or concentration of pollutants.
- t_L The 'lag time' from the time of construction to the first appearance of pollutants in drainage from the pile.
- t_M The time period during which the pollutant load or concentration in drainage from the pile exceeds L_R .

