ADVANCEMENT IN VERTICAL FLOW-HYBRID PASSIVE TREATMENT SYSTEMS

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Abstract

Abandoned mine drainage is a major source of water pollution in Pennsylvania, West Virginia, and other historical mining districts. Technology which utilizes no harsh chemicals and no electricity, and requires minimal maintenance known as passive treatment is being developed to address this pollution problem in a relatively cost-effective manner. Specifically, acidic drainage with dissolved aluminum and/or high iron content is now being successfully abated utilizing a type of passive system which uses a component known as a Vertical Flow Pond (VFP). VFPs are also referred to as Reducing and Alkaline Producing Systems or RAPS. Numerous papers and technical investigations have provided documentation on the effectiveness of these systems in treating discharges of various qualities and flow rates. Very little information, however, is available regarding the piping systems used for the collection of the water after passing through the treatment media. These piping systems are often referred to as underdrains. Experience gained during installation and from on-going monitoring of successful VFPs at the Jennings Environmental Education Center and Ohiopyle State Park (PA Dept. of Conservation and Natural Resources) and within the Slippery Rock Creek Watershed has lead to the development of an innovative double-tiered, multiple-quadrant, underdrain system. This type of underdrain has been recently installed at the De Sale Restoration Area - Phase II (De Sale II) site in Venango Township, Butler County, PA. This underdrain system is expected to aid in eliminating "dead areas" and in maintaining the hydraulic conductivity of the treatment media by improving flow distribution and by improving the ease and thoroughness of the flushing operation to remove accumulated metal solids.

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Introduction

Vertical Flow Ponds are flexible in design and can passively treat acidic discharges which contain dissolved aluminum, dissolved oxygen, ferric iron, or any combination thereof. In order to maintain hydraulic conductivity in the treatment media, however, accumulated metal solids require removal on a periodic basis. Recent tests documenting dye migration in various passive treatment system components also indicate that short-circuiting is a consideration (Peart 2000). The presentation of this paper is an effort to share information regarding promising developments including design considerations, installation and preliminary performance of vertical flow-type and other passive treatment system components in order to contribute to the on-going improvement of passive treatment technology. A recently installed system is included as an example.

De Sale Restoration Area - Phase II: System Overview

Location

The De Sale Restoration Area - Phase II (De Sale II) site is located in Venango Township, Butler County, PA within the headwaters of Seaton Creek, the major tributary, most heavily impacted by abandoned mine drainage, in the Slippery Rock Creek Watershed (Scarlift, 1970). See Figure 1.

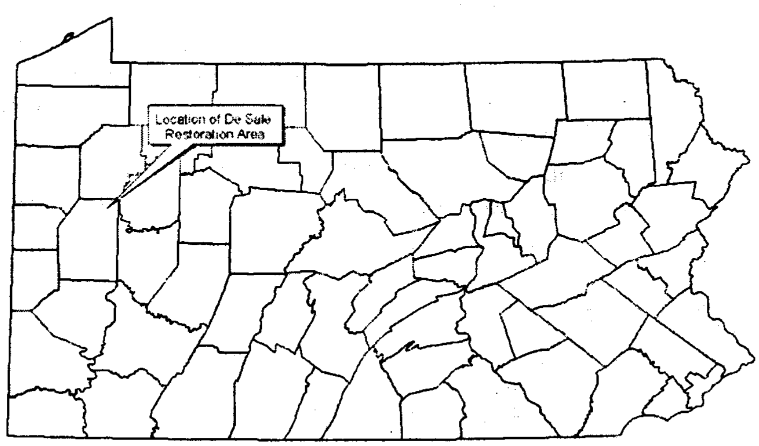

Figure 1. Location map.

Site Conditions

Pre-act surface mining on the Middle Kittanning coalbed resulted in a diffuse "toe-of-spoil" seep zone. Water emanating from this seep zone essentially formed the headwaters of an unnamed tributary to Seaton Creek. This tributary was documented both in Scarlift and the CMRS as a major contributor of pollution to Seaton Creek. (Scarlift, 1970; CMRS, 1998) Property boundaries, the stream channel, and abandoned spoil limited the location of the system to a gently sloping, wooded area.

Water Quality

Table 1. Representative pre-construction raw water data.

Statistical Summary	**Flow (gpm)**	**Lab. pH**	**Acidity (mg/l)**	**T. Fe (mg/l)**	**T. Mn (mg/l)**	**T. Al (mg/l)**
mean	134	3.5	179	9	36	7
range	22 - 338	3.0 - 4.3	32 - 420	2 - 20	10 - 81	2 - 14
75th percentile	204	3.7	233	10	50	8

Notes: n[flow] = 12 (Scarlift, 1970); n[water quality parameters] = 23 (CMRS, 1998); pH not averaged from H ion concentration; Observations and measurements of flow during pre-construction and monitoring for the CMRS report indicated that the Scarlift flow data was applicable. Comparison of individual flow measurements with corresponding water quality parameter readings indicates dilution at higher flows.

System Design

Overview

The discharge is conveyed through the following components in series: Stream Intake → Forebay → Vertical Flow Pond (2 in parallel) → Settling/Flush Pond → Wetland → Horizontal Flow Limestone Bed. See Figure 2.

Stream Intake

Due to extensive mining in the headwaters and the diffuse nature of the seep zone, the major contributor of flow to the unnamed tributary was abandoned mine drainage. This channelized flow provided the necessary collection of the drainage for the passive system. In order to prevent overwhelming the system during high-flow and precipitation events, a controlled-flow, stream intake was installed. The intake was designed to allow the 200-gpm design flow to enter the system, any excess flow crests a 16 ft wide concrete weir and remains in the stream channel. The design flow was based on the 75th percentile flow, determined from Operation Scarlift monitoring data. The flow to the system is restricted by the pipe diameter and length with the maximum available head controlled by the weir.

Forebay

The site provided a limited amount of drop (difference in elevation) within the preferred construction area. In order to obtain the needed drop, the stream intake was installed approximately 400 ft from the VFP. This required the drainage to be conveyed with very little elevation change. A long forebay was installed to inhibit settleable solids and some iron solids from entering the VFPs (Watzlaf et al., 2000). The pond-like configuration of this component allows for a small difference between inlet and outlet elevations and minimizes the maintenance issues associated with conveying abandoned mine drainage utilizing nearly flat pipes or open channels. The forebay was constructed with a 5 ft bottom width, 29 ft top width, 2:1 inside slopes, about 4.5 ft design water depth, and about 6 ft total depth. The outlet of this component is a single 10 in pipe that terminates in a 10 in x 8 in x 8 in tee. From each side of the tee the 8 in pipe extensions discharge into respective VFP. Flow rate is controlled by rotating a 90° elbow attached to the 8 in pipe with a rubber coupler.

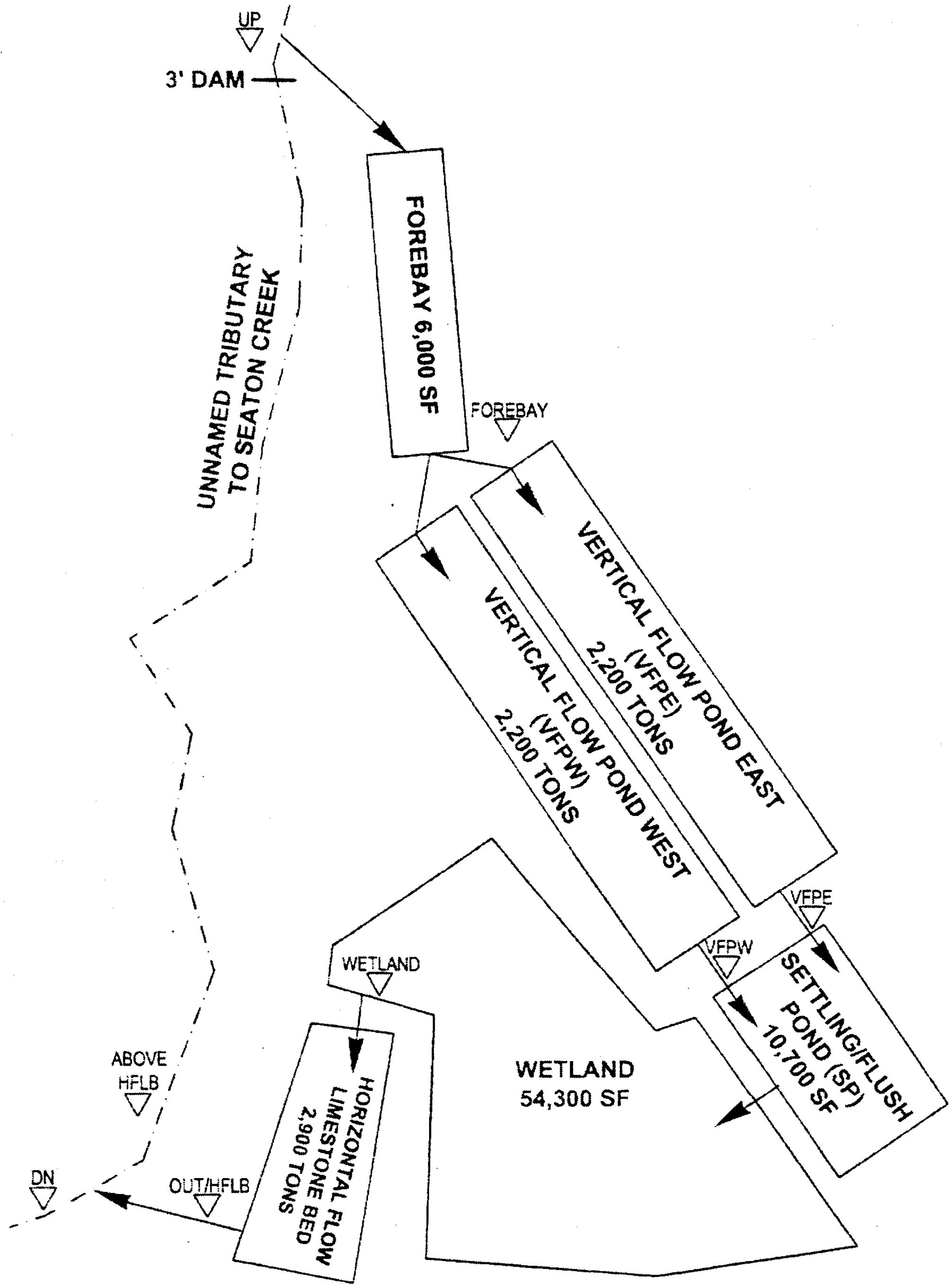

Figure 2. Flow diagram of De Sale II Passive Treatment System.

Vertical Flow Ponds

The primary purposes of this component are acid neutralization and alkalinity generation (PADEP, 1999). A parallel configuration was utilized allowing for continual treatment of water during future maintenance of this component. To address hydraulic conductivity, flow distribution and flushing, an innovative, two-tiered, quadrant-type underdrain system was installed. Both ponds were lined with geotextile fabric. 0.5 ft of "bedding stone" was overlain by the lower tier of the underdrain. Two feet of AASHTO #1 limestone (90% calcium carbonate) aggregate was spread over the first layer of pipes. A second (upper) underdrain similar to the first was installed and covered by a second, two-foot thick, layer of limestone. Spent mushroom compost (0.5 ft thickness) was then spread over the limestone. Individual flush valves and outlet controls were installed for each "cell" of the underdrain. Approximately two feet of water caps the treatment media. (For a more detailed description of the underdrain, see VFP Design Considerations.)

Settling/Flush Pond (SP)

VFPs are typically followed by a settling pond to allow for the oxidation and/or settling of metal precipitates. This convention was applied to the De Sale II site with modifications. A valved, draw-down device (10 in diameter) was added to the design. This allows the water level to be lowered about 2 ft prior to a flushing event. About one week prior to flush the water level in the settling pond is to be lowered by opening the valve on the draw-down device. Just before the flush is to occur, the valve is to be shut. Sufficient capacity was designed into the volume of the settling pond to allow the entire flush volume to be retained to allow for settling and accumulation of solids.

Wetland (WL)

The WL component is included to allow additional oxidation and/or settling of solids (Waztaf et al., 2000). To encourage natural function and maximize effective retention, microtopographic relief, directional earthern baffles, and vegetation with high species diversity and density were included in the wetland design.

Horizontal Flow Limestone Bed (HFLB)

To encourage oxidation and removal of manganese (Hellier, 1999) as well as additional alkalinity generation, a HFLB was included as the final treatment component in the system. The design is straightforward with the discharge being directed into the HFLB (containing five feet of limestone aggregate) from the WL via a rock-lined spillway. The drainage is encouraged to flow horizontally through the limestone to a perforated header along the outlet end near the base of the component. A riser pipe extends to within one foot of the top of the limestone, the design water level.

VFP Underdrain Design Considerations

Background of Underdrain Development

Underdrains have been installed in a variety of configurations. Reportedly, the standard design utilizes a single, solid header installed on the short side of the VFP with perforated laterals extending parallel to the longitudinal axis of the pond. The laterals are generally standard perforated pipe installed on 6 ft to 10 ft centers. A VFP utilizing this configuration was installed at the Harbison Walker Restoration Effort - Phase I (Harbison Walker I) site in Ohiopyle State Park (PADCNR), Stewart Twp., Fayette Co., PA (Ohiopyle, 2000). Other systems have utilized multiple header configurations such as the system installed at Jennings Environmental Education Center (PADCNR), Brady Twp., Butler Co., PA. The laterals at Jennings are connected to three separate headers which are combined into a common outlet device. Both systems have successfully treated water to the anticipated water quality, or better, since installation.

The outlet device at the Jennings site incorporates a flexible design which allows the outlet water level to be readily adjusted. At the time of installation, the Jennings VFP was anticipated to retain aluminum with the majority of iron passing through the system; however, continued monitoring indicates higher than expected levels of iron retention (Watzlaf et al., 2000; Jennings, 1999). In order to maintain sufficient hydraulic conductivity, the Jennings VFP has been periodically flushed by lowering the outlet control device.

In order to facilitate periodic flushing, the outlet device at the Harbison Walker I site included a solid, straight, flush pipe extending from the header pipe near the bottom of the VFP to a settling pond. As noted at the Jennings site, the Harbison Waker I VFP has retained significant quantities of iron (Ohiopyle, 2000). The original design utilized a threaded plug at the outlet of the flush pipe.

Both the Jennings and Harbison Walker I systems have a single-tier, underdrain system installed near the treatment media base.

<u>De Sale II Underdrain Overview</u>
A more extensive underdrain system was developed for the De Sale II VFP in an attempt to optimize flow distribution and flushing of accumulated iron and aluminum solids. The underdrain was constructed of 4 in Schedule 40 PVC pipe. Perforated laterals were placed on 4.5 ft centers and connected to a solid header with a sanitary-type tee. Perforations were hand-drilled with two, 0.5 in perforations approximately 30° from the top of pipe. The perforation spacing was equal to the lateral spacing (4.5 ft). Four separate header pipes were used for each underdrain thus dividing the surface area into approximately equal quadrants. Two underdrains are installed in each vertical flow pond, one at the base of the AASHTO #1 layer and one in the middle of the four-thick layer of limestone aggregate. This effectively divides each VFP into eight separate "cells", four upper and four lower. Two VFPs are installed in parallel producing a total of sixteen separate cells with individual discharge locations and flush valves. See Figures 3 & 5.

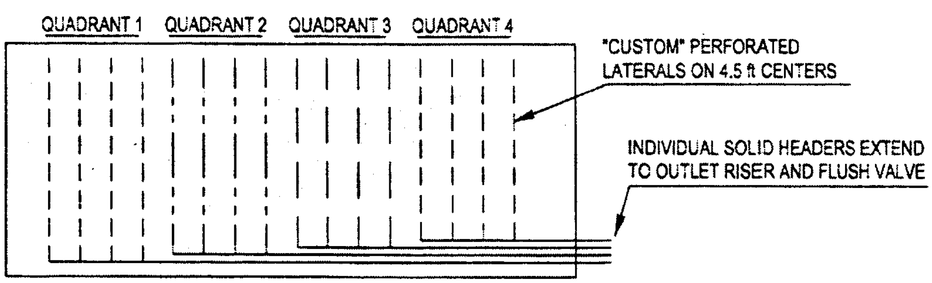

Figure 3. Typical installation of quadrant-type underdrain system.

Each header pipe extends from the treatment media through the breastwork to an individual 4 in slide-type gate valve. Prior to the gate valve, a tee was installed about mid-way through the breastwork to create a riser which leads to the primary outlet for that cell. Each outlet included a 4 in by 3 in rubber reducer into which a 3 in riser (1.5 ft section with 3 in 90° elbow) was inserted. The reducer was equipped with two stainless steel hose clamps. The 4 in hose clamp fastens the reducer to the 4 in riser pipe. The 3 in clamp was used to vertically adjust the 3 in riser. See Figure 4.

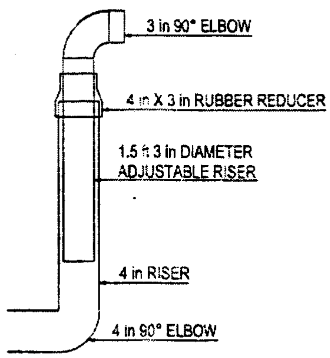

Figure 4. Typical outlet riser detail.

Flow Distribution

During normal operation of the Vertical Flow Ponds all sixteen cells discharge. This is intended to reduce short circuiting and maximize effective retention time. Short circuiting has been documented as a potential issue in the efficacy and long-term operation of vertical flow-type passive systems. This was investigated by participants in the Jennings Water Quality Improvement Coalition through the construction of an overdrain system and subsequent dye testing at Jennings and other sites. The dye testing indicated that the flow was not evenly spread throughout the system. Two separate dye tests at Jennings documented that the flow had a maximum disbursement covering less than 20% of the total treatment media surface with the momentum of the influent potentially responsible for the observed amount of distribution (Peart 2000).

To overcome this situation, the underdrain installed at the De Sale II site includes individual outlet controls for each cell. The individual outlets allow flow rates to be controlled in each cell within the VFP. With all sixteen outlets discharging approximately equal flow volumes, distribution throughout the system can be assumed; however, this does not take into account distribution variability within individual cells.

Perforation Size and Spacing

Standard perforated pipe has two, 0.625 (5/8) in perforations every 5.25 in. This is a good design for customary applications (i.e. foundation drains); however, this type of perforation configuration may not be particularly well suited for the distribution of acid mine drainage within the treatment media of a VFP. According to standard orifice flow calculations, relatively few linear feet of standard perforations are required to reach the maximum flow volume capacity of a 4 in pipe. Based on accepted formulae for Orifice and Pipe Flows, at a minimal given head (<0.1 ft), standard 4 in PVC perforated pipe reaches maximum carrying capacity within approximately 10 ft.

Through the utilization of smaller orifices which are less frequently spaced, the length of perforated 4 in pipe required to reach maximum carrying capacity is extended. At a minimal given head (<0.1 ft), two 0.5 in perforations every 4.5 ft requires about 150 linear feet to reach the maximum carrying capacity of a 4 in pipe. This potentially could increase the effective retention time within the treatment media.

To summarize, a quadrant underdrain with less frequently spaced perforations is expected to decrease short circuiting thus increasing the effective retention time within the treatment media.

<u>System Flushing</u>
Vertical Flow Ponds typically retain significant amounts of iron and aluminum (Watzlaf et al., 2000; Ohiopyle, 2000; De Sale, 2000; Jennings, 1999). The accumulation of solids in the treatment media has a potential adverse effect on hydraulic conductivity. A simple method of removing these accumulated solids is head-driven flushing. Individual flush valves were installed for each cell at De Sale II. These valves are located at approximately the same elevation as the bottom of the VFP. See Figure 5.

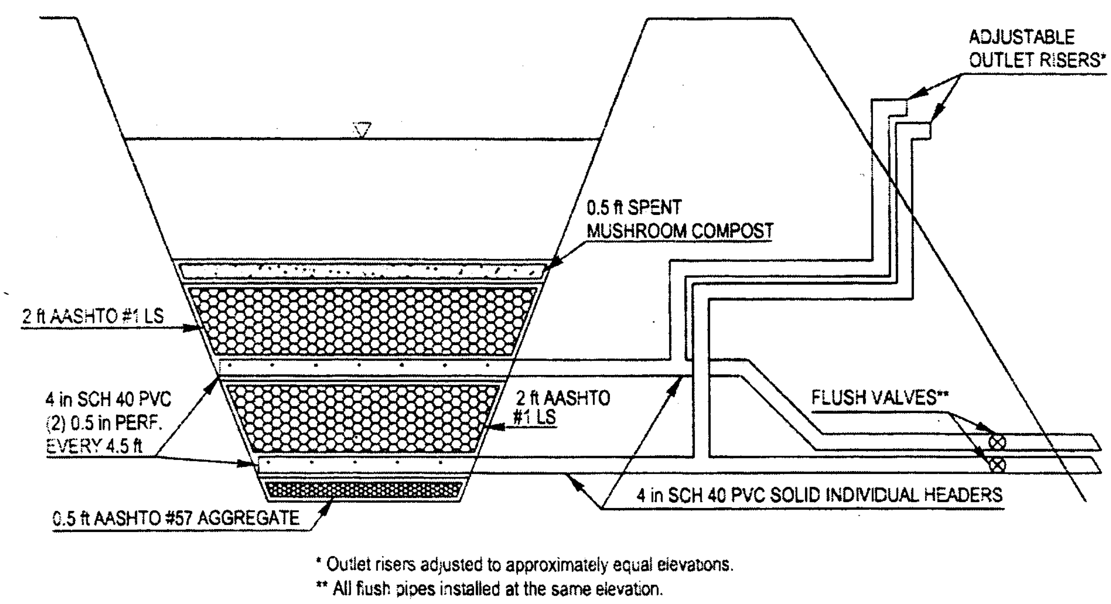

Figure 5. Typical cross section of vertical flow pond.

With a separate valve for each cell, a specific portion of the VFP can be flushed. Here again, the total volume of water which can pass through a 4 in pipe at a given head is the limiting factor, not the number of orifices. During flushing, removal of the maximum amount of accumulated precipitate throughout the entire treatment media is desired. Though smaller orifices and less frequent perforation spacing, the length of perforated pipe needed to achieve the maximum carrying capacity of a single 4 in pipe is increased. At the De Sale II site, this increase is about 15 fold.

By decreasing the total amount of treatment media volume being flushed per valve, flushing efficacy should be increased. Reducing the volume of treatment media being flushed was achieved in two ways: 1) dividing the surface area of the treatment media into quadrants and 2) installing two tiers of piping within the treatment media. This reduces the total number of orifices feeding a single 4 in pipe and subsequently increases the velocity of water traveling through each orifice. This higher velocity would tend to dislodge more metal solids in the media during a flushing event.

By increasing the number of laterals within a VFP, the average distance from within the treatment media to a perforation is decreased. In a typical VFP with three feet of treatment media underlain by laterals installed on 10 ft centers having two perforations every 5.25 inches, the maximum distance from a perforation is about 6 ft. The De Sale II design has a maximum distance of about 3.5 ft from any point within the treatment media to a perforation.

Based on preliminary test flushing of other VFPs with similar underdrain systems, a flushing event takes 15 to 20 minutes per cell. This is based on the amount of time required for the discharge to "run clear" once the valve is opened. Also, in order to increase the amount of solids removed from the underdrain system during flushing, the valve may be opened and shut several times to "agitate" the system. Due to "pipe shock", brief, yet notable discharge has been observed at the primary discharge outlet for the cell being flushed when the valve is shut rapidly. Visual observation indicates that a significant amount of solids are expelled through the primary outlet as well as the flush pipe during this procedure. This phenomena is expected to be beneficial in long-term system performance.

Work is currently being coordinated with the US Department of Energy, National Energy Technology Laboratory in Pittsburgh, PA to quantify metals retention during operation and amount of release during flushing events.

Preliminary System Performance of Each Component

Intake & Forebay

On January 31, 2001, a flow of 187 gpm was measured using a calibrated 14-gallon bucket. Due to the relatively short time needed to fill the container, this flow is subject to notable sampling error. Flows were measured on the same date at each individual VFP inlet, the sum was 203 gpm. The depth of flow over the 16' wide dam was also measured with a calculated flow of 267 gpm. This indicates the 200-gpm design flow can be achieved without overwhelming the system while excess flow remains within the stream channel.

Within the forebay, slight decreases in metal concentrations have been observed.

Vertical Flow Pond

The preliminary performance of the De Sale II site follows patterns observed at other Vertical Flow Ponds (VFPs). Both influent and effluent water quality data at the two parallel VFPs are extremely similar. For the first month of operation, sulfate, sodium and potassium concentrations were greater in the effluent than in the influent. Only in the last month or two are sulfate concentrations lowered as the water passes through the systems. However, a consistent odor of hydrogen sulfide indicates that sulfate reduction has been occurring since the beginning of operation. Dissolved oxygen concentrations have been at saturation levels in the influent (9-13 mg/L) and near zero in the effluent (<0.2 mg/L). Manganese was removed in an initial two-month period. The removal ceased, presumably due to a filling of the available adsorption sites.

Changes in other parameters have been more consistent. Influent pH values averaged 3.2 compared to 7.0 in the effluent. Total alkalinity measured in the field has been at 50 to 100 mg/L (as $CaCO_3$) in the effluent over the last four months (no alkalinity was in the influent). Influent net acidity has averaged 250 mg/L (as $CaCO_3$). The effluent water has always been net alkaline and has averaged 120 mg/L (as $CaCO_3$). Most of this generated alkalinity has been used to neutralize acidity due to hydrogen ions (low pH) and acidity generated upon hydrolysis of metals. Iron and aluminum concentrations are decreased from 34 to 4 mg/L and from 12 to <0.5 mg/L, respectively. Other trace metals, cobalt, nickel and zinc have been lowered from 0.7 to <0.02 mg/L.

Rates of acidity removal on an area basis have ranged from 6 to 44 g/day/meter squared and have averaged 27 g/day/meter squared. These values are consistent with several other VFPs (Watzlaf et al., 2000). Regardless of flow, iron and aluminum are removed to low levels and pH is increased to about 7.0. Therefore, these acidity removal rates are dependant on flow and are greater at higher flows.

Settling Pond & Wetland

The settling pond component was installed primarily for use during flushing events. The combined surface area of both components are considered during evaluation. Monitoring is conducted of the wetland effluent. The settling pond and wetland were constructed within a discharge zone and preliminary monitoring and visual observation indicate the interception of degraded, shallow subsurface drainage. The quality and quantity of this drainage impacts the effluent.

Horizontal Flow Limestone Bed

To date, the HFLB has consistently generated an average of about 20 mg/l of alkalinity. Some manganese, 2 to 6 mg/l, has been removed by this component. A similar system installed at the Harbison Walker I site was observed to remove significant amounts of Mn after approximately 8 months of operation.

Water Monitoring Data

Table 2. Preliminary System Function (range in values after system on-line 9/00).

Station	Flow (gpm)	pH		Alkalinity (mg/l)	Acidity (mg/l)	Fe(mg/l)		Mn(mg/l)		Al(mg/l)	
		lab	field			total	diss.	total	diss.	total	diss.
Forebay (raw)	21 - 203	3.1 - 3.8	2.8 - 4.5	0	42 - 331	5 - 39	4 - 30	13 - 75	13 - 74	2 - 13	2 - 13
VFPE (east)	6 - 118	6.4 - 7.2	6.3 - 7.3	50 - 450	0 - 83	2 - 13	1 - 13	8 - 61	8 - 63	<1 - 2	<1
VFPW (west)	6 - 99	6.6 - 7.3	6.8 - 7.3	47 - 222	0 - 52	2 - 5	1 - 5	6 - 67	6 - 68	<1 - 1	<1
Wetland	NM	6.8 - 7.9	6.5 - 7.9	38 - 160	0 - 27	2 - 6	<1 - 5	16 - 46	15 - 43	<1 - 1	<1
Horizontal Flow LS Bed	23 - 200	7.0 - 7.3	6.8 - 7.5	64 - 157	0	<1 - 15	<1 - 3	16 - 47	16 - 41	<1	<1

Notes: n(forebay) = 15; n(VFP east & west) = 11; n(wetland) = 3; n(HFLB) = 10; degraded, untreated, shallow, subsurface flow entering Settling Pond/Wetland; limited field alkalinity monitoring similar to lab results.

Conclusion and Recommendations

Based on the preliminary monitoring data, the double-tier underdrain allows effective flushing of accumulated iron and aluminum solids without affecting the treatment efficacy of the Vertical Flow Pond. Additional demonstration is required in order to determine long-term function relating both to flushing and flow distribution. Variations in water quality require specific design consideration in the configuration and application of underdrains, outlet controls, and flushing devices. Systems installed to treat discharges with high metal concentrations may require more piping and more frequent flushing than those discharges with low metal concentrations. Ideally, passive systems require minimal maintenance, this means low maintenance *not* no maintenance. These maintenance requirements should be sufficiently addressed in the initial system design.

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