Field Trials and Tribulations From Bench Scale to Mine Bench

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Various pressures compel coal mine operators to attend to the quality of the environment. Included among these are social and legal pressures from both the surrounding community and the environmental community, legal or regulatory requirements following from state and federal mandates, and internal ethical motivations. The actions taken to protect the environment traditionally include:

1. Pre-mining environmental assessments including:

    a. baseline water quality studies
    b. lithologic and structural categorization of the geology of the mining site
    c. acid generation categorization of the overburden via acid base accounting (EPA 600) or correlation
    d. soil and subsoil characterizations for post-mining revegetation
    e. the determination of probable hydrologic consequences of mining
    f. and the determination of subsidence or soil stability plans;

2. 2. Development of mining plans to avoid environmental degradation including:

    a. classification and segregation of overburden in restructuring the backfill
    b. treatment of toxic overburden or payment with ameloriates, eg: liming the pit floor
    c. designing mining plans which promote faster pit reclamation
    d. designing surface and in some cases subsurface drainage controls to avoid water contact with toxic materials and
    e. use of pillar support to avoid subsidence;

3. Use of post-mining environmental controls to affect quality

    a. use of water neutralization systems
    b. use of deep mine entry seals/flood
    c. post-mining water monitoring.

These actions taken to protect or minimize environmental degradation are expensive, threatening operational profits and at times corporate viability.

Pre and Post Mining Costs

The costs associated with these traditional measures are made more onerous due to their ineffectiveness or long term nature. For example most mining permit procedures require an acid base account of the overburden to be encountered while mining. Many operators and most regulators agree that typical acid base accounts are not effective in predicting future acid generating capabilities of the overburden. However the practice continues. The expense of this luxury is, of course, variable, however one site we investigated required 5 overburden specimen holes costing $9950 in direct drilling and laboratory cost, $3200 in interpretation and report preparation cost and when the permit was initially denied $25,000 in legal costs and $9200 in expert testimony cost.

At the post-mining end of the spectrum consider acid mine neutralization systems. A wide range of expenditure for the system installation, caustic reagent, system maintenance, sludge disposal, monitoring cost and labor costs are required to protect the effluent quality.

The difference between the post mining costs and pre-mining or concurrent mining costs is that the former are long term and potentially perpetual costs which occur regardless of corporate profits or losses. The present day worth of these costs is illustrated by one site which required an average sodium hydroxide cost of $16,000 per month, labor of $4,200 per month and maintenance/sludge disposal cost of $980 per month. The present worth of this monthly cost is equal to $ 2,542,600 invested today in an account yielding 10% annual interest. Obviously the costs associated with environmental control justify more than a passing interest in the issues.

Research Goals

Research into acid mine drainage abatement intends to introduce and simplify procedures necessary to protect the environment or to improve the efficacy of procedures. Unfortunately most researchers skilled at developing bench scale experimentation are not equipped economically or through expertise to effectively scale up their research from the bench to the field. Likewise most mining organizations are not predisposed toward attempting to scale up bench experiments no matter how promising. Most consultanting organizations financially exist to perform services requested and authorized by their clients. Since their mining clients better understand surveying, drafting and permitting requirements needed in support of mining they are more inclined to authorize this type of work. Another group claiming interest in environmental protection is the "environmentalists." Unfortunately most environmental groups seek to protect the status of the environment by stopping mining altogether through litigation or legislative measures rather than by supporting technological controls.

The last group which should be interested in the scale up of research to field demonstration, state and federal regulatory agencies, have not actively moved to do so. Some AML funds have been released for sealing old mine entries and stabilization and beautification of abandoned strip sites. Bu t by in large, little has been achieved in governmental promotion of a unified scheme for scale up of acid mine drainage laboratory work.

KISS Engineering Corporation in cooperation with researchers at West Virginia University, predominately Drs. Stiller and Renton, has over the past four years attempted to take on the task of extrapolating from the controlled laboratory environment to the uncontrolled field environment. Technically the process is called engineering similitude or modeling. In a simplified scheme shown in Figure 1, unmeasureable or uncontrolled elements and relationship between elements in the field are reduced or modified to measurable and controlled elements and relationships in a laboratory. Experiments are designed, results generated and if the transfer equations or relationship are known the results of the experiment can be extrapolated to what will happen in the field. The degree of conformity between the laboratory results and the field results is a measure of predictive validity of the model.

As contrasting examples of the modeling process consider two of the so called predictive experiments used to model the acid mine drainage process, acid base accounting (EPA 600/2-78-054) and one the Renton-Stiller method of Soxhlet extraction.

Field Environment

Elements:

water infiltration (vertical-precipitation);

percolation (horizontal-vertical distribution)
variable quality/quantity relationships

overburden variable size distribution

variable segregation
variable chemical constituents

air -- variable partial pressure distribution

Relationships:

4 to 28 acid generation equations (temperature, constituents, time)
dissolution rates - variable (pH, flow rate, compounds, time)
sequence of reaction - variable leaching/oxidation cycles

Physical Results:

Acidity
Alkalinity
Metals in ionic concentration
pH

Acid Base Accounting

Elements:

pyritic sulfur content - size controlled by preparation calcium
carbonate equivalence (calculated from reaction of Hot HCL with fine)

Relationships:

Not tested - idealized mathematic combination

$S\ H_2SO_4 + CaCO_3\ H_2O + CO_2 + CaSO_4$

Physical Results:

%S, $CaCO_3$ Equivalent

Soxhlet Extraction

Elements:

water - infiltration - recycle

- initial quality - distilled/deionized

overburden - variable size distribution field collection

air - consistent partial pressure

Relationships:

4 to 28 acid generation equations (temp, constituents, time)

dissolution rates - variable (+pH, flow rate)

sequencing - controlled on alternating schedule

Physical Results:

Acidity
Alkalinity
Metal in ionic concentrations
pH

As can be easily seen on the chart the elements and relationships existing in the field are modeled on a one to one correspondence by the Soxhlet model with the physical results of the experimentation yielding the same qualitative data as result on the actual site. No semblance of one to one corresponding can be claimed for the case of the traditional acid base accounting procedure, and as likewise expected, the physical results of acid base accounting do not in anyway approximate the qualitative conditions at the site.

KISS Engineering conducted soxhlet extraction on Site I which was mentioned earlier in discussion of costs, in an effort to better predict the nature of acid generation potential. The overburden analysis is shown in Table 1. The consultants' analysis of these data abstracted from the original report indicated that the lower section contains the only potentially toxic material and if ... overburden analysis show that all test holes contain net excesses of neutralizing material down to the level of the Upper Freeport Rider Coal ... It The material handling plan called for liming the pit pavement and covering with four feet of neutralizing materials available from above the U.F. Rider seam. This strategy is depicted in Figure 2.

KISS Engineering Corporation conducted soxhlet experiments on the same site in an effort to validate the acid base conclusions. Without discussing all of the specific tests and procedures we concluded the following:

1) Although the sandstone horizons located above the Upper Freeport Rider were classified as alkaline producing/nontoxic we found that after a projected 60 days of atmospheric exposure the alkalinity rapidly declines and that from thirty days onward high manganese production for these horizons can be expected.

2) Although the immediate top (roof rock) was classified as toxic we found that the materials from this stratum were neutral to slightly alkaline.

3) Although the payment was classified as "slightly toxic" we found it to be extremely acidic and highly toxic in production of both iron and manganese ions.

The mining plans originally called for a segregation plan that laid the sandstone horizons onto the payment and brought the roof rock to a "high dry" environment within the backfill. We predicted that this original plan would produce outflow from the backfill of the following, pH - 3.5 to 4, Fe - 150 ppm to 300 ppm, and Mn - 40 ppm to 50 ppm. At our last presentation to the client we found that a neighboring reclaimed surface mine was yielding these same relative values of water quality. Because of the treatment cost the adjacent operator went bankrupt. Our recommendation was not to mine the property without significant alteration of the mining plan or further amelioration strategies.

Site 2

Not all scale up work is as clean and accurate as the above. Consider if you will, one of the first cases we undertook. An active GOB pile in the southern part of West Virginia was having an acid problem. Built in 1978, the first year acid generation cost was zero. The next year the operator installed an automatic briquette feeder. For the year the briquette cost approximately $1,200, a modest cost. The next year briquettes were still being used but a lime mixer feeder had been added to the system. In summer of 1982 the briquettes and lime mixer were insufficient to control the metals and sodium hydroxide was added to the reagents. That year the average monthly cost to treat the acid mine discharge was $2,175. For reference the present worth of the reagent alone for this drainage was $261,000 which does not include labor, sludge disposal cost and monitoring cost. Another factor not included in calculation of the amortization of prolonged treatment is that acid mine drainage tends to worsen rapidly in the initial years. Thus the treatment costs for this year may be a deceptively low predictor of next year's expenditures.

For reference sake some of the water quality parameters with this site were as follows:

acidity:	1500 to 3500
Fe:	1200 to 2600
pH:	2.2 to 2.6
Mn:	15 to 20

Contemporaneously Drs. Stiller and Renton of WVU had just completed some preliminary investigations into the effect of phosphate rock upon decreasing the electrical potential for pyrite to react to form oxidation products (eg: acid) (see past AMTAC-WVSMRA Symposium presentation). Additional laboratory work was underway and Island Creek Coal Company (now Enoxy) had undertaken an ambitious field demonstration project. All of the bench scale results were indicative of success at this site.

We reviewed the site, drew up a proposal which included confirming bench scale work, small scale demonstration and monitoring and finally, after the site was fully described and scaling parameters known, full scale field introduction. The client was less than enthused; as he informed us that first his job was "to mine and wash coal not support some off the wall research project," second this "acid business" was costing him "too damn much" and lastly "the permit to operate the site was expired and his normal consultant didn't know what to do." In other words if you want to work do something NOW with the GOB pile.

In typical consulting fashion we said no problem we can estimate the reaction parameters and scale up functions. The following assumptions were made to facilitate our calculations:

a) the drainage from the GOB pile is influenced by near surface hydrology effected principally by precipitation - indicated by interview

b) the near surface acid generation is influenced by partial pressure of oxygen in the pile and below the first 4 feet of surface horizon acid generation is inconsequential, and

c) underdrains provide sufficient drainage of percolating groundwater from the pile.

The net result of not following our original research plan was a costly amelioration strategy which failed to address the real problem source. Water quality parameters did improve, however far from the expectations of all concerned. Worse than the economic loss was the psychological impact of the failure. The client, initially skeptical, was now convinced that field research was worthless to him. The State Water Resources inspectors were equally disappointed and understandably more skeptical about successful extrapolation to the field of bench scale work. Finally, we were disappointed, nearly bankrupt, and much, much more cautious concerning the offering to field research work without first having all of the relevant site data.

Site 3

The last site to be discussed today covers an abatement strategy applied to a post mining seep located in the Laurel Highlands of Pennsylvania. The seam of coal which was surface mined in 1974, was deep mined in the 19th century to service a local sponge iron production facility. Figure 3 shows the approximate layout of the mine.

At the time of mining, low wall barriers were still being used in Pennsylvania adopting the " flood the pavement strategy," which was to exclude oxygen and thereby avoid acid mine drainage. To further this objective, and to help with drainage control during the mining sequence, a series of three to four feet high dikes were constructed from the low to the high wall and left in place upon reclamation. The entire overburden consisted of sandstone which was said to have an excess of calcium carbonate equivalent (acid base accounting).

Water quality parameters at the seep were generally as follow:

pH	2.3 ppm
Al	192 ppm
Ca	202 ppm
Fe	383 ppm
Mn	73 ppm
SO_4	3808 ppm

Various geo-hydrology studies were commissioned by the operator in an effort to gain bond release or at least some relief from $400/month perpetual treatment. These data along with laboratory experiments were used to develop two soluble phosphate reagents for use at the site. Two methods of ameliorate introduction were proposed: the first a system of contour ditches designed to intercept surface runoff, and thereby allow the phosphate rich water to percolate through and interact with the backfill. The second a system of four boreholes, down which ameliorate can be pumped thereby affecting the pavement and hopefully preventing acidification of the recharge groundwater. These two systems are shown on Figure 4.

Our proposal was met with some reservation, with the operator requesting a compromise plan of a phased introduction of the borehole injection after the successful demonstration of the contour ditches.

To this we agreed.

In August, 1984, the ditches were completed. By December, 1984, three months of seep data revealed that absolutely nothing had changed the water quality of the discharge. Another three months went by and still nothing, However, in talking with the company environmental engineer we discovered that no NaOH treatment had been required for the past four months.

Expanded water sampling in the region revealed that the reclaimed spoil was less porous than we had initially speculated and that instead of runoff entering the ditches and percolating through the back fill it merely entered a near surface flow regime only to exist as a phosphate rich runoff. The seep discharge would intermingle with the runoff waters in the roadway ditches producing the neutralizing control prior to entering the settling ponds.

Thus far the operator is content, unfortunately so much so he has yet to authorize the injection phase of this project.

Summary

The intent of this paper has been to nonrigorously report on the problems and the urgent need to systematically introduce bench scale research work onto the mine bench sites. The techniques currently employed to do this are very rough and unsophisticated, but as more data and experiences are gained, and shared in forums such as this, better and less costly laboratory data extrapolation systems will be developed. The mine companies and individual operators have every reason to be wary. However, the alternatives to not doing this are far worse.

DEPTH (FEET)	ROCK TYPE	FIZZ	COLOR	%S	MAX. FROM %S	AMT. PRESENT	MAX. NEEDED (pH7)	EXCESS	PASTE pH
0-1	Soil			<0.01	0.31	6.0		5.7	6.09
1-3	SS			<0.01	0.31	0.7		0.4	5.19
3-5	SS			<0.01	0.31	0.6		0.3	5.23
5-10	SS			0.04	1.25	0.8	0.4		5.18
10-14	SS			<0.01	0.31	1.0		0.7	5.16
14-17	SS			0.06	1.88	1.4	0.4		5.38
17-21	SS			<0.01	0.31	3.0		2.7	5.19
21-25	SS			0.05	1.56	6.1		4.5	7.09
25-28	SS			0.03	0.94	3.6		2.7	6.50
28-32	SS			0.03	0.94	10.7		9.8	7.46
32-34	SS			0.02	0.62	5.8		5.2	7.38
34-37	SS			0.02	0.62	11.7		11.1	7.24
37-38	SS/MR			0.66	20.62	24.1		3.5	6.35
38-39	MR/SS			0.67	20.94	19.2	1.7		6.33
39-42	MR			0.52	16.25	16.4		0.2	5.96
42-45	MR			0.46	14.38	21.4		7.0	6.36
45-47	MR			0.39	12.19	21.9		9.7	5.59
47-49	MR			0.37	11.56	20.9		9.3	6.75
49-51	MR			0.02	0.62	26.6		26.0	5.90
51-53	MR			0.02	0.62	25.4		24.8	6.82
53-55	SH			0.42	13.12	21.9		8.8	6.33
55-57	SH			0.45	14.06	6.3	7.8		6.17
57-58	MR/CARB			1.21	37.81	4.2	33.6		5.64
58-61	Coal								
61-62	MR/CARB			1.71	53.44	8.8	44.6		5.81

Table 1: Typical Acid-Base Accounting Overburden Analysis Data -- Site 1

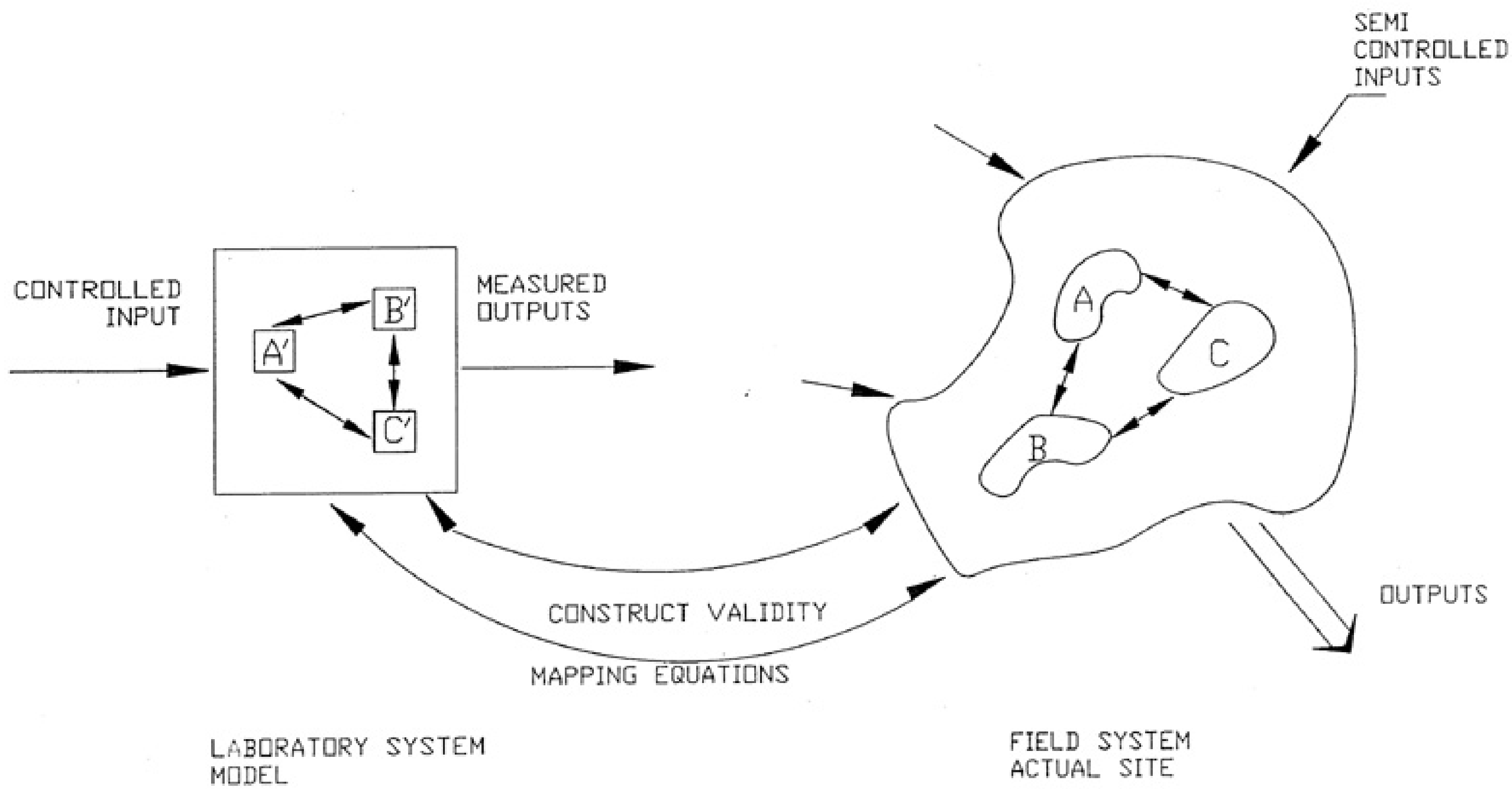

FIGURE 1: SCHEME OF ENGINEERING SIMILITUDE

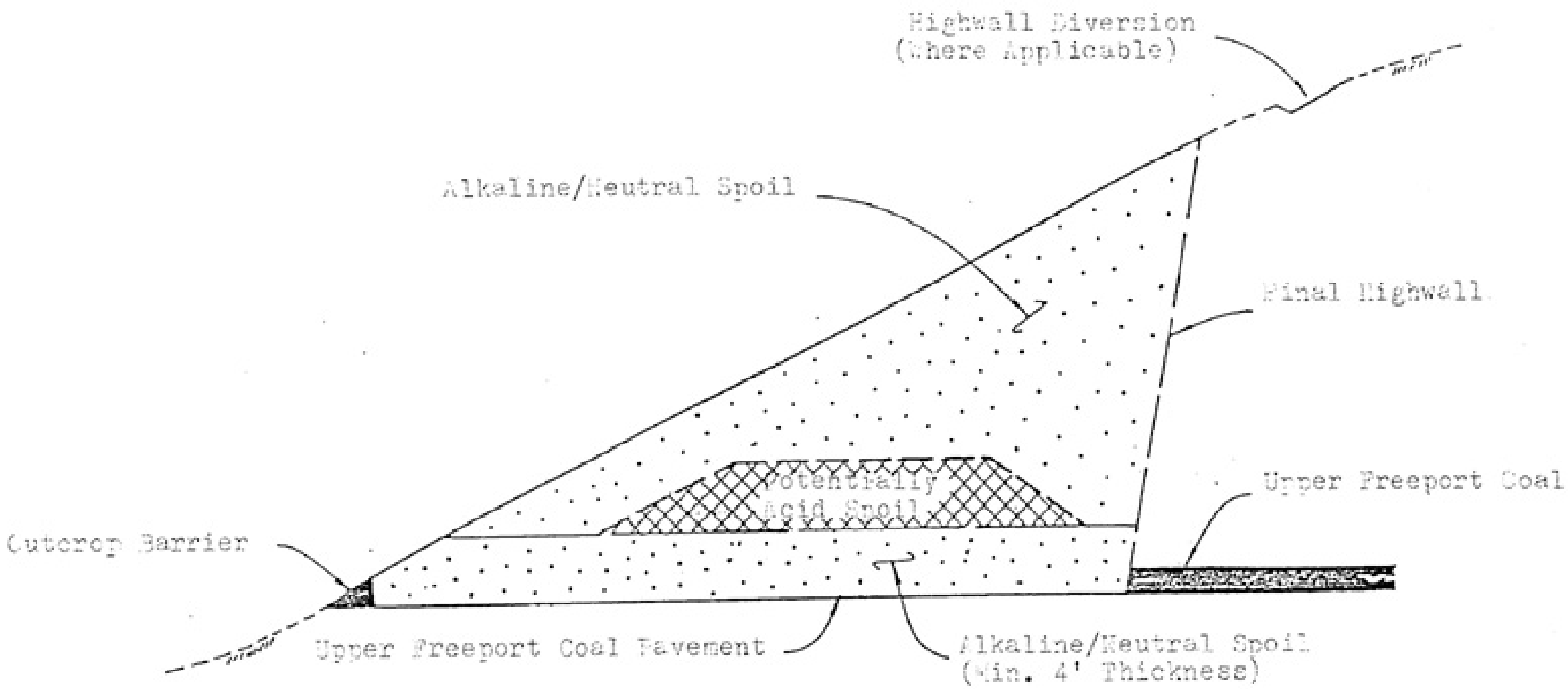

Figure 2: Typical Overburden Placement -- Site 1

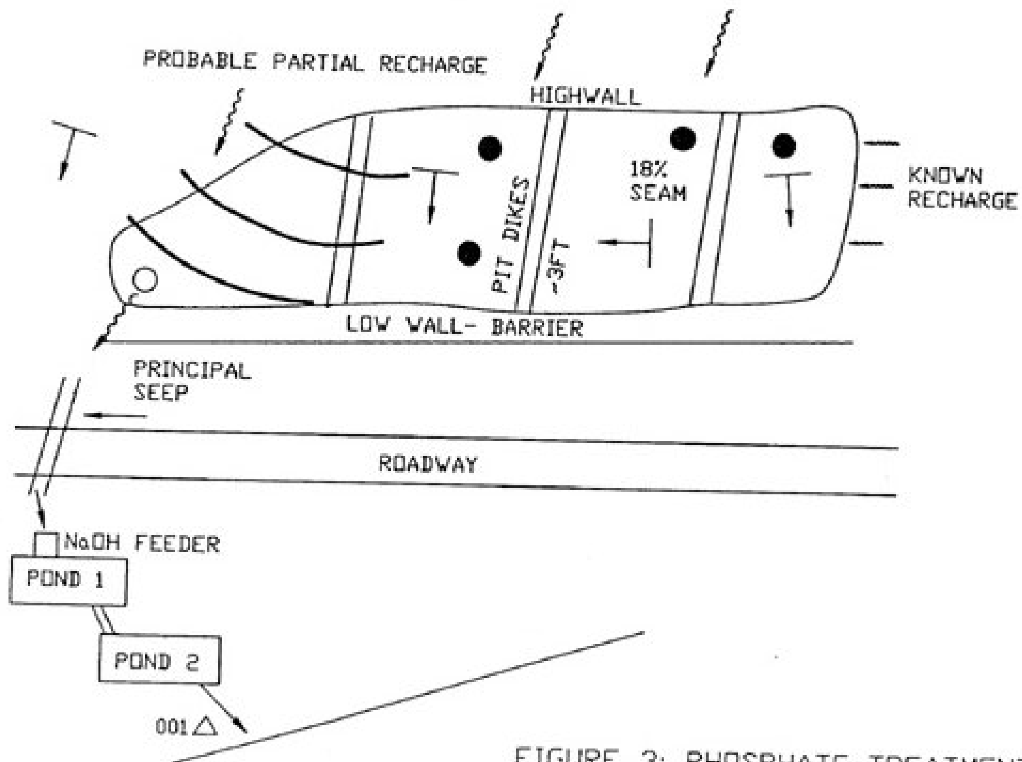

FIGURE 3: PHOSPHATE TREATMENT STRATEGIES

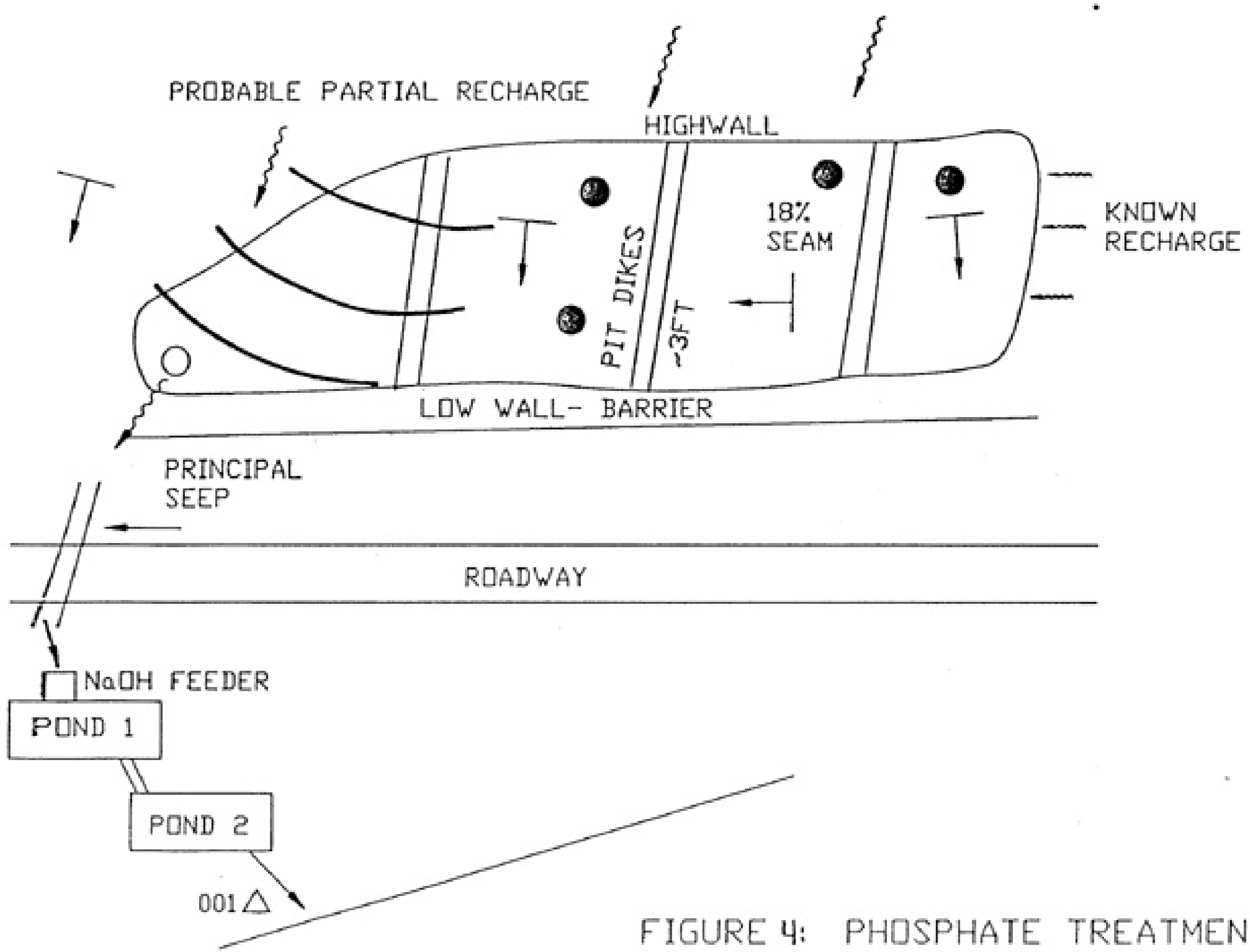

FIGURE 4: PHOSPHATE TREATMENT STRATEGIES