A total of 136 abandoned coal mine sites with a total area of 460 ha in south west Pennsylvania were reclaimed between 1980 and 1992. Wetlands were constructed on 11 sites to mitigate acid mine drainage, and a soil cover was used on 2 sites. The average cost of reclamation was US$9500 per acre (equivalent to A$31 000 ha^{-1}) (Bogovich 1992).

3 Survey of acid drainage at mine sites in Australia

Information for this study was collected during visits to mine sites, by discussions and meeting with company environmental officers, State Chambers of Mines, officers from State Departments responsible for mining and environmental issues and by distribution of questionnaires to mine sites where the mineralogy suggested there was a chance of having to manage potentially acid generating wastes.

3.1 Visits and meetings

Discussions were held with a wide range of people who had experience and knowledge of acid mine drainage in Australia, including corporate officers of mining companies who were responsible for environmental issues, State Government officials responsible for regulating the environmental issues at mine sites and other consultants and experts. In addition, eighteen representative mine sites were visited for discussions with mine environmental officers to gain a better understanding of local conditions and the options for managing potentially acid generating wastes. Some visited sites were dealing with significant amounts of potentially acid generating wastes, whilst others had very little. Mine sites were visited in most States, and included gold, coal and base metal mines as well as some of the classic historic mines known to generate acid drainage. The major visits and meetings are listed in Appendix C2.

3.2 Questionnaire

A questionnaire was prepared which contained a series of questions about surface water management, ground water, open cuts, underground workings, waste characterisation, the types of wastes and the acid generating potential of mine wastes. A copy of the questionnaire is in Appendix C3.

A database of mine site contacts was purchased from the Australian Mining Series Pty Ltd, which provided names of up to four executives at each operation, the mine address, fax and phone number and a short description of the operation. The database contained information on 531 significant mining operations in Australia, including metal mines, gold mines, coal mines, major quarries, new mines under development and significant prospects.

Of the 531 sites in the database, 317 sites were considered to have a potential need to manage potentially acid generating wastes. These included antimony, base metal, coal, copper, diamond, gold, iron ore, mineral sands, nickel, pegmatite, sapphire, vanadium and uranium mines. The number of sites in each category are listed in table 3.1. It was decided to include mineral sands mines in the survey because some sites do have acidity problems, even though the type of acidity and solutions can be more related to the presence of acid sulphate soils.

The types of mines excluded from the survey include:

- sites under development, including at exploration, at feasibility and at project identification stage where mine plans are still being developed;
- sites mining resources with high neutralising capacity, including, bauxite, gypsum, lime, limestone, magnesite and magnesium;

- sites mining benign materials which are inherently not acid producing, including salt;
- sites where the requirement for clean product means that the resource being mined is very unlikely to be contaminated by pyrite and other sulphides, including clay, garnet sand, talc;
- quarries, which were not considered to be part of this survey. It is, however, noted that some quarries operating near sea level have had problems with acidity produced by acid sulphate soils (see Section 6.8);
- oil and gas sites.

Table 3.1 Types of mines included in the survey of mine sites, and the number of sites in each category

Type of mine	Number
Antimony	1
Base Metal [Ag/Pb/Zn (7), Base Metal (4), Zn/Cu (1), Zn (2), Pb/Cu/Zn (1), Pb/Zn (1), Pb/Zn/Cu/Ag (1), Pb/Zn/Cu/Au/Ag (1)	18
Coal	104
Copper [Cu (7), Cu/Ag/Pb/Zn (1), Cu/Au (1), Cu/Au/Ag (1), Cu/U/Ag/Au (1)]	11
Diamond	2
Gold [Au (122), Au/Ag (2), Au/Cu (6), Au/Cu/Ag (1) , Au/Sb (1), Au/Sb/As (1)]	133
Iron ore (16), Magnetite (3)	19
Mineral sands	11
Nickel	8
Pegmatite	1
Sapphire	3
Tantalum	1
Tin	3
Vanadium	1
Uranium	1
Total	317

The number of sites excluded from the survey in each category are listed in table 3.2.

On 30 June 1996, a preliminary form of the questionnaire was sent to 21 mines to assess the type of information. The preliminary questionnaire was also discussed and distributed during the visits in July and August to mine sites and to corporate offices. By the end of August 1996, copies of the preliminary form had been distributed to 36 mine sites. The questionnaire was modified slightly to take into account comments received.

On 29 September 1996, questionnaires were sent to the remaining mine sites included in the survey sites. The questionnaire was addressed to the mine manager named on the Australian Mining Series database, with a copy to the Environmental Officer at each mine site. A copy of the letter of support from David Buckingham, Executive Director, Minerals Council of Australia, was sent with each questionnaire (see Appendix C1). On 25 October 1996, reminder letters were sent to the Environmental Officer at those mine sites that had not responded.

Table 3.2 Types of mines not included in survey

Type of mine	Number
Associated sites	3
Bauxite	6
Iron ore beneficiation (Cockatoo Island)	1
Clays [Bentonite (3), Kaosil/Damarite (1)]	4
Diatomite [Diatomite(1), Diatomaceous earth (1)]	2
Garnet sand	1
Gypsum	2
Lime [Lime (2), Lime sand (1), Earthy lime (1)]	4
Limestone	2
Magnesite	2
Manganese	2
Mines at exploration [Exploration(18), Prefeasibility (2)]	20
Mines at feasibility	46
Mines at project	27
Oil and gas	20
Peat	1
Quarries [Quarries (57) Granite (1)]	58
Salt mines	8
Silica mines	2
Talc	3
Total	214

The information provided on the questionnaires will only be used for the purpose of this study and will not be used for any other purpose unless further approval is sought from and given by the mine operator. At completion of this study, the raw data were archived by the Minerals Council of Australia on behalf of the Australian Centre for Minesite Rehabilitation Research (ACMRR).

A total of 313 mine sites were asked to fill in questionnaires. This number is less than the 317 sites listed in table 3.1 because of the inadvertent exclusion of 6 mineral sands sites and the inclusion of one manganese and one magnesite site. Five mineral sands sites were included in the initial mail-out. The information from the manganese and the magnesite sites, neither of which reported any potential acidity, has not been included in the analysis reported in this section. Information on the mineral sands sites initially excluded have been included in the overall findings, but not in the specific review in section 3.2. Omission of information about the six mineral sands sites does not appear to significantly alter the conclusions of this study.

As of 17 January 1997, 171 responses had been received (148 questionnaires, 9 phone calls, 14 letters) and 10 questionnaires were returned address unknown. Excluding the 10 address unknown responses, this corresponds to a 171/307 = 56% response. Of the responses 43% are from gold mines and 33% from coal mines (table 3.3).

During the study, 18 mine sites, which handle varying amounts of potentially acid generating wastes, were visited and detailed discussions were about two sites. Although seven of these sites did not return a questionnaire, enough information was provided during discussions to allow the sites to be included in the survey. Hence the sites used in the following analysis were the 171 which responded to the questionnaires, plus the 7 visited or discussed that did not return a formal questionnaire, less the manganese mine and the magnesite mine included in the mail out, giving a total of 176 sites.

Table 3.3 Number of different types of mine providing responses to survey

Type of mine	Number questionnaires sent	Completed questionnaires	Completed questionnaires and visit/meeting	Visit/meeting but no questionnaire	Total in survey
Base metal/ Cu/ Ag/ Pb /Zn	29	11	3		14
Coal	104	52	3	1	56
Gold	133	68	6	5	79
Iron Ore /Magnetite	19	8	1	1	10
Mineral Sands	11	3			3
Other	21	16			16
Subtotals	317	158	13	7	178

Note: Total of 178 includes one magnesite and one magnesium mine site which are excluded from following tables.

3.3 Site characteristics from questionnaire responses

Surface water treatment

Questions 8 to 10 in the questionnaire asked

Is surface water released from lease treated? (Y/N)

Type of water treatment?

Annual flow ML/y?

A 'No' response to the first question could mean either that no water was released or that water released was not treated. There could also be some confusion because surface water from different parts of the lease are often treated differently. The results from questions 8 and 9 are summarised in table 3.4.

Table 3.4 Surface water treatment

Category	Number of sites	Type of treatment	Number of sites
Released water treated	45	Acid dosed	2
		Neutralisation (lime etc)	9
		Flocculant	3
		Flocculant + wetland	1
		Polymer dosing	1
		Recycle	1
		Sediment/silt pond, settling	18
		Wetlands	6
		Filter (sand/emplaced waste)	2
		Unknown	2
No release or released water not treated	99		
Not answered	32		
Total	176		

Ground water

Questions 11 to 12 asked:

Premining ground water quality?

Is ground water quality monitored?

Most sites used the suggested categories of fresh, brackish, saline and very saline water in the terms of total dissolved salts shown on the questionnaire (table 3.5). Some sites, however, expressed their water quality in terms of electrical conductivity. For these sites, it was assumed that water with a conductivity <2000 μS/cm was fresh, <7000 μS/m was brackish, and <20 000 μS/cm was saline. This definition is based on the relationship used in Australian Water Quality Guidelines (ANZECC 1992, pp 2–25) which assumes that the filterable residue in mg/L is equal to 0.68 x conductivity (μS/cm).

Table 3.5 Quality of pre-mining ground water

Groundwater quality	Salinity, mg/L TDS	Number of sites	Proportion (%)
Fresh	<1500	51	43
Brackish	1500–5000	18	15
Saline	5000–15 000	26	22
Very saline	>15 000	24	20
Not known/ not answered		57	
Total		176	100

The ground water is monitored at 103 sites, not monitored at 25 sites, and no answer from 48 sites.

Opencuts

Questions 13 to 16 asked:

Opencuts?

Is seepage water pumped?

Pumping rate?

Water quality?

Table 3.6 Opencuts

Category	Number of sites	Proportion (%)	Comment
Sites with opencuts	114	79	80 sites pump seepage water from the opencuts
Sites with no opencut	30	21	
No answer	32		
Total	176		

At most sites, the total dissolved solids in water in the opencut was similar to the quality of the pre-mining ground waste. Only six sites reported acid water (pH <5) and four of these were coal mines. The amount of acid pumped ranged up to 200 L/s.

Questions 17 to 19 asked:

Any water-filled opencuts/voids?

How much water contained (ML)?

Water quality?

Table 3.7 Water-filled voids

Category	Number of sites	Proportion (%)	Comment
Water-filled voids	60	42	Includes flooded historic underground workings
No water-filled voids	84	58	
No answer	32		
Total	176		

At most sites the quality of the waste in the water filled void was similar to the quality of the pre-mining ground water. Seven sites (4.9% of the sites answering the question) reported voids containing acid water in the range pH 2.5 to 3.5. The volumes of these voids containing acid water ranged from 10 ML to 3000 ML, with a total of about 6000 ML. This excludes tailings dams and evaporation ponds. If the 4.9% of the sites is representative of the sites in the survey, then it is estimated that about 15 sites have voids containing acid water.

Underground workings

Questions 20 to 22 asked:

Any underground workings/adits?

Is there seepage water, and if so how much?

Water quality?

Table 3.8 Underground workings/adits

Category	Number of sites	Proportion (%)	Comment
Sites with underground workings and/or adits	76	52	Includes 6 sites which have old underground workings
Sites with no underground workings	69	48	
No answer	31		
Total	176		

At most sites the quality of the waste pumped from underground workings and adits was similar to the quality of the pre-mining ground water. Eight sites reported acid (pH<5) seepage water from adits of underground workings. The flows ranged up to 14 ML/d, and at some sites the seepage rate depended on rainfall. If the eight sites are representative of the sites in the survey, then at about 17 sites have acid seepage water in underground workings or from adits.

3.4 Waste characterisation

This section on waste characterisation was prepared in association with Dr Josick Comarmond, ANSTO Environment Division.

Questions 23 to 25 asked:

Have any acid-base accounting measurements been carried out?

If so what sort and how many?

Any other prediction measurements eg leach columns?

Acid base accounting (ABA) and the net acid generation (NAG) test are the two static tests most widely used in Australia. These tests will be reviewed in Appendix A.

Table 3.9 Acid base accounting

	Number of sites	Proportion (%)	Comment
Have undertaken some acid base accounting	56	32	Also NAG tests 26 NAG without ABA 2
Have not undertaken any acid base accounting	82	47	
No answer	38	21	
Total	176		

Of the 176 respondents (representing 56% of the total surveyed) to the survey, 32% replied that they had undertaken acid base accounting tests, 47% replied that they had not undertaken any acid base accounting tests and the remaining 21% did not specify either way. Of those who undertook ABA tests, half also carried out NAG tests. One per cent of respondents undertook NAG tests without ABA tests. The samples used for acid base accounting were generally from exploration drill cores, pit wastes, tailings and coal reject.

One third of the respondents (19) who undertook ABA tests indicated the number of samples used for the tests. This varied between one and more than 3000 samples. The breakdown is shown in table 3.10. Table 3.11 shows the minimum number of samples for each rock/overburden type during initial sampling, as recommended by the Department of Minerals and Energy, Queensland (1995).

To assess whether or not the surveyed mines have been appropriately sampled, one would need to know the number of rock types and associated volume of each type. Since this information is not available from the survey, no attempt has been made to correlate the number of samples for waste characterisation with volumes of potential mine waste. However, it is apparent from tables 3.10 and 3.11 that for most sites, the number of samples used for ABA tests has been much less than recommended by the Department of Minerals and Energy, Queensland (1995).

Sixty per cent of respondents to the questionnaire replied to the question of other tests. Of these, 83% replied that they did not carry out other tests or thought that they were not applicable. The nature of the other tests as specified by the respondents included on-going water quality measurements, pH monitoring, monitored (kinetic) NAG tests, the geochemical abundance index (GAI) and leach column testwork. Eight respondents undertook leach column tests. One respondent specified on-going water quality monitoring coupled with predictive modelling. All the above tests will be reviewed in Appendix A.

The relatively small numbers of tests carried out at most sites raises real doubts about how well wastes are characterised across the mining industry. It also makes it difficult in this study to be quantify the amount of potentially acid generating wastes at Australian mine sites.

Table 3.10 Total number of samples used for ABA tests at different sites

Range	Number of sites	Proportion of sites undertaking ABA (%)
1–10 samples	6	11
11–100 samples	8	14
101–1000 samples	2	4
>1000 samples	3	5
not specified	37	66
Total	56	100

Table 3.11 Minimum samples required for geochemical prediction program (DME Queensland 1995)

Mass of each separate rock type (tonnes)	Minimum number of samples of each rock type
<10 000	3
<100 000	8
<1 000 000	26
<10 000 000	80

3.5 Overall AMD/ARD potential

The information from the questionnaires has been combined with information from mine site visits to estimate the number of sites in Australia that are managing potentially acid generating mine wastes. Much of the information received in the questionnaires was not definitive which presented difficulties in estimating the extent of the acid mine drainage at the sites. Although some sites have clearly recognised the need to manage their potentially acid generating wastes and have waste management plans that are well integrated with mine operations, there are many other sites where the amount of information provided suggests that insufficient waste characterisation has been undertaken to properly address the need for a management strategy for sulphidic waste.

The sites that responded were classified into five categories to indicate the significance of potentially acid generating wastes being mined (table 3.12). The allocation of sites to a category was based on the information provided by the sites, including any waste characterisation, water quality or comments provided. The categories are:

- sites managing ***significant*** amounts of potentially acid generating material where:
  - the site recognised acid drainage was an important issue,
  - the amount of potentially acid generating waste was greater than 10% of the wastes, or
  - the amount of potentially acid generating waste was greater than 10 Mt;
- sites managing ***minor*** amounts of potentially acid generating material where:
  - the site reported managing minor or small amounts of potentially acid generating wastes,
  - some samples had been shown to be potentially acid generating, or

- low pH seepage water had been observed;

- sites *unlikely* to have acid generating material based on the information available;
- sites where on the basis of mineralogy, seepage pH levels or waste characterisation tests the acid generating potential is *none*;
- sites where information provided was inadequate and it is *not known* from the information supplied if the site is dealing with potentially acid generating wastes.

Table 3.12 Number of sites with different potential for acid generating wastes

Potential	Number of sites	% (excluding not known)
Significant	26	17
Minor	32	20
Unlikely	37	24
None	62	39
Not known	19	
Total	176	100

Inevitably, assigning mine sites to these categories was a value judgement based on the understanding of the information provided. For many sites, it was difficult to estimate the amounts of potentially acid generating material being managed. In some cases, this appears to reflect the lack of knowledge of the site about its own wastes. In other cases, the mine sites could have more information than was provided in the questionnaires. Some of the sites in the unlikely/none/not known could have some potentially acid generating wastes.

From the information in table 3.12, about 37% of the sites in the survey appear to be managing some potentially acid generating wastes (sum of the sites classified as significant and minor). It is assumed that mine sites categorised as *not known* will have distribution similar to those sites for which more is known.

The proportions in table 3.12 are expected to apply to all the sites in the survey. Scaling the proportions in table 3.12 to the 317 sites surveyed, it is estimated that about 54 mine sites in Australia are managing significant amounts of potentially acid generating wastes and about 63 sites are managing minor amounts of potentially acid generating wastes.

The survey results shows that excavation of material with some pyrite content occurs at many mines in Australia. In many cases the amounts of pyritic material are small, and the operators say that the small amount of potentially acid generating wastes can be readily managed. On the other hand, several sites that reported no acid generating wastes did not appear to have carried out an assessment of the mineralogy or on any tests for acid generating potential.

3.6 Total amounts of mine waste

In order to determine the costs of managing potentially acid generating wastes at Australian mine sites, it is necessary to estimate the amount of wastes at a typical site. Table 3.13 lists the amount of tailings and waste rock at those sites that provided information and were considered likely to be managing significant amounts of potentially acid generating wastes, as defined in section 3.5. The mines with significant amounts of potentially acid generating wastes had on average about 20 Mt of waste rock covering 46 ha and about 14 Mt tailings covering 94 ha.

Table 3.13 Aggregate mass, volume and areas of mine wastes at sites where there is significant potential for acid generating wastes

No	Type	Waste rock (Mt)	Waste rock (Mm^3)	Waste rock (ha)	Tailings (Mt)	Tailings (Mm^3)	Tailings (ha)
1	Au						
2	Ag/Pb/Zn				9	9	
3	Cu						
4	Au	110		168	56		310
5	Au	5.5	2				
6	Au	22		130	14		154
7	Cu/Au	0.2	0.1	3.5	0.46		15
8	Iron ore	34					
9	Iron ore	50					
10	Au		2.4	24			
11	Au/Cu	15	20	16	12	16	60
12	Au	15			1.5		
13	Au/Ag		33 (1)	55	12		
14	Sn	0.8	0.25	5	30	11.3	76.3
15	Pb/Zn/Cu/Au/Ag	0.089			7	4.4	68
16	Zn		0.14	3	2	1	25
17	Au	6.9	3	16	7.5	2.9	60
18	Base metal		1.56	13		2.16	40
19	Base metal	0.5					
20	Pb/Cu/Zn			100	12		120
21	Coal						22
22	Coal					10	70
23	Coal	1.8	1.4				150
24	Coal				5.7	6.4	80
25	Coal	24	12	15		2.5	22
26	Coal						
	Total	285.8 Mt for 14 sites	74.9 Mm^3 for 11 sites	548.5 ha for 12 sites	169.2 ha for 13 sites	65.7 Mm^3 for 10 sites	1272 ha for 15 sites
	Ave	20.4 Mt	6.8 Mm^3	45.7 ha	13.0 Mt	6.57 Mm^3	84.8 ha

(1) site reported 22 million bank cubic metres, which has been converted to waste assuming a 50% expansion

Although the questionnaire asked for information on mine wastes/residues/stockpiles that contain or might contain potentially acid generating material, many sites reported their total wastes. Nevertheless, the averages provide a reasonable estimate of the amount of wastes at a typical mine site.

3.7 Management strategies for sulphidic wastes

The comments on the questionnaires and visits to mine sites showed that a wide range of isolation, cover and encapsulation methods are being used to manage the potentially acid generating mine wastes, including selective placement, encapsulation within waste dumps, isolation within waste emplacements, different cover designs and sometimes use of separate dumps for potentially acid producing wastes. Covers being used for waste rock dumps include compacted clay and top soil, compacted materials and non-compacted materials. The waste management strategies are listed in table 3.14 for sites considered to have significant amounts of acid generating wastes and in table 3.15 for sites considered to have minor amounts of acid generating wastes.

Table 3.14 Management strategies for managing wastes at sites considered to have significant amounts of wastes with acid generating potential

(a) Waste rock

Strategy	No. of sites	Proportion (%)	Details of options (and mine site number)
Return waste underground	3	13	(341, 354, 380)
Encapsulate and cover	4	17	Encapsulate and cover: potentially acid generating (PAF) wastes (+0.5%S_t, mean 1%S_t) concentrated in top centre of dump, surrounded by non-PAF waste rock. Will be covered with compacted cap. PAF from underground will be dumped in opencut below water table (310) Encapsulate and cover (323) Encapsulating waste rock dump with basal oxide layer, a 20 m thick oxide layer on sides and minimum 3x0.5m thick compacted clay cap, 0.5 m rock mulch, drainage structures (312) Selective placement of mineralised waste in centre of dump. Engineered soil cover to retain 96% water (195)
Cover	10	43	Cap with clay spoil, top soil, establish vegetation, no ponding of water (560) Capped rehabilitated (419) Co-disposal of tailings and rejects rehab by capping and vegetation (541) Cover with low NAG and benign material (259) Cover (unsaturated) on one dump containing all acid generating black shale (275) Dumps being reshaped and covers (524) Rehab cap with impermeable layer (378) Seal with compacted porphyry (257) Cover with minimum of 1 m. Only compaction will be from trucks and dozers (524) Cover, wetland (92)
Encapsulate	5	22	Encapsulate sulphide rock with clay and topsoil (375) Encapsulate within tailings: Sulphide waste will be encapsulated within the tailings dam to prevent any oxidation and acid water discharge (236) Encapsulate: Rejects to be trucked back to spoil dumps and entombed in the dump (612) Encapsulation (309) Encapsulation of black shale in discrete layers and pods with 15 m inert material between shale and dump face (273)
SAPS	1	4	Successive Alkalinity Producing Systems (346)
No comment	3		(113, 154, 543)
Total	26		

(b) Tailings

Strategy	No. of sites	Proportion (%)	Details of options
Cover	13	62	Cover and revegetate (543) Cover dry or place in pit (419) Cover sulphide ores by non-sulphide ores within the tailings dam (236) Dewater, cover with clay top soil, establish vegetation capping depth > 1.0 m. (560) Cover with oxide tailings (323) Cover with stockpiled top soil and reveg (380) Cap with impermeable layer (354) Capped on closure (612) Tailings forms impermeable crust, rehab will include multi layer cover (113) Cover with low permeability clay cover (378) Cover: tailings to be clay sealed with oxide rock break layer and top soil (375) Covered with 1 m inert material and topsoil (524) Tailings, cover sulphide tailings with oxide tailings and revegetate (312)
Water cover	2	10	(259, 346)
Other	6	29	Develop wetlands (341) Tailings not acid generating (195, 273, 275)) Reclaim (539) Liming in process (310)
No comment	5		(92, 154, 257, 309, 541)
Total	26		

Table 3.15 Management strategies for managing wastes at sites considered to have minor amounts of wastes with acid generating potential

(a) Waste rock

Strategy	Number	Details of options
Encapsulate and cover	2	Encapsulate in oxide material, sulphide waste to be completely covered by impermeable clay barrier (320) Encapsulate wastes with clean wastes, 20 m on side and 5 m on top. All wastes are clay like (049)
Cover	7	Cover shape topsoil & reveg (364) Cover: Capping of contained final waste rock produced (336) Cover: Intention to cap areas at mine closure (508) Cover: rehab by ground capped with 2–2.5 m of inert material + topsoil and replanted to natives (606) Effectiveness of covers being assessed (540) Cover: Waste with pyrite under at least 2 m cover (003) Potentially acid material to be capped with up to 5 m material and clay capped (300)
Encapsulate	5	Material with potential for ARD (less than 5 % of total waste volume will be contained within dump or backfill within pit (146) Bury AMD material deep in pit with >10 m overburden, although not considered to be a problem, it is easier to bury this material than to investigate its true potential (547) Selective placement, potentially acid generating wastes surrounded by neutralising wastes, very small amount (<10 truck loads) potentially acid generating waste rock to date (294) Dumps will be designed to maximise internal dumping of material (035) encapsulate: horseshoe waste dump containing hazardous waste in the middle (355)

Table 3.15 cont.

Co-dispose	2	Co-disposal study with sand mine clay tailings (523) Co-disposed randomly: pyritic shale to be randomly co-disposed with bulk of wastes (267)
Other	7	No AMD from waste rock apart from isolated pods (513, 517) Waste rock no potential (098) Acid water retained in pit (554) No serious sulphide oxidation problem but ongoing surface and ground water monitoring to continue (151) Very small amount of coal reject will be disposed of upon mine closure, and pad area rehabilitated. Considering having a hydrological study done, re sealing of mine (542) Proposal for management is under investigation (397)
No comment	9	(039, 051, 055, 135, 252, 258, 379, 500, 519)
Total	32	

(b) Tailings

Strategy	Number	Details of options
Cover	7	Dome and cap with negative NAPP tailings, topsoil and revegetate (364) Intention to cap areas at mine closure (508) Cover with compacted clay layer (294) Rehab by stabilise slopes, coat with oxide material, topsoil, rip and seed (051) Soil cover Treat oxide last to cap sulphides, plant with native grasses. Wetland filter (055) Capping of dams to direct rain water down walls (098)
Other	2	trials to be undertaken to raise pH using lime and reveg (035) seepage monitoring, drainage and sumps (pumps) around toe edge mainly to remove winter rains from soaking toe of batters (252)
No comment	23	(003, 039, 049, 135, 146, 151, 267, 300, 320, 336, 355, 379, 397, 500, 513, 517, 519, 523, 540, 542, 547, 554, 606
Total	32	

3.8 Climate: Rainfall, evaporation and storms

The climate at mine sites has an impact on the effectiveness of mine waste emplacements and the potential release of pollutants. In most of Australia, the annual pan evaporation exceeds annual rainfall by a substantial margin (fig 3.1 and 3.2). Hence it is of interest to assess the effect of climate on sulphidic wastes and acid mine drainage. Rainfall is provides the means for especially transporting oxidation products from the waste emplacements to surface and ground waters. In addition, many covers constructed of natural materials depend on an appropriate water content to maintain their effectiveness.

Annual rainfall and pan evaporation data were obtained from the maps in the Climatic Atlas of Australia (Bureau of Meteorology 1988a). These 1:12 500 000 maps provide an integrated picture across Australia of annual rainfall and pan evaporation based on long-term meteorological records. These data are expected to be more representative of site conditions than the data available at most mine sites where records have usually been collected for a limited period. However, the effect of local geographic conditions has been ignored. Rainfall (50 percentile median) and pan evaporation (Class A pan with bird guard) were read from the Bureau of Meteorology (1988a) maps for the locations of the 317 mine sites included in this survey.

Figure 3.3 shows the distribution of mine sites as a function of annual rainfall and annual pan evaporation. The mine site distribution in fig 3.3 shows two populations. The first group in humid to semi-arid conditions centred on a rainfall of 800 mm/y and a pan evaporation of 1500 mm/y. For this group, rainfall will exceed pan evaporation over several months during the wet season. The second population of mine sites is centred on a rainfall of 250 mm/y and a pan evaporation of 3200 mm/y. There are also a few sites, mainly in north-west Tasmania where annual rainfall exceeds annual pan evaporation.

Figure 3.4 is a plot of the distribution of mine sites as a function of rainfall and pan evaporation for those sites identified in this survey as managing significant amounts of potentially acid generating wastes. Their distribution is very similar to the distribution of sites in fig 3.3. The similarity of the two distributions shows that sites managing potentially acid generating wastes occur under all rainfall/evaporation regimes. The likelihood of having potentially acid generating wastes at a particular site is largely unrelated to the rainfall or evaporation at that location.

However, the off-site impact of acid drainage is likely to be different in different rainfall/evaporation regimes. The rainfall/evaporation regimes of the historic sites listed in section 5.1 are shown in fig 3.5. It is clear that a greater proportion of historic sites are in the higher rainfall and lower evaporation regions of Australia. Most likely this is because the environmental impact of sulphide oxidation and the release of polluted water are more likely to occur where there is more water percolation and seepage. However, an additional effect could be that historic sites identified as being of concern are likely to be closer to urban populations which predominantly live in the more humid regions of Australia.

The climate at mine sites can also affect the management options for managing sulphidic waste. The different climatic zones (tropical, subtropical or temperate) were taken from the Bureau of Meteorology Climatic Atlas of Australia, Map Set 5 (1975); and the Year Book of Australia (Australian Bureau of Statistics 1994, p14). A tropical climate is characterised by rainfall strongly limited to summer, subtropical is characterised by less seasonality but the peak rainfall still occurs in summer, and temperate is characterised by rainfall mainly occurring in winter. For this study, the 'Arid (winter or non-seasonal rain) – Warm Temperate to Subtropical' region shown on the Bureau of Meteorology maps, which extends from Broken Hill, NSW to Carnarvon WA, has been classified as temperate. These zones of tropical, subtropical and temperate climates in Australia are shown in fig 3.6.

The numbers of mine sites in the different climate zones are listed in table 3.16. The results suggest a significantly greater proportion of sites managing significant amounts of potentially acid generating wastes in the tropics rather than in temperate zones. This appears to be related to the distribution of ore bodies in Australia rather than to any direct effect of climate. In particular, the Bowen Basin, the Mt Isa Inlier and the Pine Creek Geosyncline geological regions are all in the tropics and have a significant number of sites with potentially acid generating wastes.

An important consideration, particularly in tropical regions and arid climates, is the maximum storm that can occur at a site. Even though there might be no seepages under normal conditions at sites in arid regions, seepage can occur following one of the infrequent major storms. Figure 3.7 shows the design rainfall isopleths for a 3 day duration rainfall event with a 50 year recurrence interval (Canterford 1987). Over much of the tropical north, waste emplacements can expect a major storm which deposits in excess of 300 mm rain over 3 days with a recurrence interval of 50 years.

Table 3.16 Number of mine sites in different climates

	Sites managing significant amounts of potentially acid generating wastes		Sites managing either significant or minor amounts of potentially acid generating wastes		Sites in survey	
	Number	%	Number	%	Number	%
Tropical	11	42	17	29	54	17
Subtropical	6	23	12	21	62	20
Temperate	9	35	29	50	201	63
Totals	26	100	58	100	317	100

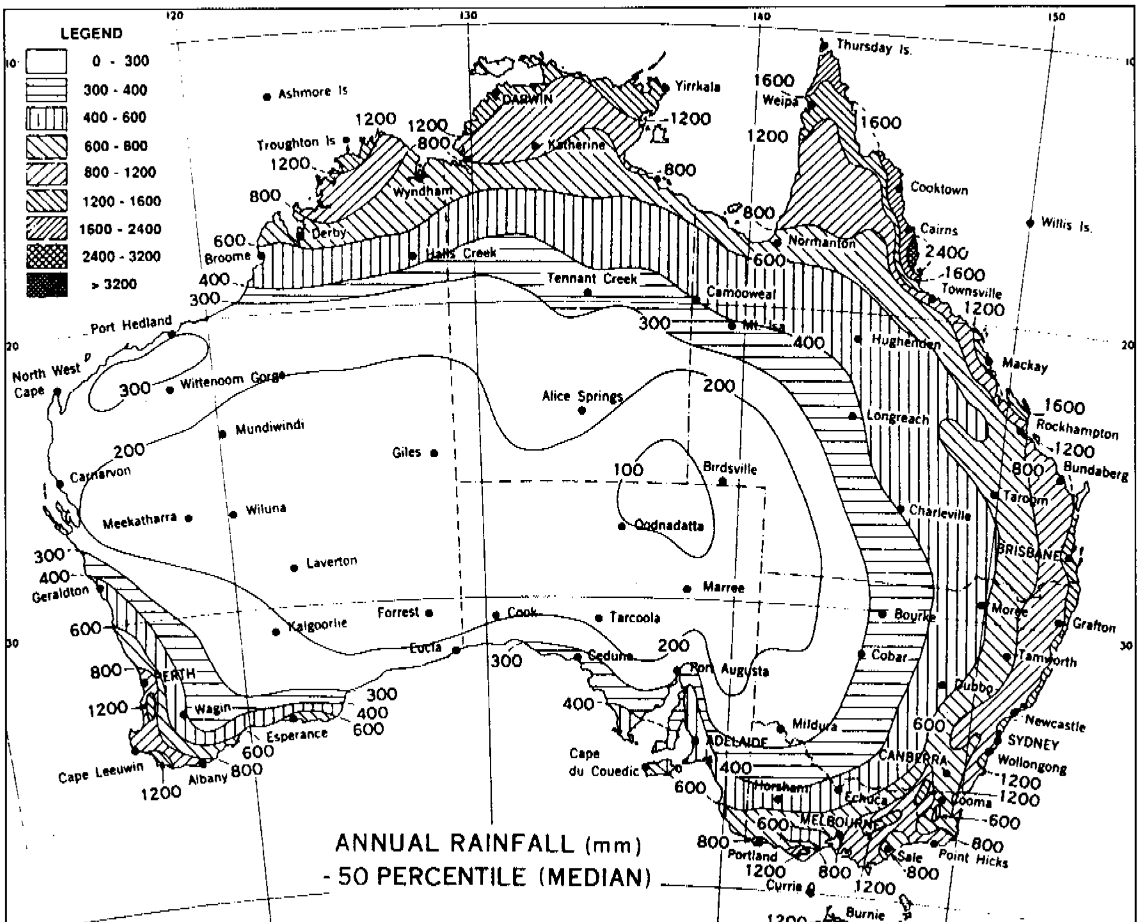

Figure 3.1 Median annual rainfall (mm) in Australia (ABS 1994)

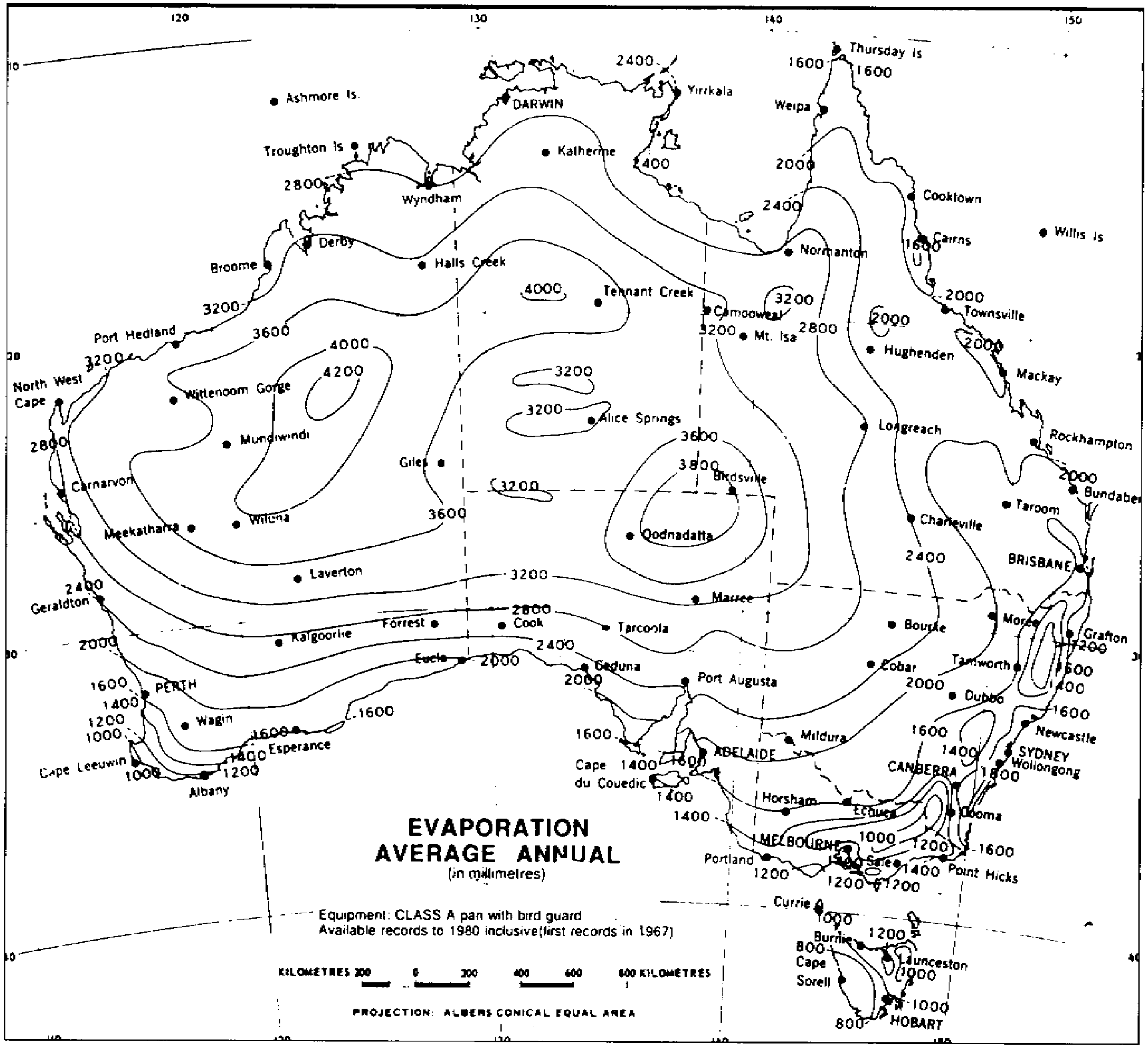

Figure 3.2 Average annual pan evaporation in Australia (ABS 1994)

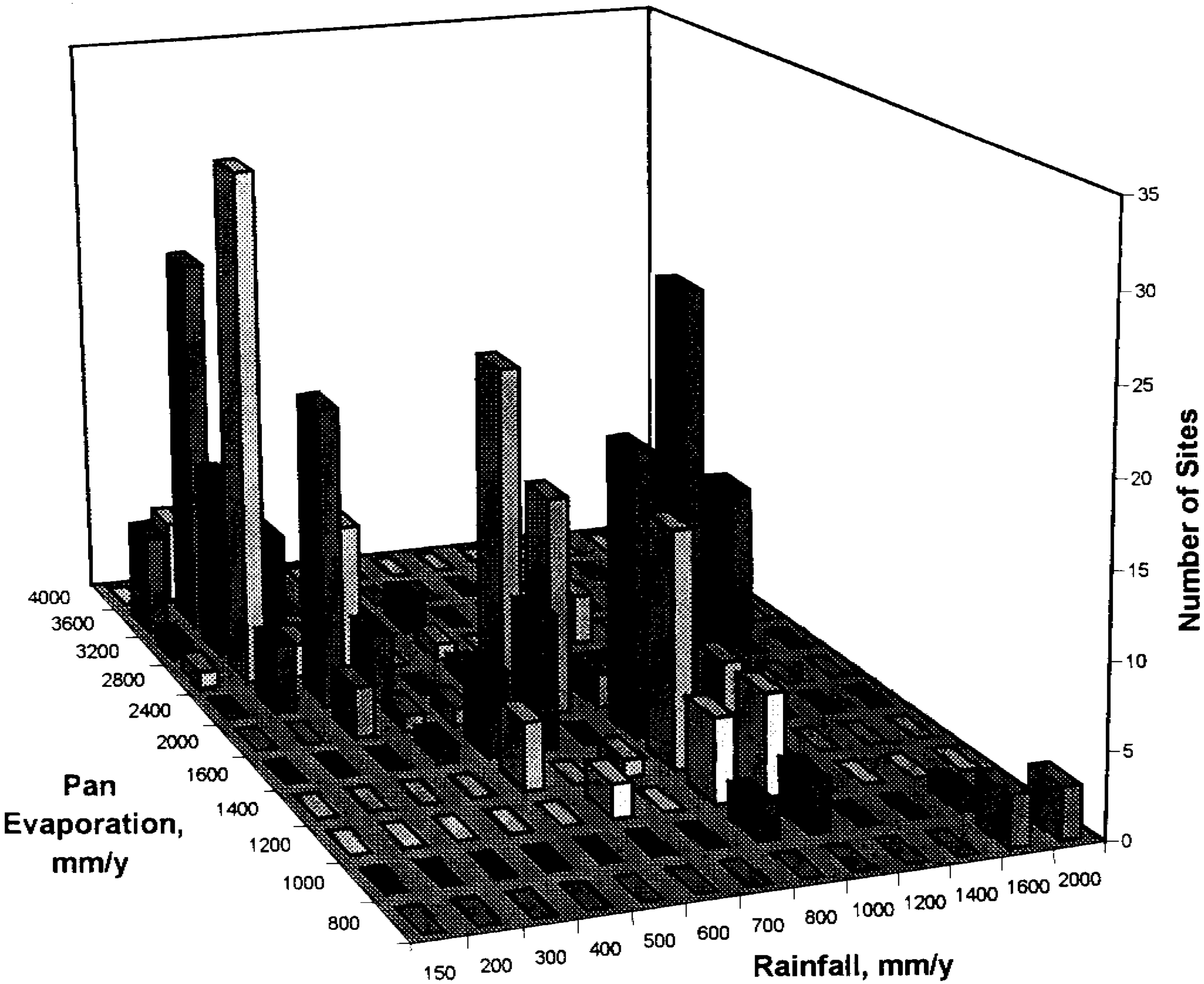

Figure 3.3 Distribution of rainfall and pan evaporation at all mine sites in the survey

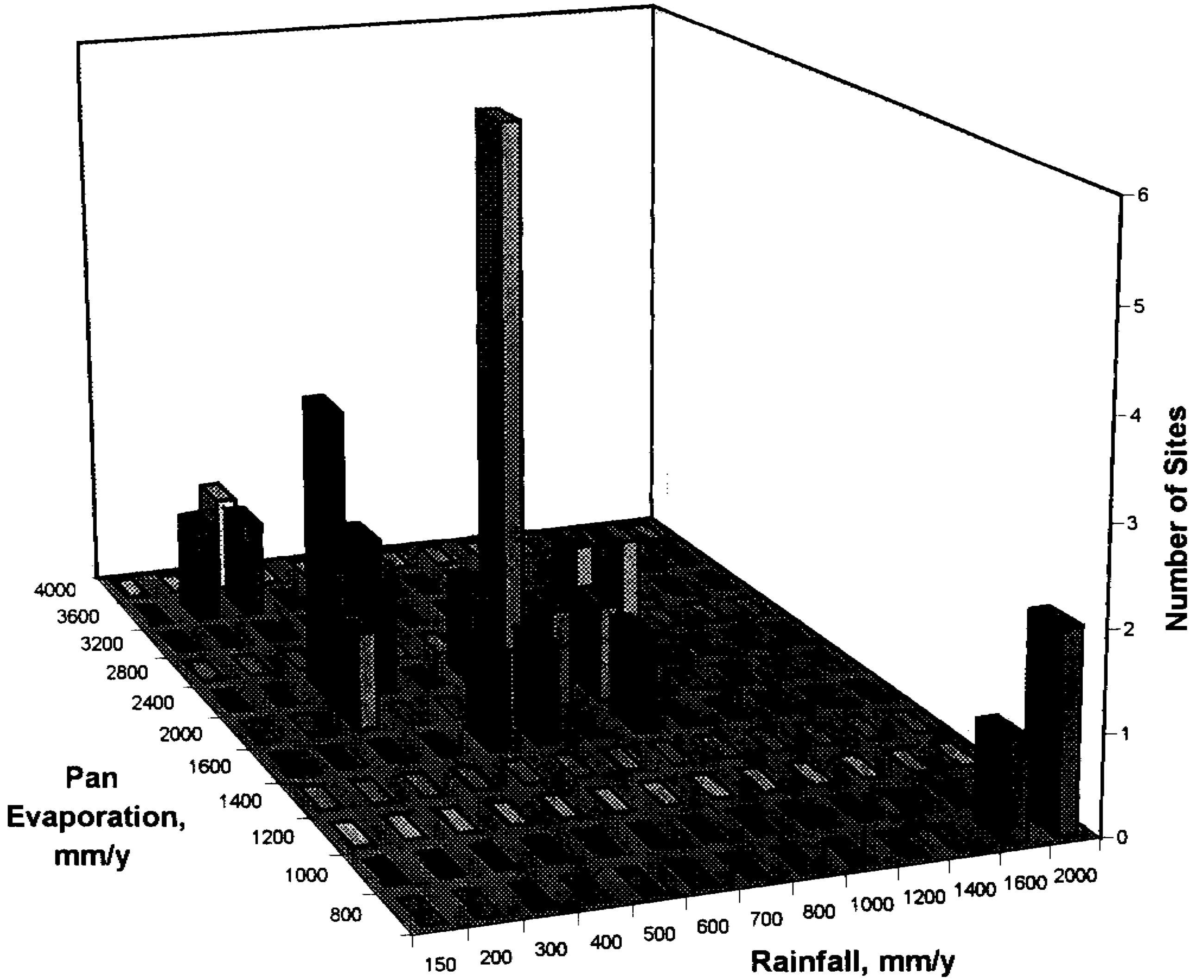

Figure 3.4 Distribution of rainfall and pan evaporation at mine sites managing significant amounts of potentially acid generating wastes

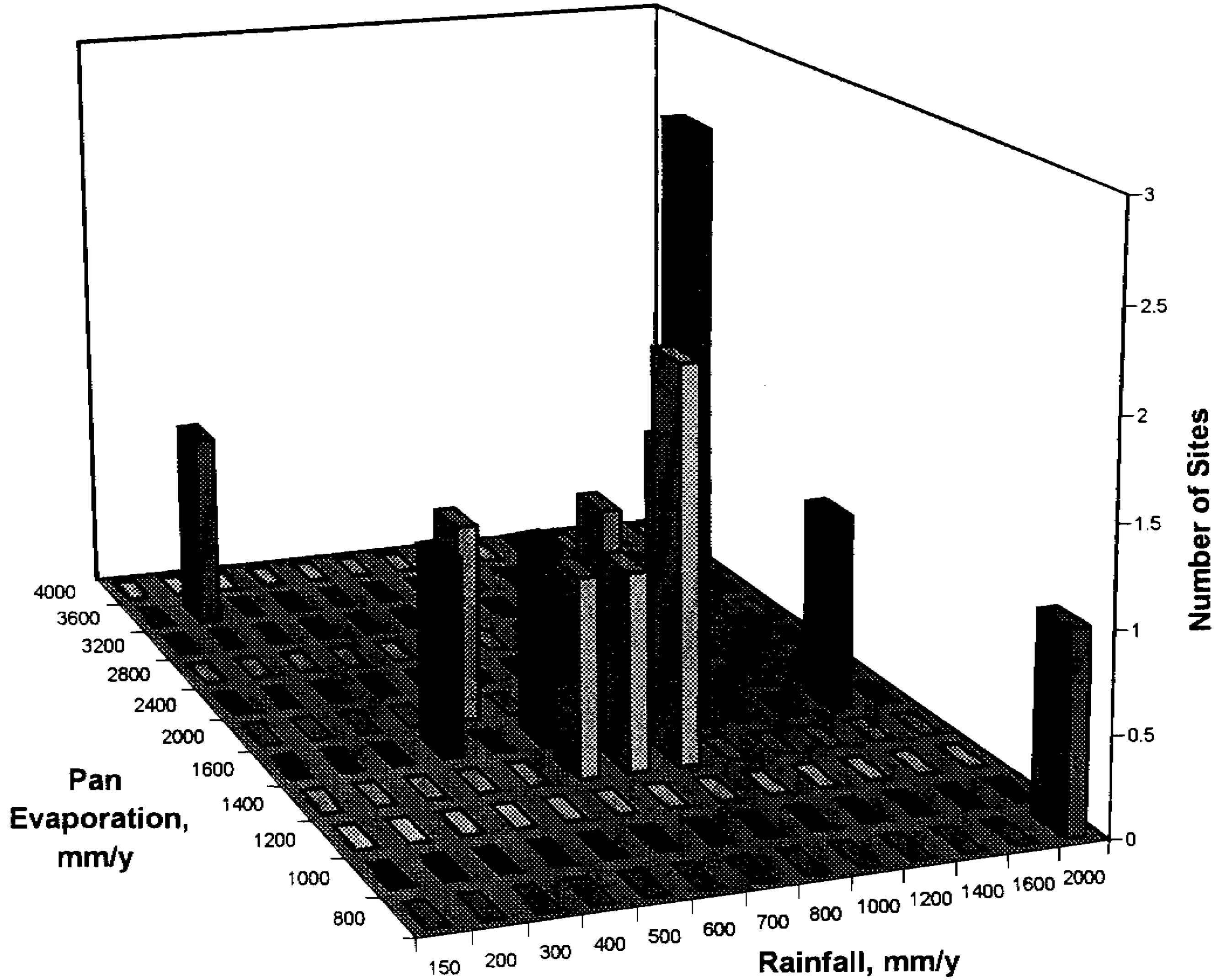

Figure 3.5 Distribution of rainfall and pan evaporation at historic mine sites with significant acid drainage

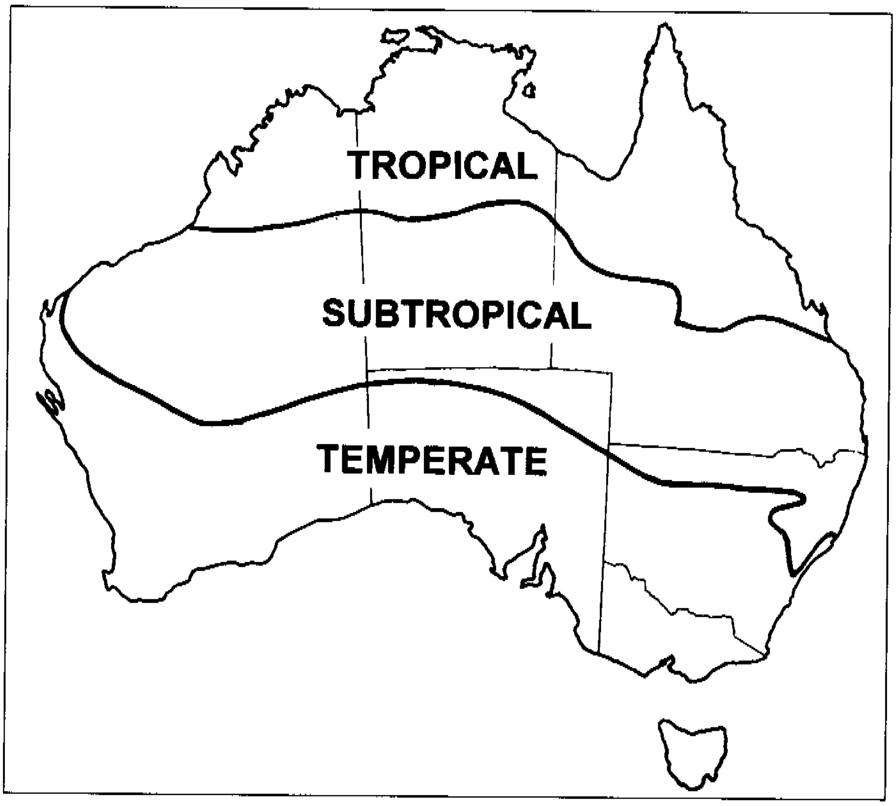

Figure 3.6 Seasonal rainfall zones—tropical, subtropical and temperate (based on Climatic Atlas of Australia, Bureau of Meteorology 1988)

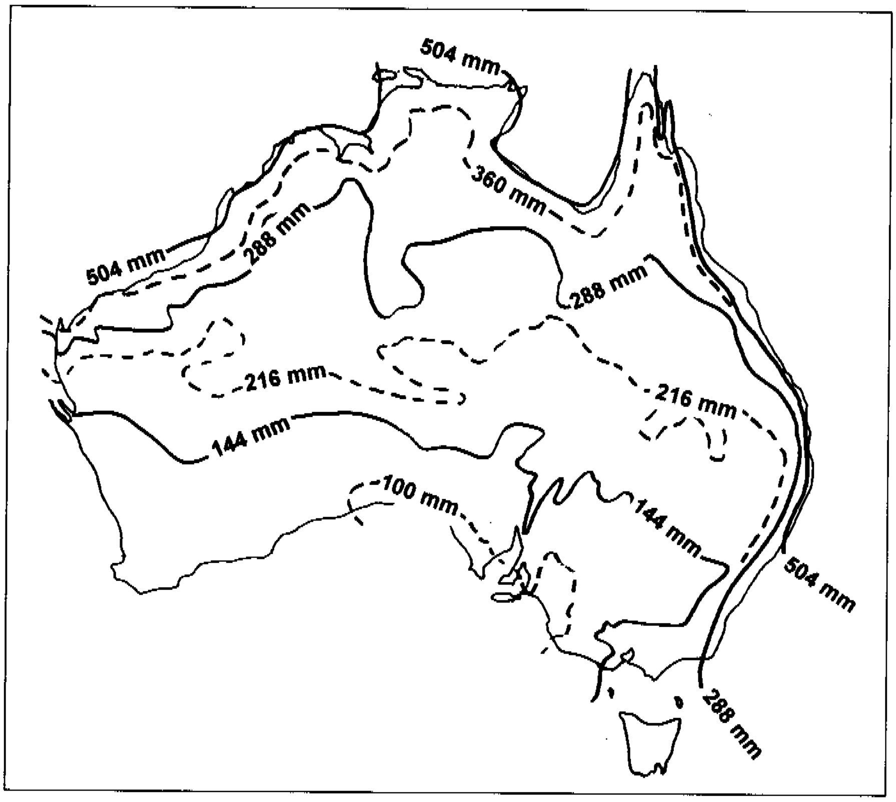

Figure 3.7 Design rainfall isopleths for 3 days duration and a 50 year recurrence interval. Contours show total rainfall over the 3 days (based on Canterford 1987).