7 Soil survey and land evaluation

7.1 Objectives and survey requirements

This section discusses: the different needs for soil information of land-use planners, project managers, farmers, and engineers; the methods by which surveyors can provide this information, including practical details of methods of analysis relevant to acid sulphate soils; and, finally, some of the problems of assessing the performance, or potential performance, of the land.

Soil surveys identify the different kinds of soil in a landscape, group like soils into homogeneous units, and map their distribution. These mapping units are then characterised so that their performance can be predicted and an effective system of management worked out. By dividing a landscape into units, a soil survey enables more accurate predictions to be made about soil properties and their response to management than would be possible for the landscape as a whole.

Soil survey is not a simple process of mapping discrete parcels of land. There are no discrete parcels waiting to be mapped. Each soil property changes more or less gradually, both vertically and horizontally; change in one characteristic is not always in phase with changes in others; so identical combinations do not necessarily reappear in the landscape. Also, acid sulphate soils change palpably, over a few months or years once reclamation is begun. However soil mapping units are defined, many boundaries will be arbitrary.

Clearly the first task of the surveyor and the user of the survey, working together, is to define the specific purpose of the survey. Then it can be decided what characteristics of the landscape should be surveyed, what kind of soil mapping units will be used, and what scale will be suitable.

7.1.1 Land-use planning

Land-use planning objectives may include:
- Reclamation and settlement, or more intensive use, of areas that will support new communities and will yield a good return for the effort and cost of development;
- Conservation of the existing productive capacity of areas that cannot support viable developments. Avoidance of long-term environmental damage;
- Improvement of the productive capacity of acid sulphate soils that are already being farmed.

For strategic planning, we need to know whether or not there is enough potentially useful land to make development worthwhile. Not all areas containing acid sulphate soils are useless and unproductive. Soil surveys can show which areas are potentially useful, and which are not. They can also identify the nature and severity of the problems.

Where large areas are involved, survey scales between 1:100000 and 1:50000 are appropriate. Uniform coverage is needed, but not necessarily a soil map. Point observations along equally-spaced transsects, using a general purpose classification, will be sufficient to estimate the extent of the area affected by soil hazards.

For project feasibility studies, we need to know the distribution of suitable and unsuitable soils and the kind and severity of soil problems. These should be shown on a map. (Figures 6.2 and 6.4 are examples from soil surveys in support of project feasibility studies.) A soil map alone, however, is not enough. Planners and decision-makers require interpretations of the mapping units in terms of:
- Projected production, probably under a range of alternative management systems;
- The initial and ongoing cost of obtaining this production;
- The time scale involved in any land reclamation or improvement;
- The social and environmental impact of alternative systems of land use.

At this stage of planning, a decision must be made; either the project can support a limited extent of unfavourable soils, or the area affected by the soil problems and the cost of reclamation will be so great as to abort the project.

7.1.2 Project design and implementation

For project design and implementation, we need to know more details on a range of soil properties, so as to have a basis for the design of engineering works and to predict the response of the land to the projected management. Usually, a range of crops, management systems, and farm sizes will be considered. Critical soil characteristics will include:
- Existing or potential acidity;
- Lime requirement;
- Salinity;
- Soil texture;
- Ripeness;
- Available water capacity.

This basic survey should be at a scale between 1:25000 and 1:10000 and should show simple mapping units (series and phases of series) or specified individual soil characteristics.

Very detailed data may be required for special purposes. At the sites of major engineering works, for example, a precise topographic survey will be needed, as well as a geotechnical survey to provide data on particle-size distribution, unit weight, shear strength, compressibility and settlement, permeability, and liquid and plastic limits – all to a depth of several metres – while attention also has to be given to the corrosive effects of acid and sulphate-rich waters. However, the measurement of some soil engineering attributes can be incorporated easily in a general purpose soil survey and problem materials such as deep peat and unripe mud (low strength) and sand (excessive permeability) will be identified.

Geomorphological interpretation of basic soil survey data can narrow the required field of special investigation, and seismic survey can provide some information about the depth, thickness and general nature of subsurface layers. But for many purposes, there is no alternative to closely-spaced field measurements and sampling for laboratory tests.

7.2 Soil survey

Methods of soil survey are discussed in detail by Dent and Young (1981) and in summary by Ilaco (1982) and Landon (1984). The discussion here is confined to topics of special relevance to acid sulphate soils. A check list for survey planning is given in Table 7.1.

Table 7.1 Check list for survey planning

Activity	Responsibility
1. Identification and definition of objectives: – Location and boundaries of survey area; – Problems to be solved; – Time available.	User
2. Survey design: – Publication scale; – Observation intensity, location, depth and data recorded; – Role of air photos and other remote sensing; – Laboratory requirements; – Recording and handling of data; – Soil classification and map legend; – Land evaluation and other interpretative studies.	Surveyor initially, details agreed in consultation with user
3. Organisation: – Check availability and suitability of air photos, topographic base, climatic, geological, and agronomic data; commission photography as required; – Survey schedule; – Staffing; – Mobilisation and logistics – field base, travel and transport for field parties and equipment, personal services, communications; – Equipment; – Laboratory facilities, treatment and transport of samples.	Surveyor
4. Publication of results	User
5. Costing	Surveyor, firm agreement or contract with user

7.2.1 Survey design

Soil survey is always a compromise between speed, or cost, and the excellence of the data. Properties that can be assessed by hand and eye – such as texture, ripeness or colour – and those that can be measured easily in the field – such as pH or shear strength – can be mapped more cheaply and accurately than properties requiring laboratory tests – such as levels of soluble aluminium and iron, n-value, liquid limit, or mineralogy. Properties that are closely related to surface features (i.e. to topography, vegetation, surface colour or wetness), can be mapped quickly and precisely, especially if their surface expression can be identified on air photos. One of the first tasks of soil survey is to establish the field relationships between critical soil properties and surface features or other easily-mapped characteristics (see Sections 4 and 6).

Even when a survey is limited to soil characteristics that can be measured quickly, there is a practical limit to the number of observations that can be made. Some sampling strategy must be adopted. Statistical sampling techniques can establish the range of variation of soil properties and the sampling intensity needed to map any selected property or category. If critical soil properties are not obviously related to surface features, the optimum intensity of field observation can be assessed statistically from randomly selected pairs of sample sites located at fixed distances apart, for example 10, 50, 250, 1 000 m. Where difficulties of access and precise location of sample sites prevent rigorous application of this procedure, quite effective coverage of a survey area can be achieved by sampling along two intersecting transects.

At each site, the soil properties of interest are measured. These data can be subjected to nested analysis of variance (Webster 1977; Nortcliff 1978). Alternatively, the semi-variance of difference between all pairs of sampling points separated by each chosen distance, can be plotted against their distance separation. Semi-variance is a measure of the average similarity between sample points that are a given distance apart: the more alike the samples, the smaller the semi-variance (Burgess and Webster 1980).

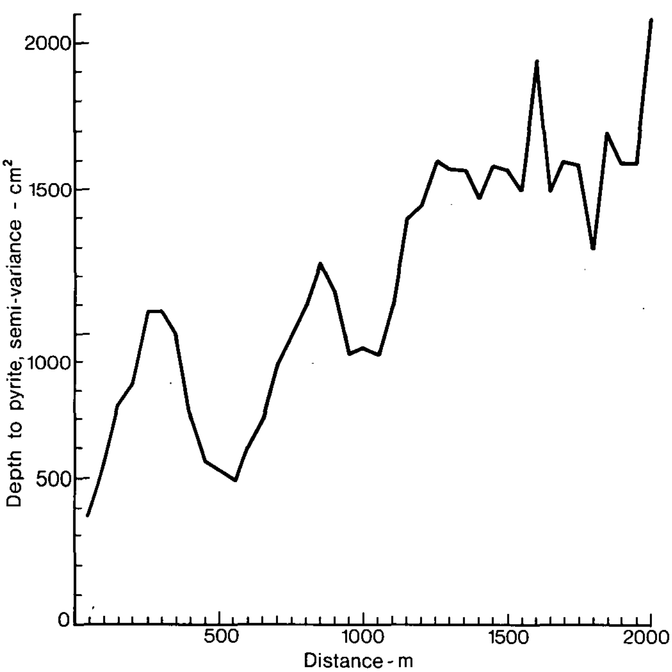

Figure 7.1 Semi-variogram showing the relationship between depth to pyrite and distance separation of sample sites, Do Hoa, Saigon Delta, Vietnam (from Bos and van Mensvoort 1984)

Bos and van Mensvoort (1984) have applied these techniques to acid sulphate soils in South Vietnam. Figure 7.1. shows one of the relationships they found between the semi-variance of the depth of pyrite, and the distance between sites. In this example:

- There is little increase in semi-variance at separation distances greater than 1 200 m. To obtain any useful information on the distribution pattern of this property, the sample interval needs to be less than 1 200 m;
- There appears to be a recurring pattern at separation distances of 500 and 1 000 m;
- There is a significant variation between sites at even the closest interval – in this case the sample spacing is 35 m and semi-variance at this spacing is 400 cm^2 (average variation of depth to pyrite is 20 cm). To reduce this uncertainty, a sampling interval closer than 35 m will be needed.

A rigorous statistical sampling exercise is itself a major research task. Computing facilities and suitable programmes are essential (for example Burrough 1981), and interpretation of the data is not straightforward. Nevertheless, we should know about the scales of variation of critical soil properties. Even where sophisticated statistical analysis is not appropriate, much insight may be gained by sampling at clusters of points at different intervals along transects, and simple plotting of raw data, such as depth to the potentially acid layer, against the separation distance of samples.

In the absence of a special determination of optimum survey intensity, the following rules of thumb apply: for mapping at a scale of 1:10000, the average observation spacing should be 100 to 200 m (one per 1 to 4 ha); for scale 1:25000, the average spacing should be 250 to 500 m (one per 6 to 25 ha). The time needed for surveys at different intensities is indicated in Table 7.2.

Mapping can be undertaken by making observations on a rectangular grid or, alternatively, by free survey. Grid survey achieves even coverage; it can be carried out by inexperienced staff; and there is no alternative where there are no adequate topographic maps or air photos.

A danger of using a grid is that the sampling interval may coincide with some underlying regularity of the soil pattern. For example, in the area represented by Figure 7.1, observations on a 500 m grid would give a wrong impression of the depth to pyrite. This risk can be avoided by random location of observation sites within each grid square, but this technique requires good access and precise location of sites. Very often, exact site location is impossible unless determined by measurement. In these circumstances, statistical validity is lost if the man on the ground ends up by choosing sites subjectively in the general area of the grid intersections.

Grid survey is also inherently wasteful; access may be interrupted by creeks and ditches, and many sites may be unrepresentative. Only someone who has been compelled to map by grid observations can know the frustration of not having information from other points where it would be more useful.

An alternative method is to establish field relationships between soil characteristics and visible features of the landscape that can be mapped directly in the field or on air photos. In this way, the surveyor builds up a conceptual model of the way the landscape functions. Using this model, he decides which characteristics to look for, selects each observation point where it will yield the most useful information, and interpolates soil boundaries between observation points. Later, the model will assist him in producing a range of predictive or interpretative maps from the basic data.

Table 7.2 Observation density and time requirements associated with different intensities of survey on alluvial soils

Purposes	Scale	Average of observations 0.5 per cm^2 of final map	Rate of progress per 22-day month*	Approximate time (days per month) required for different activities**			
				Field survey	Representative profile description and sampling	Field tests	Office and laboratory
Implementation of land reclamation or irrigation projects; management problems; urban and industrial development; soil problems critical	1:5 000 1:10 000	2 per ha 1 per 2 ha	250 – 500 ha 450 – 800 ha	8	2	8	4
Project planning; simple soil pattern; limited extent of problem soils	1:25 000	1 per 12.5 ha	1 000 – 1 500 ha	11	3	5	3
Project feasibility and regional land-use planning	1:50 000	1 per 50 ha	30 – 150 km^2	11	3	5	3

* Time requirements are increased by about 30 per cent for difficult access, for example boat work and delays due to tides and crossings of creeks and rivers. A further 10 to 30 per cent should be added for contingencies such as bad weather.

** Time exclusive of final report preparation, which may take up to 6 months, depending on the size and complexity of the project.

7.2.2 Remote sensing

LANDSAT *satellite imagery* is inexpensive, and is readily available for all parts of the world from EOSAT, Eros Data Center, Sioux Falls, SD 57198 U.S.A., and from several regional ground stations. Useful analysis of regional landforms and vegetation patterns can be carried out, without any special equipment, using 1:250000 false-colour images. Better definition, and so larger scale images, will be achieved by the new generation of satellite-born sensors. Because repetitive coverage is available, it is possible to identify progressive changes in land use.

Air photographs are almost indispensable for navigation on the ground, and make excellent base maps for field survey and final publication. Difficulties of access, and working conditions in tidal swamps and other undrained wetlands, encourage reliance on air-photo interpretation for the mapping of soil boundaries. (What lies within these boundaries still has to be found by field observations.)

Since topography is usually slight and is often concealed by vegetation, air-photo interpretation of wetlands boils down to the interpretation of vegetation and drainage patterns. This is most useful in virgin swamp, where there are direct relationships between current soils, hydrology, and vegetation, and in drained areas where acid sulphate soils have already developed. Interpretation is more difficult where there has been a degree of management, such as mangrove forestry or sporadic burning, which can produce spurious patterns, or uniform pasture management that imposes a uniform vegetation.

If the photographs are to be used as field survey sheets, it is useful to have photography at about twice the intended publication scale of the map. This leaves ample room for writing on the field sheets. It also allows for a reduction in scale from field survey to publication, to reduce the imperfections of mapping (or to counter the misleading impression of accuracy).

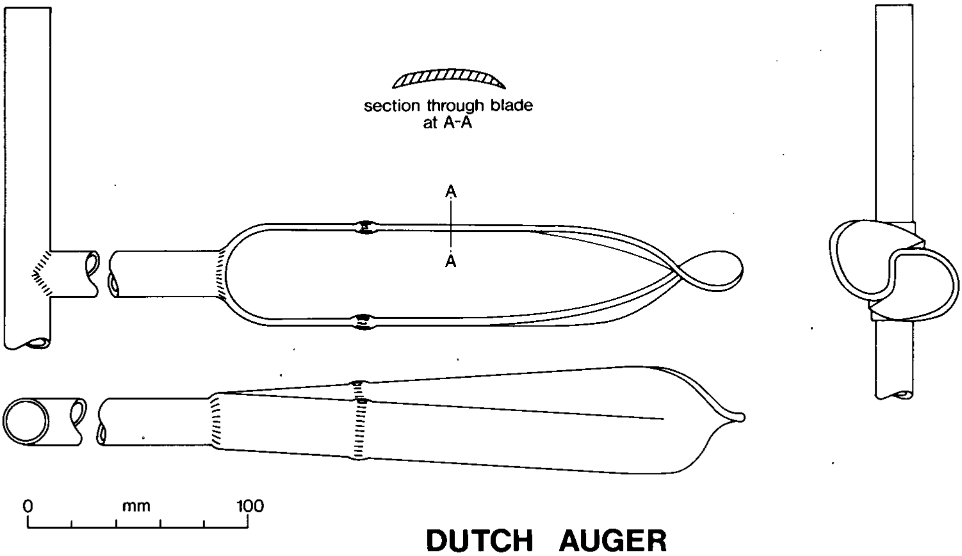

Figure 7.2 Design for a Dutch auger

Good quality, panchromatic 'black-and-white' photography is suitable, but film sensitive to infra-red, either 'black-and-white IR' or 'false-colour', affords greater contrast in wetland environments. Water and wet soil absorb infra-red radiation strongly, so they appear very dark on air photos; and there is more contrast between the reflectances of different plant species in the infra-red range, compared with visible light. On false-colour photography, this appears as a range of colours, depending on the kind of film used, through blue, green, orange, and red. Crops suffering stress or disease commonly show very clearly on infra-red photography. Where aerial photography is to be specially commissioned for soil survey of wetland areas, specification of infra-red-sensitive film should be seriously considered.

7.2.3 Equipment

Transport arrangements are of prime importance in any large survey. Where the survey area is tidal and intersected by creeks, field work is regulated by the tides, and a shallow-draught boat provides the most convenient transport.

A check list of equipment is given in Table 7.3. The basic equipment for surveys in moist, ripe soils includes a Dutch (Edelman) auger (Figure 7.2). It collects samples which are sufficiently undisturbed for identification of most morphological features and large enough for most laboratory purposes. However, a Dutch auger will not bring up samples from half ripe or practically unripe soils. For these, a gouge auger is needed. The large model shown in Figure 7.3 can be made cheaply from cold-drawn, seamless steel tube, 60 mm diameter, 2 mm wall thickness. This is cut as shown and formed to a conical shape by hand-beating on a round steel bar. The handle is cut and welded from steel tube approximately 20 mm diameter (Dent and Robinson 1982). As described, the auger weighs 2.7 kg. The dimensions are not critical, but the conical shape enables 10 to 20 cm of wet sand to be brought up, as well as any overlying cohesive material.

Undisturbed profiles of 1 m can be collected from half ripe soils in a few seconds by pushing the gouge auger vertically into the soil, turning through 180°, and lifting out gently. Undisturbed sub-samples can be collected in 45 mm diameter alloy cylinders, sharpened at one end, by pushing these down from the top of the sample in the auger and cutting out with a knife. The clean auger hole can be used directly for measurement of saturated hydraulic conductivity below the watertable. Since the auger core is removed at once, no bailing is needed.

For collecting deep samples of unripe soils, a variety of specialist equipment is available, of which a conventional peat sampler is the simplest to maintain and operate.

A bailer is necessary to pump out soil profile pits below the local watertable. A length of pipe with a one-way flap at the end, used in an auger hole sump, is simple and effective.

7.3 Characterisation of soil and site

Acid sulphate soils are easy to identify; often they are of striking appearance. It is more difficult to identify potential acid sulphate soils. But identification is not enough.

If we are to make use of experience gained on similar soils elsewhere, or apply technology developed elsewhere, adequate characterisation of soil and site is essential. This means a full description of:

- Thickness of non-acid topsoil;
- Depth, thickness, and reserves of acidity in acid or potentially acid layers;
- The kinds of acidity present:
  - Free (sulphate) acidity;
  - Soluble iron II and aluminium;
  - Exchangeable iron and aluminium;
  - Potential (pyrite and organic) acidity;
- The lime requirement;
- Soil texture profile;
- Ripeness;
- Salinity;
- Microtopography;

Table 7.3 Check list of field equipment

Standard field kit	Additional items, for special purposes
Air photo field sheets	Heavy, pointed spade; for unripe soils, a long-handled shovel; bailer; peat sampler and extension rods
Pencils (B and photo marker), pencil sharpener and rubber	
Clipboard or map case	
Notebook or pro-forma description cards	Hydraulic conductivity (auger hole) kit
Dutch auger	Infiltration equipment
Gouge auger for peat and unripe soils	Sampler and cylinders for undisturbed samples
Broad-bladed knife	Hand shear vane
Soil colour charts	pH/mV meter, electrodes, buffer solutions, distilled water
2-m tape	
Field pH kit	EC meter
Wash bottle	Surveying level, tripod and staff, 30-m tape, ranging poles
Acid bottle	
Sample bags and spirit marker	Stereoscope
Compass, waterproof wristwatch	Camera
Personal comfort and survival kit	Dictaphone

- Present and projected watertable;
- Crop water requirements;
- Amount, distribution, and reliability of rainfall, and especially the duration of drought periods;
- Availability and quality of irrigation water.

Much of this information can be obtained in the field or in a simple field laboratory. If sufficient field tests are performed to indicate the distribution, severity, and variability of acid and potentially acid soils, laboratory studies can be reserved for detailed analysis of a small number of representative samples.

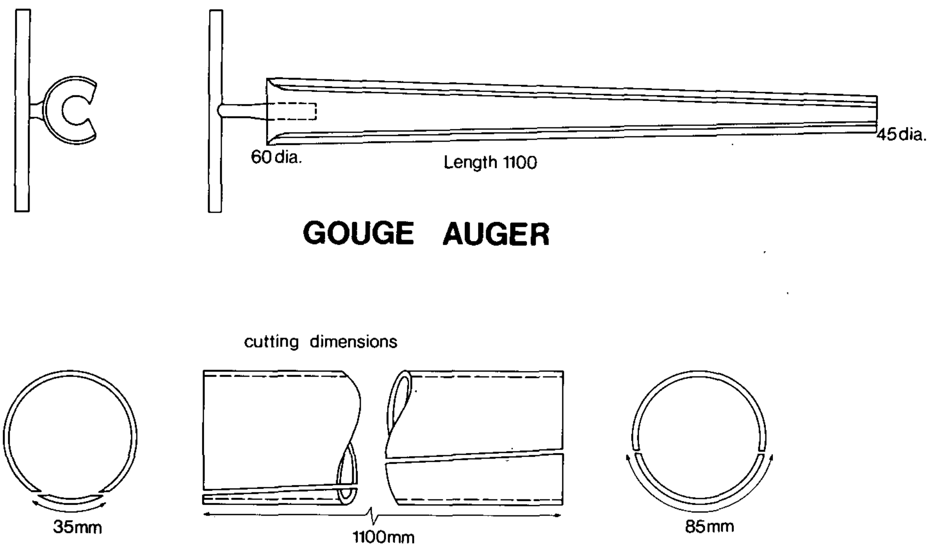

Figure 7.3 Design for a gouge auger

7.3.1 Morphology

The morphology of acid sulphate soils and potential acid sulphate soils was discussed in detail in Section 4. The salient points are as follows:

Acid sulphate soils:
- In mineral soils, acid sulphate conditions are characterised by pale yellow mottles of jarosite in a grey or pinkish grey matrix. Yellow mottles are often first seen in spoil from ditches. However, yellow mottles are not an infallible indication of severe acidity. Ultimately, in ripe soils, they lose their sharp outline and fresh, pale yellow colour, becoming ragged and associated with reddish brown iron oxide deposition. Jarosite may persist in the soil long after the phase of severe acidity has passed;
- In poorly-drained soils, especially in peat and muck, severe acidity may develop without yellow mottles;
- Large amounts of mobile iron are associated with all young acid sulphate soils. The iron appears as ochre on ped faces and in drainage waters. Sometimes, pipe drains and ditches can be blocked by gelatinous iron deposition;
- In young acid sulphate soils, both the severely acid horizon and underlying layers

remain unripe;
- Acid peats tend to dry irreversibly once they are drained, and a crunching sensation is felt and heard when they are augered. The peat below the oxidised layer is commonly intensely black.

Potential acid sulphate soils:
- Waterlogged;
- Dark grey to dark greenish grey colours, commonly with black mottles;
- Typically unripe;
- Usually contain a lot of blackened, partly decomposed organic matter;
- Smell strongly of hydrogen sulphide;
- Do not contain a lot of shell.

7.3.2 pH

Under dryland crops, severe acidity can be identified on the spot with pH indicator paper. MERCK Spezialindikator is mounted conveniently on plastic tabs and is supplied in wide range (pH 0 to 6) and narrow range (2.5 to 4.5 and 4.0 to 7.0). To estimate the pH, press the indicator directly onto the wet soil for 20 seconds, then compare the colour of the indicator with the standard chart. If the soil is too dry, wet it with distilled water. In practice, it is difficult to estimate pH close to the limit of the indicator's range. In this case, check the pH using an indicator of the next overlapping range. A problem sometimes encountered with near neutral soils is the bleaching of the indicator dye when the paper is left in contact with the soil for more than a few seconds.

A battery-powered pH meter fitted with a combination electrode may also be used in the field, but in swamps and flooded rice fields it is difficult to keep equipment clean and to check readings against a buffer solution. In peat and unripe mud, the electrode may be inserted directly into the soil. Hard, sandy, and shelly materials may damage the sensitive tip and, in these cases, it is best to measure the pH in a paste made up with distilled water. Commonly, there is significant point-to-point variation in pH within any horizon. In raw acid sulphate soils, very low values develop along pores and fissures, while the soil matrix may remain 2 or more pH units higher. Obviously, it is worthwhile making several determinations on each soil horizon, but very precise measurements are not justified because of the inherent variability.

In waterlogged acid sulphate soils, for example in flooded rice fields, pH is raised by reduction processes. A pH determination after a few days or weeks of flooding may give no indication of acidity under oxidised conditions. This also applies to undrained potential acid sulphate soils. So long as they remain waterlogged, no acidity will develop. Potential acid sulphate conditions can only be positively identified by comparing the initial pH with the pH following incubation, or treatment with hydrogen peroxide.

Incubation

Potential acid sulphate soils can be identified by incubating moist samples in open, thin-walled polythene bags. This procedure simulates oxidation under natural conditions: although no leaching can take place in the bag, neutralisation by carbonates and some finely-divided silicate minerals does occur. A sample size of about 500 cm³ is suitable. Sometimes, pH drops rapidly within a few days and, with samples of this size, may continue to drop for at least a year if the sample is kept moist. For the sake of standardisation, three months incubation should be allowed.

Hydrogen peroxide

Treatment of a small sample with hydrogen peroxide (van Beers 1962) offers a quicker method of prediction. About 5 cm³ of soil is treated with 20 cm³ of 100 volumes hydrogen peroxide, heating if the mixture does not heat spontaneously to a temperature high enough to decompose the peroxide. The pH is determined after the peroxide is completely spent. pH values obtained by this method are usually lower than those obtained by incubation, and certainly lower than those developed in the field, because only finely-divided calcium carbonate is instantly effective in neutralising the acidity. In the field, and during several months incubation, coarse particles of calcium carbonate and more-slowly-acting minerals buffer the soil pH. This is not reflected by the peroxide test. Incomplete oxidation of organic matter also produces acidity.

Brinkman and Pons (1973) suggested a tentative limit for dangerous acid sulphate soils of pH 2.5 after peroxide treatment. This works well in practice – Figures 7.4 and 7.5 compare the pH values produced by incubation and peroxide treatment of peat and mineral soils.

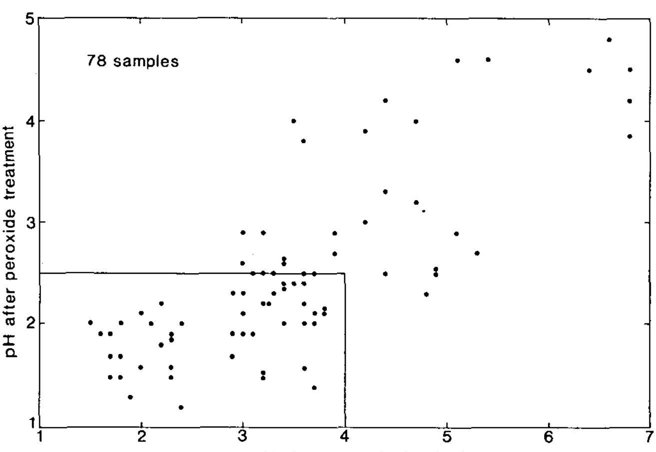

Figure 7.4 Relationship between pH after incubation and pH after peroxide treatment for peat soils, Norfolk, U.K.

Driessen (personal communication) has used hydrogen peroxide to test the microvariability of potential acid sulphate soils in the field as follows:

Clean the soil-profile face or gouge-auger sample and spray with universal soil pH indicator. Where the pH is in the range 6 to 8, an overall green colour is produced. Spray with hydrogen peroxide. Spray again with indicator. This time, concentrations of pyrite show as bands or patches of yellow or red.

BEWARE: 100 volumes hydrogen peroxide is a very hazardous reagent. Avoid contact with the skin and wash off any splashes immediately.

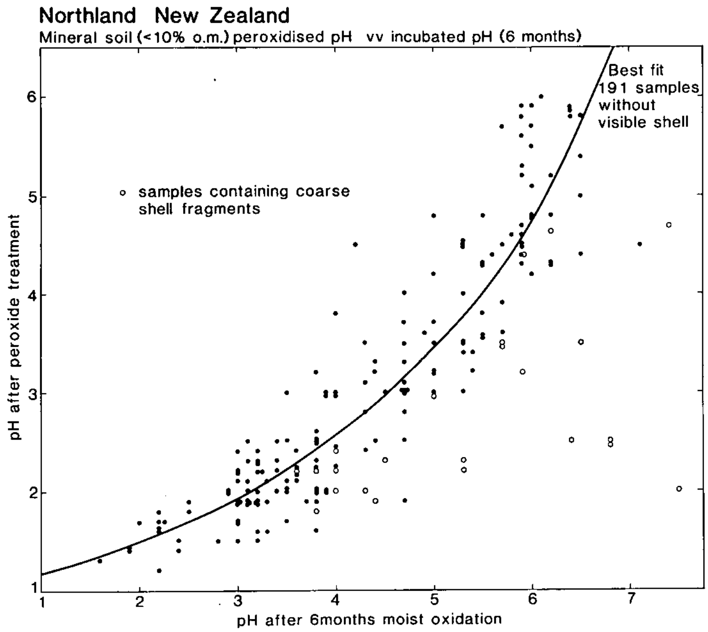

Figure 7.5 Relationship between pH after incubation and pH after peroxide treatment for mineral soils, Northland, New Zealand

7.3.3 Red lead

Wiedeman (1973) and others have used stakes painted with red lead to detect sulphidic material. Red lead is blackened within a few days by FeS and H_2S evolved in reduced sulphidic horizons. This indicates a pyrite-accumulating environment, but not the amount of pyrite present.

7.3.4 Sodium azide

Edelman (1971) developed a semi-quantitative method to estimate pyrite using sodium azide solution. Brinkman and Pons (1973) describe it as follows:

In a test tube, add 1 cm^3 concentrated soap solution (liquid detergent) and about 0.5 cm^3 sodium azide solution. (To prepare this solution, dissolve 1.27 g sublimated iodine and 2.4 g KI in 8 cm^3 water; dilute to 100 cm^3; add 3 g NaN_3 and dissolve; keep in brown bottle; prepare new solution frequently.) Add sample material equivalent to 0.2 g dry soil; stir carefully to avoid making bubbles, three times in 1 minute. The nitrogen gas, formed by the catalytic action of any sulphides present, makes foam.

The quantity of foam after 2 minutes is an indication of the sulphide present. For a few samples from Thailand, the following relation applied:

Foam 2 cm high	1.4 per cent sulphide S
Foam 0.3 cm high at margin and covering whole surface of liquid	0.8 per cent sulphide S
Foam 0.3 cm at margin not covering centre of liquid surface	0.4 per cent sulphide S
No foam	No sulphide S.

Coarse pyrite crystals will have less effect than an equal mass of finer crystals or aggregates. Other sulphides or organic sulphur compounds present might cause an exaggerated reaction, especially finely-divided FeS, or organic matter with a relatively high S content. However, within a local area, the size of pyrite crystals, the kind of organic matter, and other modifying factors might be fairly constant.

7.3.5 Calcium carbonate

Whether or not an acid sulphate soil develops depends upon both the amount of pyrite present and the amount of neutralising minerals, especially calcium carbonate. Shells can be seen in the soil profile. Finely-divided carbonates can be detected by the application of 10 per cent hydrochloric acid. The guidelines adopted by the Soil Survey of England and Wales (Hodgeson 1979) are as follows:

$CaCO_3$ %	Audible effects (hold close to ear)	Visual effects
0.1	None	None
0.5	Faintly to slightly audible	None
1	Faintly to moderately audible	Slight, just visible effervescence confined to individual grains
2	Moderately to distinctly audible; heard away from ear	More general effervescence visible on close inspection
5	Easily audible	Moderate effervescence; obvious bubbles up to 3 mm diameter
10	Easily audible	Strong effervescence; ubiquitous bubbles up to 7 mm diameter

Where FeS is present, treatment with hydrochloric acid gives rise to the characteristic smell of hydrogen sulphide. Pyrite does not react with hydrochloric acid.

7.3.6 Shear strength

The strength of materials can be measured on site most conveniently with a hand