AMD/TIME
A SIMPLE SPREADSHEET FOR PREDICTING ACID MINE DRAINAGE

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ABSTRACT

Prediction of acid mine drainage has been a primary regulatory and industrial planning need for decades, yet there still is no satisfactory method. The most widely accepted method is acid base accounting (ABA) which only estimates whether there will or will not be a problem. It does not estimate ultimate acid loading, treatment costs nor duration of acid mine drainage.

However, the principles behind acid base accounting are reasonable: that there is a relationship between the acid generation and neutralization potentials of a given rock mass. This paper presents a spreadsheet which uses ABA data in a dynamic fashion to predict acid generation, loading, concentration and duration. The spreadsheet uses conventional variables plus three new ones: sulfur flux (%Sf), net deliverable neutralization (NDN) and net deliverable acidity (NDA).

The spreadsheet and preliminary validation is presented though it is recognized that a great deal of work is needed before this becomes a reliable prediction tool.

INTRODUCTION

Acid Base Accounting.

Acid Base Accounting (ABA) was developed in the early 1970's by researchers at West Virginia University to identify and classify geologic strata encountered during mining (West Virginia University, 1971). A history of Acid Base Account is provided by Skousen et al. (1990).

Since its development, ABA has been used extensively in the United States and several other countries for premining coal overburden analysis. Its popularity largely stems from its simplicity. However, it has been subject to criticism since it does not account for the different rates of acid and alkali-generating reactions in rock. Modifications to ABA have been recommended (Smith and Brady, 1990; and diPretoro, 1986). Other methods have developed which accelerate or otherwise control the oxidation and leaching process in rock samples. One such procedure, that of Renton et al. (1988), was employed in this study to simulate the rate of weathering of acid-producing rock samples alone and in combination with alkaline amendments. The results are compared with traditional ABA parameters

Recent Studies.

diPretoro and Rauch (11988) found poor correlations (reported R squared = 0. 16) between a volume-weighted acid base net neutralization potential (NP) and net drainage alkalinity near thirty mine sites in West Virginia. Erickson and Hedin (1988) showed similar poor correlation between maximum potential acidity **(MPA), NP, net NP from ABA** and net alkalinity from drainage water. Both papers related that factors other than overburden characteristics were involved in predicting post-mining water quality.

diPretoro and Rauch (1988) found that sites which had greater than 3% calcium carbonate equivalent (NP) in overburden produced alkaline drainages while at 1 % or less acidic drainage resulted. Erickson and Hedin's results indicate that 2% calcium carbonate or less produced acidic drainage while 8% or more produced alkaline drainage. (in this later study there were no sampling points between 2% and 8%).

O'Hagan and Caruccio (1986) found that the addition of calcium carbonate at 5% by weight to a coal refuse containing 1% S produced alkaline drainage. In Minnesota, Lapakko (1988) found that 3% calcium carbonate neutralized an overburden material with 1.17%S.

Hedin and Erickson (1988) compared water quality from rocks weathered in humidity cells to ABA values. Cumulative sulfate from humidity cells was strongly correlated with total sulfur (R squared = 0.69), while cumulative acidity/alkalinity was correlated with net NP (R squared = 0.37). They also showed sulfate from humidity cells was significantly correlated to sulfate from drainage water (R squared = 0.17), but the correlation was not strong enough to predict post-mining drainage quality.

Bradham and Caruccio (1991) conducted several overburden analytical tests on pyritic wastes from Canada. They found water quality resulting from column leachings, ABA projections, and soxhlets correctly predicted eight out of ten sites where drainage was monitored from refuse piles, with weathering cells predicting ten out of ten results.

There have been several modifications in using ABA in predicting drainage quality. The Pennsylvania Department of Environmental Resources (PaDER) (Smith and Brady, 1990) developed a spreadsheet which calculates mass-weighted maximum potential acidity (MPA), NIP, and net NIP. The spreadsheet also summarizes the overburden analysis in terms of the ratio of NP/MPA and the percent sandstone. The spreadsheet of ABA data can be compared to significant thresholds or numerical limits for NP and %S and other factors can be changed to estimate the impact on drainage quality. For example, Brady and Hornberger (1989) suggested threshold values of NP equal to or greater than 3% and %S less than 0.5 as guidelines for delineating alkaline-producing strata.

In the development of its spreadsheet, PaDER (Cravotta et al., 1990) reviewed the calculation of NP in ABA. In current ABA usage, 3.125 g calcium carbonate equivalent is required to neutralize acidity resulting from oxidation of 1 g S. Cravotta et al. (1990) argue that this ratio should double to 6.25:1. Volume-weighted maximum acidities are subtracted from NP giving a positive or negative net NP for the mined area. A negative, or deficient, net NP is interpreted to indicate the amount of calcite that must be added to equalize the deficiency and prevent AMD formation.

Other alkaline materials have higher NP's than calcite. Quicklime, kiln dust and hydrated lime all have higher activities than calcite, though it is not clear that the kinetics of pyrite oxidation favor readily soluble sources of alkalinity.

Brady et al. (1990) conducted a study of 12 sites where ABA data were available. They computed net NP based on both 3.125% and 6.25% to 1 % S. Alkaline addition on the sites was conducted to abate potential AMD problems. When using 6.25%, the sign of the net NP (+ or -) matched the sign of the overall net alkalinity of water at 11 of 12 sites.

The results of their study concluded that NP and traditional estimates of MPA (e.g. 3.125% to 1% S) were not equivalent and that overburden NP must be twice the MPA to produce alkaline mine drainage. They also concluded that mining practices (such as alkaline addition, selective handling, and concurrent reclamation) enhanced the effect of alkaline addition on reducing acidity. Lastly, they concluded additional studies are needed to determine the rates, application and placement of alkaline material during mining.

Brady and Hornberger (1990), after summarizing the work on AMD prediction by ABA made the following conclusions in a recent PaDER Mining and Reclamation Manual. First, NP from ABA shows the strongest relationship with actual post-mining water quality. This relationship is only qualitative (e.g. acid vs. non-acid), and NP must significantly exceed MPA in order to produce alkaline water. If NP and MPA are similar, AMD will most likely result. Sites with less than 0.5% S will not be significant AMD producers, except where little or no NP exists. High sandstone composition in the overburden (greater than 65%) will almost always result in acid drainage.

Factors Which Induce Error in Acid Base Accounting.

The foregoing discussion makes it clear that interpretations of ABA are diverse. Given the policy and economic implications of ABA it is considered useful to better understand the basis for ABA predictions and, where acid problems are identified, to generate cost-effective solutions.

Errors in conventional application of ABA result from variance in total S content (Rymer et al. 1991), and perhaps more significantly, non-homogeneous placement of spoils. For example Schueck (1990) reported AMD generation from a surface mine site in Pennsylvania resulted largely from buried refuse and pit cleanings within an otherwise neutral to alkaline spoil matrix as identified by ABA.

<u>Acid neutralization in spoil dumps-a paradigm</u> '. Obviously, some spoils will be composed entirely of acid forming rocks. Others such as refuse tend to have little NP at all. But in cases where AMD forms despite significant alkalinity in the overburden, it appears to originate from localized sites within the backfill. While finding the path of least resistance to the downstream side of the dump, the acidity is influenced only the alkalinity directly in its path. Once this is overcome, AMD flows freely to the nearest stream while the remaining alkalinity persists as a spectator to the process. This is to be expected since dissolution of calcite is controlled by pH and the partial pressure of carbon dioxide. Where pore water gas is confined, and exposed to

mineral acidity, its pH will remain around 6.2 the-buffering point of bicarbonate and carbonic acid. In the absence of mineral acidity, its pH will reflect bicarbonate saturation - 8.3. In either case, additional calcite will dissolve only upon addition of acidity and outgassing of carbon dioxide. So, unless contacted directly by acidity, most of the spoil calcite will simply remain in solid form. So, the presence of alkalinity in the clump does not ensure that it will be a factor in neutralizing acidity. To be an efficient process, the acid-forming and alkaline rock must be thoroughly mixed.

This largely becomes a materials handling issue. Where there is insufficient alkalinity available it would be necessary to add it to the rock. Otherwise, if one relies on random spoil dumping the system would need an overwhelming supply of alkaline rock. This probably accounts for the above reported field observations that twice or more NP is required for each unit of MPA.

THE AMD/TIME SPREADSHEET

The above introductory remarks are a necessary background for development and application of the AMD/TIME spreadsheet. For example, without good mixing of acid producing and alkaline rock, neither ABA nor AMD/TIME will correctly estimate the outcome. Without reliable estimates of %pyrite sulfur and neutralization potential, neither ABA nor AMD/TIME will correctly estimate the outcome.

In developing AMD/TIME the following assumptions were made:

1. Within fairly narrow limits pyrite oxidizes at a nearly fixed rate. It is about 7% per year.
2. The pyrite oxidation rate is the rate limiting step.
3. Rock geometry and porosity are simple multipliers. For example the following factors might be multiplied against 7%.

sandstone	100%
shale	50%
refuse with fines	20%

4. The resulting value is called sulfur flux.

AMD/TIME uses conventional variables plus the following:

%Sf/yr	Percentage of remaining pyritic sulfur oxidized and leached per year.
FLOW	Annual rainfall (inches) X 102970 X surface area (acres) X net infiltration (%)- yielding liters per year.
NDN	Net deliverable neutralization potential. This is the proportion of NP that is exposed to acid water and is able to react with it.
NDA	Net deliverable acidity. This is the proportion of MPA that oxidizes.

AMD/TIME operates on the Quatro Pro spreadsheet developed by Borland International, Inc. Quatro Pro is similar to Lotus 1,2,3 and, except for the graphics would probably work equally well. The spreadsheet only uses several hundred KRAM so it will work on nearly all IBM compatible desktop computers. Naturally, machine power and higher order Intel chips will make it work more quickly.

AMD/TIME was developed for simplicity, not elegance. It uses simple, empirical rather than deterministic variables. Table 1 shows the working end of AMD/TIME indicating where data is input through the variable block. The user only needs to enter the following data:

target NP/MPA ratio
years of mining
acid rock production (tons of rock produced in mining)
surface area (acres)
%Sf/yr
%S pyritic (from ABA)
%NP natural (from ABA)
%NP added
%NDN
%NDA
cost of alkaline amendment $
amendment NP (%)

TABLE 1. AMD/TIME SPREADSHEET

ESTIMATED LONG TERM ACID GENERATION AND COSTS OF TREATMENT.

SITE	ABC MINING
TARGET NP/MPA	1
YEARS OF MINING	2

VARIABLE BLOCK

ACID ROCK PRODUCTION ARP (T)	14976000
SURFACE AREA (ACRES)	60
RATE OF S LOSS (%S/YR)	5.00
FLOW (L/YR)	222026400
%S	0.227
%NP NATURAL	0.061
%NP ADDED	0.000
%NP TOTAL	0.061
% NET DEL. NEUTRALIZATION (NDN)	100
%NET DELIVERABLE ACIDITY (NDA)	50
REQUIRED NP (%)	0.29
REQ'D ALKALINE AMENDMENT (%)	0.31
COST ALK. AMENDMENT ($/TON)	12.00
AMENDMENT NP (%)	95
COST OF WATER TRT CHEMICAL ($/T)	60
ACID CAPITAL (T)	53118
ALKALINE CAPITAL (T)	9198

RESULTS BLOCK

LIFE OF MINE PRODUCTION	(TONS)	648000
COST OF WATER TREATMENT	($)	2002773
COST OF ALKALINE AMENDMENT	($)	0
COST OF WATER TREATMENT	($/RAW TON)	3.09
COST OF ALKALINE AMENDMENT	($/RAW TON)	0.00
TOTAL COST-WATER TREATMENT + AMENDMENT	($/RAW TON)	3.09

YEAR	YEAR 1 ACID (T/YR)	YEAR 2 ACID (T/YR)	YEAR 3 ACID (T/YR)	YEAR 4 ACID (T/YR)	YEAR 5 ACID (T/YR)	TOTAL ACID PRODUCTION (T/YR)	ALKALINE RESERVE (T)	NET ALKALINITY (T/YR)	ACID LOAD (T/YR)	[ACID] (MG/L)	WATER TREATMENT CHEMICAL COSTS ONLY: ANNUAL WATER TRT COST	CUM. WATER TRT COST	AMENDMENT COST MATERIALS ONLY: ANNUAL AMEND. COST	CUM. AMEND. COST	TOTAL CUMULATIVE COST
1	1328					1328	9198	7870	0	0	0	0	0	0	0

cost of water treatment chemical ($/T)

life of mine coal production (T)

AMD/TIME will then estimate acid loads, concentrations, alkalinity pools for the next several hundred years. AMD/TIME automatically estimates the chemical cost of water treatment for the life of amd production. It also automatically estimates the required amount of alkaline amendment needed to reach a target NP/MPA ratio. If you enter that amount at the "%NP added" block the spreadsheet will estimate the cumulative cost of amendment. Costs in current dollars are given in absolute amounts and in dollars per raw ton of coal.

Table 2. shows the complete AMD/TIME spreadsheet extended to 70 years. In the scenario given roughly one half of the required alkaline amendment was added to the rock so the costs reflect combined amendment and chemical treatment costs.

COMPARISON OF ESTIMATES TO SMALL SCALE FIELD DATA:

As configured AMD/TIME is an acidity model. It can also be simplified to a sulfate model. This was used to compare various variable combinations to 11 year old 400 ton test pile data at Island Creek's Upshur Complex (Table 3). Two net infiltration values and three %Sf and %NDA rates were tested a factorial arrangement. %Sf was calculated for each pile between each two week sampling period. In each pile, %Sf was very slow during the first six months, then accelerated rapidly to a maximum within about 10 months. Three estimates of %Sf were evaluated in this study: 1) low-%Sf integrated over one year, 2) medium-%Sf integrated over the last 7 months and 3) high-%Sf integrated over the last 5 months.

The column on the left of the table indicates observed sulfate concentrations at the end of year one and at the end of year 11. The best fit for each pile and variable combination was chosen and is indicated by the shading.

The best fits were either of the two variable combinations:

PILES:	1,3	2,4,5,10
NET INFILTRATION %	50	75
%Sf	low	high
NDA(%)	100	50

PILES:	1,3	2,4,5,10
NET INFILTRATION %	50	75
%Sf	low	high
NDA(%)	100	50

It was surprising that only two scenarios captured the best fits for all of the test piles. Additionally, piles 1 and 3 were primarily sandstone while the other piles were mainly shale. It is logical that high NDA fits better with the sandstones given its greater porosity. Why net infiltration appeared higher on the shale than on the sandstone is a mystery unless this actually estimates residence time of water. This analysis is far from definitive. It is just the beginning of what will be a rigorous process of identifying NDA, NDN, %Sf and net infiltrations for various rock types.

TABLE 2. AMD/TIME SPREADSHEET

ESTIMATED LONG TERM ACID GENERATION AND COSTS OF TREATMENT.

SITE ABC MINING

TARGET NP/MPA 1

YEARS OF MINING 2

VARIABLE BLOCK

ACID ROCK PRODUCTION ARP (T)	14976000
SURFACE AREA (ACRES)	60
RATE OF S LOSS (%S/YR)	7.00
FLOW (L/YR)	222026400
%S	0.100
%NP NATURAL	0.061
%NP ADDED	0.045
%NP TOTAL	0.106
% NET DEL. NEUTRALIZATION (NDN)	100
%NET DELIVERABLE ACIDITY (NDA)	50
REQUIRED NP (%)	0.09
REQ'D ALKALINE AMENDMENT (%)	0.10
COST ALK. AMENDMENT ($/TON)	12.00
AMENDMENT NP (%)	95
COST OF WATER TRT CHEMICAL ($/T	60
ACID CAPITAL (T)	23400
ALKALINE CAPITAL (T)	15937

RESULTS BLOCK

LIFE OF MINE PRODUCTION	(TONS)	648000
COST OF WATER TREATMENT	($)	332919
COST OF ALKALINE AMENDMENT	($)	85127
COST OF WATER TREATMENT	($/RAW TO	0.51
COST OF ALKALINE AMENDMENT	($/RAW TO	0.13
TOTAL COST-WATER TREATMENT + AMENDMENT	($/RAW TO	0.65

											WATER TREATMENT CHEMICAL COSTS ONLY		AMENDMENT COST MATERIALS ONLY		
YEAR	YEAR 1 ACID (T/YR)	YEAR 2 ACID (T/YR)	YEAR 3 ACID (T/YR)	YEAR 4 ACID (T/YR)	YEAR 5 ACID (T/YR)	TOTAL ACID PRODUCTION (T/YR)	ALKALINE RESERVE (T)	NET ALKALINITY (T/YR)	ACID LOAD (T/YR)	[ACID] (MG/L)	ANNUAL WATER TRT COST	CUM WATER TRT COST	ANNUAL AMEND COST	CUM AMEND COST	TOTAL CUMULATIVE COST
1	819					819	15937	15118	0	0	0	0	42563	42563	42563
2	762	819				1581	15118	13537	0	0	0	0	42563	85127	85127
3	708	762	0			1470	13537	12067	0	0	0	0	0	85127	85127
4	659	708	0	0		1367	12067	10700	0	0	0	0	0	85127	85127
5	613	659	0	0	0	1271	10700	9428	0	0	0	0	0	85127	85127
6	570	613	0	0	0	1182	9428	8246	0	0	0	0	0	85127	85127
7	530	570	0	0	0	1100	8246	7146	0	0	0	0	0	85127	85127
8	493	530	0	0	0	1023	7146	6124	0	0	0	0	0	85127	85127
9	458	493	0	0	0	951	6124	5173	0	0	0	0	0	85127	85127
10	426	458	0	0	0	885	5173	4288	0	0	0	0	0	85127	85127
11	396	426	0	0	0	823	4288	3466	0	0	0	0	0	85127	85127
12	369	396	0	0	0	765	3466	2701	0	0	0	0	0	85127	85127
13	343	369	0	0	0	711	2701	1989	0	0	0	0	0	85127	85127
14	319	343	0	0	0	662	1989	1327	0	0	0	0	0	85127	85127
15	297	319	0	0	0	615	1327	712	0	0	0	0	0	85127	85127
16	276	297	0	0	0	572	712	140	0	0	0	0	0	85127	85127
17	256	276	0	0	0	532	140	0	392	1768	0	0	0	85127	85127
18	239	256	0	0	0	495	0	0	495	2229	17895	17895	0	85127	103022
19	222	239	0	0	0	460	0	0	460	2073	22570	40465	0	85127	125592
20	206	222	0	0	0	428	0	0	428	1928	20990	61455	0	85127	146582
21	192	206	0	0	0	398	0	0	398	1793	19521	80976	0	85127	166103
22	178	192	0	0	0	370	0	0	370	1668	18154	99131	0	85127	184257
23	166	178	0	0	0	344	0	0	344	1551	16884	116014	0	85127	201141
24	154	166	0	0	0	320	0	0	320	1442	15702	131716	0	85127	216843
25	144	154	0	0	0	298	0	0	298	1341	14603	146319	0	85127	231445
26	133	144	0	0	0	277	0	0	277	1247	13580	159899	0	85127	245026
27	124	133	0	0	0	258	0	0	258	1160	12630	172529	0	85127	257656
28	115	124	0	0	0	240	0	0	240	1079	11746	184275	0	85127	269401
29	107	115	0	0	0	223	0	0	223	1003	10924	195198	0	85127	280325
30	100	107	0	0	0	207	0	0	207	933	10159	205357	0	85127	290484
31	93	100	0	0	0	193	0	0	193	868	9448	214805	0	85127	299931
32	86	93	0	0	0	179	0	0	179	807	8786	223591	0	85127	308718
33	80	86	0	0	0	167	0	0	[illegible]	751	8171	231762	0	85127	316889
34	75	80	0	0	0	155	0	0	[illegible]	698	7599	239362	0	85127	324489
35	69	75	0	0	0	144	0	0	[illegible]	649	7067	246429	0	85127	331556
36	65	69	0	0	0	134	0	0	134	604	6573	253002	0	85127	338129
37	60	65	0	0	0	125	0	0	125	561	6113	259115	0	85127	344241
38	56	60	0	0	0	116	0	0	116	522	5685	264799	0	85127	349926
39	52	56	0	0	0	108	0	0	108	486	5287	270086	0	85127	355213
40	48	52	0	0	0	100	0	0	100	452	4917	275003	0	85127	360130
41	45	48	0	0	0	93	0	0	[illegible]	420	4573	279575	0	85127	364702
42	42	45	0	0	0	87	0	0	[illegible]	391	4252	283828	0	85127	368955
43	39	42	0	0	0	81	0	0	8	363	3955	287783	0	85127	372909
44	36	39	0	0	0	75	0	0	[illegible]	338	3678	291461	0	85127	376587
45	34	36	0	0	0	70	0	0	70	314	3421	294881	0	85127	380008
46	31	34	0	0	0	65	0	0	65	292	3181	298062	0	85127	383189
47	29	31	0	0	0	60	0	0	60	272	2958	301021	0	85127	386147
48	27	29	0	0	0	56	0	0	56	253	2751	303770	0	85127	388899
49	25	27	0	0	0	52	0	0	52	235	2569	306331	0	85127	391457
50	23	25	0	0	0	49	0	0	49	219	2380	308710	0	85127	393837
51	22	23	0	0	0	45	0	0	45	203	2213	310923	0	85127	396050
52	20	22	0	0	0	42	0	0	42	189	2058	312981	0	85127	398108
53	19	20	0	0	0	39	0	0	39	176	1914	314895	0	85127	400022
54	17	19	0	0	0	36	0	0	36	164	1780	316675	0	85127	401802
55	16	17	0	0	0	34	0	0	34	152	1655	318331	0	85127	403458
56	15	16	0	0	0	31	0	0	31	141	1540	319870	0	85127	404997
57	14	15	0	0	0	29	0	0	29	132	1432	321302	0	85127	406429
58	13	14	0	0	0	27	0	0	27	122	1332	322634	0	85127	407761
59	12	13	0	0	0	25	0	0	25	114	1238	323872	0	85127	408999
60	11	12	0	0	0	23	0	0	23	106	1152	325024	0	85127	410151
61	11	11	0	0	0	22	0	0	22	98	1071	326096	0	85127	411222
62	10	11	0	0	0	20	0	0	20	91	996	327091	0	85127	412218
63	9	10	0	0	0	19	0	0	19	85	926	328017	0	85127	413144
64	8	9	0	0	0	18	0	0	18	79	862	328879	0	85127	414006
65	8	8	0	0	0	16	0	0	16	74	801	329680	0	85127	414807
66	7	8	0	0	0	15	0	0	15	68	745	330425	0	85127	415552
67	7	7	0	0	0	14	0	0	14	64	693	331118	0	85127	416245
68	6	7	0	0	0	13	0	0	13	59	644	331762	0	85127	416889
69	6	6	0	0	0	12	0	0	12	55	599	332362	0	85127	417489
70	5	6	0	0	0	11	0	0	11	51	557	332919	0	85127	418046
TOTALS						23249			7310		332919		85127		
							-15937								

TABLE 3. USE OF SIMPLIFIED AMD/TIME SPREADSHEET TO PREDICT SULFATE CONCENTRATIONS AT ICC UPSHUR COMPLEX 400 TON PILES AFTER 11 YEARS. RESULTS OF FIELD OBSERVATIONS AND 18 SIMULATIONS ARE PRESENTED. SHADED COLUMNS REPRESENT CLOSEST FITS TO OBSERVED VALUES.

PILE 1 100% SANDSTONE CONTROL

ROCK MASS (KG)		377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410	377410
AREA (AC.)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
FLOW (L/YR)		200250	200250	200250	200250	200250	200250	200250	200250	200250	133500	133500	133500	133500	133500	133500	133500	133500	133500
%S		0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
PYRITE S (KG)		377	283	189	377	283	189	377	283	189	377	283	189	377	283	189	377	283	189
TOT. SO4 (KG)		1132	849	566	1132	849	566	1132	849	566	1132	849	566	1132	849	566	1132	849	566
NET INF. (%)		75	75	75	75	75	75	75	75	75	50	50	50	50	50	50	50	50	50
%S!		0.0670	0.0670	0.0670	0.1300	0.1300	0.1300	0.1800	0.1800	0.1800	0.0670	0.0670	0.0670	0.1300	0.1300	0.1300	0.1800	0.1800	0.1800
NDA (%)		100	75	50	100	75	50	100	75	50	100	75	50	100	75	50	100	75	50
YEAR	OBS [SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1875	1227	920	613	2136	1602	1068	2723	2042	1361	1840	1380	920	3204	2403	1602	4084	3063	2042
2		961	720	480	1329	997	665	1412	1059	706	1441	1081	720	1994	1495	997	2117	1588	1059
3		752	564	376	827	620	413	732	549	366	1128	846	564	1240	930	620	1098	823	549
4		589	442	294	515	386	257	379	285	190	883	663	442	772	579	386	569	427	285
5		461	346	231	320	240	160	197	147	98	692	519	346	480	360	240	295	221	147
6		361	271	181	199	149	100	102	76	51	542	406	271	299	224	149	153	115	76
7		283	212	141	124	93	62	53	40	26	424	318	212	186	139	93	79	59	40
8		221	166	111	77	58	39	27	21	14	332	249	166	116	87	58	41	31	21
9		173	130	87	48	36	24	14	11	7	260	195	130	72	54	36	21	16	11
10		136	102	68	30	22	15	7	6	4	204	153	102	45	34	22	11	8	6
11	84	106	80	53	19	14	9	4	3	2	159	120	80	28	21	14	6	4	3

PILE 2 100% SHALE CONTROL

ROCK MASS (KG)		365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920	365920
AREA (AC.)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
FLOW (L/YR)		200250	200250	200250	200250	200250	200250	200250	200250	200250	133500	133500	133500	133500	133500	133500	133500	133500	133500
%S		0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310	0.310
PYRITE S (KG)		1134	851	567	1134	851	567	1134	851	567	1134	851	567	1134	851	567	1134	851	567
TOT. SO4 (KG)		3403	2552	1702	3403	2552	1702	3403	2552	1702	3403	2552	1702	3403	2552	1702	3403	2552	1702
NET INF. (%)		75	75	75	75	75	75	75	75	75	50	50	50	50	50	50	50	50	50
%S!		0.0204	0.0204	0.0204	0.0500	0.0500	0.0500	0.0800	0.0800	0.0800	0.0204	0.0204	0.0204	0.0500	0.0500	0.0500	0.0800	0.0800	0.0800
NDA (%)		100	75	50	100	75	50	100	75	50	100	75	50	100	75	50	100	75	50
YEAR	OBS [SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2323	1219	915	610	2835	2126	1417	4303	3228	2152	1829	1372	915	4252	3189	2126	6455	4841	3228
2		1132	849	566	2362	1771	1181	3214	2410	1607	1698	1273	849	3543	2657	1771	4820	3615	2410
3		1051	788	525	1968	1476	984	2400	1800	1200	1576	1182	788	2952	2214	1476	3600	2700	1800
4		975	731	488	1640	1230	820	1792	1344	896	1463	1097	731	2460	1845	1230	2688	2016	1344
5		905	679	453	1366	1025	683	1338	1004	669	1358	1018	679	2049	1537	1025	2007	1506	1004
6		840	630	420	1138	854	569	999	750	500	1261	945	630	1707	1281	854	1499	1124	750
7		780	585	390	948	711	474	746	560	373	1170	878	585	1423	1067	711	1119	840	560
8		724	543	362	790	593	395	557	418	279	1086	815	543	1185	889	593	836	627	418
9		672	504	336	658	494	329	416	312	208	1008	756	504	988	741	494	624	468	312
10		624	468	312	549	411	274	311	233	155	936	702	468	823	617	411	466	350	233
11	220	579	434	290	457	343	229	232	174	116	869	652	434	686	514	343	348	261	174

TABLE 3. USE OF SIMPLIFIED AMD/TIME SPREADSHEET TO PREDICT SULFATE CONCENTRATIONS AT ICC UPSHUR COMPLEX 400 TON PILES AFTER 11 YEARS.
(cont.) RESULTS OF FIELD OBSERVATIONS AND 18 SIMULATIONS ARE PRESENTED. SHADED COLUMNS REPRESENT CLOSEST FITS TO OBSERVED VALUES.

PILE 3 LAYERED SHALE/SANDSTONE CONTROL

ROCK MASS (KG)		405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680	405680
AREA (AC.)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
FLOW (L/YR)		200250	200250	200250	200250	200250	200250	200250	200250	200250	133500	133500	133500	133500	133500	133500	133500	133500	133500
%S		0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180	0.180
PYRITE S (KG)		730	548	365	730	548	365	730	548	365	730	548	365	730	548	365	730	548	365
TOT. SO4 (KG)		2191	1643	1095	2191	1643	1095	2191	1643	1095	2191	1643	1095	2191	1643	1095	2191	1643	1095
NET INF. (%)		75	75	75	75	75	75	75	75	75	50	50	50	50	50	50	50	50	50
%SI		0.0330	0.0330	0.0330	0.0600	0.0600	0.0600	0.1000	0.1000	0.1000	0.0330	0.0330	0.0330	0.0600	0.0600	0.0600	0.1000	0.1000	0.1000
NDA (%)		100	75	50	100	75	50	100	75	50	100	75	50	100	75	50	100	75	50
YEAR	OBS [SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1633	1241	931	621	2152	1614	1076	3345	2509	1673	1862	1397	931	3227	2421	1614	5018	3764	2509
2		1101	825	550	1728	1296	864	2322	1742	1161	1651	1238	825	2593	1944	1296	3484	2613	1742
3		976	732	488	1388	1041	694	1612	1209	806	1463	1098	732	2083	1562	1041	2418	1814	1209
4		865	649	432	1115	837	558	1119	839	560	1297	973	649	1673	1255	837	1679	1259	839
5		767	575	383	896	672	448	777	583	388	1150	863	575	1344	1008	672	1165	874	583
6		680	510	340	720	540	360	539	405	270	1020	765	510	1080	810	540	809	607	405
7		603	452	301	578	434	289	374	281	187	904	678	452	867	651	434	562	421	281
8		534	401	267	465	348	232	260	195	130	801	601	401	697	523	348	390	292	195
9		474	355	237	373	280	187	180	135	90	710	533	355	560	420	280	271	203	135
10		420	315	210	300	225	150	125	94	63	630	472	315	450	337	225	188	141	94
11	881	372	279	186	241	181	120	87	65	43	558	419	279	361	271	181	130	98	65

PILE 4 SANDSTONE/SHALE LAYERED WITH 1% LIMESTONE AMENDMENT

ROCK MASS (KG)		376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000	376000
AREA (AC.)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
FLOW (L/YR)		200250	200250	200250	200250	200250	200250	200250	200250	200250	133500	133500	133500	133500	133500	133500	133500	133500	133500
%S		0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
PYRITE S (KG)		1241	931	620	1241	931	620	1241	931	620	1241	931	620	1241	931	620	1241	931	620
TOT. SO4 (KG)		3722	2792	1861	3722	2792	1861	3722	2792	1861	3722	2792	1861	3722	2792	1861	3722	2792	1861
NET INF. (%)		75	75	75	75	75	75	75	75	75	50	50	50	50	50	50	50	50	50
%SI		0.0110	0.0110	0.0110	0.0200	0.0200	0.0200	0.0300	0.0300	0.0300	0.0110	0.0110	0.0110	0.0200	0.0200	0.0200	0.0300	0.0300	0.0300
NDA (%)		100	75	50	100	75	50	100	75	50	100	75	50	100	75	50	100	75	50
YEAR	OBS [SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]	^[SO4]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1038	732	549	366	1309	981	654	1928	1446	964	1097	823	549	1963	1472	981	2892	2169	1446
2		703	527	351	1217	912	608	1728	1296	864	1054	791	527	1825	1369	912	2592	1944	1296
3		675	506	338	1131	848	565	1549	1162	774	1013	759	506	1696	1272	848	2323	1742	1162
4		649	486	324	1051	788	526	1388	1041	694	973	730	486	1577	1183	788	2082	1562	1041
5		623	467	312	977	733	489	1244	933	622	935	701	467	1466	1099	733	1866	1400	933
6		598	449	299	908	681	454	1115	836	558	898	673	449	1363	1022	681	1673	1255	836
7		575	431	287	844	633	422	999	750	500	862	647	431	1267	950	633	1499	1124	750
8		552	414	276	785	589	393	896	672	448	828	621	414	1178	883	589	1344	1008	672
9		531	398	265	730	547	365	803	602	401	796	597	398	1095	821	547	1204	903	602
10		510	382	255	678	509	339	720	540	360	765	573	382	1018	763	509	1079	810	540
11	312	490	367	245	631	473	315	645	484	322	734	551	367	946	709	473	967	726	484

TABLE 3. USE OF SIMPLIFIED AMD/TIME SPREADSHEET TO PREDICT SULFATE CONCENTRATIONS AT ICC UPSHUR COMPLEX 400 TON PILES AFTER 11 YEARS.
(cont.) RESULTS OF FIELD OBSERVATIONS AND 18 SIMULATIONS ARE PRESENTED. SHADED COLUMNS REPRESENT CLOSEST FITS TO OBSERVED VALUES.

PILE 5 SANDSTONE/SHALE LAYERED WITH 0.5% LIMESTONE AMENDMENT

ROCK MASS (KG)		432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810	432810
AREA (AC.)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
FLOW (L/YR)		200250	200250	200250	200250	200250	200250	200250	200250	200250	133500	133500	133500	133500	133500	133500	133500	133500	133500
%S		0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640
PYRITE S (KG)		2770	2077	1385	2770	2077	1385	2770	2077	1385	2770	2077	1385	2770	2077	1385	2770	2077	1385
TOT. SO4 (KG)		8310	6232	4155	8310	6232	4155	8310	6232	4155	8310	6232	4155	8310	6232	4155	8310	6232	4155
NET INF. (%)		75	75	75	75	75	75	75	75	75	50	50	50	50	50	50	50	50	50
%S!		0.0100	0.0100	0.0100	0.0200	0.0200	0.0200	0.0300	0.0300	0.0300	0.0100	0.0100	0.0100	0.0200	0.0200	0.0200	0.0300	0.0300	0.0300
NDA (%)		100	75	50	100	75	50	100	75	50	100	75	50	100	75	50	100	75	50
YEAR	OBS [SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2175	1487	1116	744	2921	2191	1461	4304	3228	2152	2231	1673	1116	4382	3287	2191	6456	4842	3228
2		1434	1076	717	2716	2037	1358	3858	2893	1929	2151	1613	1076	4074	3055	2037	5786	4340	2893
3		1383	1037	691	2525	1893	1262	3458	2593	1729	2074	1555	1037	3787	2840	1893	5186	3890	2593
4		1333	1000	667	2347	1760	1173	3099	2324	1549	2000	1500	1000	3520	2640	1760	4648	3486	2324
5		1285	964	643	2182	1636	1091	2778	2083	1389	1928	1446	964	3272	2454	1636	4166	3125	2083
6		1239	929	620	2028	1521	1014	2489	1867	1245	1859	1394	929	3042	2282	1521	3734	2801	1867
7		1195	896	597	1885	1414	943	2231	1673	1116	1792	1344	896	2828	2121	1414	3347	2510	1673
8		1152	864	576	1753	1314	876	2000	1500	1000	1728	1296	864	2629	1972	1314	3000	2250	1500
9		1111	833	555	1629	1222	815	1792	1344	896	1666	1250	833	2444	1833	1222	2689	2016	1344
10		1071	803	535	1514	1136	757	1607	1205	803	1606	1205	803	2272	1704	1136	2410	1807	1205
11	332	1033	774	516	1408	1056	704	1440	1080	720	1549	1162	774	2112	1584	1056	2160	1620	1080

PILE 10 SHALE/SANDSTONE BLENDED CONTROL

ROCK MASS (KG)		389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740	389740
AREA (AC.)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
FLOW (L/YR)		200250	200250	200250	200250	200250	200250	200250	200250	200250	133500	133500	133500	133500	133500	133500	133500	133500	133500
%S		0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
PYRITE S (KG)		1169	877	585	1169	877	585	1169	877	585	1169	877	585	1169	877	585	1169	877	585
TOT. SO4 (KG)		3508	2631	1754	3508	2631	1754	3508	2631	1754	3508	2631	1754	3508	2631	1754	3508	2631	1754
NET INF. (%)		75	75	75	75	75	75	75	75	75	50	50	50	50	50	50	50	50	50
%S!		0.0280	0.0280	0.0280	0.0500	0.0500	0.0500	0.0800	0.0800	0.0800	0.0280	0.0280	0.0280	0.0500	0.0500	0.0500	0.0800	0.0800	0.0800
NDA (%)		100	75	50	100	75	50	100	75	50	100	75	50	100	75	50	100	75	50
YEAR	OBS [SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]	*[SO4]
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2400	1702	1276	851	2922	2192	1461	4436	3327	2218	2553	1914	1276	4383	3287	2192	6654	4990	3327
2		1536	1152	768	2435	1826	1217	3312	2484	1656	2305	1728	1152	3652	2739	1826	4969	3727	2484
3		1387	1040	694	2028	1521	1014	2474	1855	1237	2081	1561	1040	3043	2282	1521	3710	2783	1855
4		1252	939	626	1690	1268	845	1847	1385	924	1879	1409	939	2535	1901	1268	2771	2078	1385
5		1131	848	565	1408	1056	704	1379	1035	690	1696	1272	848	2112	1584	1056	2069	1552	1035
6		1021	766	510	1173	880	587	1030	773	515	1531	1148	766	1760	1320	880	1545	1159	773
7		922	691	461	978	733	489	769	577	385	1383	1037	691	1466	1100	733	1154	865	577
8		832	624	416	814	611	407	574	431	287	1248	936	624	1222	916	611	862	646	431
9		751	563	376	679	509	339	429	322	214	1127	845	563	1018	763	509	643	483	322
10		678	509	339	565	424	283	320	240	160	1017	763	509	848	636	424	481	360	240
11	141	612	459	306	471	353	236	239	179	120	919	689	459	707	530	353	359	269	179

COMPARISON OF ESTIMATES TO LARGE SCALE FIELD SITES:

AMD/TIME was applied to a site in northern West Virginia five years after initial mining and where water quality and flow data were available. Figure 1 shows acid load and acid concentrations as estimated and as observed for the site. For this case the key variables were set as suggested by the above sandstone piles (1,3):

NET INFILTRATION % 50

%Sf/yr	6%
NDA(%)	100

This didn't work very well, estimated acid concentrations and loads were about 4 times higher than observed in the field. Eventually a good fit (the one shown in figure 1) was found with the following settings:

NET INFILTRATION %	80
%Sf/yr	4%
NDA(%)	50

Figure 1 shows a shortcoming with AMD/TIME as presently configured: alkalinity is presumed to be consumed with 100% efficiency until it is exhausted, the acid load curve then leaps from zero to a high number in the following year. In reality this is, doubtless, a more gradual process though the net result is likely to be the same.

Extension of the curves in figure 1 to the point of acid exhaustion indicates that at year 113 acid loading will be 10 tons per year (figure 2.). Long before that, however, it will be negligible or easily treated in a passive system. AMD/TIME was used to estimate the required amount of alkaline amendment arid the effects on acid generation. Figure 3 shows that AMD/TIME slightly underestimated the required amount (probably by a roundoff error) such that at year 115 the added limestone was exhausted and a small (19 T/yr) peak in acid load appeared for a few years.

Treatment costs are automatically estimated. by AMD/TIME. Figure 4 shows the cumulative costs of limestone amendment versus 113 years of water treatment using hydrated lime. With alkaline amendment all costs were incurred during mining.

AMD/TIME is extremely sensitive to application of the wrong key variables. Figure 5, 6 and 7 show the effects of holding all variables constant while varying %Sf from 1 to 8. It is likely that many refuse piles resemble figure 5 (without the alkalinity) while most spoils are closer to figure 6. An annual sulfur flux such as the 8% shown in figure 7 is unlikely to occur outside the laboratory. Figure 8 shows a very unhappy situation where, due to poor mixing of alkaline materials, NDN :s only 75% while NDA is 100%. This is otherwise the same scenario as figure 6. Things get much worse much more quickly, however.

FIGURE 1. ACID LOADS AND CONCENTRATIONS PROJECTED AND OBSERVED @ LAUREL #3

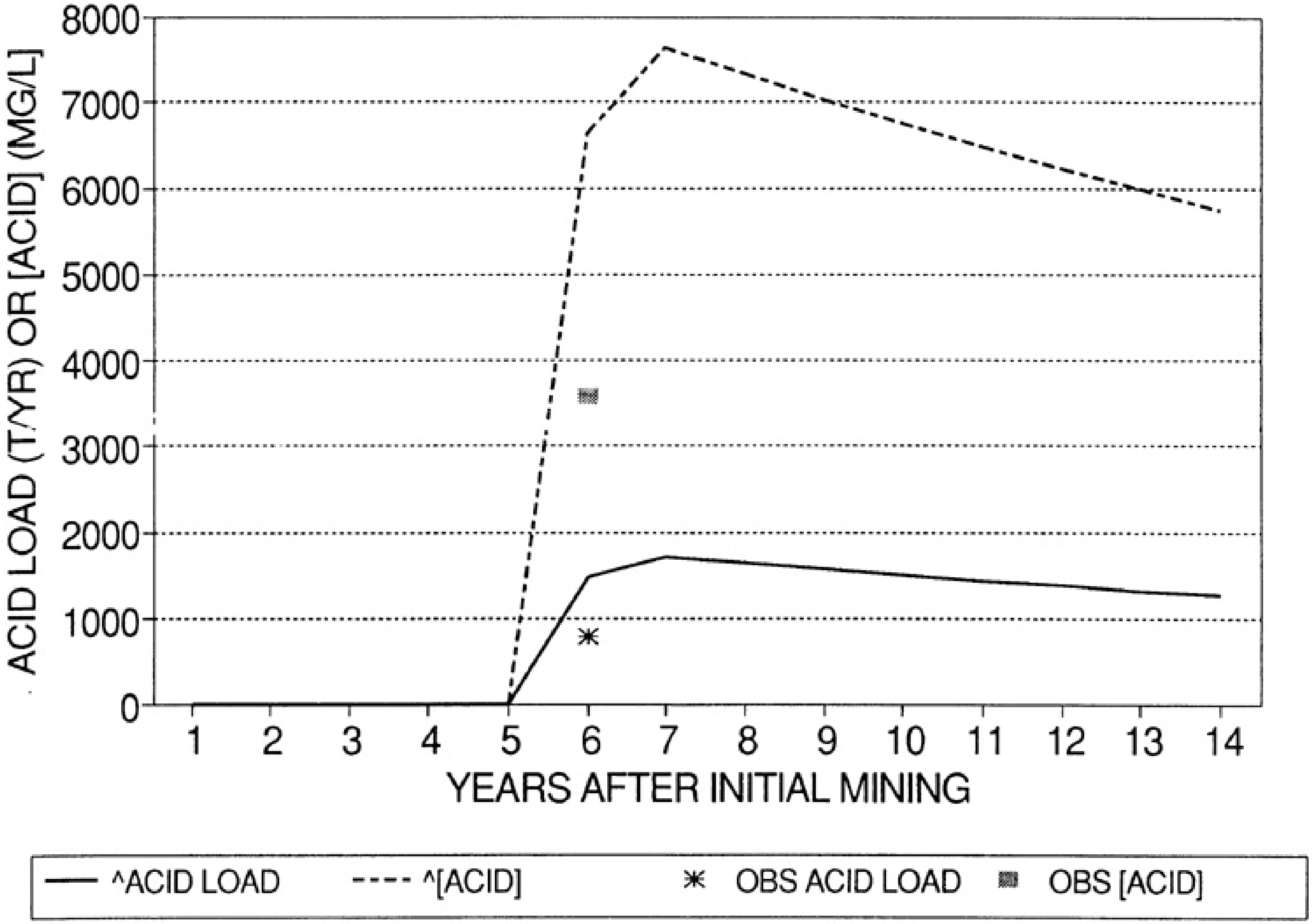


FIGURE 2. ACID LOADS AND CONCENTRATIONS PROJECTED @ LAUREL #3

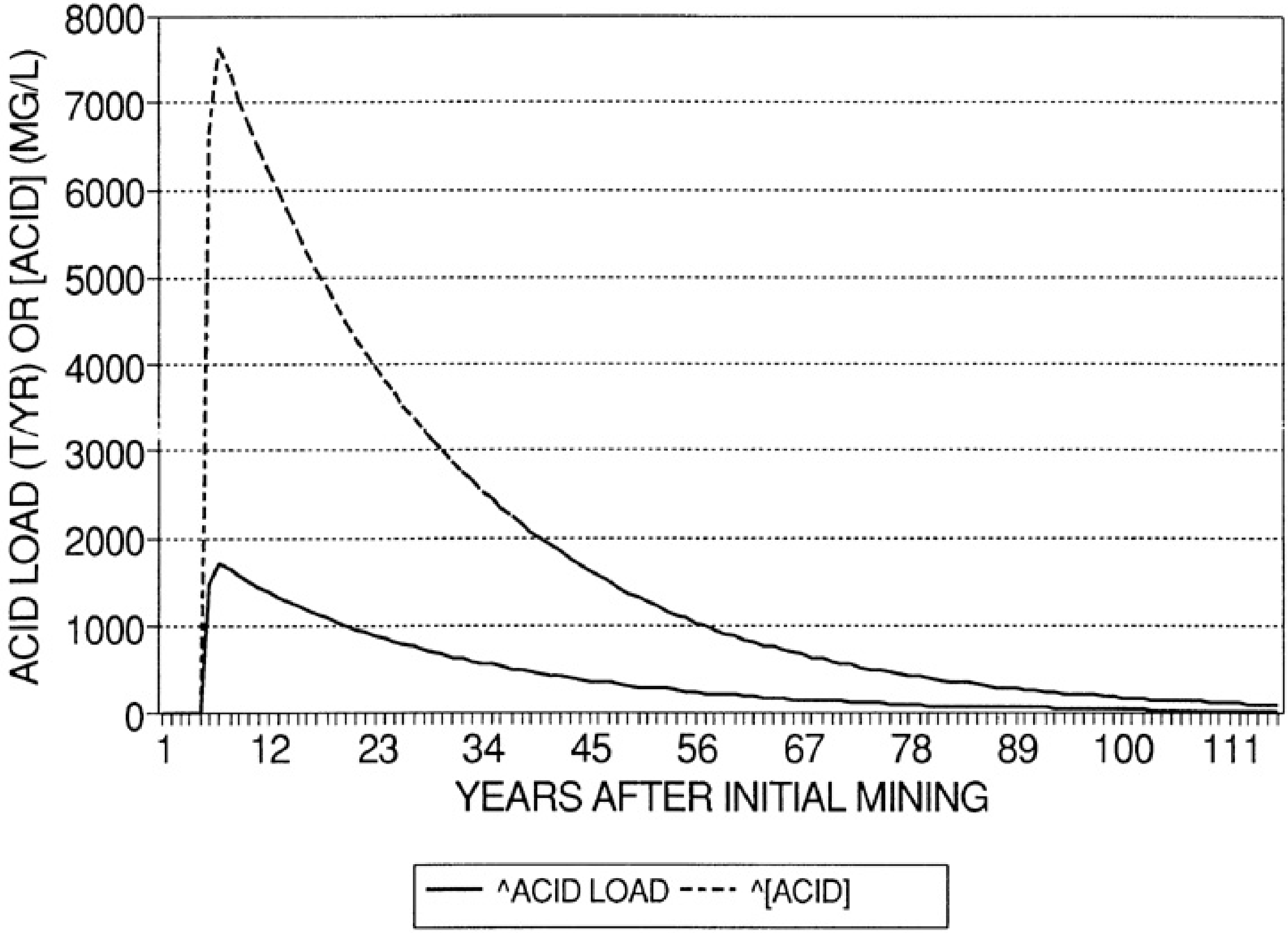


FIGURE 3. PROJECTED ACID LOAD-LAUREL #3
WITH 0.29% LIMESTONE ADDED.

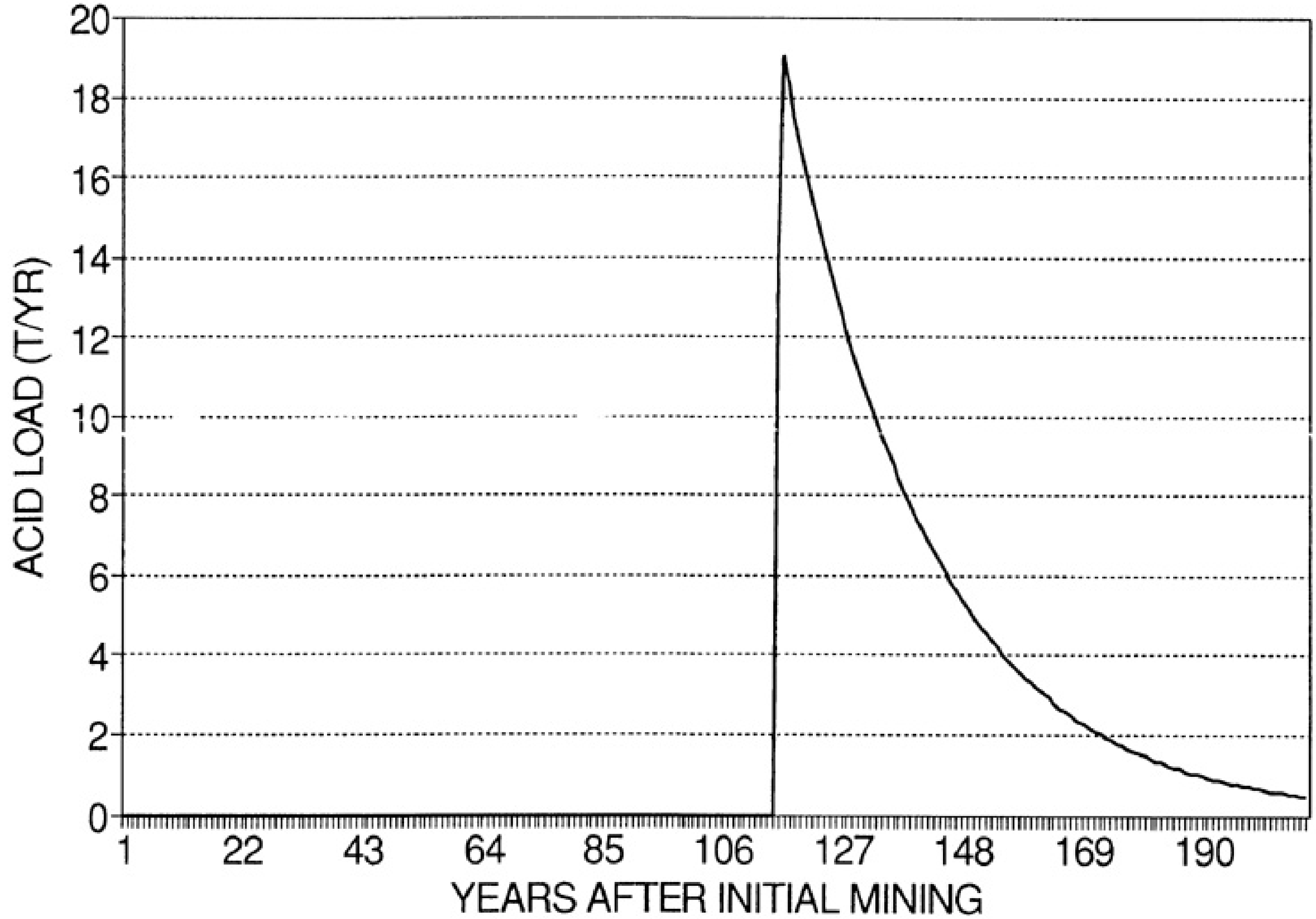


FIGURE 4. PROJECTED COST AMENDMENT VS. WATER TREATMENT WITH 0.29% LIMESTONE.

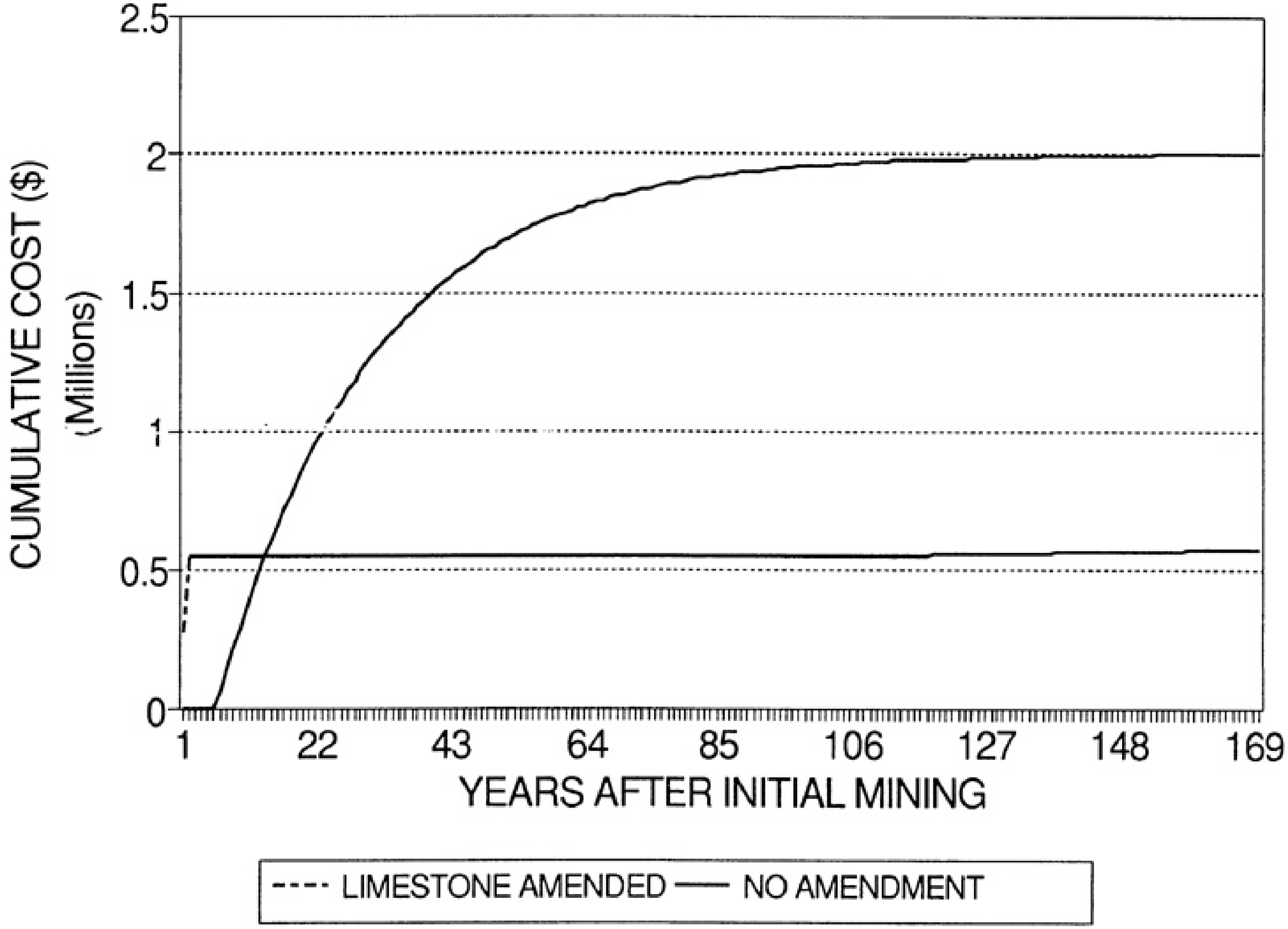


FIGURE 5. ACID LOADS AND CONCENTRATIONS
%Sf=1.0

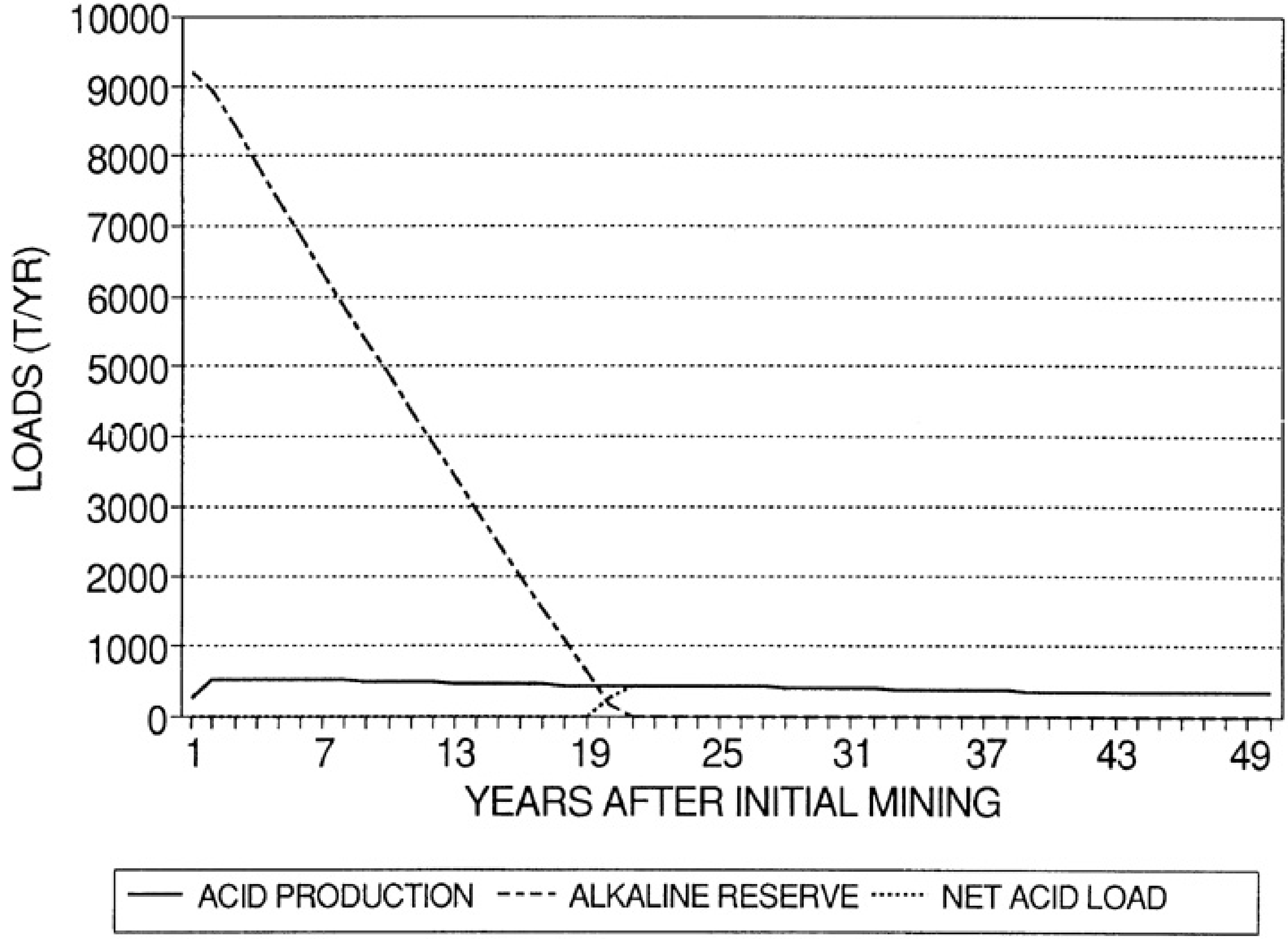


FIGURE 6. ACID LOADS AND CONCENTRATIONS
%Sf=5.0

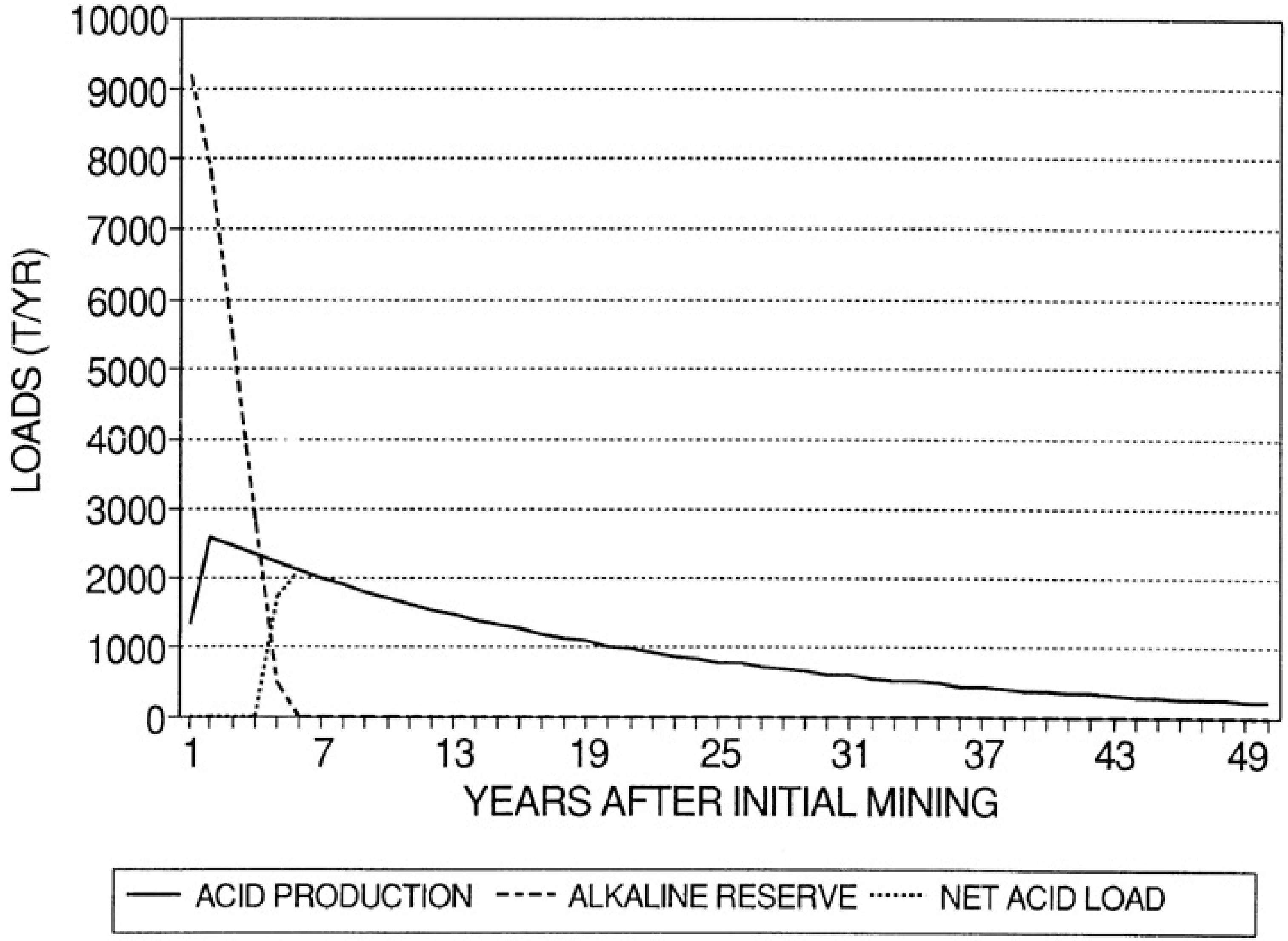
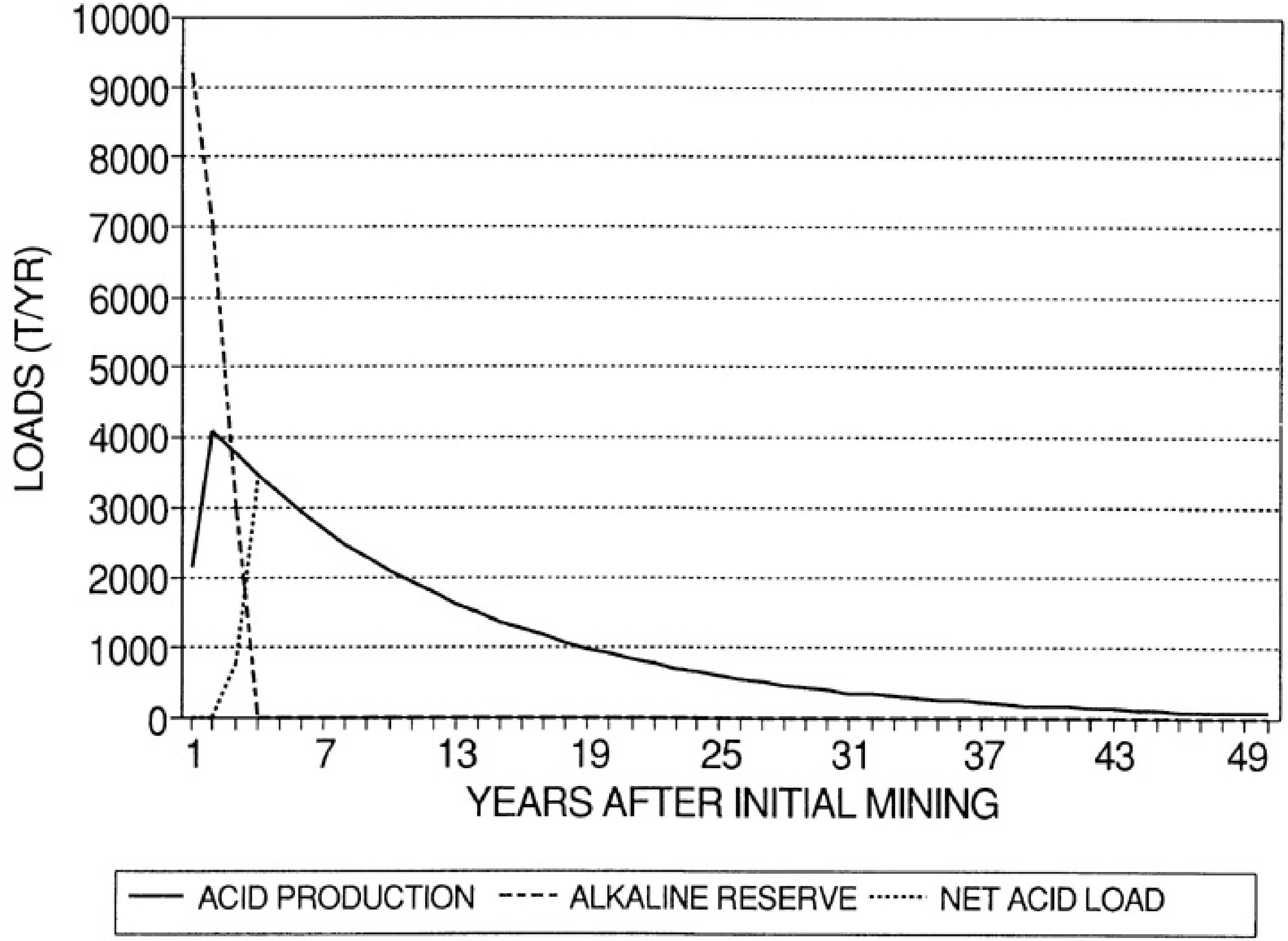


FIGURE 7. ACID LOADS AND CONCENTRATIONS
%Sf=8.0



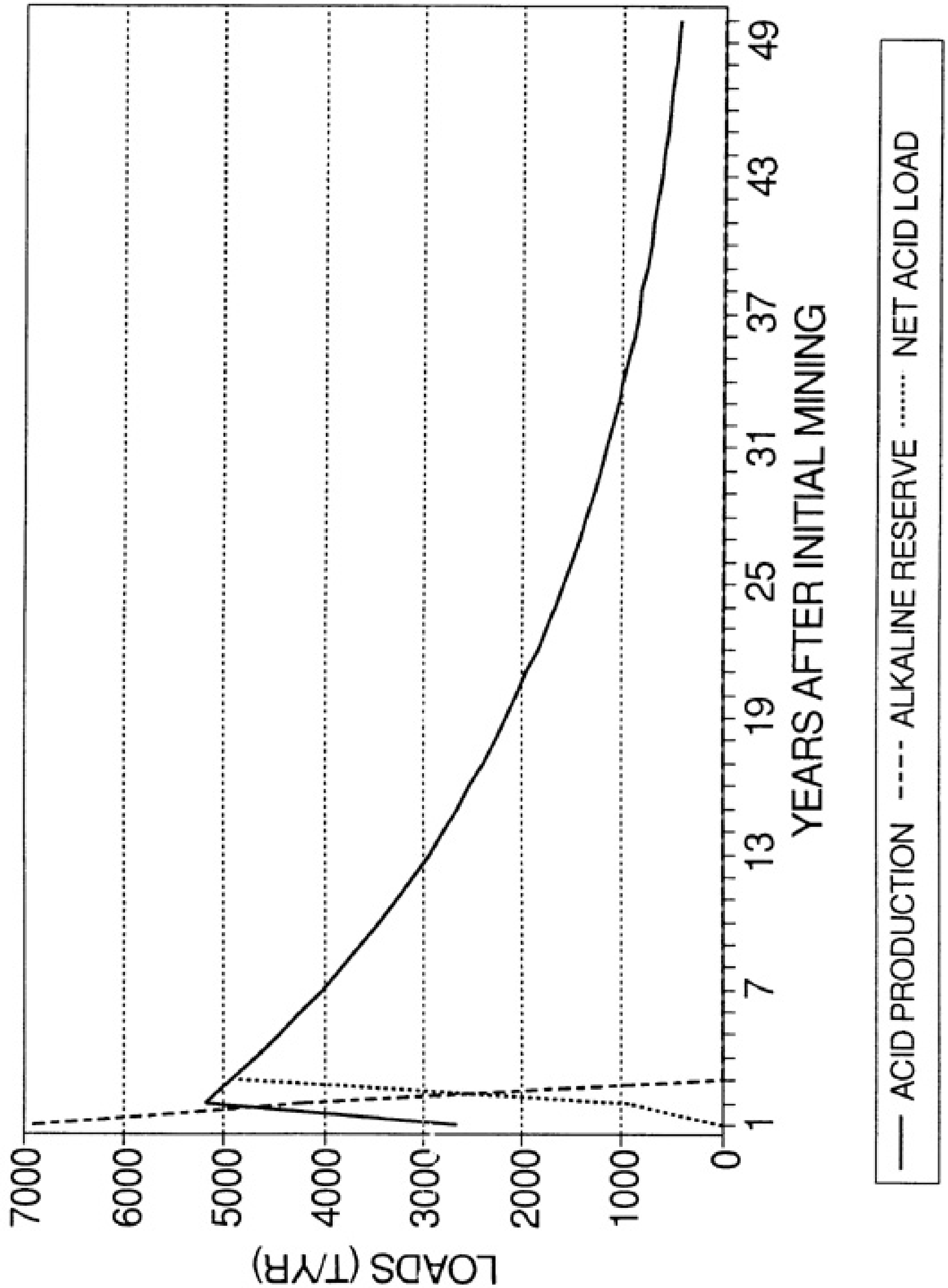


FIGURE 8. ACID LOADS AND CONCENTRATIONS
%Sf=5.0 NDN=75 NDA=100

VALIDATION OF AMD/TIME

Like all predictive tools, AMD/TIME is only as good as the variables which make it run. Since it uses empirical variables it is useful to compare predictions within set boundary conditions to field observations.

The spreadsheet is not proprietary. A copy of the codes is attached in the appendix. Feel free to copy it and use it. I only ask two favors:

1. let me know if it works for your situation. I will be happy to work with you and your data to zero in on the right variable settings.
2. If it works, I would appreciate acknowledgement, if it does not work, don't bother.

Let me know either way. My phone number is (304) 293 2867.

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APPENDIX

CODES FOR CONSTRUCTING THE AMD/TIME SPREADSHEET

THE COLUMN ON THE LEFT INDICATES THE CELL ADDRESS

DESIGNATIONS SUCH AS [W10] AND (F0)

ONLY REFER TO CELL WIDTHS AND FONTS. THEY ARE NOT IMPORTANT.

```
A5: [W10] 'AMD/TIME  ZIEMKIEWICZ
A6: [W10] 'SITE
E6: [W12] 'ABC MINING
A7: [W10] 'TARGET NP/MPA
E7: [W12] 1
A8: [W10] 'YEARS OF MINING
E8: [W12] 2
A10: [W10] 'VARIABLE BLOCK
H10: [W11] 'RESULTS BLOCK
A11: [W10] 'ACID ROCK PRODUCTION ARP (T)
E11: (F0) U [W12] 3200*78*E12
G11: [W18] 'LIFE OF MINE PRODUCTION
K11: [W11] '(TONS)
L11: (F0) [W14] 60*6*1800
A12: [W10] 'SURFACE AREA (ACRES)
E12: (F0) U [W12] 60
G12: [W18] 'COST OF WATER TREATMENT
K12: [W11] '($)
L12: (F0) [W14] +L375
A13: [W10] 'RATE OF S LOSS (%Sf/YR)
E13: (F2) U [W12] 5
G13: [W18] 'COST OF ALKALINE AMENDMENT
K13: [W11] '($)
L13: (F0) [W14] +N375
A14: [W10] 'FLOW (L/YR)
E14: (F0) [W12] 102790*45*E12*0.8
G14: [W18] 'COST OF WATER TREATMENT
K14: [W11] '($/RAW TON)
L14: (F2) [W14] +L12/L11
A15: [W10] '%S
E15: (F3) U [W12] 0.227
G15: [W18] 'COST OF ALKALINE AMENDMENT
K15: [W11] '($/RAW TON)
L15: (F2) [W14] +L13/L11
A16: [W10] '%NP NATURAL
E16: (F3) U [W12] +U717
G16: [W18] 'TOTAL COST-WATER TREATMENT + AMENDMENT
K16: [W11] '($/RAW TON)
L16: (F2) [W14] +L14+L15
A17: [W10] '%NP ADDED
E17: (F3) U [W12] 0
A18: [W10] '%NP TOTAL
E18: (F3) [W12] +E16+E17
A19: [W10] '% NET DEL. NEUTRALIZATION (NDN)
E19: (F0) U [W12] 100
A20: [W10] '%NET DELIVERABLE ACIDITY (NDA)
E20: (F0) U [W12] 50
A21: [W10] 'REQUIRED NP (%)
E21: (F2) [W12] ((E7*(E15*3.125*E20*0.01)/(E19*0.01))-E16)
```

```
A22: [W10] 'REQ'D ALKALINE AMENDMENT (%)
E22: (F2) [W12] ((E7*(E15*3.125*E20*0.01)/(E19*0.01))-E16)/(E24*0.01)
A23: [W10] 'COST ALK. AMENDMENT ($/TON)
E23: (F2) U [W12] 12
A24: [W10] 'AMENDMENT NP (%)
E24: (F0) U [W12] 95
A25: [W10] 'COST OF WATER TRT CHEMICAL ($/T)
E25: (F0) U [W12] 60
A26: [W10] 'ACID CAPITAL (T)
E26: (F0) [W12] (E11*E15*0.01*3.125)*(E20*0.01)
A27: [W10] 'ALKALINE CAPITAL (T)
E27: (F0) [W12] (E11*(E18*0.01)*(E19*0.01))
L29: [W14] '    WATER TREATMENT
N29: '  AMENDMENT COST
L30: [W14] '  CHEMICAL COSTS ONLY
N30: '  MATERIALS ONLY
B31: [W8] ^YEAR 1
C31: [W8] ^YEAR 2
D31: [W8] ^YEAR 3
E31: [W12] ^YEAR 4
F31: [W8] ^YEAR 5
G31: [W18] ^TOTAL ACID
H31: [W11] ^ALKALINE
I31: [W12] ^NET
J31: [W11] ^ACID
K31: [W11] ^[ACID]
L31: [W14] ^ANNUAL
M31: [W13] ^CUM.
N31: ^ANNUAL
O31: [W13] ^CUM.
P31: [W14] ^TOTAL
B32: [W8] ^ACID
C32: [W8] ^ACID
D32: [W8] ^ACID
E32: [W12] ^ACID
F32: [W8] ^ACID
G32: [W18] ^PRODUCTION
H32: [W11] ^RESERVE
I32: [W12] ^ALKALINITY
J32: [W11] ^LOAD
L32: [W14] ^WATER
M32: [W13] ^WATER
N32: ^AMEND.
O32: [W13] ^AMEND.
P32: [W14] ^CUMULATIVE
B33: [W8] ^(T/YR)
C33: [W8] ^(T/YR)
D33: [W8] ^(T/YR)
E33: [W12] ^(T/YR)
```

```
F33: [W8] ^(T/YR)
G33: [W18] ^(T/YR)
H33: [W11] ^(T)
I33: [W12] ^(T/YR)
J33: [W11] ^(T/YR)
K33: [W11] ^(MG/L)
L33: [W14] ^TRT COST
M33: [W13] ^TRT COST
N33: ^COST
O33: [W13] ^COST
P33: [W14] ^COST
A34: [W10] ^YEAR
A35: [W10] 1
B35: (F0) [W8] (E26/E8*(E13*0.01))
G35: (F0) [W18] @SUM(B35..F35)
H35: (F0) [W11] +E27
I35: (F0) [W12] @IF((H35-G35)<0,0,(H35-G35))
J35: (F0) [W11] @IF((H35-G35)<0,(@ABS(H35-G35)),0)
K35: (F0) [W11] +J35*1000000000/$E$14
L35: (F0) [W14] +J34*0.76*($E$25)
M35: (F0) [W13] +L35
N35: (F0) @IF($E$8<1,0,($E$11)*(($E$17/($E$24*0.01))*$E$23*0.01))/E8
O35: (F0) [W13] +N35
P35: (F0) [W14] +M35+O35
A36: [W10] +A35+1
B36: (F0) [W8] +B35-(B35*(E13*0.01))
C36: (F0) [W8] @IF(E8<2,0,B35)
G36: (F0) [W18] @SUM(B36..F36)
H36: (F0) [W11] @IF(I35<0,0,I35)
I36: (F0) [W12] @IF((H36-G36)<0,0,(H36-G36))
J36: (F0) [W11] @IF((H36-G36)<0,(@ABS(H36-G36)),0)
K36: (F0) [W11] +J36*1000000000/$E$14
L36: (F0) [W14] +J35*0.76*($E$25)
M36: (F0) [W13] +M35+L36
N36: (F0) @IF($E$8<2,0,($E$11)*(($E$17/($E$24*0.01))*$E$23*0.01))/E8
O36: (F0) [W13] +O35+N36
P36: (F0) [W14] +M36+O36
A37: [W10] +A36+1
B37: (F0) [W8] +B36-(B36*(E13*0.01))
C37: (F0) [W8] +C36-(C36*(E13*0.01))
D37: (F0) [W8] @IF(E8<3,0,B35)
G37: (F0) [W18] @SUM(B37..F37)
H37: (F0) [W11] @IF(I36<0,0,I36)
I37: (F0) [W12] @IF((H37-G37)<0,0,(H37-G37))
J37: (F0) [W11] @IF((H37-G37)<0,(@ABS(H37-G37)),0)
K37: (F0) [W11] +J37*1000000000/$E$14
L37: (F0) [W14] +J36*0.76*($E$25)
M37: (F0) [W13] +M36+L37
N37: (F0) @IF($E$8<3,0,($E$11)*(($E$17/($E$24*0.01))*$E$23*0.01))/E8
```

```
O37: (F0) [W13] +O36+N37
P37: (F0) [W14] +M37+O37
A38: [W10] +A37+1
B38: (F0) [W8] +B37-(B37*(E13*0.01))
C38: (F0) [W8] +C37-(C37*(E13*0.01))
D38: (F0) [W8] +D37-(D37*(E13*0.01))
E38: (F0) [W12] @IF(E8<4,0,B35)
G38: (F0) [W18] @SUM(B38..F38)
H38: (F0) [W11] @IF(I37<0,0,I37)
I38: (F0) [W12] @IF((H38-G38)<0,0,(H38-G38))
J38: (F0) [W11] @IF((H38-G38)<0,(@ABS(H38-G38)),0)
K38: (F0) [W11] +J38*1000000000/$E$14
L38: (F0) [W14] +J37*0.76*($E$25)
M38: (F0) [W13] +M37+L38
N38: (F0) @IF($E$8<4,0,($E$11)*(($E$17/($E$24*0.01))*$E$23*0.01))/E8
O38: (F0) [W13] +O37+N38
P38: (F0) [W14] +M38+O38
A39: [W10] +A38+1
B39: (F0) [W8] +B38-(B38*(E13*0.01))
C39: (F0) [W8] +C38-(C38*(E13*0.01))
D39: (F0) [W8] +D38-(D38*(E13*0.01))
E39: (F0) [W12] +E38-(E38*(E13*0.01))
F39: (F0) [W8] @IF(E8<5,0,B35)
G39: (F0) [W18] @SUM(B39..F39)
H39: (F0) [W11] @IF(I38<0,0,I38)
I39: (F0) [W12] @IF((H39-G39)<0,0,(H39-G39))
J39: (F0) [W11] @IF((H39-G39)<0,(@ABS(H39-G39)),0)
K39: (F0) [W11] +J39*1000000000/$E$14
L39: (F0) [W14] +J38*0.76*($E$25)
M39: (F0) [W13] +M38+L39
N39: (F0) @IF($E$8<5,0,($E$11)*(($E$17/($E$24*0.01))*$E$23*0.01))/E8
O39: (F0) [W13] +O38+N39
P39: (F0) [W14] +M39+O39
A40: [W10] +A39+1
B40: (F0) [W8] +B39-(B39*(E13*0.01))
C40: (F0) [W8] +C39-(C39*(E13*0.01))
D40: (F0) [W8] +D39-(D39*(E13*0.01))
E40: (F0) [W12] +E39-(E39*(E13*0.01))
F40: (F0) [W8] +F39-(F39*(E13*0.01))
G40: (F0) [W18] @SUM(B40..F40)
H40: (F0) [W11] @IF(I39<0,0,I39)
I40: (F0) [W12] @IF((H40-G40)<0,0,(H40-G40))
J40: (F0) [W11] @IF((H40-G40)<0,(@ABS(H40-G40)),0)
K40: (F0) [W11] +J40*1000000000/$E$14
L40: (F0) [W14] +J39*0.76*($E$25)
M40: (F0) [W13] +M39+L40
N40: (F0) 0
O40: (F0) [W13] +O39+N40
P40: (F0) [W14] +M40+O40
```