

# **THE ACID TEST**

**an expert system for acid sulphate soils**

by

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## The Program

This manual is intended to accompany the Evaluation edition (version 0.9) of the ***Acid Sulphate Soils Identikit***. In the light of formative evaluation, the manual may be revised and updated for later editions.

The two other modules in the ***Acid Test*** package (ASSESS and ASSMAN) are not yet available; links and references to them should be ignored for the time being.

The user is invited to examine and evaluate the potential usefulness of the Identikit program, and submit comments to the authors (above). It must be noted that the authors can accept no responsibility for any consequences arising from the use of the program. Identikit is intended to be a tool for environmental professionals to use, not a replacement for professional skill and judgement.

## Acknowledgements

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# Acid Sulphate Soils IDENTIKIT

## Contents

<b>Introduction</b>	4
<b>What are acid sulphate soils?</b>	7
<b>What are the hazards?</b>	7
<b>Where and under what circumstances are acid sulphate soils found?</b>	9
<b>How extensive are acid sulphate soils?</b>	10
<b>How, why and where do sulphides accumulate?</b>	11
<b>What is the process of acid generation?</b>	13
<b>How much acid can be produced?</b>	16
<b>The Identikit decision tree -</b>	
<b>Land</b>	16
<b>Water</b>	20
<b>Biology</b>	23
<b>Soil</b>	24
<b>References</b>	30
<b>Getting Started with Identikit</b>	32
<b>Installation</b>	32
<b>Describing your site</b>	34
<b>Reporting</b>	35
<b>Correcting errors</b>	35
<b>What do the numbers mean?</b>	35

# Introduction

## What does the expert system do?

It enables you to:

- **Identify** acid sulphate soil, or the likelihood of acid sulphate soil, in the field or by using site evidence;
- **Assess** the severity of the acid sulphate hazard at any site or over any area;
- **Evaluate** management options;
- **Specify** the data needed for policy planning, project design and management and gather these data;
- Using appropriate data, **prepare** management plans, design structures and landscapes and **forecast** response to particular management or design options.

## Who needs this information?

- |   |   |
|---|---|
| <b>Land users:</b>  | – farming, mangrove and <i>Melaleuca</i> forestry, aquaculture, commercial and recreational fisheries |
| <b>Developers:</b>  | – commercial, industrial, residential, leisure facilities   |
| <b>Public bodies and agencies:</b>                        | – coastal and environmental protection  |
|   | – drainage boards   |
|   | – waste disposal  |
|   | – public health   |
|   | – water supply and quality  |
| <b>Civil engineers:</b>                                   | – land reclamation  |
|   | – drainage and flood relief   |
|   | – coastal protection  |
|   | – harbour and estuarine works   |
|   | – earthworks, dredging  |
|   | – steel and concrete structures, pipelines  |
|   | – soft engineering  |
| <b>Policy-makers, planners and regulatory authorities</b> | – management and conservation of coastal areas and wetlands   |
|   | – environmental law   |
|   | – land reclamation and drainage   |
| <b>Agronomists and extension workers</b>                  | – tropical wetland crops  |
|   | – grassland   |
|   | – management of fen, marsh and swamp soils  |
| <b>Consultants</b>  | – environmental impact  |
|   | – management and conservation of coasts and wetland resources   |
| <b>Teachers, students and researchers</b>                 | – coastal and wetland management and conservation   |
|   | – soils, ecology and land use   |
|   | – policy studies  |

## **How does the system work?**

The system works by question and answer. Because many and varied users have different needs and bring with them a wide range of technical expertise and experience, many ways into the knowledge are provided.

Questions are the keys to the system, seeking either to define the information you need or to elicit specific information from you about the site or area of interest. Questions and answers are presented at various technical levels so that you can give and take information at whatever technical level is appropriate.

In giving answers, the expert's confidence depends on the quality of the data that you provide and on the difficulty of the question. For some questions there is a lot of relevant information and experience, for others only theory.

The expert system shows the reasoning behind the answers, the data considered and the degree of confidence in the diagnosis. The whole knowledge base and the rules for decision making are accessible.

The expert system can be updated and improved with new and better information. Hooks are provided for you to add your own knowledge to the system.

## **Your responsibility**

The quality of the output depends on the quality of your input. It is your responsibility to check the accuracy of the data that you enter.

The knowledge on which the system is based is stated explicitly and is the best current information and current best practice. The system is continually updated and you should ensure that you are using the most recent update and that the assumptions and data used are appropriate to your own particular application.

## **Which part of the system do you need?**

- Background information about acid sulphate soils...
- Soil identification keys...
- Field tests...
- Qualitative assessment of acid sulphate hazards...
- Definitions...

### **... Use ASS IDENTIKIT**

Quantitative assessment of the acid sulphate hazard:

- Soil survey...
- Laboratory measurements and methods...
- Calculations...

### **... Use ASSESS**

Management options:

- Engineering design...
- Management programs for fisheries, grazing, oil palm, pineapple, rice etc...

### **... Use ASSMAN**

## What are acid sulphate soils?

Acid sulphate soils are the nastiest soils in the world. They generate sulphuric acid that leaks into drainage and floodwaters, dissolves aluminium, heavy metals and arsenic from soil minerals, and corrodes steel and concrete.

Dissolved aluminium kills vegetation and aquatic life, causing massive fish kills<sup>3</sup> for example. In sub-lethal doses it stunts growth, and breaks down defences against disease<sup>5</sup>. High concentrations of dissolved heavy metals are also toxic, and heavy deposits of ochre can choke vegetation and block drains.

Generations of people depending on these soils have been impoverished and, probably, poisoned by their drinking water.



## What are the hazards?

Different hazards are posed by different kinds of acid sulphate soil (sulphidic or potential acid sulphate soils, raw acid sulphate soils and ripe acid sulphate soils). There are hazards on site, and hazards from acid drainage and floodwaters.

The most severe hazards are presented by raw acid sulphate soils that are actively generating sulphuric acid and which have further reserves of acidity in the form of oxidisable sulphides.

In the case of sulphidic soils, the hazards associated with acidity are potential hazards and will not materialise unless the soils are drained or excavated. However, sulphidic soils are commonly saline, and sulphidic clays and peats are also unripe (soft and of low bearing capacity).

## On-site hazards

Soil pH is less than 4 and may be as low as 2. This extreme acidity is damaging in its own right and, also, brings into solution toxic concentrations of aluminium, heavy metals and arsenic.

Under these conditions, soil micro-organisms are decimated (Nguyen Thi Than Phung and Phan Lieu 1993) which restricts the release of plant nutrients from decomposition of organic matter; natural vegetation is limited; the range of crops that can be grown is severely restricted and yields are low (Dent 1986).

Acidity may be corrected by liming but raw acid sulphate soils may require more than 100 tonnes of limestone per hectare and this must be incorporated throughout the normal rooting depth of the crop. Unless limestone is available locally, it is not practicable to apply anything like the required amount.

Flooding, for rice cultivation, usually eliminates acidity but iron toxicity and possibly sulphide or other toxicities may then occur.

In addition to chemical hazards, there are physical limitations. Root development is restricted so water reserves in the subsoil are not available to the crop. Soil ripening is arrested, so the soil remains soft and saline at shallow depth.

Engineering hazards include corrosion of steel and concrete, low bearing strength and uneven subsidence, very high permeability of undisturbed muds but low permeability and slow consolidation of reworked material, and the blockage of drains by ochre.

## Hazards of drainage and floodwaters

Drainage and floodwaters from acid sulphate soils can carry hazards far from the original source of acidity. Very high levels of acidity, dissolved iron and aluminium can appear in drainage waters and low levels of dissolved oxygen have been reported:

Table 1 pH and dissolved iron and aluminium in drainage waters in the Mekong Delta, Vietnam (from Ni 1984)

Place	Al (mol m <sup>-3</sup> )	Fe (mol m <sup>-3</sup> )	pH
Hoa An	8.89	0.75	-
Tan Lap	6.30	0.45	3.0
Extension farm TG	3.11	0.13	3.2
Lang Bien	10.00	5.72	2.8
Min Hai	8.52	3.28	2.5
Cuu Long	5.39	1.9	3.6

Fish kills occur when fish are trapped by a slug of acid water. Shellfish and worms are probably even more seriously affected because they are unable to escape. Death is caused by damage to the gills by both acid and aluminium (Sammut *et al.*

1996). Clogging of gills by iron precipitation has also been reported in aquaculture (Simpson and Pedini 1983).

Acid-induced skin damage has been implicated in ulcerative diseases of fish (Callinan *et al.* 1993, 1995).

Water bodies affected by repeated acid sulphate flushes become dominated by very few, acid-tolerant species such as reeds, water lilies and *Eleocharis*. The degradation of the habitat reduces its productivity, particularly in respect of spawning and nursery grounds for fisheries.

In some places, surface water or shallow groundwater draining from acid sulphate soils is the only source of potable water and irrigation water in the dry season. This water is commonly polluted by heavy metals and arsenic, and always contains concentration of aluminium (Table 1) far in excess of standards for drinking water which are set at concentrations from 5 to 1450 µg/litre ( $2 \times 10^{-4}$  to  $6 \times 10^{-2}$  mol Al m<sup>-3</sup>) (Sittig 1994).

## **Where and under what circumstances are acid sulphate soils found?**

The hazard presented by acid sulphate soils is magnified by their location - mostly in coastal wetlands where development pressures are intense.

Sulphuric acid is produced by the drainage of sulphidic mud that accumulates in tidal soils under mangrove, or salt marsh vegetation. Any tidal swamp or wetland that was once tidal is at risk. For example, peat that has been flooded by brackish tidewater may be sulphidic.

Acid sulphate soils are also associated with brackish lake and lagoon sediments, for example the extensive *Litorina* deposits that fringe the Baltic Sea; with the mining of sulphidic ores and coal; and with the excavation of sulphidic clay.

Some inland marshes subject to saline seepage also develop acid sulphate soils.

Sulphidic materials are potential acid sulphate soils. Drainage or excavation introduces oxygen into these materials and this oxygen oxidizes sulphides to sulphuric acid. Then the potential acid sulphate soil becomes an active acid sulphate soil.

## How extensive are acid sulphate soils?

Soil survey data are sketchy for most parts of the world but aggregation of the most recent estimates suggests a total of 24 million hectares world-wide where acid sulphate soils and potential acid sulphate soils are a dominant feature of the landscape. Probably there is at least as much again buried beneath peat and non-sulphidic alluvium but which might be exposed by deep drainage or excavations.

**Table 2: reported extent of acid sulphate soils, estimates in thousands of hectares**

Australia	3000	Galloway; Australian draft nat. strategy 1997
Bangladesh	226	Rahman 1990
Brazil	1111	FAO 1974
Cameroon	250	Kawalec 1973
China	100	Gong Zi Tong 1990
Central America	650	FAO 1974
Finland	163/380	Palko 1988/Puustinen <i>et al.</i> 1994
Gabon	348	FAO 1974
Gambia	160	Dent 1994
	+30	(old acid sulphate soils)
Ghana/Togo/Benin	150	Kawalec 1973
Guinea	825	"
Guinea-Bissau	1175	"
Guyanas (3)	1246	Brinkman and Pons 1968 (Mara Deposits)
India	293	Dent 1990
Indonesia	4109	Soekardi 1990
Kampuchia	211	Dent 1990
Kenya	<100	Sombroek <i>et al.</i> 1980
Liberia	30	Reed 1951
Madagascar	528	FAO 1974
Malaysia	657	Dent 1990
Mauritania	131	FAO 1974
Mozambique	168	"
Myanmar	1200	estimate
Nigeria	1000	estimate
North America	100	estimate
Philippines	<500	Brinkman + Singh 1982
Senegal	600	Khouma and Toue 1982
Sierra Leone	?	
Sweden	140	Oborn 1994
Sri Lanka	20	Dent 1990
Thailand	1500	Krishnamra 1990
Uruguay	37	FAO 1974
Venezuela	2000	van Breman 1980
Vietnam	2140	Bui Quang Tran 1990

## How, why and where do sulphides accumulate in sulphidic (potential acid sulphate) soils?

- 1) The source of sulphides (sulfides) is dissolved sulphate (sulfate) which is abundant in seawater. Other sources of sulphate include volcanoes and springs in volcanic districts, sulphate-rich sedimentary rocks and waters draining from these, acid sulphate mine drainage waters and atmospheric pollution from burning coal and oil and smelting sulphidic ores.
- 2) In waterlogged soils that are rich in organic matter, bacteria decomposing the organic matter convert sulphate to sulphides. The most stable end product of these processes is pyrite ( $\text{FeS}_2$ ).
- 3) Sulphides may be found in sand, mud (clay) and peat but sulphidic clays are most extensive and usually have the greatest sulphide contents. The sulphides that accumulate *in situ* are found within decaying organic material. Some sulphide, especially pyrite, may be inherited from the erosion and redistribution of earlier sulphidic soils and sediments.
- 4) Sulphides accumulate and are stable only in waterlogged conditions. Where dissolved oxygen is present, sulphides do not accumulate and any sulphide present is converted back to  $\text{SO}_2$  gas, sulphate or sulphuric acid.

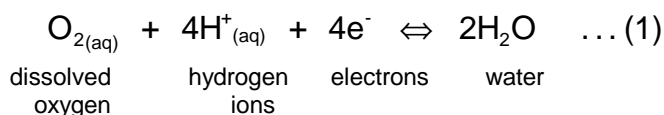
## Conditions and process of accumulation of sulphides

The essential conditions for accumulation of sulphides are:

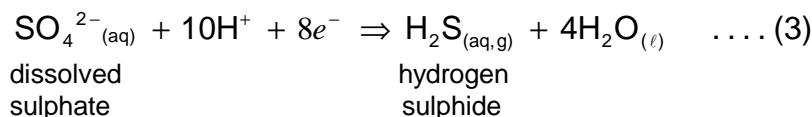
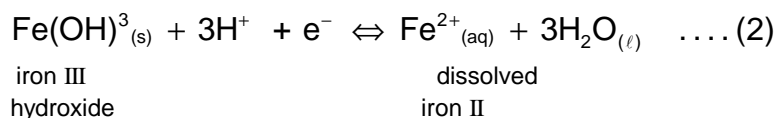
- **an anaerobic environment** provided by waterlogged soils and sediments rich in organic matter;
- **a source of dissolved sulphate**, usually brackish tidewater;
- **a source of organic matter**, usually lush vegetation;
- **a source of iron** from the soil or sediment.

## Redox (reduction - oxidation) reactions

Energy is released by the breakdown of organic matter as a stream of electrons that flows from the organic molecules to a sink. Under aerobic conditions, the ultimate electron sink is oxygen which is said to be reduced to water:



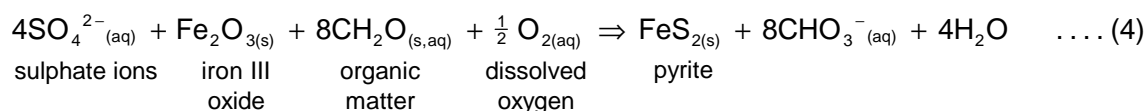
In the absence of oxygen, other electron sinks are sought. Two of the biggest are iron oxides/hydroxides (which are reduced to  $\text{Fe}^{2+}$ ) and sulphate ions (which are reduced to sulphides):



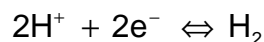
A range of reduced sulphur species is encountered including  $\text{H}_2\text{S}$  (the pervading smell of tidal swamp), elemental sulphur (seen as a milky surface deposit), and dissolved sulphide and polysulphide ions.

Pyrite ( $\text{FeS}_2$ ) is the most common and most stable end product of sulphate reduction but other sulphides found in soils and sediments include the black monosulphide of iron ( $\text{FeS}$ ), greigite ( $\text{Fe}_2\text{S}_3$ ) and organic sulphides.

The formation of pyrite from dissolved sulphate may be summarised as:



The redox potential of the system in respect of unsatisfied negative charge from electrons can be measured by inserting a platinum electrode connected to a mv meter. Relative to the potential of hydrogen in 1 mol acid solution, which is fixed at zero mv:



- reduction of oxygen (equation 1) at pH 7 occurs at +1230 mv;
- reduction of iron (equation 2) at pH 7 occurs at -180 mv;
- reduction of sulphate (equation 3) at pH 7 occurs at -220 mv.

Field measurement of redox potential using a platinum electrode is a useful way to assess the likelihood of iron and sulphate reduction or oxidation (Figure 6.1).

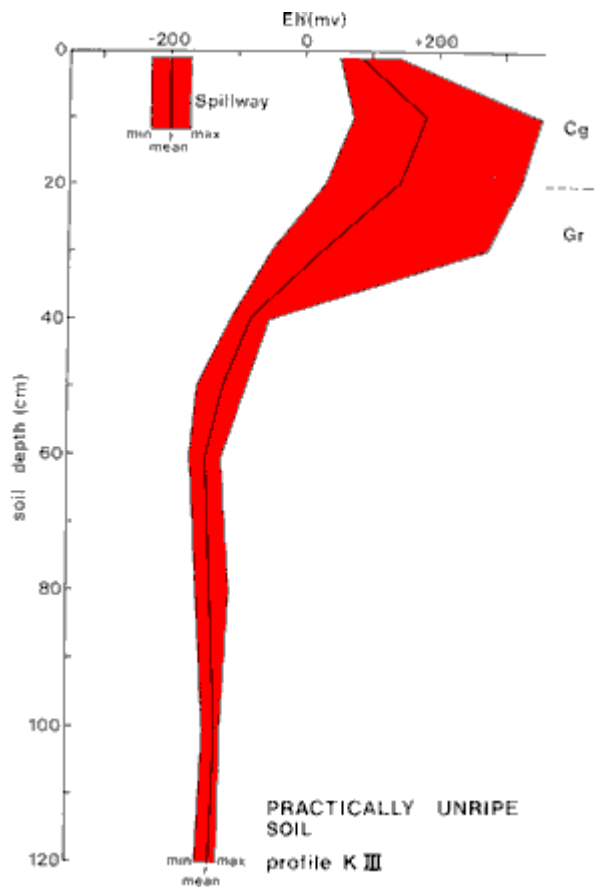


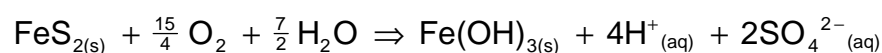
Figure 2

Eh profile of a sulphidic clay. Strongly reducing conditions prevail below 40 cm. Local variation of Eh within the root network of mangrove vegetation in the upper 40 cm.

### What is the process of acid generation?

Sulphides (sulfides) are stable under waterlogged (anaerobic) conditions but when oxygen is introduced into the system, these sulphides are oxidised to sulphuric acid.

Overall, the oxidation of pyrite (the most common sulphide) can be represented by the equation:



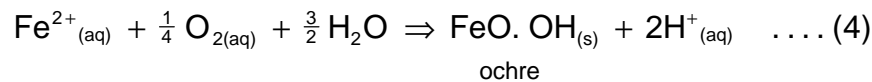
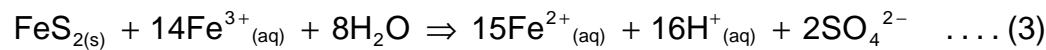
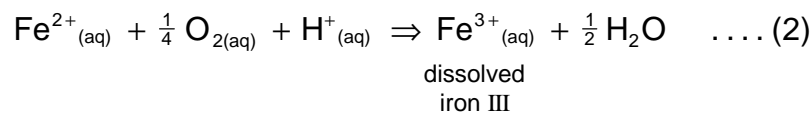
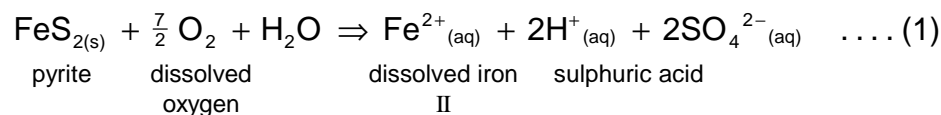
pyrite      oxygen                              ochre              sulphuric acid

4 mol (+) acid is generated from complete oxidation of 1 mol FeS<sub>2</sub>.

Chemical oxidation of pyrite is slow but the reaction is mediated by iron-oxidising bacteria, in particular *Thiobacillus ferrooxidans*, so that the optimum conditions for sulphide oxidation are the optimum conditions for *Thiobacillus ferrooxidans*, namely oxygen concentration >0.01 Mole fraction (1%); temperature 5-55°C, optimally 30°C; and pH 1.5-5.0, optimally 3.2 (Jaynes *et al.* 1984).

### The chemistry of acid generation

The several steps in acid generation can be summarised by a sequence of reactions: oxidation of pyrite to iron II and sulphate, oxidation of some iron II to iron III, supercharged oxidation of pyrite by iron III and, finally, oxidation of the remaining iron II to ochre:



Oxidation of pyrite by oxygen (equation 1) is slow. Fe<sup>3+</sup> is a more effective oxidant and oxidation of pyrite by Fe<sup>3+</sup> (equation 3) only much faster than the reaction of pyrite with oxygen but, also, much faster than the oxidation of Fe<sup>2+</sup> to Fe<sup>3+</sup> (equation 2). So the iron II to iron III transformation is, potentially, the rate-limiting step (Singer and Stumm 1970, Moses *et al.* 1987, 1991). However, generation of Fe<sup>3+</sup> is mediated by iron-oxidising bacteria, particularly *Thiobacillus ferrooxidans* (Temple and Colmer 1951, Wakao *et al.* 1982, 1983, 1984). Equation 3 depends on the pH being low enough for Fe<sup>3+</sup> to remain soluble (pH < 4), otherwise it is precipitated as ochre (equation 4), so rapid oxidation of pyrite only takes place at very low pH.

The different stages of oxidation do not necessarily occur at exactly the same point. Field and micromorphological examination of acid sulphate soils shows a distinct separation of pyrite and its oxidation products ochre, jarosite and gypsum.

Under a climate with pronounced wet and dry seasons, oxidation of pyrite may continue after flooding using the oxidising capacity stored as iron III oxide during the dry season.



## How much acid can be produced?

Total acidity is expressed in moles of acid per cubic metre ( $\text{mol (+) m}^{-3}$ ) and this may be converted to any other desired measure (e.g. tonnes of lime required to neutralise the acid).

In acid sulphate soils, total acidity (or total actual acidity TAA) ranges from 100 to 1000  $\text{mol (+) m}^{-3}$ . In terms of lime requirement this is equivalent to 5-50 kg  $\text{CaCO}_3$  or, approximately 5-50 tonnes  $\text{CaCO}_3 \text{ ha}^{-1}$  for each 10 cm of soil thickness.

For any given pH value, total acidity is very much greater in clays and peats than in sands.

Total potential acidity is TAA plus the reserves of acidity still held as oxidisable sulphides which will be released upon oxidation (TSA). In sulphidic soils and raw acid sulphate soils, TSA ranges between 200 and 5300  $\text{mol H}^+ \text{ m}^{-3}$ . In terms of lime requirement, this is equivalent to between 10 and 265 kg  $\text{CaCO}_3 \text{ m}^{-3}$  or, approximately, 10 to 265 t  $\text{CaCO}_3 \text{ ha}^{-1}$  for a layer only 10 cm thick.

That is a lot of acid. However, the rate at which this acid is generated and, maybe, released into the environment depends on management.

## The Identikit Decision Tree

The main display of the program consists of a hierarchical decision tree. A description of the site under study is built up by selecting (with a double-click) one of the mutually-exclusive options.

Shown below are the probability ratings assigned to each of the possible options in the description of a site, with explanations of why the ratings have been given, and why each characteristic of the site is important to the diagnosis of an Acid Sulphate Soil.

### Land

Land surface form can be read from a contoured topographic map. If the land is flat, no more than one contour will cross it.

#### Is the land surface:

- Quite flat? rating 0.0
- Not flat? rating -0.5

Nearly all acid sulphate soils occur in wetlands because sulphides can accumulate only under waterlogging. If the land is not flat extensive wetland is unlikely so the probability of acid sulphate soils is low.

However, acid sulphate soils do also develop in mine spoil and excavated sulphidic sediments that have remained anoxic until exposed by mining or excavation. These materials occur on any kind of land surface.

Height above mean sea level can be read from a topographic map, but local knowledge of tidal variation is needed.

**Is the land:**

- < 3 metres above high water spring tides? rating +0.2
- > 3 metres above high water spring tides? rating -0.5

Nearly all acid sulphate soils occur in Recent marine or estuarine sediments. Except in areas of recent uplift, these sediments are only found at heights up to 3 metres above high water spring tides. Recent uplift has occurred in island arcs and in Fennoscandia where extensive areas of sulphidic Litorina sediments fringing the Baltic Sea have been uplifted as much as 100 metres.

However, not all land below 3 metres is Recent marine or estuarine sediment.

**Is the site:**

- tidally flooded, or known to be reclaimed tidal land? Rating +0.3
- Flooded at least annually rating +0.2
- flooded less often than annually? rating +0.1
- never flooded? Rating -0.5

Sulphides accumulate under tidal flooding but all tidal land is not strongly sulphidic.

Land that is flooded regularly, especially if it is tidally influenced may be former tidal land, such as an estuarine terrace that may carry acid sulphate soils or sulphidic material in the subsoil.

Land that is flooded occasionally may possibly be reclaimed tidal land or a marine or estuarine terrace. However, there may be many other reasons for occasional flooding.

Land that is never flooded cannot accumulate sulphides. However, acid sulphate soils can develop on mine spoil and excavated sulphidic sediments that have remained anoxic until disturbed by mining or excavation. Such sites are not necessarily flooded.

**Is the environment, or land system:**

- Riverine, with fresh water flooding? rating +0.2
- Estuarine or deltaic sheltered brackish tidal waters, flooded at least seasonally? rating +0.4
- Marine, open coastline, with tidal flooding? rating +0.3
- Not wetland? rating -0.5

**If the land system is riverine, is the land pattern:**

- An alluvial fan? rating -0.5
- A terrace plain? rating +0.2
- A floodplain? rating +0.3

**... and is the land facet:**

- Terrace flats? rating +0.2
- A terrace swamp? rating -0.5
- A backswamp rating +0.3
- An ox-bow or lake bed? rating +0.3
- A levee? rating +0.2
- A channel, bar or scroll plain rating -0.3
- None of these? rating 0.0

**Riverine environments**

The sulphate content of fresh waters is low so significant amounts of sulphides do not accumulate, even in waterlogged environments. However, through changes in relative sea level or the progradation of the coastline land that was once tidal with brackish water flooding may become riverine with freshwater flooding and sulphidic sediments may be buried by peat or non-sulphidic alluvium.

The scoring of the different land patterns and land facets within a riverine system reflects the likelihood of buried material.

**If the land system is estuarine or deltaic, is the land pattern:**

- A terrace plain? rating +0.4
- A flood plain? rating +0.5

**... and is the land facet:**

- A terrace flat? rating +0.4
- A terrace scarp? rating +0.3
- A backswamp or backplain? rating +0.6

- A levee? rating +0.4
- A creek channel, cut-off or tidal mudflats? rating +0.4
- A beach ridge? rating -0.2
- None of these? rating 0.0

**Estuarine environments**

Sediments settling in sheltered estuarine waters commonly contain a significant amount of pyrite transported from elsewhere in the marine environment.

Brackish tidewater contains dissolved sulphate and in sheltered waters lush vegetation quickly colonises soft muds, fuelling sulphate reduction. The highest sulphide contents are found in this environment. The scoring of the different land features reflects the favourability of the different facets of sulphide accumulation.

Terrace scarps and levees are well drained and may have little sulphide, certainly in the topsoil. Also, especially in temperate regions, levees may contain abundant calcium carbonate which will neutralise acidity, so they are scored lower than backswamps,

Beach ridges within deltas commonly contain shell or coral and also have low sulphide contents.

**If the land system is marine, is the land pattern:**

- A dunefield? rating -0.2
- A beach ridge plain? rating -0.2
- A chenier plain? rating +0.3
- A marine plain? rating +0.3
- A marine terrace? rating +0.3

**... and is the land facet:**

- A dune, beach, beach ridge or sandbar? rating -0.7
- A swale? rating +0.3
- Tidal mudflats or creek channels? rating +0.4
- Plain, saltings or swamp? rating +0.5
- None of these? rating 0.0

**Marine environments**

Tidewater contains abundant sulphate, so sulphate reduction is active in marine sediments that contain abundant organic matter and where there is lush vegetation.

However, high sulphide contents only occur where mud accretes slowly. Many open coasts are subject to alleuviation of sedimentation and erosion so scores are lower than for sheltered estuarine and deltaic environments.

Dunes and beach ridges are well drained, so do not accumulate sulphides.

## Water

Drainage and floodwaters often provide the first indications of acid sulphate soils.

**Look at the water draining from the area. Is it:**

- Always black or dark brown (looks like tea)? rating 0.0
- Always muddy? rating 0.0
- Periodically milky? rating +0.4
- Periodically red, carrying an oily sheen or scum or depositing gelatinous or curdy ochre? rating +0.4
- Periodically crystal clear or blue-green? rating +0.6
- None of these rating 0.0

Freshwater swamps often produce very acid drainage water, typically the colour of tea because of its dissolved organic matter. This is not related to acid sulphate soils. These swamps may or may not overlie potential acid sulphate soils so black or brown drainage waters have no diagnostic significance and are rated 0.0.

Where acid sulphate drainage waters are neutralised by shell or coral fragments in the soil, or by agricultural lime, gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) is produced. Large amounts make the water cloudy or even milky.

Gypsum also indicates substantial neutralising capacity in the system so rating is limited to +0.3.

The oxidation of sulphides produces water that is both acid and rich in dissolved iron and sulphate. The dissolved iron is further oxidised by bacteria in drainage waters, producing an iridescent, oil-looking sheen on the water surface and, sometimes, gelatinous or curdy masses of ochre.

However, iron-rich waters are also characteristic of bogs when iron is dissolved by reduction processes unconnected with acid sulphate soils so the rating of iron-rich waters is limited to +0.4.

The extreme acidity associated with acid sulphate soils dissolves aluminium from soil minerals. Aluminium flocculates suspended clay, making drainage waters unusually clear - often seen when heavy rains flush dissolved aluminium out of acid sulphate soils into drains, streams and creeks.

Ponded waters often assume a blue-green colour which may be related to their

clarity but, also, to dissolved iron sulphate.

These are both very strong indications of acid sulphate soils and are rated +0.6.

## Taste

Excluding drainage waters that are the colour of tea, **does the water taste:**

- Fresh or sweet? rating 0.0
- Salt or brackish? rating +0.3
- Sour? rating +0.6



If there is any risk of biological contamination, the water should be boiled for 15 minutes and allowed to cool before tasting.

Sweet water has no diagnostic value in its own right. The environment is not, at present, either accumulating sulphides or producing a lot of acid. Potential acid sulphate soils may or may not be present. Rating 0.0.

Salt or brackish floodwaters indicate an environment of sulphide accumulation so rating is +0.3.

Acid sulphate soils produce very acid drainage water. If tastes acid (sour rather than salty) and also makes the eyes smart! Rating +0.6.

Raw acid sulphate soils are saline as well as acid but sulphate salinity cannot be detected by taste.

## Water analysis

Analysis of drainage water floodwater or groundwater (from a well or borehole) can give a more precise indication of any acid sulphate problem. However acid sulphate episodes in surface waters may be brief and may escape detection by random (or even by systematically collected) samples.

Is the **pH** of the water:

- Greater than 4.9? rating 0.0
- Between 3.5 and 4.9? rating +0.3
- Below 3.5? rating + 0.8

pH alone is not a good indicator of acid sulphate drainage and floodwater because pH depends not only on the amount of acid brought into the system but also the buffer capacity of the receiving system and dilution effects.

At pH values greater than 4.9 there are no problems of soluble aluminium, so pH values greater than 4.9 are discounted. pH values between 3.5 and 4.9 may be caused by acid sulphate soils and are rated +0.5. The lower the pH value, the greater the likelihood that it is caused by acid sulphate soil or acid sulphate mine drainage.

pH values less than 3.5 are almost certainly associated with acid sulphate soils or mine drainage and are rated +0.8.

No negative ratings are allocated because of the episodic nature of acid sulphate drainage.

**Is the conductivity greater than 0.5 mS cm<sup>-1</sup> AND the ratio of chloride (Cl<sup>-</sup>) to sulphate (SO<sub>4</sub><sup>2-</sup>):**

- 6 or greater? rating 0.0
- Between 4 and 6? rating +0.3
- Less than 4? rating +0.5

The chloride (Cl<sup>-</sup>) to sulphate (SO<sub>4</sub><sup>2-</sup>) ratio in seawater is 7. Oxidation of sulphides to sulphate in acid sulphate soils (and also in sulphidic ores and mine spoil) (see generation of acid) generates sulphate that will narrow this chloride to sulphate ratio.

Providing that the conductivity of the drainage water is greater than 0.5 mS cm<sup>-1</sup>, a substantial narrowing of the chloride:sulphate ratio indicates a significant addition of sulphate that is most likely to come from acid sulphate soils (or from mine drainage, sulphate-rich sediments or hot springs). A chloride:sulphate rate between 4 and 6 is rated +0.3, and a ratio less than 3 is rated +0.5.

Waters of low salinity (conductivity less than 0.5 mS cm<sup>-1</sup>) are not considered since a small addition of sulphate, for instance from atmospheric pollution, would change the chloride:sulphate ratio.

**Is the aluminium content:**

- Less than 0.1 mg/litre (<4 m mol m<sup>-3</sup>) rating 0.0
- Between 0.1 and 0.5 mg/litre (4-20 m mol m<sup>-3</sup>) rating +0.5
- More than 0.5 mg/litre (>20 m mol m<sup>-3</sup>) rating +0.8

Water of high aluminium content is one of the main hazards of acid sulphate soil. However, leaching of aluminium is usually episodic so that the absence of a high aluminium value in a sample does not necessarily indicate the absence of acid sulphate soils. Therefore negative ratings are not applied.

At present, there is little systematic experience of drainwater and floodwater aluminium values. Therefore the allocated ratings of  $>0.1 \text{ mg/l (mol m}^{-3}\text{)} = +0.5$  and  $>0.5 \text{ mg/l (mol m}^{-3}\text{)} = +0.8$  are provisional.

### Is the iron content of the water:

- Less than 10 mg/litre? ( $<0.2 \text{ mol m}^{-3}$ )                      rating 0.0
- Between 10 and 50 mg/litre? ( $0.2\text{-}1 \text{ mol m}^{-3}$ )                      rating +0.5
- More than 50 mg/litre? ( $>1 \text{ mol m}^{-3}$ )                      rating +0.8

Although iron-rich drainage water is one of the most characteristic features of acid sulphate soils it can arise in other ways. Even though a lot of iron may be released by oxidation of pyrite, much of the accompanying acidity may be neutralised within the soil. Indeed ochre deposition indicates neutralisation of most of the acidity. Rarely, under severely acid conditions, lemon yellow iron sulphate is precipitated.

Therefore, only very high dissolved iron contents are rated strongly positive:

10-50 mg/l ( $0.2\text{-}1 \text{ mol m}^{-3}$ ) = +0.5  
>50 mg/l ( $>1 \text{ mol m}^{-3}$ ) = +0.8

## Biology

### Aquatic life

- Is aquatic life varied and healthy?                      rating 0.0
- Are there only a few species of higher plants, fish and invertebrates?                      rating +0.3
- Do fish periodically exhibit ulcerative lesions (red spot) or suffer periodic kills?                      rating +0.5

Aquatic life is a sensitive indicator of water quality and may be severely affected by even brief episodes of acidity. Extreme conditions such as acid sulphate drainage or floodwaters usually lead to the dominance of only a few tolerant species that may, however, thrive so at first sight the system may appear healthy.

A strong rating is given to the most severe indications of acid sulphate waters (fish kills and red spots) but the rating is limited to +0.5 because these symptoms may have other causes.

No negative ratings are applied since varied aquatic life is associated with potential acid sulphate soils that have not been disturbed.

## Vegetation

### Is the site:

- |   |             |
|---|-------------|
| - A tidal sand flat?                                | rating +0.2 |
| - A tidal mud flat or lagoon?                       | rating +0.3 |
| - Mangrove swamp?                                   | rating +0.5 |
| - Salt marsh?                                       | rating +0.4 |
| - Brackish reedswamp and meres?                     | rating +0.4 |
| - Freshwater reedswamp or paperbark swamp and meres | rating +0.3 |
| - Other wetland?                                    | rating 0.0  |
| - Reclaimed land, formerly tidal?                   | rating +0.4 |
| - Reclaimed land, formerly freshwater flooding?     | rating +0.3 |
| - Scalds (bare or burnt patches) in reclaimed land? | rating +0.6 |
| - Not wetland?                                      | rating -0.3 |

Vegetation is a sensitive indicator of present site conditions. It defines more localised sites than surface waters and broad landforms, and it picks out areas of active acid sulphate soil sharply if acid sulphate layers occur within the normal root zone (scalds are rated +0.6).

However, vegetation provides no specific clue to potential acid sulphate soils, neither the content of sulphides nor the magnitude of neutralising capacity. The broad vegetation groups listed here are rated as indicators of sulphide accumulation (in tidal wetland) or sulphide preservation (in freshwater wetland).

With local knowledge of ecology and landscape development and with local knowledge of soils, much stronger ratings can be given than those in the universal site key.

## Soil

Soil examination provides the definitive evidence of acid sulphate soil and, also, the most localised. This is an advantage and a limitation since soils may vary significantly from point to point - for this reason, with two exceptions, negative ratings are not assigned.

## Spoil

Look first for evidence in the spoil of any excavations after a few weeks exposure to the air. **Is the spoil:**

- |                                      |             |
|--------------------------------------|-------------|
| - Mottled grey and orange or red?    | rating +0.3 |
| - Grey with pale yellow mottles?     | rating +1.0 |
| - Mottled brown and grey?            | rating 0.0  |
| - Grey                               | rating 0.0  |
| - Red, yellow or brown, not mottled? | rating -0.5 |

Excavated spoil will quickly develop acidity if it contains sulphides. Straw yellow mottles of jarosite or in the most extreme cases lemon yellow iron sulphate are definitive. These minerals only develop in the severe acidity associated with oxidation of sulphides and are rated +1.0.

Oxidation of pyrite also releases iron which is deposited as crusts, coatings and coarse mottles of ochre, usually where the acid solution is neutralised.

However, red dish brown or orange mottles may develop independently of acid sulphate conditions so their rating is limited to +0.3.

Homogeneous red, yellow or brown colours indicate a well drained soil which cannot contain sulphides. Usually these soils will be in upland areas, easy to distinguish from wetlands that may contain acid sulphate soils, so they are rated -0.5.

## Soil observations

Examine the soil in ditch sections, pits or auger borings, especially the subsoil and the deep subsoil below the watertable. **Does the soil appear:**

- |   |             |
|---|-------------|
| - Red, yellow or brown without obvious mottles?         | rating -0.5 |
| - Grey without mottles or mottled brown                 | rating 0.0  |
| - Dark grey or dark greenish grey or mottled black      | rating +0.4 |
| - Grey or dark grey, blackening on exposure to the air? | rating +0.6 |
| - Grey with straw yellow mottles or coatings            | rating +1.0 |
| - Pinkish brown (like chestnut purée)                   | rating +0.6 |

- Strongly mottled red and strong brown and grey rating +0.3
- Flecked with translucent, needle-like crystals of gypsum or bearing grubby grey gypsum deposition in fissures after dry spells rating +0.4

**Straw yellow mottles or coatings of jarosite are definitive for acid sulphate soils** and are rated +1.0. However, organic-rich acid sulphate soils that remain poorly drained do not show jarosite. These soils are often a characteristic pinkish brown (the colour of chestnut purée) rated +0.6.

Acid sulphate peat rarely shows jarosite and is difficult to identify without a chemical test.

Oxidation of pyrite releases a lot of iron, some of which is deposited in the soil as mottles, coatings, pipes and nodules of ochre. This is ultimately transformed to orange red goethite and dark red haematite. Jarosite too is gradually transformed to iron oxide.

Ripe acid sulphate soils are conspicuously mottled red and yellowish red but similar mottling can arise in other ways so the rating is limited to +0.3.

Gypsum is produced by the neutralisation of sulphuric acid by lime - either shell, coral or agricultural lime. It may be the only visible indication of an acid sulphate peat.

The rating is +0.4. Although gypsum is common in arid soils, these soils are also alkaline so easily distinguished from acid sulphate soils by a very high pH.

Dull grey colours are characteristic of waterlogged soils. Dark greenish grey and dark grey colours indicate conditions in which sulphides are formed if there is a supply of sulphate from tidewater or brackish springwater. Black mottling or an inky black colour usually indicates iron monosulphide (FeS).

Conditions for sulphide accumulation do not indicate the amount of sulphides present nor the likelihood of acid-neutralising minerals so the rating is limited to +0.4.

An unstable soil colour, particularly blackening within a few seconds or minutes of exposure to the air, indicates a very high content of oxidisable sulphides and is

rated +0.6.

## Smell

### Does the soil:

- Stink of bad eggs (hydrogen sulphide)? rating +0.3
- Not stink? rating 0.0

A smell of bad eggs (hydrogen sulphide) indicates strong reduction of sulphate to sulphide. So, at present, sulphides are accumulating. However, it does not indicate the sulphide content of the soil nor the likelihood of neutralising minerals.

Also, different people have different senses of smell so the test is only indicative and the rating limited to +0.3.

## Parent material

### Is the soil parent material:

- Rich in shell, coral or lime? rating -0.5
- Not calcareous? rating 0.0

Parent material rich in some form of lime will neutralise the acidity produced by oxidation of sulphides. Coarse-textured parent materials like shell and coral sand do not support luxuriant vegetation so their sulphide content is always low and they are rated -0.5. This negative rating is applied because these calcareous parent materials are usually obviously related to landforms such as beach ridges and levees that can be used to extend point observations.

The negative rating does not apply to non-calcareous sands. Although their sulphide content is usually low, they have no neutralising capacity so they may generate severe (if short-lived) sulphate acidity if they are drained, dredged or excavated.

Shallow-water marl deposits may be overlain by sulphidic mud, gyttja or peat. In such cases, Identikit's site key should be applied to each contrasting soil layer individually.

## Field Tests

Some very simple field tests are useful to confirm the presence of acid sulphate soils and provide a qualitative indication of the severity of the hazard.

## pH

Test the soil pH with a pH meter (check the batteries and calibrate the instrument against an uncontaminated standard) or use a MERCK/BDH pH indicator strip.

### Is the pH of any layer:

- Below 3.6? rating +0.5
- Between 3.6 and 4.9 rating +0.3
- Greater than 4.9 rating 0.0

Extreme acidity is definitive for acid sulphate soils and a soil pH of 3.5 or less is unlikely to arise in any other way in mineral soils, though extremely acid peat may arise independently of acid sulphate conditions rating +0.5.

However, there are many kinds of acid soil with pH values between 3.6 and 4.9 so rating is restricted to +0.3.

At pH values above 4.9 there is no hazard of aluminium solubility so these are rated 0.0.

## Incubated pH

Keep a soil sample warm and moist for 3 months in a thin-walled polythene bag, not sealed. **Test the pH before and after incubation.**

- After incubation, has the pH fallen by 0.5 unit to 4 or below? rating +1.0
- Not fallen below 4? rating 0.0

Incubation stimulates the oxidation of sulphides caused by drainage or excavation. Often a positive result is achieved within a few weeks.

## Peroxide test

Take 5 g soil, place in a Pyrex or polythene beaker and add 10 cm<sup>3</sup> 30 volumes hydrogen peroxide.



**CARE!** Peroxide is a hazardous reagent - avoid splashing the skin and, especially, the eyes. Wash any splashes immediately with copious water.

Warm gently or stand in direct sunlight to complete the reaction which may be violent.

### Is the pH value:

- Below 1.5 (if the soil is sandy) or below 2.5 (if a clay or peat)? rating +0.5
- Not below 1.5-2.5 rating 0.0

Hydrogen peroxide rapidly oxidises sulphides to sulphuric acid and SO<sub>2</sub> gas, producing a dramatic fall in pH which identifies a potential acid sulphate soil or, if the soil pH is already close to 4, a raw acid sulphate soil. Usually the reaction mixture turns green if severe acidity is generated.

This test is not as reliable as the incubation test. Hydrogen peroxide also generates acidity by incomplete oxidation of organic matter to organic acids.

The pH value produced by peroxide treatment is much lower than would be produced in the soil because the only neutralising capacity that has time to act is finely-divided calcium carbonate and some of the exchangeable bases.

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# Getting Started with Identikit

## The Evaluation version

Identikit is a new type of tool, and one of its design goals is to allow it to be used effectively by professionals with widely ranging skills levels. To meet this goal, it runs under Windows, and behaves as far as possible like any other Windows application.

The full version of the program will differ from this copy in several ways:

- The illustrations will be full-colour images, not the 256-colour images in this version.
- There will be more photographs, to fill in the gaps in the coverage.
- The Bibliography will be extended and updated.
- The Help system will be more extensive.
- Video clips and animations of laboratory techniques will be included.
- The automatic report generating facilities will be extended.
- The program will include links to ASSESS and ASSMAN, the other two parts of the system.
- It will be possible to add to the decision tree, and modify its contents.

## Installation

Identikit version 0.9 occupies 19.6 Mbytes of hard disc space when unpacked. To run the program requires a PC with a 486 processor or better, and a display of at least 800 X 600 with more than 256 colours. The program will run on smaller displays, but images will be cropped to fit the smaller screen.

Identikit is a 32-bit Windows program, intended for Windows '95/'98 or Windows NT. Tests have shown that it will run under Windows 3.1 provided that the Win32S extensions (version 1.30) are installed. We do not guarantee that future versions of the program will run under Windows 3.1.

The archive should be downloaded into a temporary directory on your PC. It occupies 18 Mbytes, so may take a while to download. We ask that you contact us to get the password which allows the archive to be unpacked. This allows us to keep track of who is evaluating the package.

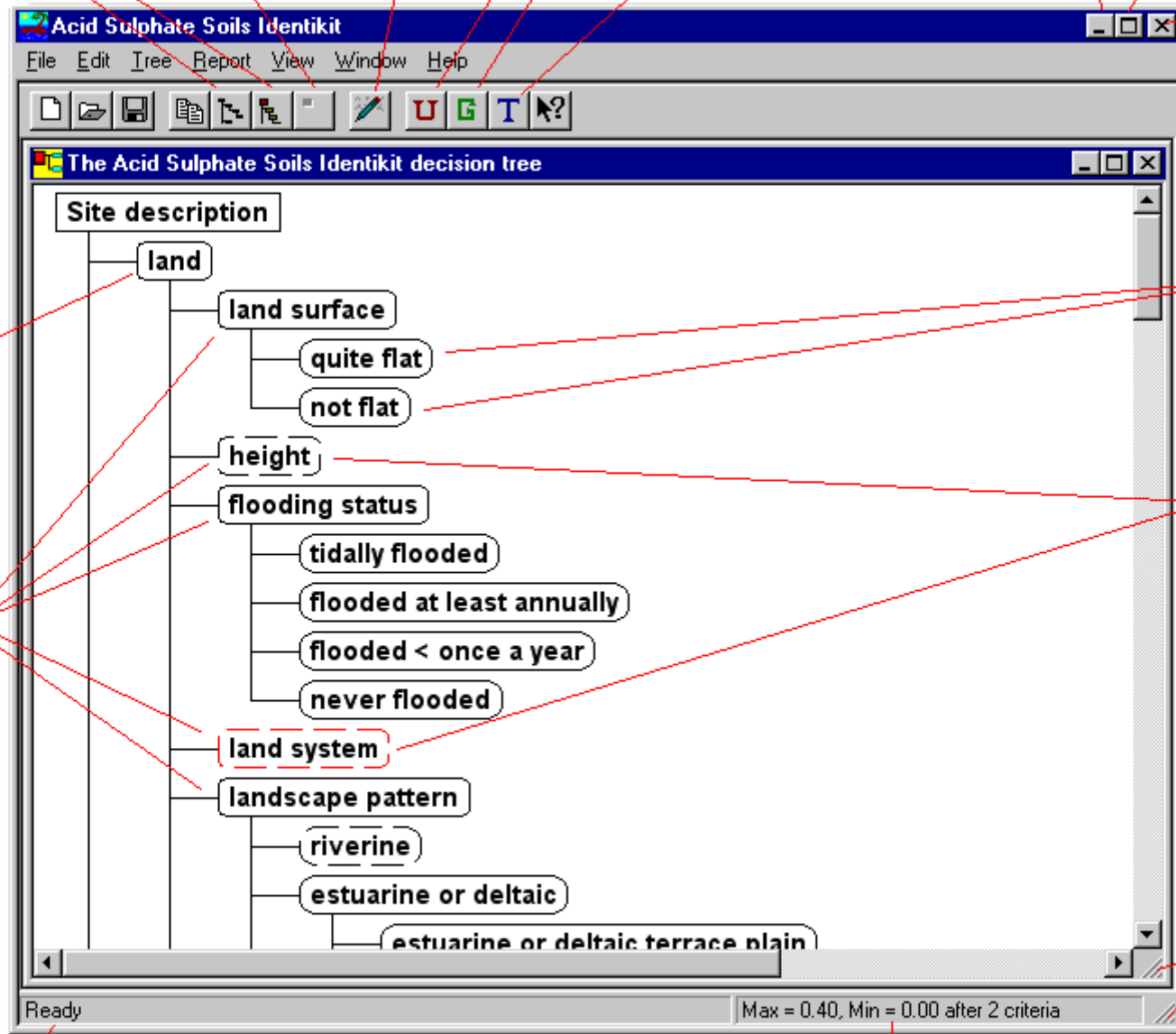
Once you have the password, the downloaded archive file can be executed, and the program installs itself in the directory of your choice. To remove Identikit from your computer, use the Control Panel's Add/Remove Programs applet in the usual way.

To run the program, double-click its icon or select it from the Start menu in the normal way.

Expand whole tree  
 Expand this branch  
 Collapse this branch  
 Report generator  
 On-line user guide  
 Glossary  
 Technical reference  
 Minimize window  
 Maximize window  
 Quit

There are 4 groups of criteria:  
 Land  
 Biology  
 Water  
 Soil

Criterion labels



Select the label which best matches your site by double-clicking the left mouse button on the label

If an option has been selected, the branch of the tree collapses and has a dashed outline

Resize window

Status information appears here

This displays the maximum and minimum probability of an Acid Sulphate Soil being present, based on the information given so far.

## Describing your site

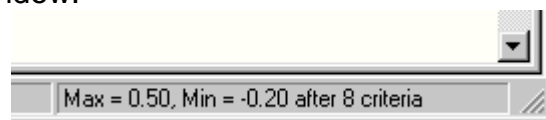
You use the Identikit program to establish whether you have an Acid Sulphate Soils problem (or potential problem) at your site. Like all identification keys, the more information you can supply, and the more accurate that information is, the more reliable the outcome.

The primary display is the Decision Tree window, which offers selectable options in a hierarchical tree structure. When the program first starts, it loads the tree, with all of its branches displayed. The tree is larger than the screen, so parts of it will only be seen if you scroll the window.

The object of the exercise is to describe your site by selecting one of the mutually-exclusive options presented for each criterion. An option is selected by double-clicking the left mouse button on the option label. In response, that branch of the tree retracts, and the tree structure is redrawn with a dashed outline to the criterion label.

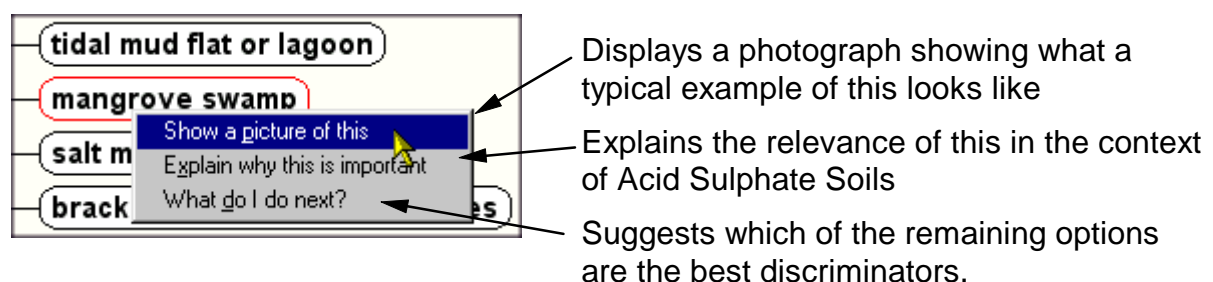
As you work down the Decision Tree, scrolling to bring the lower parts into view, the criteria change from those which a field investigator can specify by direct observation to those which require laboratory analysis. You may not have this information yet. The Golden Rule in this situation is: ***if you don't know, don't select anything***. Identikit will suggest what pieces of information are the best discriminators to use, based on the information you have supplied so far.

A running count of your progress through the Decision Tree is given at the bottom right of the Identikit window:



In the example shown above, 8 options have been selected so far, the highest positive indicator of Acid Sulphate soils scores +0.5, but one or more of the choices are slight counter-indications, with a deviation of -0.2.

Identikit has built-in support for your decision-making. Every leaf node in the tree (i.e. any text box at the end of a branch) has associated help screens, which can be called up by right-clicking on the node, as shown below:



## Reporting

Two types of text report can be generated by Identikit (only one of which can be viewed at a time). The “Summary” report lists the options you have selected so far to describe your site, with notes of any contradictory indicators that have been selected. The “What Next?” Report lists the options you have *not* yet selected, with an indication of which are the best discriminators.

A summary report can be generated from the Report menu, or by clicking the Pen button on the toolbar. This causes Identikit to scan the entire decision tree and summarise the decisions you have made so far, with the probability of an Acid Sulphate Soil being present. The report can be copied to the Clipboard for use in another application, or printed directly from Identikit.

The second type of report is generated when you select “What do I do next?” from the pop-up menu associated with every leaf node. It lists all the criteria for which you have not yet selected anything. The criteria in this list which have high positive or negative probabilities are the best discriminators, and should be selected next **if, and only if, they accurately describe your site.**

Remember that because each report is the result of a fresh scan of the tree, it takes any corrections you have made into account. The previous report is deleted when a new report is created. Always run the report writer before printing the text, to ensure that the report is up to date.

### **Correcting errors**

The report will indicate the score for each of your selections. If you want to change a selection, double-clicking on the criterion label will reverse the selection process and expand the branch of the tree so you can select another option (or leave all of them unselected). The running count is automatically updated to reflect the fact that a criterion has been de-selected.

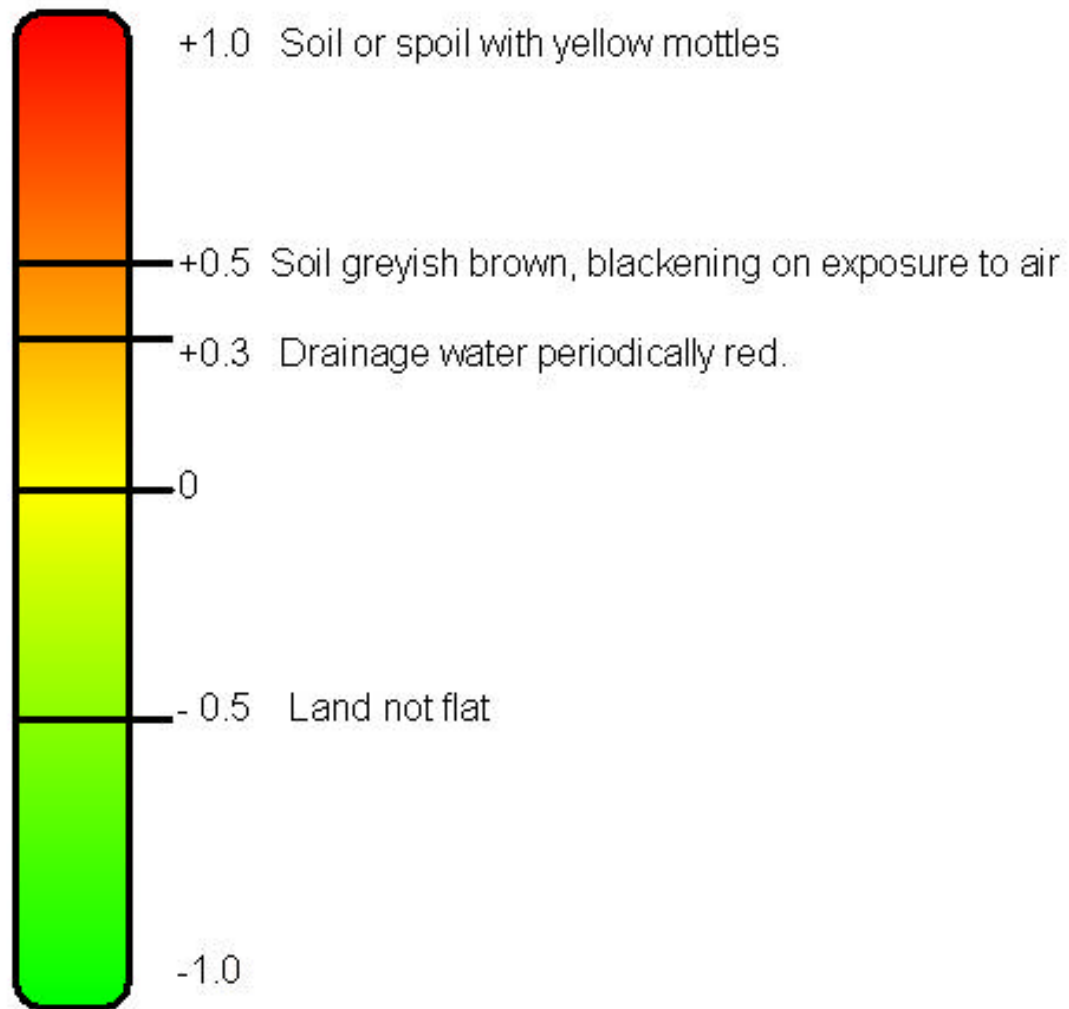
To clear all selections and start again, click on the ‘Expand whole tree’ button.

Note that these actions *cannot* be undone - you will lose all of your entries if you start again.

### **What do the numbers mean?**

Each of the possible options (there are currently 104 of these) has been rated with a value which reflects its strength as an indicator of an acid sulphate soil being present, or that the conditions for an acid sulphate soil being produced (i.e. a potential acid sulphate soil) when the soil is drained are present.

The rating scale is from +1.0 (= definitely an acid sulphate soil) to -1.0 (= no chance of an acid sulphate soil). This is illustrated below:



A value of +0.5 can be interpreted as being “as good as proven” that Acid Sulphate soils exist. A value of +0.2 can be interpreted as showing that acid sulphate soils could exist here, but there may be other causes of the observed state of the site.

Negative values indicate that acid sulphate soils are unlikely. The greater the negative magnitude (-0.7 having a greater negative magnitude than -0.3) the stronger the indication that acid sulphate soils, or the conditions for producing them, are not present.

You would not expect to have both high positive and high negative values on the same site. If Identikit indicates that this is the case, you should use the reports to double-check which criteria are causing the high values, in case there has been an error in describing your site.