PRELIMINARY INVESTIGATION OF INFLUENT DISTRIBUTION IN A VERTICAL FLOW SYSTEM[1]

by

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Abstract. The problem of conveyance and distribution of highly polluted, metal-bearing coal mine drainage in passive vertical flow treatment systems can present comparatively unique and difficult design challenges. Obtaining relatively full efficacy, efficiency and longevity of the treatment media presumes avoidance of "dead areas" in the treatment media resulting from "short circuiting" of a significant portion of the media. Further, hydraulic computations from pure energy equations presume relatively clean water, but iron bacteria and metal precipitates may significantly affect presumptive maintenance requirements in the relatively new passive treatment technology, where low maintenance and longevity of up to 25 years is projected. Several dye test studies of the full scale, 165' (50.23 m) by 65' (19.81m), compost-limestone vertical flow system installed at the Jennings Environmental Education Center research site were recently conducted in an initial attempt to investigate these problems.

Additional Key Words: passive treatment, acid mine drainage, dye test, and vertical flow system

Introduction and Description

Project 6 is a full scale Vertical Flow System (VFS) located at the research site of the Pennsylvania DCNR Jennings Environmental Education Center in northern Butler County on the east side of State Route 8. The VFS was constructed under an EPA 319 grant to Hedin Environmental, Inc., although there were many other participants and volunteers, including students of Slippery Rock University, Grove City College, Jennings staff and volunteers, Girl Scouts of the Keystone Tall Tree Girl Scout Council and other interested persons. The VFS is an earthen pond-type structure about 165' (50.23 m) in length by 65' (19.81 m) in width at the top, and about 6' (1.83 m) deep. A plan view and sections of the VFS pond are shown on Figure 1 and Figure 2. As designed, Acid Mine Drainage (AMD) from an abandoned deep mine enters a Flow Splitter Box (FSB), where it is separated into three equal parts which then course through three 2" (5.08 cm) black poly-plastic feeder pipes extending to a single, continuous 2" (5.08 cm) non-perforated PVC header pipe. The 2" (5.08 cm) header pipe feeds a lattice-work "overdrain" of 3/4" (1.91 cm) PVC pipes spaced 6' (1.83 m) apart and perforated with 1/4" (0.64 cm) holes. The holes are spaced about 4' (1.22 m) apart and are intended to distribute the influent AMD uniformly over the VFS. At the bottom of the VFS is an "underdrain" imbedded in #57 gravel almost identical in design to the overdrain, except with the 1/4" (0.64 cm) hole perforations at 2' (0.61 m) spacing.

The cross-section detail (Figure 2) shows the as-built construction and passive treatment fill media. The section shows the maximum 18" (45.72 cm) water cap to minimize oxygenation, which is kept at about 1' (0.3 m) depth. The "overdrain" is laid on the fill media. The fill media has a settled depth of about 26" (66.04 cm) and is composed of 300 tons of "fortified" spent mushroom compost, meaning it was blended with 380 tons of fine #9 special limestone to "fortify" alkalinity production. The compost-limestone mixture was not particularly well blended during construction. The underdrain, comparable to the overdrain, is imbedded in #57 gravel and covered with geotextile fabric to prevent clogging. It extends in three separate 2" (5.08 cm) PVC pipes, which join at the Outlet Control Box (OCB) The OCB controls the water level in the VFS.

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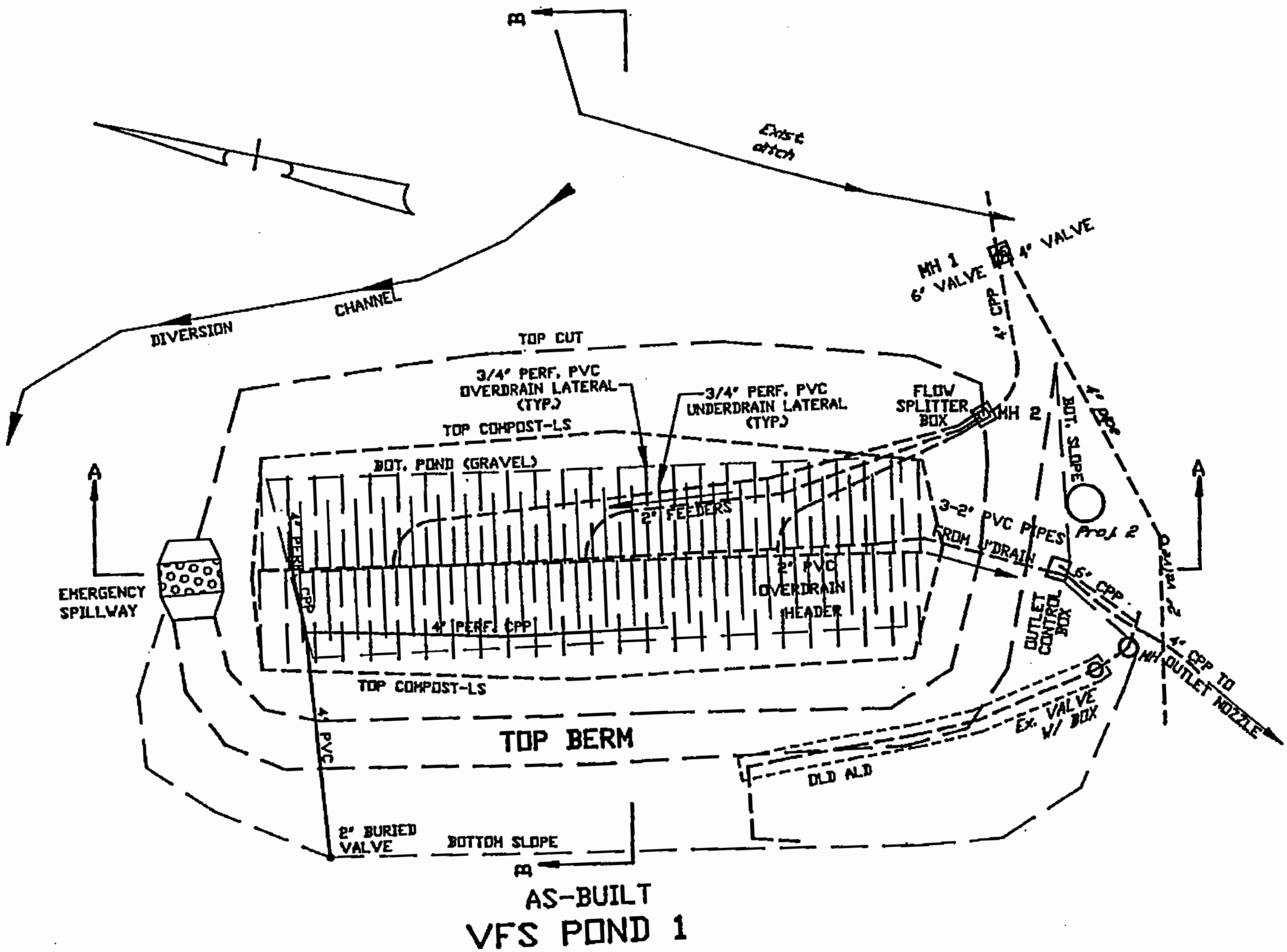


Figure 1. Plan View of Vertical Flow Pond

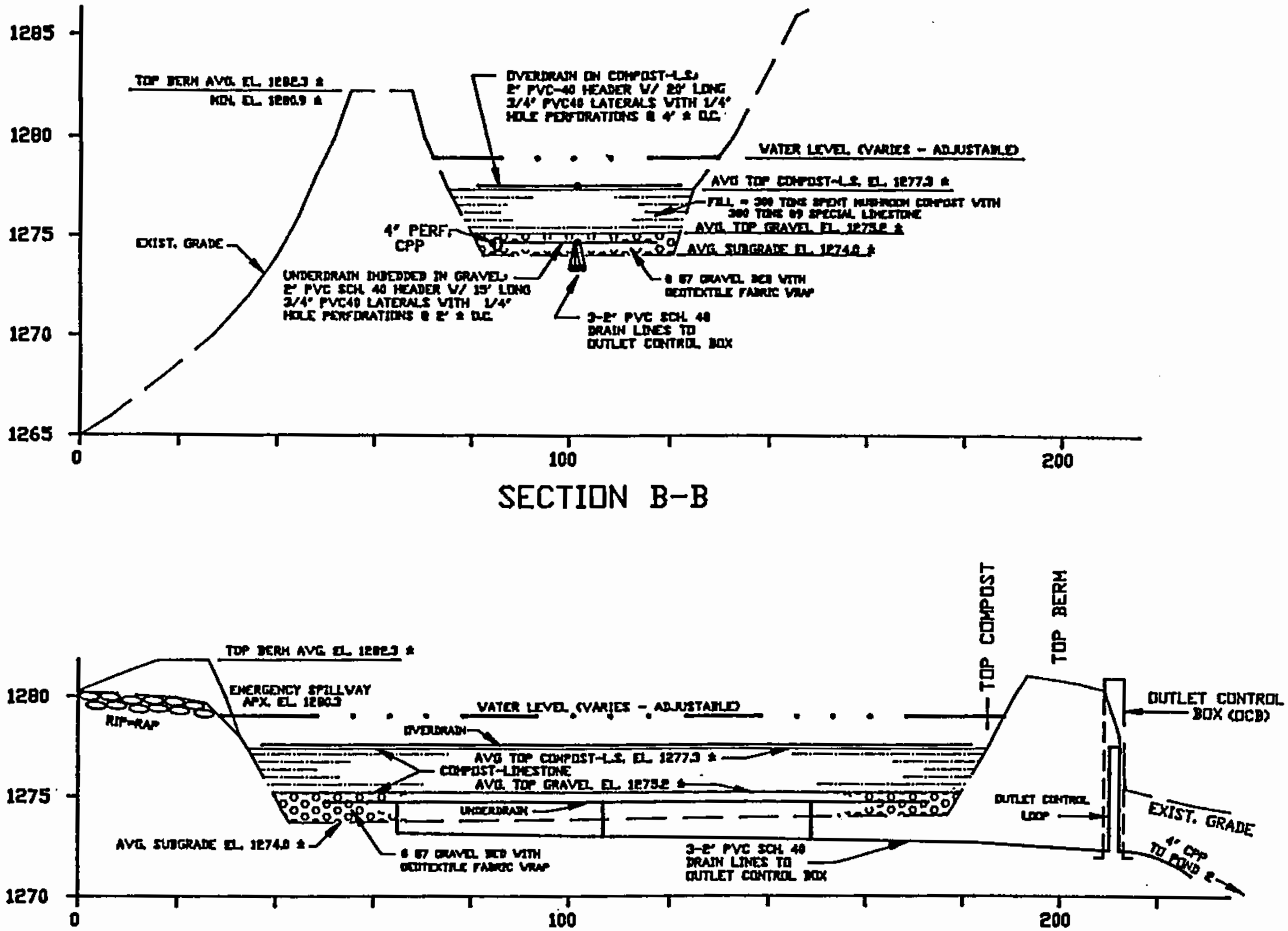


Figure 2. Cross-section Detail of Vertical Flow Pond

The character of the Acid Mine Drainage from the abandoned deep mine at Jennings is as follows:

pH	Alkalinity	Acidity	Iron
3.3	0 mg/l	258 mg/l	67 mg/l

Aluminum	Manganese	Sulfate
19 mg/l	7 mg/l	607 mg/l

It is highly acidic, with moderate to high levels of metals including, iron, manganese and aluminum. The water is anoxic (meaning low oxygen). Influent flows to the VFS vary from well over 30 gpm in the spring of 1998 to less than 9 gpm in the fall of 1998.

It was presumed in the design that if the AMD is anoxic, and the pH low (say 4 or less), that the iron would remain in the dissolved ferrous form until the alkalinity is raised. The resulting increased pH effluent mine drainage could then be oxygenated for conversion of iron to the ferric state, and subsequent precipitation of the familiar reddish "yellow boy" in a pond and/or aerobic wetland. Dissolved aluminum will precipitate at a pH of about 4.5, with or without oxygen, which is a primary reason for the use of spent mushroom manure compost. Apparently, however, even in quite anoxic and acid influent water conditions, filamentous anaerobic and aerobic iron bacteria formed in the open water of the Flow Splitter Box, causing conversion of dissolved ferrous iron to ferric iron precipitate, clogging the hole perforations in the overdrain after a number of months. However, the overdrain is readily accessible and easy to clean, as was demonstrated during the testing.

Background and Objectives

The design of the Vertical Flow System (VFS) evolved from experience with prior projects at the Jennings research site, components of which still exist or are visible at the site.

The primary consideration of this study is to determine whether uniform distribution of mine drainage in a vertical flow passive treatment system can be assumed, or should steps be taken in design to effectively avoid "short-circuiting". Ancillary considerations are precipitate clogging of distribution pipes and other facilities. Figure 3 shows schematic sections depicting several design scenarios or routings. Case 1 shows typical VFS design with influent AMD simply entering by channel or pipe at a point. Our dye testing addressed whether this design would lead to "short circuiting" of a substantial portion of the passive treatment fill media. Case 2 shows the condition intended to simulate with Dye Tests 2 and 4, which indicates substantial short circuiting. Case 3 depicts our interpretation of the results of reasonably uniform distribution of the influent AMD as per Dye Test 3.

Some Applicable Formulae

BERNOULLI EQUATION
for points 1 and 2 in a body of fluid water:

$$\frac{P1}{\delta} + \frac{V1^2}{2g} + Z1 = \frac{P2}{\delta} + \frac{V2^2}{2g} + Z2 \qquad (1)$$

where:
P = Pressure (lb/s.f.)
δ = density of water (62.4 lb/c.f.)
V = Velocity (ft/s)
g = acceleration due to gravity (32 ft/s2)
Z = elevation (ft.)
from the above may be derived the

ORIFICE FORMULA

$$Q = C\,a\,\sqrt{2gH} \qquad (2)$$

where:
Q = flow (cfs)
C = Coefficient for sharp edged orifice (0.61)
a = area of orifice (sf)
g = acceleration due to gravity (32 ft/s2)
H = vertical height of water (ft), ie (Z1 - Z2)

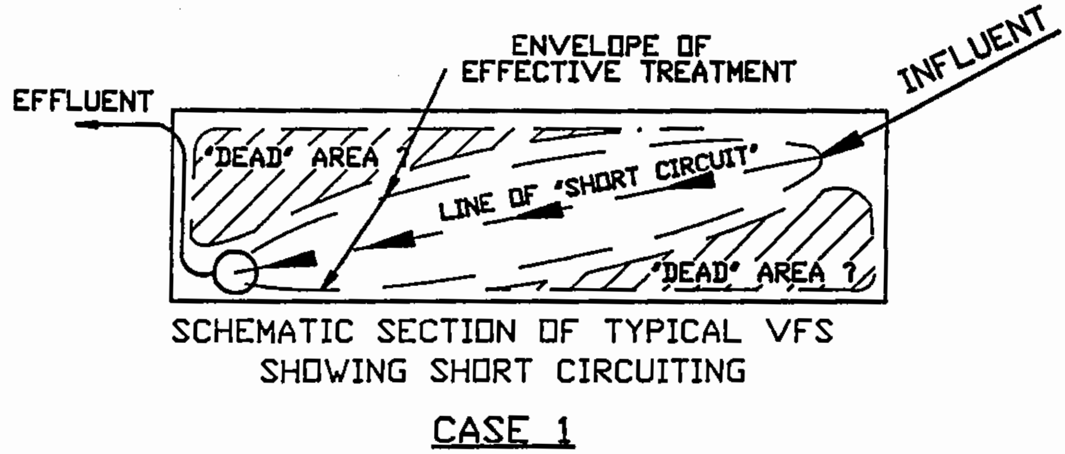
Experiment and Procedures

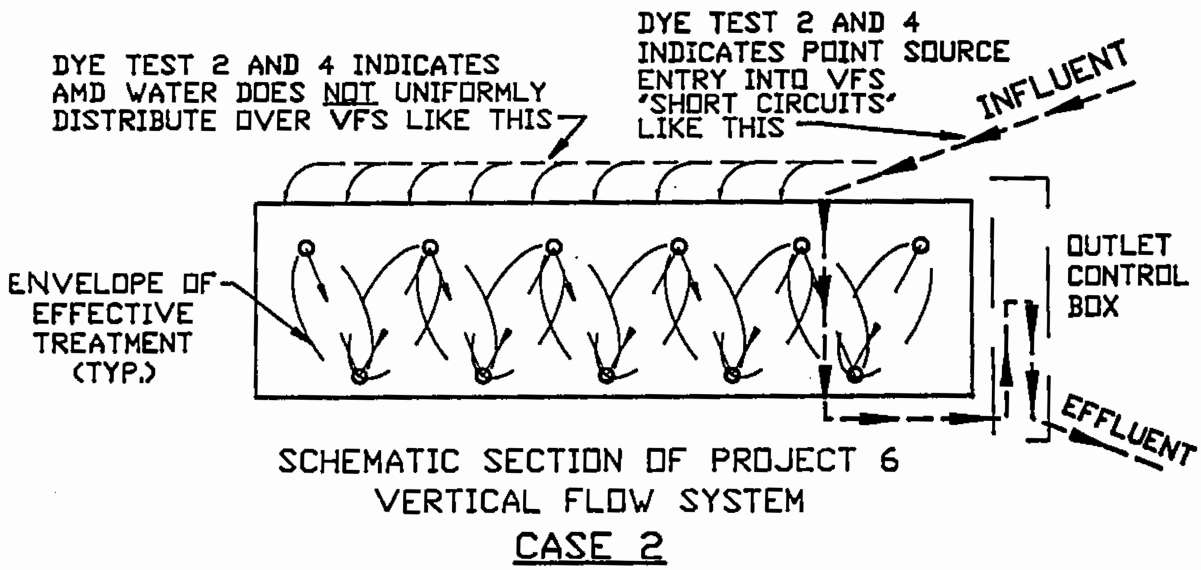
For all the dye tests, 5/8" (1.59 cm) diameter non toxic iridescent red dye tablets were added to the flowing water stream at the Flow Splitter Box. Generally, the distribution of the dye in the VFS pond was observed for a maximum of three hours after dye addition was terminated. For the most part, the areas where the dye plume was evident during dye addition eventually became clear with residual staining of the outlying areas. This residual staining is believed to be due to water momentum or dispersion rather than downward flow through the compost-limestone fill media.

Data and Observations

Dye Test 1

The results of Dye Test 1 are shown in Figure 4. This test was performed on September 14,





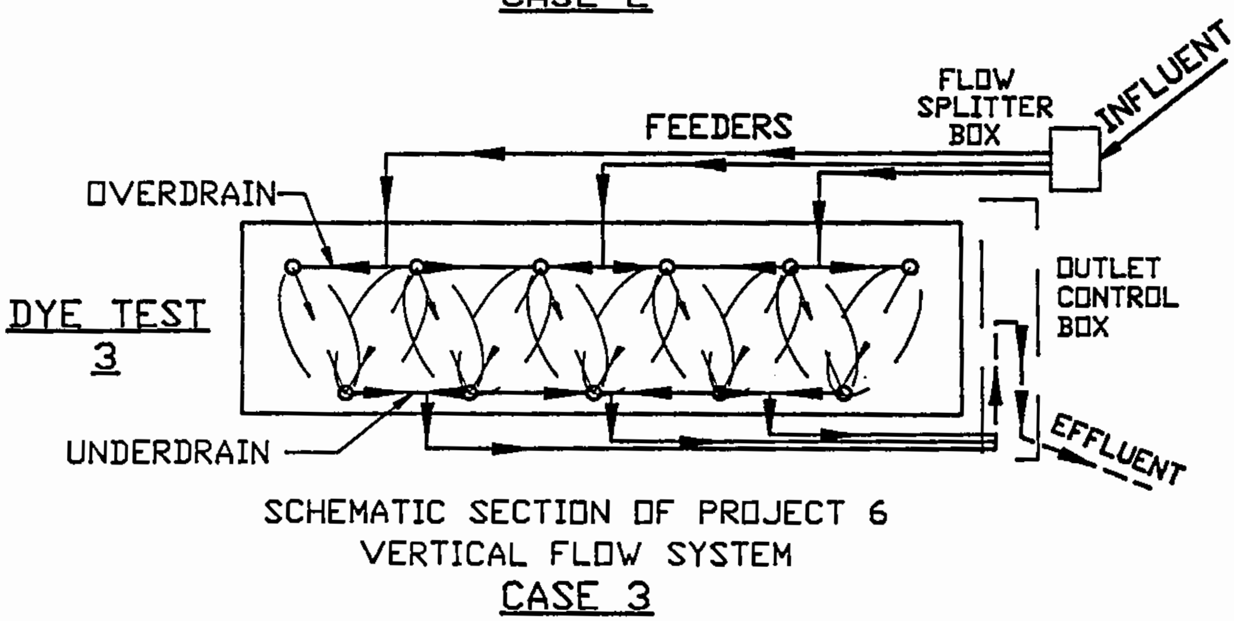


Figure 3. Design Scenarios Through Vertical Flow Pond

1998 with the 2" (5.08 cm) black poly-plastic feeder lines disconnected from the 2" (5.08 cm) PVC header due to prior clogging of the perforated 3/4" (1.91 cm) laterals. We were in seasonally low flow (15.6 gpm) and there was also a low water cap level in the VFS pond. Some exposure of vegetation on the surface of the compost-limestone was visible. The test began on 9/14/98 at 14:50 (2:50 PM) as iridescent red dye tablets were added at the flow splitter box. The filamentous iron bacteria and iron precipitate, which is probably responsible for clogging the 1/4" (0.64 cm) perforations in the 3/4" (1.91cm) laterals, were clearly visible in the Flow Splitter Box (FSB). At 20 minutes, approximate 8' (3.44 m) plumes had developed at the feeder pipe ends. At 1 hour 26 minutes the plumes were approximately 16' (4.89 m) to 18' (5.49 m) in diameter, although some dye represented residual staining after dispersion of the dye. After dye addition was discontinued, and thereafter for the rest of the day, an approximate 8' (3.44 m) diameter clear area developed at the ends of the three feeders surrounded by 20' (6.09 m) to 25' (7.62 m) of residual dye staining. Therefore, it was concluded that the influent water was forming a plume of only approximately 8' (3.44 m) in diameter then coursing downward and short circuiting. This assumption was substantiated by subsequent dye testing. It should be noted that no dye was ever observed in the effluent of the vertical flow system. The dye apparently adheres to the soil-type fill material and the color dissipates there.

Dye Test 2

This test was performed on September 23, 1998 and is shown on Figure 5. The center 2" (5.08 cm) black poly plastic feeder pipe was disconnected near the Flow Splitter Box, with the other two FSB outlets plugged.

This test was intended to simulate channel or pipe influent into the VFS at a single point, as is reportedly accepted in some designs. If the supposition of uniform dispersion is correct, we would expect to see relatively uniform dispersion of the dye throughout the VFS.

At approximately 1 hour 10 minutes the dye has extended to its approximate maximum. It is reasonable to assume that much of the dispersion was due to the momentum of the influent water from the feeder pipe. The results of this test therefore imply substantial short-circuiting under these influent conditions.

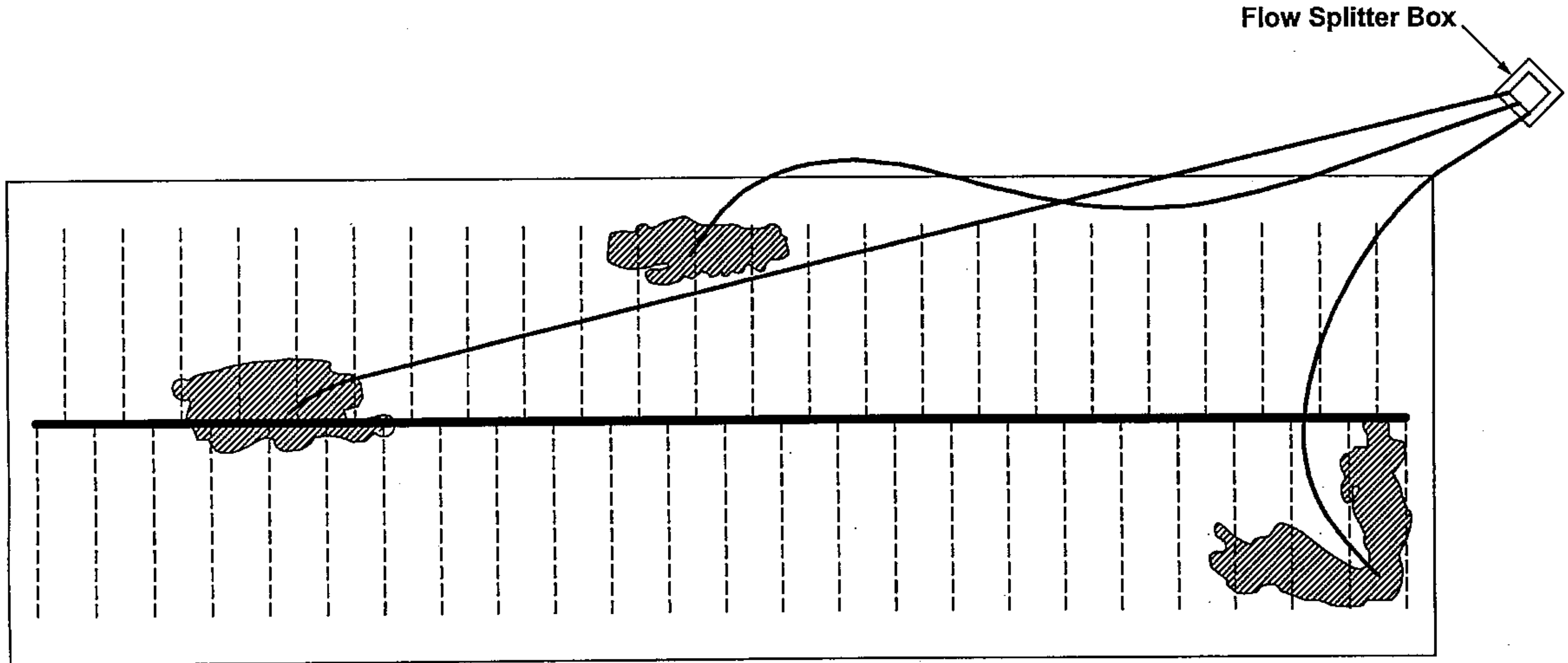
Dye Test 3

On September 21, 1998 the 3/4" (1.91 cm) perforated PVC laterals were disconnected, removed and readily cleaned by rodding with a fish wire. The iron and/or iron bacteria precipitate was protruding and clogging the 1/4" (0.64 cm) perforation hole. Gas, probably carbon dioxide, was also observed bubbling through crevices in several places in the compost-limestone fill material from an unidentified type of crust, possibly aluminum precipitate, developing on top of the fill medium.

With the 3/4" (1.91cm) laterals cleaned and reinstalled, and the level of the water cap raised to its design depth of approximately 1' (0.3 m), Dye Test 3 was conducted on October 14, 1998, as shown in Figure 6. In this test we distribute the AMD through the overdrain as designed. Within a few minutes, the dye began to appear at the 1/4" (0.64 cm) holes nearest the 2" (5.08 cm) header, and in less than 10 minutes, the dye appeared to be flowing evenly and uniformly through all the 1/4" (0.64 cm) hole perforations. It had been presumed in the design that flow might be greater at the holes nearer the 2" (5.08 cm) header pipe due to velocity head loss along the length of the laterals. However, the flow through the holes was quite even and uniform along the entire length of the individual laterals. It should be noted that the flow during the experiment was quite low (12.9 gpm) compared to the springtime flows of 30 + gpm, although it is probable that the overdrain, when clean, also functions quite adequately at the higher flows.

Dye Test 4

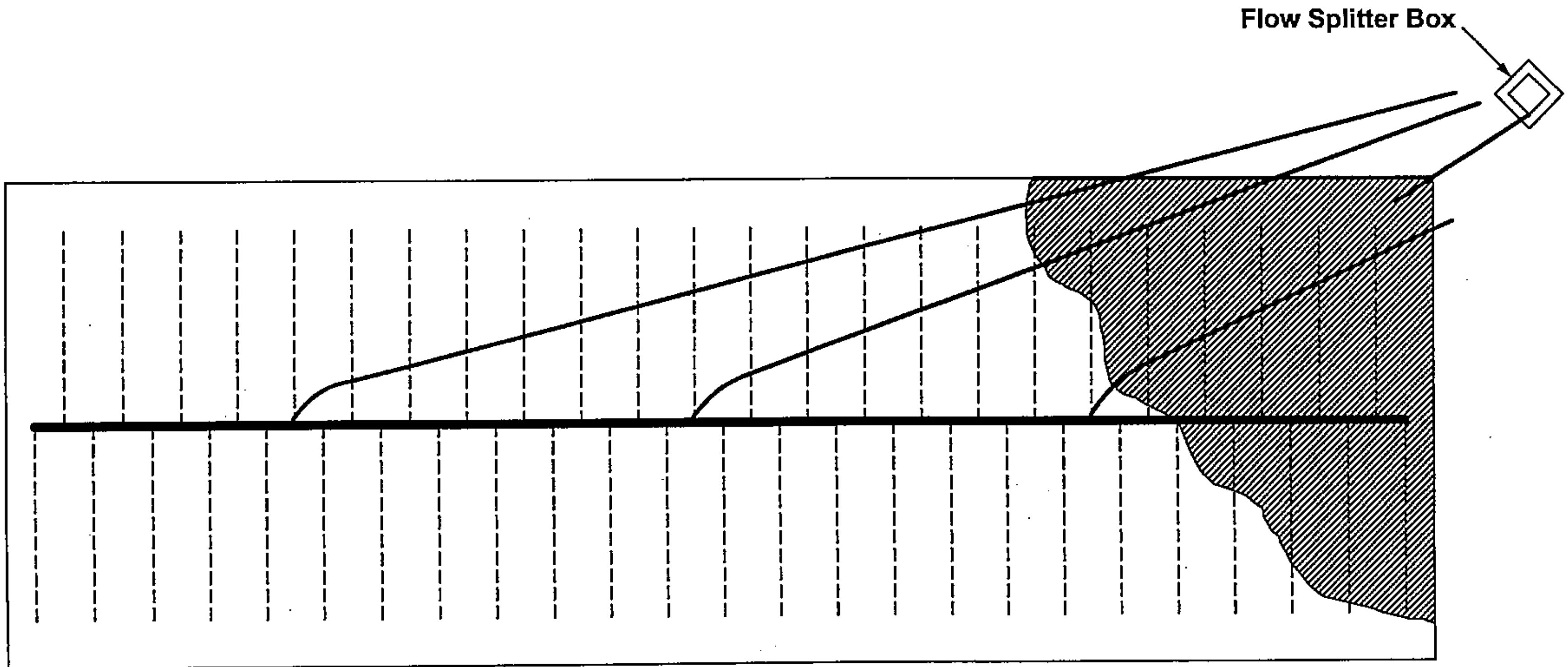
There had been some concern that the low level of the water cap during Dye Tests 1 and 2 might be impeding the distribution of the AMD over and through the Vertical Flow System. Therefore, Dye Test 4 was conducted on October 21, 1998 with the level of the water cap at the normal depth of approximately 1' (0.3 m) as shown in Figure 7. The three 2" (5.08 cm) black poly-plastic feeder pipes were disconnected directly below the Flow Splitter Box. Again, this test is intended to simulate a channelized or piped influent at a point entrance into a vertical flow system. The red dye tablets were added at the Flow Splitter Box as in the previous tests. The results of Dye Test 4 were quite similar to Dye Test 2, with the plume being somewhat smaller, perhaps due to the reduced velocity and momentum of water because the flow was split among all three feeders.



Dye Test 1
(at 3-2" feeder ends: 15.6 gpm)
9/14/98: 15:15 (1 hour 26 min)
Approximately 16-18' plumes at feeder ends

- Dye Plume
- 2" Feeder Solid Pipes (connected)
- 2" Distribution Solid Header Pipe (disconnected)
- 3/4" Distribution Perforated Lateral Pipe (disconnected)

Figure 4. Schematic of Dye Test 1 illustrating dissconnected feeder pipes from header pipe.



Dye Test 2
(single feeder @ SE cor VFS; 12.8 gpm)
9/23/98; 12:12 PM (1 hour 10 min)
Plume expanded to approximate maximum-
42' on north side and 45' on west side

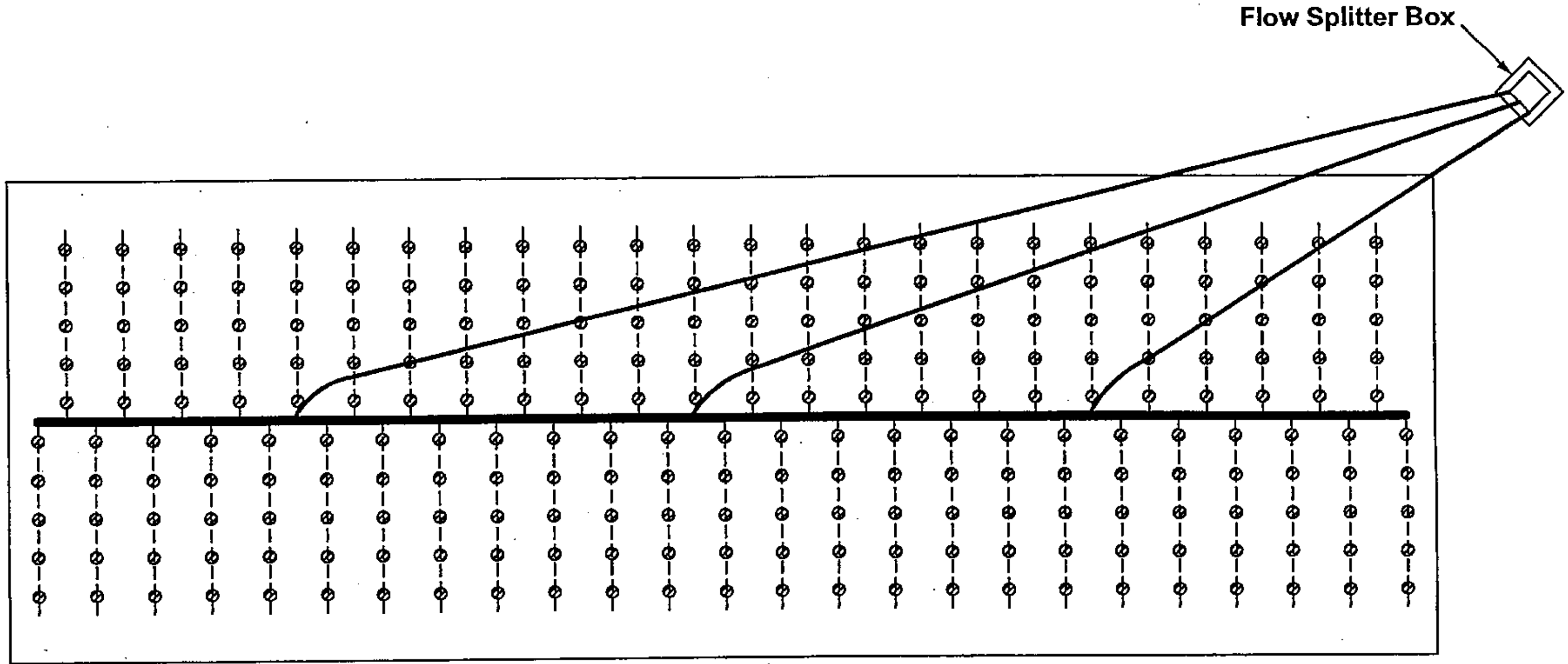
▨ **Dye Plume**

——— **2" Feeder Solid Pipes (one connected)**

▬▬ **2" Distribution Solid Header Pipe (disconnected)**

- - - - - **3/4" Distribution Perforated Lateral Pipe (disconnected)**

Figure 5. Schematic of Dye Test 2 illustrating single point of influent.



Dye Test 3
(through cleaned overdrain; 12.9 gpm)
10/14/98; 10:50 (10 min)
Dye appears at 1/4" holes at lateral ends

- Dye Plume
- 2" Feeder Solid Pipes (connected)
- 2" Distribution Solid Header Pipe (connected)
- 3/4" Distribution Perforated Lateral Pipe (connected)

Figure 6. Schematic of Dye Test 3 illustrating distribution through cleaned overdrain.

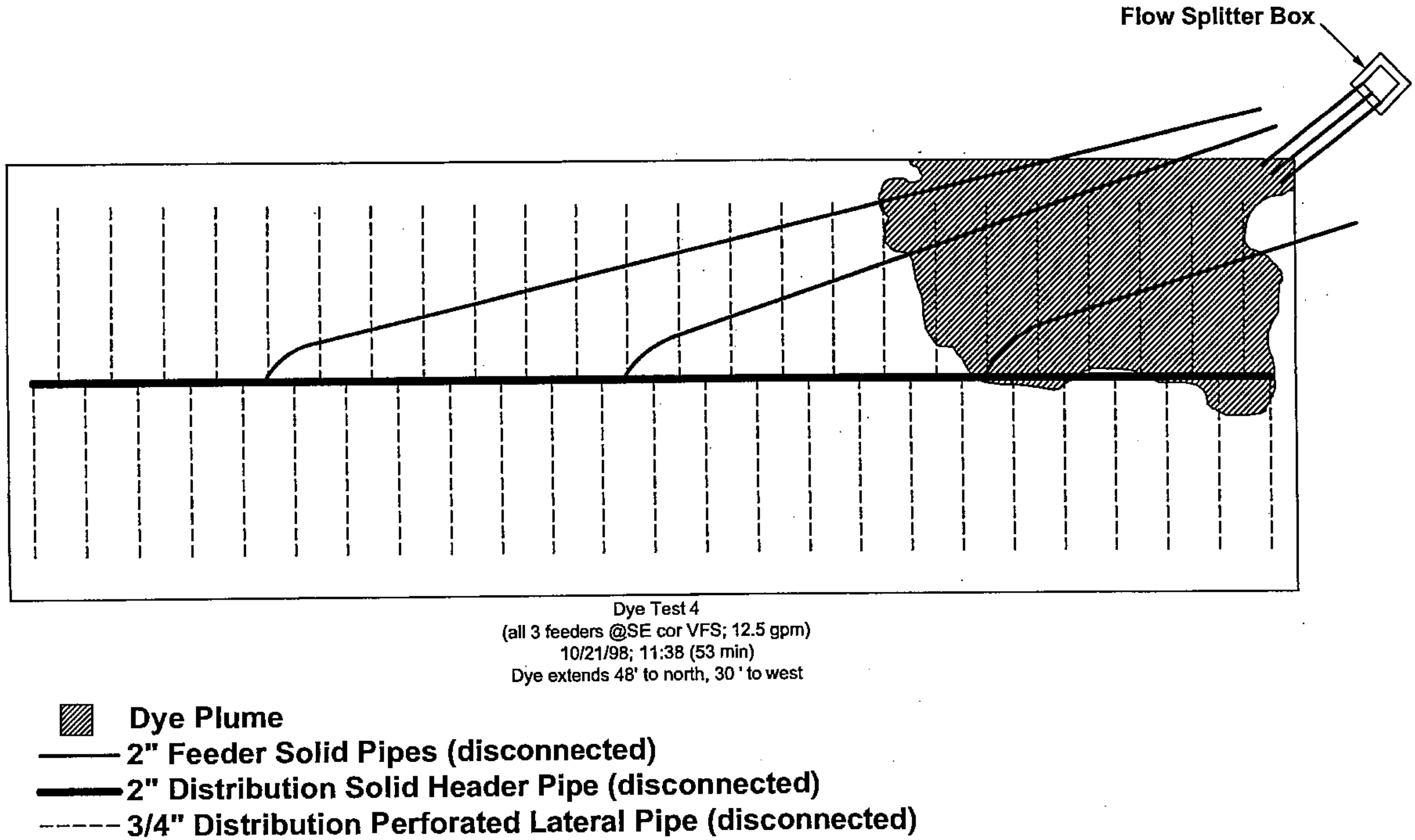


Figure 7. Schematic of Dye Test 4 illustrating influent through all three feeder pipes disconnected at SE corner of VFS.

Summary and Conclusions

The dye tests conducted during fall of 1999 on the newly constructed Vertical Flow System at the Jennings research site were reasonably successful and meaningful:

First, in the design of vertical flow and similar passive treatment systems one should not simply presume uniform distribution of raw mine drainage throughout the system. Adequate control and distribution of influent raw water is an important consideration not only for economy of treatment, but most probably for longevity and ease of maintenance as well.

Second, it may be necessary to revisit the supposition that dissolved iron would remain in the ferrous form and not precipitate in 3.3 pH anoxic water. The appearance of filamentous aerobic and anaerobic iron bacteria, with iron precipitate, that developed in the open bore of the Flow Splitter Box, even in relatively anoxic AMD conditions, deserves further consideration.

Third, considering the need for adequate control, transport and distribution of the raw mine drainage in passive treatment systems, design requirements to deal with precipitates such as aluminum, iron and iron bacteria during alkalization of AMD require special attention to minimize clogging.

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