# Investigation of the Webster Passive Treatment System

**Technical Report Provided by Hedin Environmental through the Trout Unlimited AMD Technical Assistance Program December 2013**

The Webster Discharge Passive Treatment System was installed in Nanty Glo in 2004 by the US Army Corps of Engineers. The system utilizes two vertical flow ponds and a wetland to treat a low pH deep mine discharge contaminated with acidity, iron (Fe) and aluminum (Al). The system was effective for two years after which the treatment performance declined significantly and rapidly. The Cambria County Conservation and Recreation Authority (CCCRA) was the local sponsor for the project and is currently considered its owner. The CCCRA requested an investigation of the treatment system that might identify the cause(s) of the failure and any corrective actions that might be warranted.

## Review of Monitoring Data and General System Design

A variety of sources of information on the project were obtained. Monitoring data, generated by the PADEP, were downloaded from DataShed. As-built drawings and the Operation and Maintenance (O&M) Plan were obtained in paper form from the CCCRA and in digital form from the PADEP. The pdf plans were overlain on current LIDAR mapping and transferred into a digital file using AutoCAD. Surface areas and quantities were calculated from these digitized plans. The portions of the construction specifications pertinent to the organic substrate were obtained from GAI Consultants. A report by Paul Ziemkiewicz dated August 11, 2009 and titled “South Branch Blacklick Creek Ecosystem Restoration Webster Mine Discharge, Assessment of Treatment System Failure” was provided by CCCRA.

### System Design

The treatment system layout is shown in Figure 1. The Webster Discharge is located in a residential neighborhood in Nanty Glo along Lloyd Street. The discharge is collected and piped beneath State Route 271, beneath Pergrin Run, and into two vertical flow ponds (VFPs). The water is split into six flows that discharge into VFP#1 which is connected to VFP#2 by four surface pipes. As such, the VFPs are set up in parallel. Both VFPs were constructed similarly and contain 2.5 feet of AASHTO #1 limestone overlain with 1.0 feet of alkaline organic substrate that is a mixture of spent mushroom compost and limestone fines. The VFPs contain underdrain piping that was placed 4 inches off the bottom of the aggregate. VFP#1 contains five runs of perforated pipe that are combined into two discharge pipes. VFP#2 contains six runs of perforated pipe that are combined into two discharge pipes. The VFPs discharge to a single wetland cell that produces the final discharge to Pergrin Run.

Water flows through the VFPs in two manners. Figure 2 shows the hydraulics of the system. The preferred flow is down through the organic substrate and limestone to the underdrain pipes. When this flow path is realized the water should contact alkaline substrates and the AMD should be treated. In the absence of head losses, the water elevation of the VFP discharge pipes controls the water elevation on the VFPs at 1.0 ft above the surface of the organic substrate. If there are head losses, then the water elevation in the VFPs rises. If the head loss is more than 3.5 ft, then the water rises to the emergency spillway and discharges to the wetland by this overland route. Much of the water following this flow path does not contact alkaline substrates and there is little treatment of the AMD.

Water discharging through the wetland is passively aerated, which promotes reactions that oxidize iron and manganese and degrade dissolved organic compounds released from the organic substrate. Solids that form should be retained in the wetland by settling or by filtration by vegetation.

Table 1 shows the approximate size of the system components and the quantities of materials. The units and the quantities are very large. Each VFP is approximately 3.5 acres. These are the largest VFPs constructed to date in Pennsylvania, by a factor of 3.

***Table 1. Treatment unit sizes and major material quantities for the Webster treatment system.***

| **Unit** | **Parameter** | **Units** | **quantity** |
|---|---|---|---|
| Vertical Flow Ponds | total surface area | $ft^2$ | 314,421 |
| Organic Substrate | depth | ft | 1.0 |
| Organic Substrate | Volume | CY | 11,300 |
| Organic Substrate | Limestone addition | ton | 665 |
| Limestone | Depth | ft | 2.5 |
| Limestone | Quantity | ton | 36,700 |
| Wetland | total surface area | $ft^2$ | 83,279 |

System Performance

Figure 3 shows acidity concentrations for the influent and final effluent (wetland weir) between December 2004 and October 2013. They system produced a final effluent with neutral pH, low metal concentrations, and net alkalinity until late 2006. In December 2006 the system began discharging net acidic water containing elevated concentrations of Al. The sudden change in treatment effectiveness is apparent from the discharge of the VFPs. Figures 4 and 5 show the acidity of the VFP underdrain discharges over a shorter time frame. The sudden change from net alkaline to net acidic conditions in December 2006 is striking.

These conditions have generally been sustained since. For the last three years the final effluent has been marginally better than the influent.

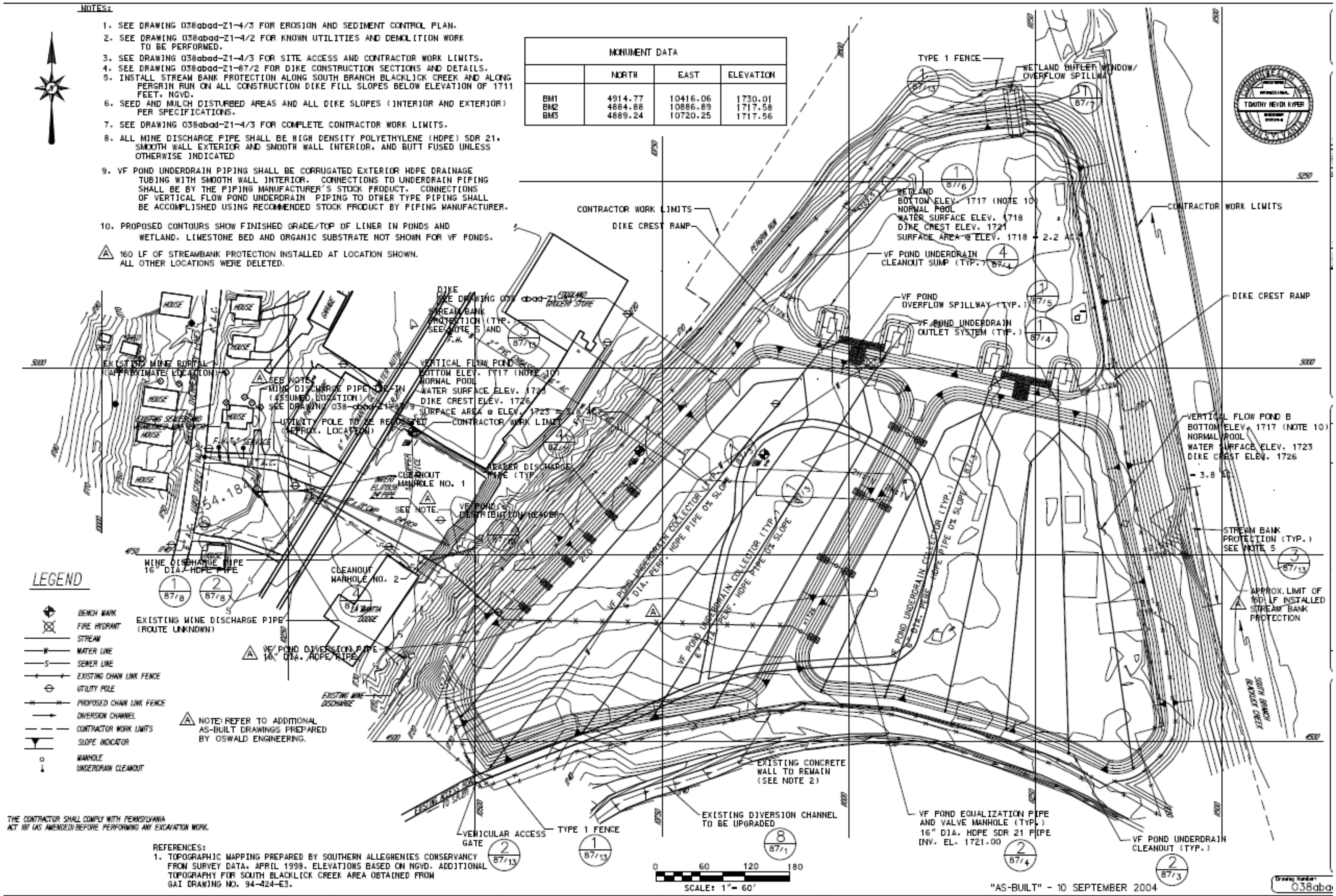


*Figure 1. Plan view of the Webster passive treatment system.*

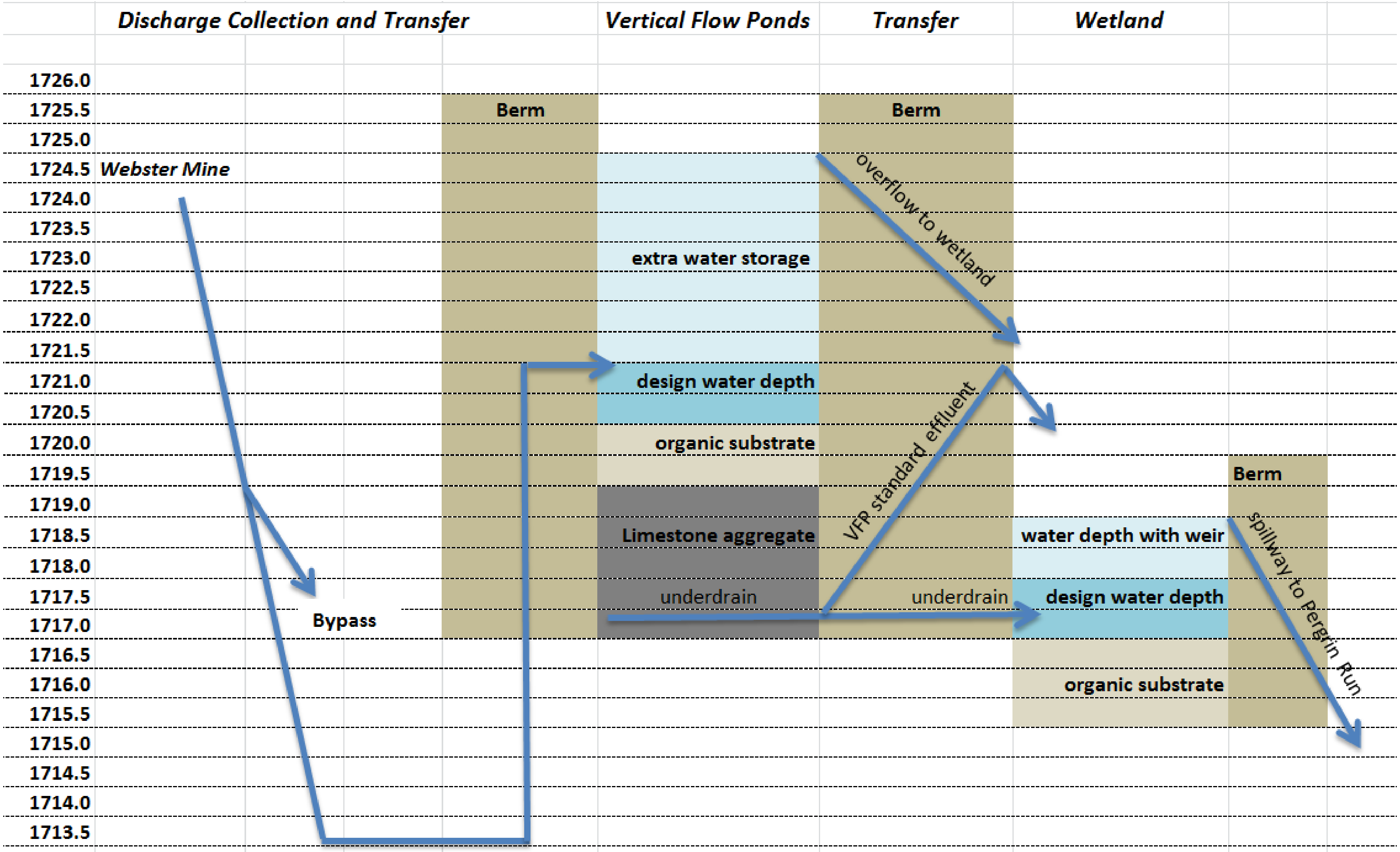


*Figure 2. Cross section of system showing key elevations. Horizontal is not to scale.*

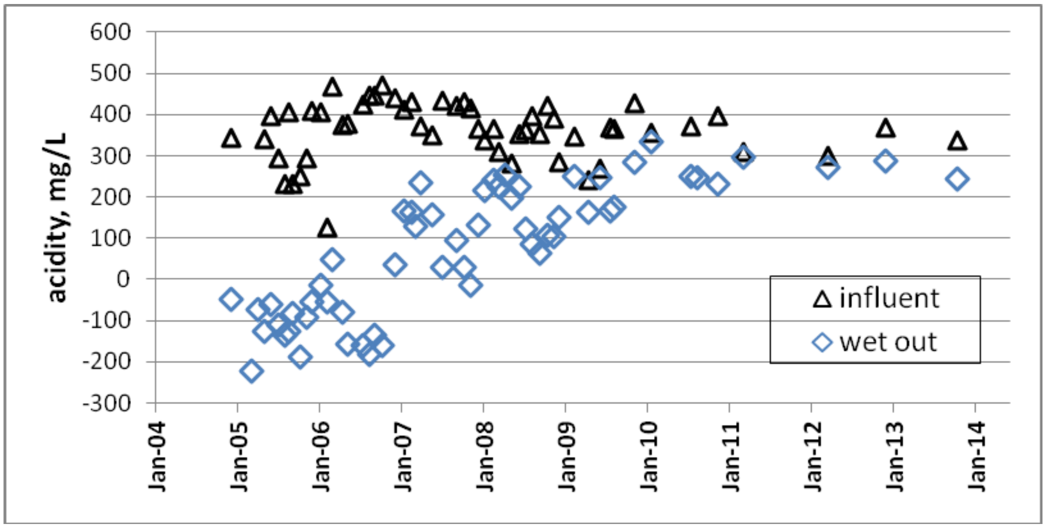


*Figure 3. Concentrations of acidity at the influent and final effluent stations.*

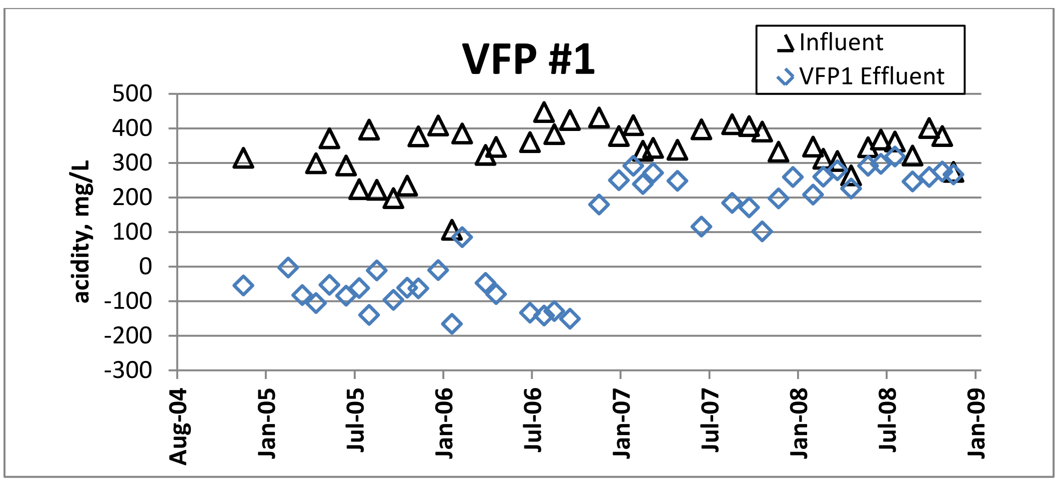


*Figure 4. Concentrations of acidity at the influent and VFP#1 underdrain effluent.*

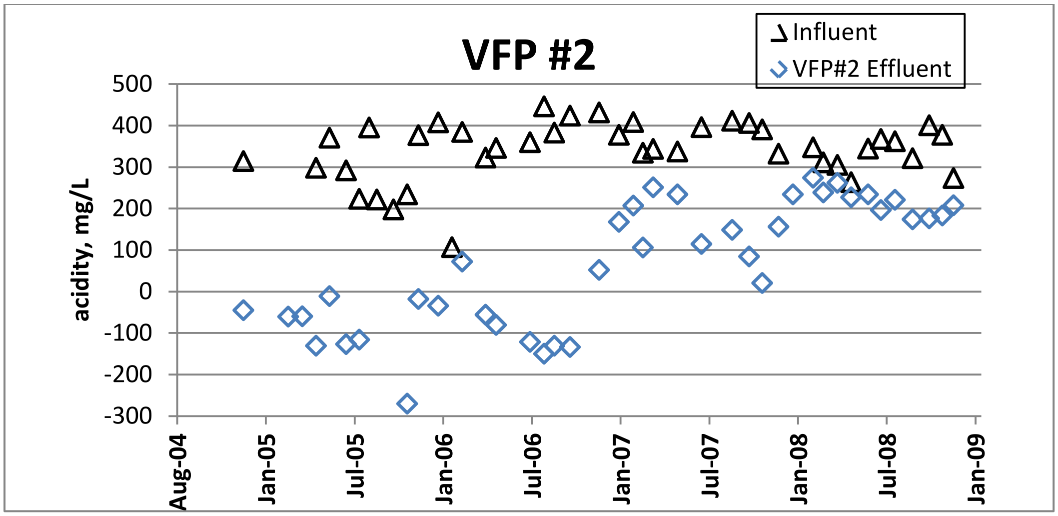


***Figure 5. Concentrations of acidity at the influent and VFP#2 underdrain effluent.***

The failure of the Webster passive system could have resulted from a variety of factors including chemical or hydrologic characteristics of the influent, system design, or system O&M. These factors are considered below.

<u>Webster Discharge Characteristics</u>
The severity of the Webster Discharge is commonly noted in discussions about the treatment system. Available data were reviewed to determine if the chemistry of the discharge has changed since the project was first conceptualized. Table 2 shows average values for the Webster Discharge in the 1990s, when the project was being conceptualized and over the last nine years. The discharge chemistry has improved by 15%.

***Table 2. Average chemical conditions of the Webster Discharge.***

| **Period** | **N** | **Measure** | **Acid** | **Fe** | **Al** | **Mn** | **SO4** |
|---|---|---|---|---|---|---|---|
| | | | mg/L | mg/L | mg/L | mg/L | mg/L |
| 1990-97 | 19 | Average | 410 | 41 | 40 | 5 | 599 |
| 2004-13 | 53 | Average | 356 | 23 | 36 | 5 | 583 |

"N" is number of water samples

The possibility that the system is treating much more water than was intended was investigated. Summary flow statistics are shown in Table 3 and compared to the 1990s measurements. The flows measured from the system effluent have averaged 54 gpm higher than was measured in the 1990s. One factor contributing to this difference is the location of the flow measurements. The 1990s measurements were made near the mine discharge. The system measurements were made at the final effluent which is affected by the system's 15 acre footprint. Forty inches of precipitation onto this acreage would produce on average 30 gpm of flow (no evaporation). This analysis indicates that the flow rates did not change substantially between the design and treatment periods.

| Table 3. Webster Discharge flow and acidity loadings. | | | | |
|---|---|---|---|---|
| **Period** | **N** | **Measure** | **Flow** | **Acid** |
| | | | gpm | kg/d |
| 1990-97 | 19 | Average | 308 | 665 |
| 2004-13 | 36 | Average | 391 | 651 |
| 1990-97 | 19 | 75th percentile | 384 | 881 |
| 2004-13 | 36 | 75th percentile | 481 | 844 |
| 1990-97 | 19 | 90th percentile | 516 | 1,022 |
| 2004-13 | 36 | 90th percentile | 620 | 1,117 |

"N" is the number of flow measurements.

The variability of the flow measurements was considered because the Webster system does not have a functional high flow bypass. Figure 6 shows all the flow measurements. Two very high flows have been measured, however they occurred after the system's effectiveness declined. It does not appear that the system's failure was related to a single measured flow event. On December 15, 2006, when the system's failure was first noted, the measured flow rate was 341 gpm, which is below average. It is possible that an extreme event occurred that was not measured. To investigate this, the precipitation records for the airport in Johnstown were reviewed. There were no extreme precipitation events between August and December 2006. In the month before the December 2006 sampling, the total precipitation was 1.8" which is below normal. No evidence of an extreme event was found.

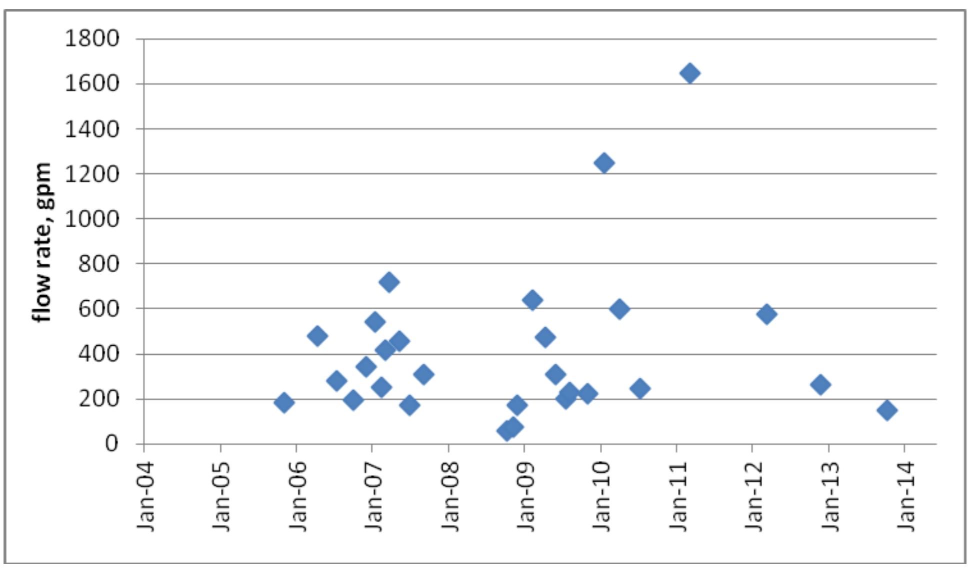


***Figure 6. Flow rates measured at the final weir (wetland effluent).***

Acidity loadings are shown in Table 3. The system loadings were calculated from the influent chemistry and the effluent flow rates. This approach overestimates acidity loadings because of the inputs of precipitation noted above. Even with this error, the acidity loadings that have been received by the system have been similar to the acidity loadings measured in the 1990s.

In summary, the analysis of flow and chemical data for the Webster Discharge collected both before and after the system was constructed indicates that there has been little change in AMD conditions. The failure of the system cannot be explained by deterioration of the AMD conditions between its design and installation.

Appropriate Treatment Technology and Sizing Analysis

It is possible that the system design has a fundamental flaw that took two years to develop. Two reasonable considerations are: 1) that the chemistry may be too severe or inappropriate for passive treatment with vertical flow ponds, or 2) that the system may not be large enough to treat the acidity loadings. These potential issues were investigated in two manners: 1) by calculating acidity loading values and comparing them to loadings considered appropriate by current design practices and, 2) by comparing the Webster system to another large passive treatment system that has successfully treated severe AMD for nine years.

The choice for a comparative study is the Hunters Drift (HD) passive system. The system was constructed by the Babb Creek Watershed Association in 2003/04 to treat an acidic deep mine discharge in Tioga County. The HD system consists of four vertical flow ponds followed by a constructed wetland. The system's design and early performance are described in the paper, "Passive Treatment of Acid Coal Mine Drainage: the Anna S Mine Passive Treatment Complex" which is available in the journal Mine Water and the Environment and also downloadable at http://www.hedinenv.com/pdf/Anna_S_paper.pdf. The system is sampled 3-4 times annually and the sampling results are available on DataShed.

Table 4 shows the influent and effluent chemistry of the two treatment systems between 2004 and 2013. The influent chemistries are remarkably similar. Both have low pH and contain 20-40 mg/L of Fe and Al. Table 4 shows the average effluent of each system between 2008 (after the Webster discharge had failed) and 2012. The recent effluents from the systems are dissimilar. The Webster effluent is acidic with high concentrations of Al and Fe. The HD effluent is net alkaline with low concentrations of metals. The effectiveness of the HD system indicates that the Webster AMD is not too severe for passive treatment by vertical flow ponds.

***Table 4. Comparative chemical conditions at the Webster and Hunters Drift (HD) treatment systems***

| | pH | Alk | Acid | $Fe^T$ | $Fe^{2+}$ | Al | Mn | $SO_4$ |
|---|---|---|---|---|---|---|---|---|
| **Average influent chemistry, 2004 – 2013** | | | | | | | | |
| Webster | 2.9 | 0 | 356 | 23.4 | 2.4 | 35.8 | 5.1 | 584 |
| HD | 2.8 | 0 | 358 | 34.4 | na | 33.0 | 6.7 | 548 |
| **Average final effluent chemistry, 2008 – 2012*** | | | | | | | | |
| Webster | 3.4 | 0 | 209 | 13.0 | 8.0 | 25.8 | 5.2 | 564 |
| HD | 7.3 | 127 | -102 | 0.6 | na | 0.2 | 2.4 | 521 |

** 2013 data not considered because of rehabilitation of HD organic substrate*

The second parameter considered is flow. Table 5 shows flow data for both systems. The HD flows are measured at the VFP influents. The Webster flows are measured at two locations: the VFP discharge pipes and the weir at the wetland effluent. The flows from the VFP underdrain discharge pipes have been measured 30 times. The flow at the weir has been measured 28 times. The difference between the measures is mainly due to overflows from the VFPs which are not included in the pipe measurements but are included in the total flow measurement at the weir. Overflows occur when the head losses of the VFPs are greater than 3.5 ft. On average, about 71% of the water has flowed through the underdrains while about 29% of the water has flowed through the overflows. Lately, the overflow proportion has been much higher. On January 27, 2010, the VFP pipes produced 305 gpm while the weir flow rate was 1,250 gpm, indicating a 945 gpm overflow rate. In October 2013, under low flow conditions, the pipes only discharged 122 gpm and the overflow was 30 gpm.

The HD VFPs contain overflow structures but they have never been observed to flow because the head loss in the HD VFPs has always been less than 0.5 ft.

Combining the weir and pipe flow measurements results in 36 daily flow values. Using these values ("Webster inflow" in table 5), it is apparent that the Webster system receives higher flows than HD. The difference increases at higher flow rates. This is because the HD system has a bypass that diverts flows greater than ~400 gpm around the system. The Webster system does not have a functional bypass system.

**Table 5. Flow summaries for the Webster and Hunters Drift VFP systems.**

| | **Webster VFP Pipes** | **Webster Weir** | **Webster Final*** | **HD inflow pipes** | **Web Final/ HD Inflow** |
|---|---|---|---|---|---|
| Average, gpm | 293 | 410 | 391 | 242 | 162% |
| Min, gpm | 67 | 61 | 61 | 71 | 86% |
| 50$^{th}$ percentile, gpm | 253 | 295 | 295 | 221 | 133% |
| 90$^{th}$ percentile, gpm | 503 | 663 | 620 | 385 | 161% |
| Max, gpm | 580 | 1650 | 1650 | 393 | 420% |
| N | 30 | 28 | 36 | 30 | |

**Combination of weir and pipe flow rates*

Table 6 compares the two treatment systems in terms of surface area, material quantities, and loading rates. The general design of the VFPs was similar. Both contain a one foot depth of limestone-amended spent mushroom compost. The HD limestone amendment rate was larger than the calculated Webster amendment rate. Both systems contain limestone underdrains constructed with AASHTO #1 aggregate. The depth of the limestone in the HD system is 0.5 ft greater than the Webster system. Both systems contain pipe underdrains placed at the bottom of the limestone aggregate. The pipes are spaced farther apart (50-60 ft) in the Webster system than the HD system (15 ft). The pipes in the Webster system are bedded in AASHTO 57 stone. There is no bedding stone in the HD system underdrain.

The Webster system receives more acidity loading than the HD system, however the Webster system is larger. From a loading perspective, the Webster system has an average area-adjusted acidity loading of 22 $g/m^2/day$ while the HD's rate is 29 $g/m^2/day$. The recommended acidity loading rate for vertical flow ponds is 30-40 $g/m^2/day$. At the 75$^{th}$ percentile and 90$^{th}$ percentile conditions, the area-adjusted acidity loadings for the Webster system are 30 $g/m^2/day$ and 43 $g/m^2/day$, respectively. Under all but the most severe conditions, the Webster system receives a loading rate that is consistent with current VFP design practices[1]. The system's poor performance is not due to sizing errors.

***Table 6. Components of the Webster and Hunters Drift (HD) passive treatment systems.***

| | **Webster** | **Hunters Drift** |
|---|---:|---:|
| First treatment | Dec 2004 | Jan 2004 |
| Average acid loading, kg/d | 651 | 417 |
| Average acid loading, lb/d | 1,432 | 917 |
| VFP Design | | |
| Number of VFPs | 2 | 4 |
| Total VFP surface area, ft2 | 314,421 | 156,937 |
| Limestone (LS) Bed | | |
| Aggregate specification | AASHTO 1 | AASHTO 1 |
| Limestone depth, ft | 2.5 | 3.0 |
| Limestone CaCO3 | 85% | 90% |
| Limestone source | New Enterprise | P Stone |
| Limestone tons | 36,700 | 18,479 |
| Organic Substrate (OS) | | |
| OS depth, ft | 1.0 | 1.0 |
| OS type | SMC* | SMC, wood chips, hay |
| OS, CY | 11,300 | 5,108 |
| OS LS amendment, ton | 750** | 2,299 |
| Total LS in system, ton | 38,670 | 20,778 |
| Underdrain pipe, | | |
| Pipe Spacing, ft | 50-60 | 15 |
| Total pipe length, ft | 5,175 | 7,352 |
| Loading, gAcid/$m^2$/day | 22 | 29 |
| Underdrain loading, $ft^2$/linear ft | 61 | 21 |
| Treatment Effectiveness | | |
| Initial Discharge | Alk, low metals | Alk, low metals |
| 2012 discharge | Acid, high metals | Alk, low metals |
| LS dissolution, tons, Oct 2013 | 2,484 | 2,517 |
| % LS dissolved | 4.9% | 13.5% |

* SMC is spent mushroom compost

** LS necessary to produce 10% $CaCO_3$ by weight assuming substrate density of

[1] Rose, AW and Dietz JM. 2002. Case studies of passive treatment systems. In Proceedings of the 2002 National Meeting of the American Society of Mining and Reclamation, Lexington KY. P.776-797.

1,000 lb/CY (fresh weight) and limestone with 85% $CaCO_3$

## Aspects of the System Design that Might Explain the System Failure

The previous review indicates that the failure of the Webster system cannot be attributed to simply AMD chemistry or overloading with acidity or metals. The range in flow rates is high, but this is unlikely to explain the sudden failure of the VFPS which occurred under normal precipitation conditions. A detailed consideration of the system design and field operation was conducted to try to identify weaknesses in the system design that might explain its failure. Several potential causes were identified.

Underdrain Pipe Design

A primary functional goal of all VFPs is that AMD on the surface of the pond should flow diffusely downward through the alkaline organic substrate and into the limestone aggregate underdrain. As this occurs, the water contacts alkaline substrates that neutralize acidity and remove metals. The downward flow is promoted by a network of perforated pipes placed at the bottom of the limestone aggregate. The network of pipes provides multiple points of inflow into the underdrain, which in theory promote diffuse flow and lessen the development of preferential flow paths between the surface water and underdrain pipes that would negate the treatment value of the substrates.

The Webster underdrain system is unusually designed in several respects. First, the Webster underdrain contains less pipe than other effective VFPs. Figure 7a shows the layout of Webster underdrains. The underdrains consist of 5-6 runs of perforated 6 inch diameter HDPE pipe that are separated by 50-60 ft. Figure 7b shows the layout of the HD underdrain. It consists of 6 runs of perforated 4 inch diameter HDPE pipe that are separated by 15 ft. Table 6 shows the total length of underdrain pipe in each system. The HD system contains more underdrain pipe despite being half the size. The Webster system contains 61 $ft^2$ of water surface for each foot of pipe, while the ratio for the HD system is 21. A system with too little underdrain pipe is likely to provide inefficient hydraulics and have areas of limestone aggregate that provide little treatment benefit. In addition, concentrating the flow potentially concentrates the deposition of metal solids precipitated at part of the treatment process. This accumulation of solids produces head loss and ultimately plugging.

A second unusual aspect of the Webster underdrain system is that the pipes are completely enveloped with AASHTO 57 non-calcareous aggregate (Figure 8). It is uncommon for the perforated underdrain pipes in VFPs to be completely enveloped with small gravel. In most VFPs, the perforated underdrain pipes are placed directly within the limestone aggregate. The consequences of surrounding the underdrain pipes with gravel are unknown. If solids are forming in the underdrain, they would likely be trapped in the gravel surrounding the pipes, which would eventually plug the underdrain system.

A third unusual aspect of the Webster underdrain is that the underdrain pipes have cleanouts that extend up through the limestone aggregate, organic substrate, and surface water onto berms where they are accessible by cleanout equipment. It is not advisable to have pipe protruding through the substrates in a VFP because flow paths can develop along the pipes that bypass the organic substrate.   This problem is potentially accentuated by the presence of AASHTO 57 bedding that follows the underdrain pipes to the surface.  The gravel, which is non-calcareous, would provide an easy flow path for untreated surface water to the underdrains.

Either individually or in combination, these features of the underdrain plumbing would result in water reaching the underdrain untreated.  However, there would also be treated water that flows downward through the full cross-section of the substrate and reached the underdrain plumbing as intended.  When these treated and untreated waters mixed around and within the underdrain they would have produced metal solids that could plug the underdrain stone, bedding, and the pipe.

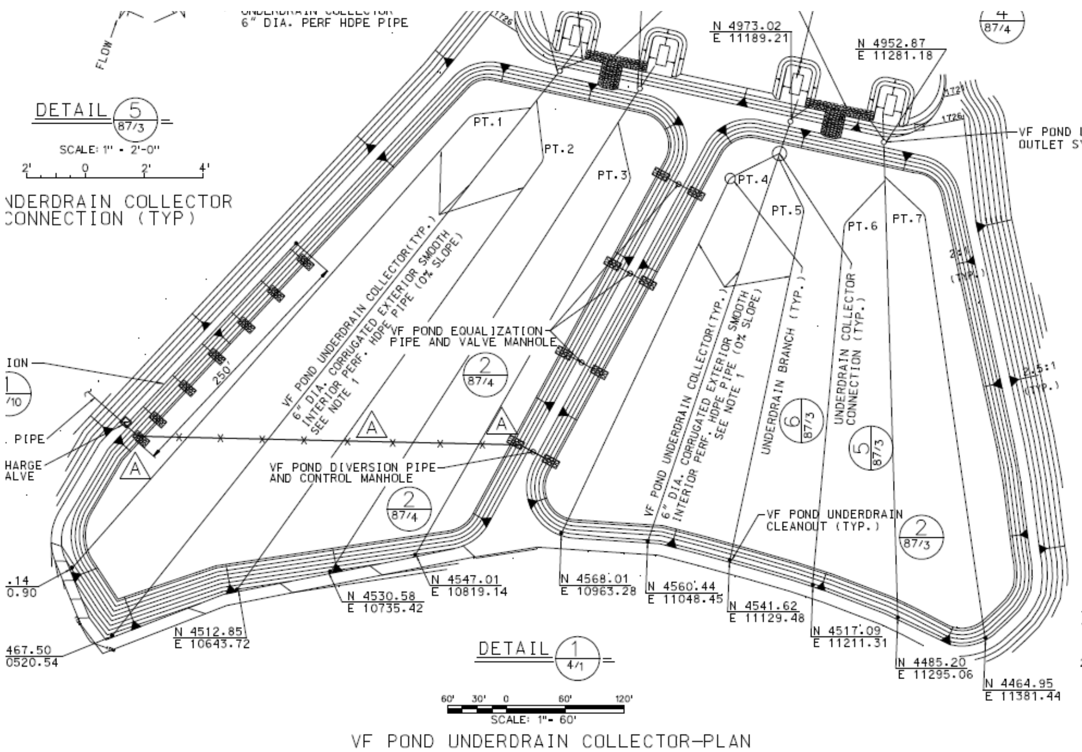


***Figure 7a.  Webster System underdrain design.  The thin lines within the two VFPs are 6 inch perforated pipes that discharge collected water to the wetland.***

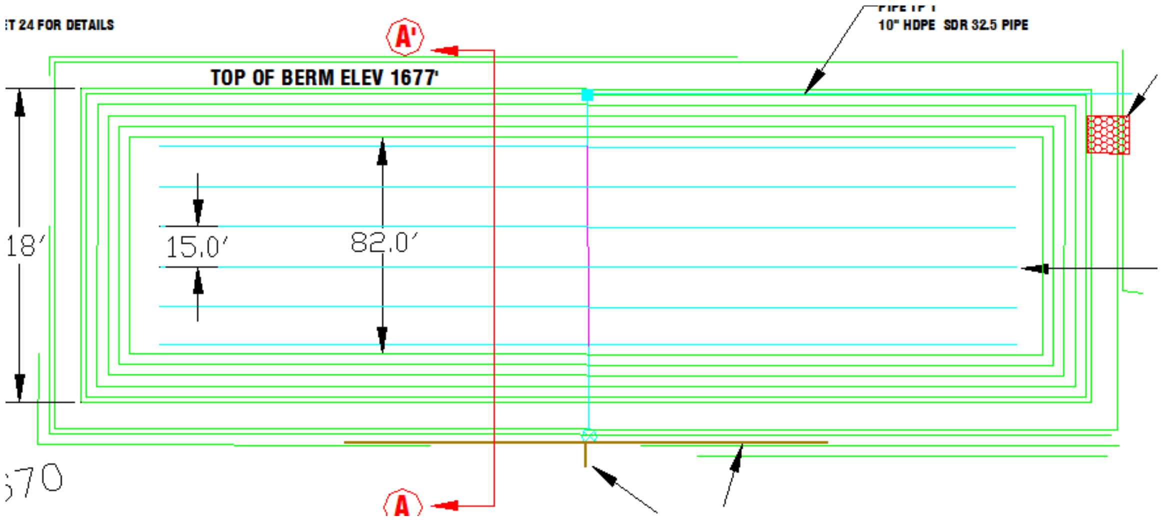


***Figure 7b. HD underdrain design. The blue lines are 4" perforated pipes. The purple line in the center is an 8" solid manifold pipe that discharges collected water to a wetland.***

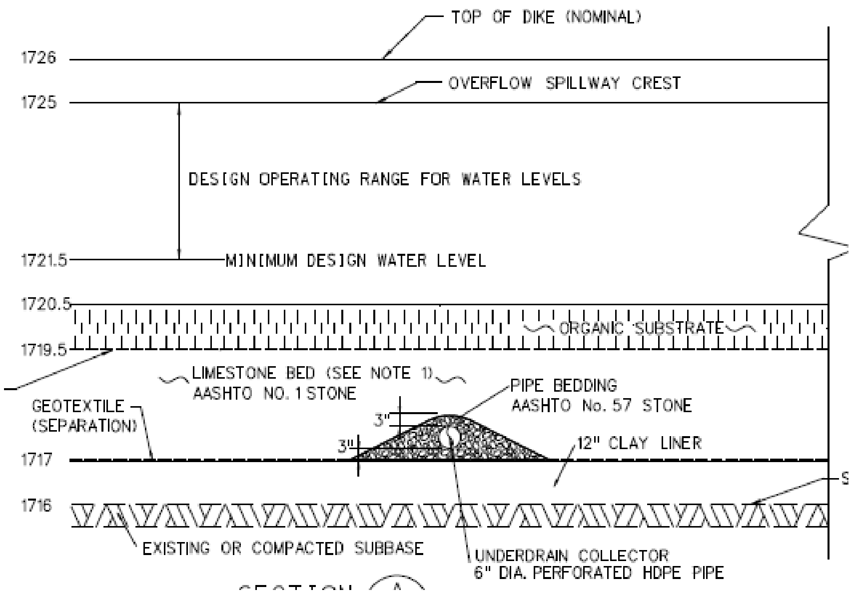


***Figure 8. Detail of the Webster system underdrain. The pipes are bedded in 3 inches of AASHTO 57 noncalcareous gravel.***

Inadequately Neutralized Organic Substrate The intended flow path for AMD in a vertical flow pond is down through the organic substrate and into the underlying limestone aggregate. The purpose of the organic substrate is to provide a fertile alkaline environment where microbial activity can remove oxygen and reduce ferric iron to ferrous iron.  The alkaline substrate also neutralizes acidity by raising the pH and precipitating ferric iron and aluminum.  These neutralization reactions appear to be very important in maintaining the viability of the organic substrate.  Spent mushroom compost is naturally alkaline, which is one reason it has historically been useful for the treatment of acid mine drainage.   Supplementing the alkalinity of the organic substrate is an important component of the successful treatment of acidic mine water with VFPs[2].

The organic substrates in the Webster VFPs and the HD VFPs were both amended with limestone to increase their neutralizing capacity.  The amendment to the HD system was substantially larger than the Webster system (Table 6).  The HD organic substrate was amended with limestone fines on a 3:1 volume basis so that the final substrate had a $CaCO_3$ content of approximately 43% (by weight).  According to the construction narrative, the organic substrate in the Webster system was amended to 10% $CaCO_3$ with fine limestone.

The potential significance of the differing rates of alkaline amendment was evaluated by comparing the quantities of alkaline addition to the quantities of alkalinity generation by the two systems.  The Webster organic substrate was amended with approximately 664 tons of limestone.  In the first two years of the Webster system's operation the system generated 757 tons of net alkalinity ($CaCO_3$) which would have required the dissolution of 781 tons of limestone.   If a primary flow path during this period was through the organic substrate and a large portion of the alkalinity was generated in the substrate, then the limestone amendment (~750 tons) would have been largely exhausted in December 2006 when both VFPs experienced a rapid decline in effectiveness.  Once the alkaline characteristic of the organic substrate is exhausted, mine water flows into the underdrain with little treatment which allows Fe and Al to contact limestone and form solids that eventually decrease performance.

In comparison the HD organic substrate was amended with 2,299 tons of limestone.  This limestone amendment was able to supply all the observed alkalinity generation during the system's first eight years of operation, when the system provided continuous highly effective treatment.

## Aspects of the System Design that Prevent Maintenance Operations

All treatment systems should be designed to accommodate maintenance activities. Maintenance can involve major repairs or rehabilitations that require the treatment cell to be shut down and drained.   A good design allows treatment of the mine water to continue when these activities occur.  The design of the Webster system has several shortcomings that make routine and major maintenance difficult.

Inability to Isolate Both VFP Cells

AMD enters the Webster system in VFP1 and flows across the substrate to VFP2.  Valves in the pipes that connect the VFPs can be closed which allows isolation of VFP2 while all

[2] Rose, AW. 2006. Long-term performance of vertical flow ponds – an Update. In Proceedings of the 7th International Conference on Acid Rock Drainage, St Louis, MO. P.1706-1716.

water is treated by VFP1. VFP1 cannot be isolated with the installed plumbing because there is no means to direct the AMD into VFP2 and bypass VFP1. The only way to isolate VFP1 is to bypass all of the AMD to the stream without treatment.

Inability to Drain the VFPs

The VFPs cannot be passively drained empty because they discharge to the wetland which has a water elevation higher than the bottom of the VFPs. The current water elevation in the wetland is about 1719 ft which is only 0.5 ft below the top of the limestone aggregate (see Figures 2 and 8 for elevations). The inability to completely drain the VFPs makes investigation of the condition of the limestone aggregate or the underdrain pipes very difficult because most of the excavation will be underwater. The VFPs can, in theory, be pumped empty but this would involve at least a week of 24-hour pumping, assuming that the underdrain is not plugged. In fact, both underdrains are partially plugged at this time. Assuming the 130 gpm flow rate that VFP2 was discharging in October 2013, it would take 12 days of round-the-clock pumping to drain VFP2 empty.

Presence of High Maintenance Valves

The system contains eleven valves which, according to the O&M Plan, require maintenance every 6-12 months. This is a large number of valves and maintenance. The valves are located in concrete boxes, many of which are flooded. In order to access the valves, the boxes must be pumped empty. Several of boxes require descending into a closed space which cannot occur until air quality is assured.

Vehicular Access to Maintenance Points is Blocked

Pumping and heavy tools are required to open/close valves and to drain the VFPs (as much as is possible). While the berms within the system were constructed wide enough to allow vehicles and trucks, every berm is blocked by either valve manholes (internal berms) or a security fence which was placed within the perimeter berms. Because of this blockage, pumps and tools must be carried to maintenance points. The mobilization of a large diesel pump to the VFP effluents (for pumping down the VFPs) is impossible.

No Method for Bypassing High Flows

Many treatment systems have plumbing that bypasses flows in excess of a maximum amount around the VFPs. Ideally, the bypassed water flows into a pond or wetland where it mixes with treated water before being discharged. The Webster bypass does not operate in this manner. The bypass is located on the opposite side of Pergrin Run as the system and is at a lower elevation than the system influent pipes. The bypass discharges directly to Pergrin Run. When the bypass is open, water preferentially flows directly to Pergrin Run. Water only flows into the treatment system when the AMD flow rate exceeds the capacity of the bypass. This operation is the opposite of the desired condition where bypass occurs only after treatment capacity is exceeded.

Influent Pipes are Lower than the VFP Spillways

The VFP influent pipes are at 1721.5 ft which is lower than the VFP spillway elevation of 1725.0 ft. When the VFPs experience head losses, the influent pipes are underwater.

Because of the design of the bypass (lower than the influent pipes), when the bypass is open the VFPs can drain backwards through the bypass. There are no apparent benefits to having the influent pipes at the 1721.5 ft elevation. The discharge was collected from Webster mine at 1724.3 ft, so the influent pipes could be raised 2-3 ft.

## Summary of Failure Investigation

A primary goal of this project was to identify reasons for the failure of the Webster treatment system. The findings of the review of the system design and monitoring data are summarized below.

- The system did not fail simply because the water chemistry is too severe. There are passive systems in PA that have been successfully treating similar water chemistry for up to ten years.
- The Webster system did not fail because it was overloaded with acidity or metals. The average loading rate for the system has been 22 $g/m^2$/day of acidity. The recommended loading rate for VFPs is 30-40 $g/m^2$/day of acidity.
- The Webster system does not have a functional high flow bypass. There have been periods of very high flow and acidity loading. This is not advisable and could contribute to the long-term decline of treatment effectiveness. However, there is no evidence that the rapid decline in treatment effectiveness in December 2006 was associated with a high flow event.
- Studies of effective VFPs have indicated that the alkalinity of the organic substrate can be an important factor. The Webster system organic substrate was amended with limestone to 10% $CaCO_3$. This is a low amendment rate. The organic substrate in the Hunters Drift VFPs (which have effectively treated similar AMD chemistry) was amended to a 43% $CaCO_3$.
- It is possible that the system failed because the organic substrate's alkalinity was exhausted. The calculated alkalinity generation during the first two years of the Webster systems operations is approximately equal to the alkaline content of the organic substrate.
- The underdrain system contains several unique characteristics that could have contributed to the systems failure.
    1. The underdrain piping system is small. The Webster VFPs contain about one-third the pipe density of the Hunters Drift system. This could result in less efficient distribution of AMD in the substrates.
    2. The underdrain system has cleanouts that extend through the limestone and organic substrate to the surface. Untreated AMD could follow the outside of these pipes directly into the underdrain. The introduction of untreated water directly into the limestone aggregate is not recommended because it can cause premature fouling and failure of the underdrain system.
    3. The underdrain pipes are buried with small gravel. If solids are forming in the limestone aggregate, the gravel around the pipes would likely become plugged long before the limestone aggregate plugged. The cleanout pipes

are enveloped in gravel. This porous substrate could provide a substantial flow path for untreated AMD to flow directly into the underdrain.

## Rehabilitation of the Webster System

A second goal of this project was to identify actions that could rehabilitate the system and provide more effective treatment and benefits to Blacklick Creek. This goal was tempered during a November 14, 2013 site meeting when the PADEP Bureau of Conservation and the Restoration indicated that it did not intend to commit any more funding to the passive treatment project. Instead, the PADEP is pursuing an active treatment plan where the Webster discharge would be piped to a local lime treatment plant operated by a third party. Given this context, the rehabilitation recommendations that follow are conceptual in nature. Should the PADEP reconsider its position on establishing an effective passive system at the site, these recommendations should be explored in much more detail.

Rehabilitation of the system should be based on design principles used for VFPs that are effectively treating similar AMD chemistry. Several improvements are apparent.

Plumbing Improvements/Modifications

- The system should contain a flow distribution system that allows direct control of flow to each VFP and the bypassing of high flows to the wetland. This change could be accomplished with pipe installed on the existing central berm and the new berm identified below.
- New underdrain plumbing must be installed. The current underdrain is inadequate and must be replaced with a header-lateral setup.
- The manholes that obstruct movement of equipment on site should be removed.
- The valves should be replaced with water level control structures which involve much less O&M.

Layout Improvements/Modifications

- Each VFP should be split in half so that the rehabilitated system would contain four VFPs. This will allow maintenance to occur on one VFP while treatment is maintained by the other three VFPs without overloading them. This change could be accomplished by installing a new earthen berm through the center of existing VFPs. This will require approximately 5,000 CY of dirt that would probably need to be sourced off-site.
    - Installation of the berm will reduce the effective treatment area of the system. If this addition caused a 10% reduction, then the redesigned VFPs would have a total surface area of 283,000 $ft^2$. The four VFPs would have a loading of 25 $g/m^2$/day acidity at average conditions and 32 $g/m^2$/day acidity at $75^{th}$ percentile conditions. These loadings are consistent with current VFP sizing standards.

- The bottom of the VFPs should be higher than the wetland water elevation so that they can be drained empty. This can be accomplished by either lowering the wetland or raising the bottom of the VFPs.
    - Lowering the wetlands involves excavating the bottom of the wetland. This may not be possible due to soils limitations, groundwater elevation or other factors. Excavated materials could be used to construct a berm to divide the VFPs described above. This option has the advantage of reusing much of the existing limestone by cleaning it in place and avoids buying new stone. The estimated cost is approximately $1.8 million.
    - Raising the bottom of the VFPs is fairly straightforward because it uses the top of the existing limestone layer as the new bottom of the VFPs. The existing organic substrate would be stripped off and new underdrain plumbing and limestone installed directly on top of the existing stone. Then new organic substrate would be installed on top of the new limestone. This option involves minimal earthwork but requires that all new limestone be purchased and installed. The estimated cost is approximately $2.8 million.

The estimated cost of reconstructing the system is $1.8 to $2.8 million. The original cost of the system was reportedly about $4 million. Based on the performance of the Hunters Drift system (similar chemistry and loading), the redesigned system would provide reliable treatment with no major maintenance for 8 to 10 years. After this period, replacement of the organic substrate would be necessary at a cost of approximately $600,000 per event. The estimated present value cost (20 year, 5%) for the two reconstruction scenarios including two major maintenance events is $2.5 – 3.5 million.