Oven Run B Passive Treatment System

Shade Township, Somerset County, Pennsylvania

Operation & Maintenance Plan

September 2022

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Operation & Maintenance Plan

Project Information

Project Name:	**Oven Run B Passive Treatment System Redesign & Construction**
Coordinates (approx. center):	40.112275, -78.912004
Site Access:	Koonztown Road, Shade, PA 15563 (40.11581667, -78.91405833)
Hydrologic Order:	Oven Run B → Stonycreek → Conemaugh R. → Kiskiminetas R.
Project Owner [Project #]:	PA DEP, Bureau of Abandoned Mine Reclamation [AMD 56(2524)103.1]
Landowners:	Somerset County Conservancy (majority of project); James H. & Donnalee B. Weaver (access road); Jay D. & Margaret Ann Shaulis and Shawn & Melissa Gross (SP3/system outlet area)
Design & Construction:	BioMost, Inc., Mars, PA, www.biomost.com
Construction Contractor:	Earth Shapers, LLC, Ebensburg, PA
Project Sponsor:	Stream Restoration Incorporated
Anticipated Design Life:	20 years

Overview

The Oven Run B Abandoned Mine Drainage (AMD) Passive Treatment System (System) is located in Shade Township, Somerset County near Stoystown, PA. As shown in Figure 1, AMD issues from five 18-inch SCH40 pipes that extend from an abandoned underground coal mine to a Moat. Other AMD discharges are either collected by the three rock drains or enter the various treatment components as diffuse seep zones. After flowing from the moat via a flume, the AMD is held in the Holding Pond (HP) prior to being dosed to one of the three Automatic Flushing Vertical Flow Ponds (AFVFP1, AFVFP2, AFVFP3). The AFVFPs contain limestone to raise the pH, neutralize acidity, and cause both aluminum and iron to precipitate. Settling Pond 1 (SP1) and subsequently Settling Pond 2 (SP2) received the flush water and permit the metal solids to settle. Further acid neutralization, metal precipitation, and alkalinity generation takes place in two Jennings-type Vertical Flow Ponds (JVFP1, JVFP2) prior to final solids removal in Settling Pond 3 (SP3). A dewatering basin (DB) is provided to facilitate future maintenance.

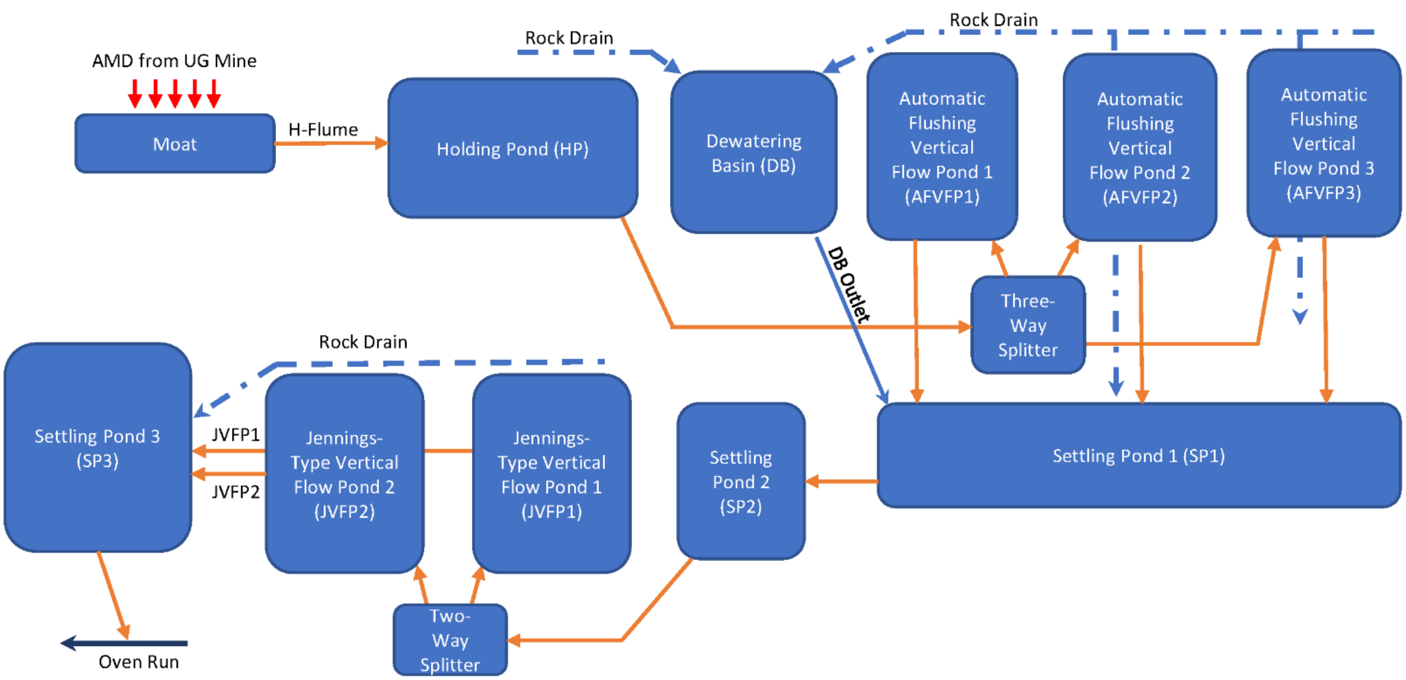


Figure 1. Oven Run B System Flow Diagram

System Components

Raw Water Inlet

Raw water draining through wet seals from the underground coal mine is conveyed from the Moat by an 18-inch SCH40 PVC pipe to a concrete channel approach section that outlets via a 1.5-foot fiberglass H-flume. The flume is equipped with a staff gauge and the water depth is used with the lookup table in Appendix 1 to determine the flow. In addition, there is a stilling well fitted with an ultrasonic transducer that measures the flow depth connected to a flow controller (meter) located in the pole-mounted solar enclosure. The controller reports flow in gpm and transmits flow depth data via a node radio to the telemetry system in the Three-Way Flow Splitter. Additional information regarding the transducer, controller, radio, telemetry, and other equipment is provided in Appendix 2 (Equipment Manuals). (See also: Telemetry System Parts 1 & 2.)

Holding Pond (HP)

The Holding Pond is used to collect water prior to being fed into the three AFVFPs and facilitate batch treatment using a chosen hold time. Research conducted as part of the design of the Puritan Discharge Passive Treatment System (See: www.datashed.org/project-puritan-discharge) indicated that filling an AFVFP all at once can provide more effective treatment when compared to traditionally flooding a limestone-filled pond gradually. The later was the case with all known components of this type prior to the construction of the referenced Puritan Discharge Passive Treatment System. Therefore, to take advantage of this increased treatment efficiency, the Oven Run B Passive Treatment System has been designed to utilize timed, batch treatment. This is achieved by collecting and holding the water in the Holding Pond which was constructed by using the entire original Collection Basin (Pond 1) and expanding the Holding Pond into a portion of the former SAPS #1. Three Agri Drain Smart Drainage Systems (Smart Drains) were installed in the Three-Way Flow Splitter to dose water into the three AFVFPs at set timed intervals. The Smart Drains that are used to distribute water to the AFVFPs are referred to as Fill Valves.

A flush volume was estimated based on the assumed void volume in the AFVFPs. Using a bulk density for limestone of 1.35 tons per cubic yard and an assumed 50% void space (typical maximum void for clean AASTHO #1 aggregate), the estimated flush (void) volume for one of the 3,000-ton AFVFPs is about 224,000 gallons. The working volume of the HP is measured from the elevation of the outlet pipe invert to the crest of the emergency spillway. The area of the pond at the outlet pipe invert elevation is approximately 13,700 square feet and the area at the emergency spillway crest elevation is about 19,800 square feet with a vertical distance of 2.9 feet. This results in a total working volume of 49,000 cubic feet or 367,000 gallons. A bar guard was installed at the inlet of the pipe to help prevent debris from entering the outlet pipe. A rope was affixed to the bar guard and tied to a stake along the edge of the HP to allow the guard to be removed to facilitate maintenance if needed. The stop logs in the Fill Valves were set at an elevation approximately 1 foot below the crest elevation of the Holding Pond emergency spillway so that during high flow periods raw water will be distributed evenly among the three AFVFPs between the timed fill events.

Maintenance of the Holding Pond should be minimal and consist of mostly removing debris from the bar guard as needed and visual checks for erosion. The expanded area of the HP was clay lined which was armored with R-4 riprap in the wetted zone of the pond inside slopes. Due to the constant change in water elevation due to flush cycles, visual inspection should be done whenever on site and any erosion within this zone should be immediately addressed. The HDPE liner of the existing holding pond area was left in place and should also be inspected and repaired as needed. As the emergency spillway of the Holding Pond drains to SP3, a sudden pH drop at the system outlet (Monitoring point ORBO) could indicate plugging of the bar guard or 18-inch PVC pipe.

Three-Way Flow Splitter

The Three-Way Flow Splitter is a 9-foot x 9-foot x 11.5-foot-deep open-top concrete box that is partially filled with approximately 4 feet of aggregate and is accessed via a ladder affixed to the exterior and interior walls. Water inlets from the HP via an 18-inch pipe, flows through an HDPE manifold to the Fill Valves. The fill cycle is controlled by the Fill Valve Control Box. When a Fill Valve opens, flow is directed to the selected AFVFP.

Telemetry System Part 1 (Login and H-Flume)

The Telemetry System is also housed in the Three-Way Flow Splitter. A solar panel is mounted on the south side of the Three-Way Flow Splitter and is used to power the Fill Valves, radar meters, and telemetry system. The telemetry system is used to monitor the flow depth at the H-Flume, the water levels in the three AFVFPs, and pH at the outlet of Settling Pond 2 [(ORBSP2 pH (Flow Splitter Box)] and the outlet of the system at Settling Pond 3 [ORBO pH (SP3)]

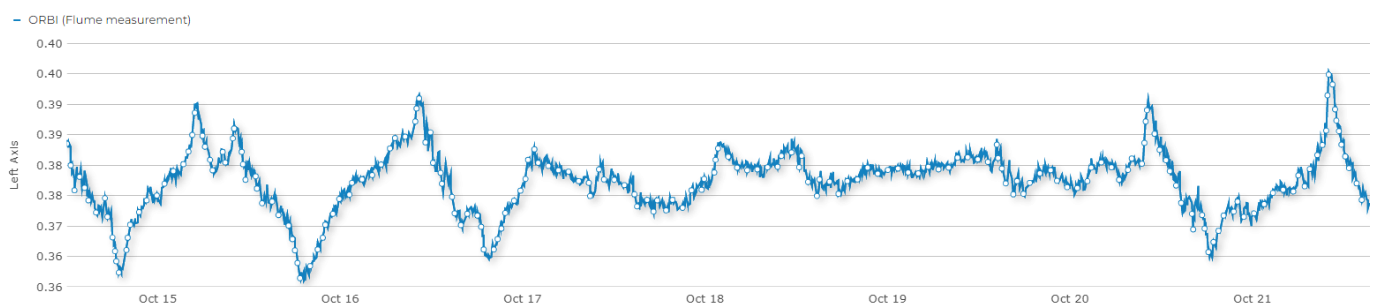
To view the telemetry system using the Banner Cloud Data Services website:

Website: bannercds.com

Login: ovenrunPADEP

Password: Ovenrun@1

The flow depth at the 1.5-foot H-Flume can be displayed when the ORBI (Flume Measurement) register is selected as shown in Figure 2. An example approximate depth of 0.38' is recorded which indicates a flow of 114 gallons per minute (gpm). The daily variability is attributed to diurnal temperature differences that affect the sensing equipment and appear to be muted when it is overcast or precipitating. Per the note on As-Built Sheet 1 in Appendix 3 the average design flow is 158 gpm while the maximum design flow is 367 gpm.



Color	Gateway	Register	Type	Value	Unit	Axis	Remove
●	Oven Run	ORBI (Flume measurement)	Register	0.3738	FT	Left Axis	✖

Figure 2. Flow Depth at H-Flume Example

Automatic Flushing Vertical Flow Ponds (AFVFP1, AFVFP2, & AFVFP3)

Using an estimated bulk density of 1.35 tons per cubic yard and an assumed 50% void space, the three AFVFPs have a collective void volume of 673,000 gallons. With equal spacing of the AFVFP fill events over a 24-hour period, the three AFVFPs would be capable of accepting up to about 470 gallons per minute without causing the water level to rise in the limestone to a point where the stop logs in the Smart Drain outlets (Flush Valves) would over top and the AFVFPs would enter flow-through mode.

Each AFVFP contains approximately 3,000 tons of high-calcium (~99% $CaCO_3$ equivalent/92% as $CaCO_3$) limestone. When Fill Valve #1 opens, raw AMD will enter the AFVFP1 from the HP and be held for 8 hours per the initial programming of the Flush Valves followed by AFVFP2 and AFVFP3. The initial AFVFP programming is shown below in Table 1. The hold time may be changed depending on future water quality measurements or changes to System parameters. Ideally, the hold time should be adjusted to the shortest period that achieves the treatment goals. As the primary purpose of the AFVFPs is to cause ferric iron and aluminum to precipitate, maintaining pH above 5 at the outlet of SP2 should indicate proper system function.

Table 1. Initial AFVFP Programming

Pond	Fill Start	Fill Duration	Fill End	Flush Start	Flush Duration	Flush End	Retention Time
AFVFP1	1430	90 min.	1600	0000	90 min.	0130	8 hour
AFVFP2	2230	90 min.	0000	0800	90 min.	0930	8 hour
AFVFP3	0630	90 min.	0800	1600	90 min.	1730	8 hour

Time is shown in military format and programmed in UTC. To adjust for Eastern Standard Time, subtract 5 hours (1430 UTC is 0930 Eastern).

The AFVFPs have underdrain systems comprised of 6-inch DR17 HDPE perforated lateral pipes connected with non-shear flexible couplers as needed. A 12-inch DR26 HDPE perforated header pipe parallels the length of each pond and is joined to the laterals with 6-inch flexible saddle tees. The 12-inch DR26 HDPE is connected with non-shear flexible couplers at each joint and as it transitions to SCH40 PVC pipe where it extends into the embankment to the Flush Valves. The 12-inch header has 12-inch SCH40 PVC caps installed (dry fit) at each end.

Maintenance of the AFVFPs will include monitoring the operation of the Flush and Fill Valves and the pH at SP2 using the telemetry system, cleaning and lubricating the stop logs in the Fill and Flush valves, periodic cleaning, eventual addition or replacement of the limestone, and visual inspections for debris and erosion. The inlet pipes from the Three-Way Flow Splitter should be inspected during each site visit and any accumulated debris removed as needed. Vegetation and other debris should be removed from the emergency spillways as needed. As with any pond structure, the embankment should be inspected for erosion and any adverse conditions rectified in a timely manner.

<u>AFVFP Water Level Meters</u>

Radar-type water level meters are installed in the Agri Drain Smart Drainage Systems at the outlet of each AFVFP (i.e., Flush Valves). 4-inch SCH40 PVC pipe stilling wells were placed on the upstream side of the stop logs and valve. The water level indicates when each AFVFP is being filled by observing an increase of water level in the limestone and when each pond is being flushed as indicated by the drop in water level. The initial flush and fill durations were set at 90 minutes (1.5 hours).

To view the chart shown in Figure 3, login to the Banner Cloud Data Services (Banner CDS) website per the Telemetry System section. Once logged in, under Device Management click on Details. Under the Data Section, click on any of the AFVFP registers (ORBAF 1, ORBAF 2, ORBAF 3), this will create a chart showing the water elevation in the selected pond. Additional ponds can be added to the chart by checking the box next to 'Add to Chart'. There are a number of variables that can be modified including the time displayed (e.g., last 6 hours, last day, last week, etc.) and custom charts can be generated if desired. If all three AFVFPs are selected and the last day (or longer) is selected for the timeframe, each fill/ flush cycle for the three AFVFPs will be displayed. If any of the ponds are not shown to flush/fill as per the current programming, it is indicative of a fault in the radar meter installed in the Flush Valve or an issue the Fill or Flush Valves and a site inspection should be conducted as soon as possible. Proper Fill and Flush Valve function over a week-long period is shown in Figure 3. It should be noted that selecting the other parameters monitored in the System (i.e., ORBI Flume measurement) may affect the Left Axis and the flush/fill curve will falsely appear linear.

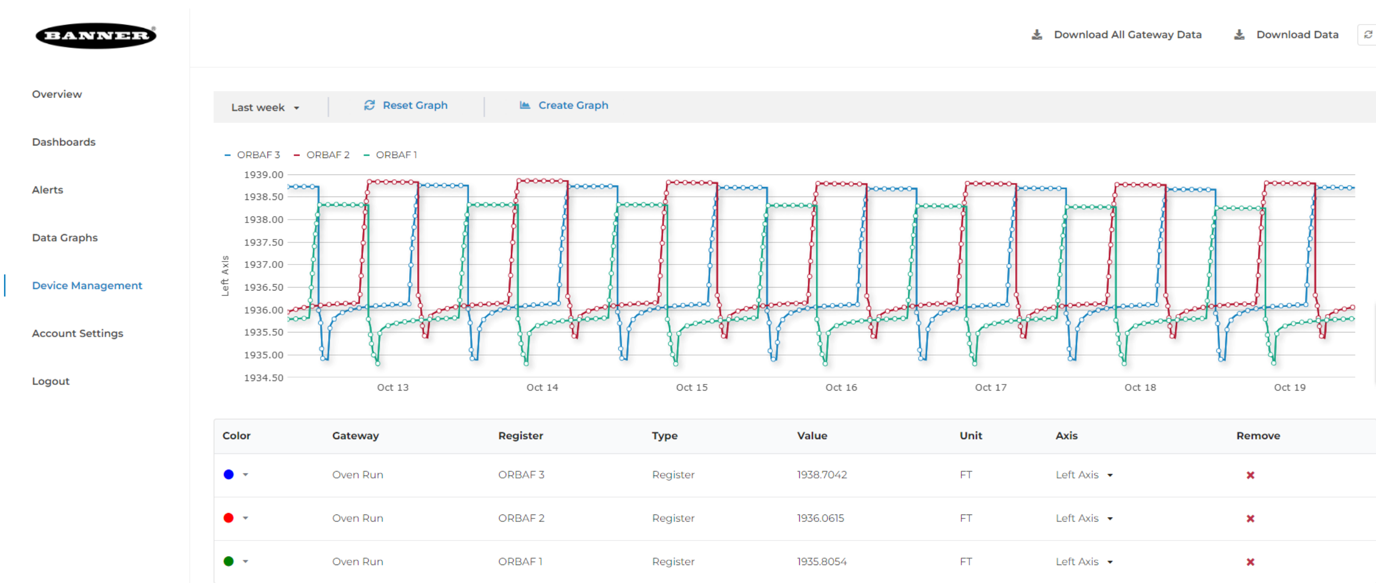


Figure 3. Banner Cloud Data Services Chart of AFVFP Water Elevations Showing Proper Function for 7 Days.

When the Fill Valve opens for a given AFVFP, the water level increases either until the Fill Valve is shut or the Holding Pond is emptied. During a flush event, a large initial drop is observed as the hydraulic conditions equilibrate between the capacity of the underdrain to supply water to the Flush Valve and the capacity of the valve, and then drops more gradually as the pond is emptied and available hydraulic head decreases. Once the Flush Valve is shut, the water fills the pipe between the Flush Valve (which is set lower than the AFVFP pond bottom elevation) and Underdrain and then stabilizes near the lower pond bottom elevation of about 1936. As indicated on the As-Built drawings (Appendix 3) the three AFVFP ponds have bottoms that are sloped from 1936.0 on the west up to 1937.0 on the east.

Fill & Flush Valve Maintenance

The stop logs of both the Fill and Flush valves should be removed once per year, cleaned, lubricated (with Lubriplate No. 105 Motor Assembly Grease or equivalent), and replaced. The valve itself is mounted to a larger stop log that can be removed if desired, however, this will require significant effort and is not needed unless there is an issue with the valve. Other than valve failure, the only reason the valve stop log would need to be removed is if the pin that holds the push tube from the actuator breaks at the top of the valve stem. If the valve needs to be removed, the actuator should also be removed and the valve can be opened manually (unless the pin is broken and the valve is in the closed position). A strap can be fed through the open valve and used to pull the stop log out of the Agri Drain structure. There are brackets located on the valve stop log that can be used with the stop log puller tool if a strap cannot be fed through the open valve.

Trigger for AFVFP Limestone Maintenance

AFVFP limestone maintenance will be triggered based on poor water quality in SP2 or when overflow from the AFVFPs occurs daily during average or below average flow conditions. The pH measured at the outlet of SP2 (12-inch SCH40 PVC pipe outlet in Two-Way Flow Splitter) should always be 5.0 or above. A **pH less than 5.0** indicates that the limestone has become passivated. **Daily overflow** from the AFVFPs when inflow rates are average (158 gpm) or less indicate that the void volume within AFVFP has become excessively filled with metal precipitates.

The overflow elevation of all three AFVFPs is 1941.0 (approximately equal to initial top of stone elevation in the three AFVFPs). If water is observed to be above 1941.0 in any of the AFVFPs, overflow is likely occurring. Overflow during above average (>158 gpm) flow is not unexpected and as long as the pH at SP2 is 5.0 or above, the system is functioning as intended. If the maximum flow of 367 gpm is exceeded, a pH below 5.0 at SP2 is not unexpected. However, when the pH at SP2 is consistently below 5.0 and the flow is 367 gpm or below, maintenance of the AFVFPs is likely needed. The timing of the washing of the limestone should be based on System performance and it projected that the first cleaning of the AFVFP stone may be needed within the first 5-10 years and at a similar to lessened intervals thereafter. If the pH in SP2 is below 4.5 and the flow is below the maximum design (367 gpm), then the AFVFP limestone should be cleaned as soon as feasible.

AFVFP Limestone Cleaning

Washing of the limestone should be to a depth as low as possible without compromising the clay liner. Geotextile was placed on top of clay liner and will function as a witness layer. Typical cleaning efforts will involve lowering the water level in AFVFP to about three to four feet, stirring the limestone to wash accumulated solids from the stone surface, then removing the solids by either draining the pond through the underdrain to Settling Pond 1 or pumping the solids into the Dewatering Basin. The underdrain piping may be left in-place during washing or temporarily removed if desired. The underdrain pipes are HPDE and, if care is taken, usually can be moved with equipment without damage. The limestone should be excavated to the bottom of the pipes and the accumulated solids removed so that the clean limestone is placed around the underdrain pipes. All three AFVFPs have a sloped bottom to help facilitate sludge removal. The pond is approximately 1' lower on the western side compared to the eastern side to help precipitates flow towards the outlet.

Once the limestone is cleaned and the accumulated solids removed from the AFVFPs, replace the underdrain piping if needed, replacing any damaged pipe sections or flexible couplers as needed, and place the cleaned limestone around the pipes, being careful to maintain joint integrity during stone placement. Once all the limestone is in-place, allow the AFVFP to fill with water and grade the stone evenly using the water surface as a level indicator. Remove one or more stoplogs from the Agri Drain structure as needed to set a temporary water level. Once the stone is level, replace the stop logs so that the maximum water surface is just below the top of the limestone when the valve is shut and the AFVFP is full (water is flowing over the top of the stoplogs). As it is not uncommon for aggregate to enter the underdrain piping during maintenance, it is recommended that the Flush Valves be manually opened and shut several times to ensure that the valve seat is free from rock fragments or other debris, using the valve actuator when there is either rock or debris in the valve can result in damage to the actuator and/or valve.

AFVFP Limestone Replacement

As the purpose of the AVFPs is to dissolve limestone in order to neutralize acidity, the limestone will eventually need to be either supplemented or replaced. Once washing no longer results in sufficient restoration of system performance, additional stone may need to be added to supplement the remaining limestone or the limestone may need to be removed and replaced.

The AFVFP limestone should be evaluated before adding more aggregate. If the majority of the limestone is less than 1.5-inch in diameter, removing and replacing the limestone may be advisable. One potential approach is to wash the limestone in all three beds and move the used, washed stone from one AFVFP to one or both of the other AFVFPs and place new stone only into the evacuated pond. This approach may result in keeping the stone size as uniform as possible in the ponds with the older stone and the pond that receives the new stone. AASHTO #1 limestone aggregate with at least 85% Calcium Carbonate ($CaCO_3$) content and >90% Calcium Carbonate Equivalent (CCE) is recommended. Smaller aggregate (i.e., AASHTO #3) would provide more surface area and greater reactivity, however, the larger (AASHTO #1) limestone should allow the greatest interval between stone cleaning events while providing the level of treatment needed for the initial acid neutralizing step in the System as the subsequent JVFPs are designed to neutralize the remaining acidity.

Settling Pond 1 (SP1) & Settling Pond 2 (SP2)

SP1 & SP2 pond capacities are calculated from the pond bottom to the emergency spillway crest elevations shown on the as-built drawing. SP1 is approximately 7,700 cubic yards and has a maximum water capacity of about 1,600,000 gallons. SP2 is approximately 5,600 cubic yards and has a maximum water capacity of 1,100,000 gallons of water.

The primary SP1 outlet is an 8-inch SCH40 PVC outlet pipe sized to help mitigate the flow variability created by the AFVFP flush events. The 8-inch SCH40 PVC pipe extends to a spillway leading to SP2. A stainless-steel bar guard helps prevent large debris from entering the pipe. If the bar guard is obstructed, water will rise and exit SP1 via the rock-lined emergency spillway.

The primary SP2 outlet is the 12-inch SCH40 PVC pipe leading to the Two-Way Flow Splitter. A stainless-steel bar guard helps prevent large debris from entering the pipe. If the bar guard is obstructed, water will rise and exit SP2 via the rock-lined emergency spillway to JVFP2.

Routine inspections should be conducted during each site visit to check for erosion of embankments and spillways. Any erosion shall immediately be graded as needed and stabilized utilizing seed and mulch, in cases of excessive erosion due to flooding or vandalism, erosion control fabric may be needed. The pipe and spillway outlets of both ponds should be kept free from debris and vegetation, this includes cleaning material from both bar guards.

Settling Pond Maintenance

During the life of the System, it is possible that the settling ponds will become filled to a level that no longer allows sufficient retention time during flush events for effective settling of the precipitates. This will be indicated by suspended solids (≥35 mg/L TSS) discharging from SP2 and settling on top of the JVFP treatment media. When this occurs, the sludge will need to be removed from the settling ponds. Pond cleaning may be accomplished by pumping or excavating material as needed and placing it into the Dewatering Basin.

The original synthetic (HDPE) liner was left in place in SP1. The original synthetic (HDPE) liner was left in place in a portion of SP2 (bottom, south, and east) while new clay liner was installed in sections affected during System rehabilitation. Care should be taken during the cleaning of SP1 and SP2 to prevent damage to the liners. If damaged, the liners should be repaired as needed with clay, clay geosynthetic (e.g., Bentomat), or synthetic (e.g., HDPE) liner.

Two-Way Flow Splitter

The Two-Way Flow Splitter box is a 7-foot x 7-foot x 5-foot-deep concrete box with a 1-inch-thick aluminum grating cover. Water inlets from SP2 and is distributed evenly between both JFVP1 & JVFP2. The volume of water and flow to each JVFP in the splitter box is controlled by 90° elbows on each outlet pipe that can be turned. All pipes of the component are 12-inch SCH40.

pH Meter 1 (ORBSP2 pH)

To monitor the effectiveness of the AFVFPs, there is a pH measurement device installed at the inlet of the Two-Way Flow Splitter powered by a solar panel (See Telemetry System Part 2). This meter is inserted through the top of the 12-inch PVC pipe from SP2. There is flexible conduit that is dry fit to allow the pH probe to be removed, cleaned, and calibrated. Please see the pH Meter Calibration Procedure section.

Jennings-Type Vertical Flow Ponds (JVFP1 & JVFP2)

Both JVFP1 and JVFP2 contain a mixture of limestone, spent mushroom compost, and hardwood woodchips using a by-volume mixture rate of three parts limestone, two parts woodchips, and one part spent mushroom compost. Both JVFP1 and JVFP2 contain approximately 2,800 tons (2,100 CY) of AASHTO #67 high-calcium limestone, 1,400 CY of single-shredded wood chips, and 700 CY of spent mushroom compost.

JVFP1 and JVFP2 have four-cell underdrains comprised of 4-inch SDR35 perforated laterals connected to 6-inch SDR35 header pipes. The 4-inch laterals are standard, factory-perforated pipe. The 6-inch header pipes are solid with ¼-inch perforations drilled into the top midway between each lateral to help prevent potential air lock. The JVFP1 header pipes transition to solid 8-inch SCH40 PVC pipe before extending through the embankment and under the bottom of JVFP2 before their outlet into SP3. JVFP2 header pipes transition to solid 8-inch SCH40 PVC pipe before extending through the embankment to their outlet to SP3. Both JVFP1 and JVFP2 outlet to SP3 through adjustable 6-inch riser pipes connected to vertical 8-inch pipes with 6-inch x 8-inch flexible rubber couplers. Each outlet pipe extends to an 8-inch Valterra gate valve that can be used to drain the JVFPs if desired. The riser pipes can be adjusted to control the amount of treatment media being used per JVFP or to raise or lower the water level.

The biological activity in the treatment media will produce both alkalinity and hydrogen sulfide gas. Depending on flow, temperature, and the age of the treatment media, nuisance odors may occur. If odor becomes a problem, it is recommended that the treatment media be 'burned in' by changing which cell is used in each JVFP on a monthly basis through the colder months. As the weather warms and the flow potentially decreases, one of the JVFPs may need to be taken offline to control odor. The flow to the JVFPs can be controlled using the adjustable inlet pipes located in the Two-Way Flow Splitter. Over time, which may be several years, odor should abate as the treatment media ages. Eventually, both JVFPs should be operated year-round utilizing all of the underdrain cells. There should always be a noticeable odor near the outlet pipes of the JVFPs, which indicates they are functioning as designed; However, as long as the treatment goals are being met, the level of treatment may be adjusted as needed to control nuisance odors.

<u>JVFP Treatment Media Stirring</u>
Over time, compaction of the treatment media and accumulation of metals may reduce permeability to the point where water can no longer readily pass through the treatment media. The water level in the pond will increase and eventually discharge through the emergency spillway, significantly reducing treatment. Stirring of the treatment media can often address this issue. The JVFPs are installed in parallel to allow flow to be diverted to one JVFP while maintenance work is conducted on the other as described in the below steps:

1. Divert flow away from the JVFP to be stirred.
2. Open drain valves to drain the selected JVFP.
3. Allow media to dry (usually one week or more depending on weather) to facilitate use of mini-excavator or other equipment with relatively low ground pressure to run on the media.
4. Stir entire volume of treatment media, leaving behind loose uncompacted material. Take care not to damage underdrain piping, repair piping as needed. Stirring should stop at the underdrain stone/treatment media interface.
5. Close drain valves and allow pond to fill.
6. Open drain valves to flush stirred JVFP in order to wash fine material from piping system.
7. Close drain valves and allow pond to fill once again. Reset, as needed, the adjustable outlet risers to the normal operating elevation.

<u>JVFP Treatment Media/Underdrain Replacement</u>
If stirring the treatment media does not restore satisfactory hydraulic conductivity or treatment, the complete replacement of treatment media will be needed. Again, the Two-Way Flow Splitter can be used to divert flow into one JVFP while work is conducted on the other. The process to replace the media is described in the following steps:

1. Divert flow away from the JVFP to be rehabilitated.
2. Open all drain valves and completely drain the subject JVFP
3. Allow media to dry to facilitate removal.
4. Remove spent treatment media and, if needed underdrain bedding stone and piping.
5. Place spent media in the Dewatering Basin. Alternatively, the media may be placed on-site and revegetated.
6. Replace underdrain stone and piping if needed and thoroughly mix and place fresh treatment media. The existing system quantities are listed above and included on the As-Built Drawings (Appendix 3). New developments in water treatment technologies, as well as potential changes in water quality and flow should be evaluated prior to replacing the treatment media.

<u>Settling Pond 3 (SP3)</u>
The capacity of SP3 is calculated from the pond bottom to emergency spillway crest elevations shown on the as-built drawing (Appendix 3). The water volume of SP3 is approximately 10,900 cubic yards or 2,200,000 gallons.

Routine inspections should take place to check for erosion of the embankment and spillway. Any erosion shall immediately be graded as needed and stabilized utilizing seed and mulch, in cases of excessive erosion due to flooding or vandalism, erosion control fabric may be needed.

The primary SP3 outlet is the 12-inch SCH40 PVC pipe exiting the system and leading to Oven Run. A tee is dry fit to the inlet of this pipe to help prevent debris from entering the pipe. If the 12-inch opening is obstructed, water will rise and exit SP3 via the rock-lined emergency spillway.

During the life of the System, it is possible that SP3 will become filled to a level that no longer allows sufficient retention time for effective settling of precipitates. This will be indicated by elevated levels of suspended solids (≥35 mg/L TSS) discharges at ORBO when flows are at or below the maximum design (367 gpm). When this occurs, SP3 will need to be cleaned. Sludge removal may be accomplished by pumping or excavating sludge as needed and placing the material into the Dewatering Basin. Care should be taken to avoid damaging the synthetic liner that was installed when the original system.

pH Meter 2 (ORBO pH)
To help monitor the overall performance of the Oven Run B Passive Treatment System, a pH meter has been installed in the outlet pipe that is connected to the telemetry system and can be monitored through the Banner CDS website. (See Telemetry System Parts 1 & 2) If the pH drops below 6.3 when the inflow is below the maximum design of 367 gpm, performance issues should be assumed and a full site inspection conducted to assess the problem and determine steps required to restore system performance. It should be noted that if the Holding Pond primary outlet (18-inch PVC pipe with bar guard affixed to inlet) becomes obstructed, raw water may enter SP3 and cause the effluent pH to drop precipitously. The pH sensor (probe) is inserted through the top of the 12-inch PVC SP3 outlet pipe and may be removed by loosening the compression fitting using a wrench. Once the sensor is removed, it may be cleaned and calibrated. Please see the pH Meter Calibration Procedure section.

Dewatering Basin
To facilitate the removal of accumulated precipitates from the settling ponds and AFVFPs, and the eventual removal of spent limestone from the AFVFPs and spent treatment media from JVFPs, a Dewatering Basin was installed in a portion of the original SAPS #1 pond. The Dewatering Basin has approximately 4,800 CY of available storage that could be used to place material removed from the various components. Two rock drains outlet to the Dewatering Basin. The DB has an outlet comprised of perforated drain pipe bedded in aggregate situated in the pond bottom and a perforated riser. The perforated riser and drain pipe are attached to an 8-inch SCH40 PVC pipe that drains to Settling Pond 1 (SP1). An 8-inch Valterra valve is situated on the outside embankment of the DB that allows the pond to remain normally dewatered and that can be shut as needed during pumping operations.

The Dewatering Basin maintenance should be minimal and consist of mostly visual checks for erosion and debris accumulation around the perforated riser. Visual inspection should be done whenever on site and any erosion within this zone should be immediately addressed. The valve should be exercised at least once per year. The Dewatering Basin has an emergency spillway that leads to AFVFP1 should future use fill the basin and clog the drain pipe.

Telemetry System Part 2 (Flow and pH)
The first pH measurement device is in the outlet of the 12-inch SCH40 PVC pipe of SP2 into the Two-Way Flow Splitter (ORBSP2 pH). The second measurement device is in the outlet of the 12-inch SCH40 PVC pipe of SP3 (ORBO pH). Both pH probes are an Electro-Chemical Devices model S80-00-00-01-0-400-0010 pH probe. A flow measurement device is positioned in a stilling well at the outlet of the H-Flume. The flow meter is a Siemens ultra-sonic transducer (water level sensor) and controller (meter).

Each instrument and the control box are powered by a solar panel mounted on a steel pole adjacent to the instrument. The readings are then wirelessly transmitted to the Telemetry System Box in the Three-Way Flow

Splitter. The calibration process is attached inside the control box located at each pH meter. Along with calibration, each probe should be removed from the holstering and cleaned with a soft brush to remove solids from the probe. Water from the system should be used or standardized 4 pH solution should be used to preserve the electrodes on the pH probes. Distilled or deionized (DI) water should *not* be used to clean the pH sensors.

Baffle Curtains

Baffle curtains are installed within each settling pond. The baffle curtains extend to a depth of three feet and are anchored to 3-inch SCH40 steel pipes using stainless steel cable at an elevation approximately equal to the crest elevation of the emergency spillway. The curtains in both SP1 and in SP3 are directional baffle curtains intended to direct flow in a circuitous route to extend effective retention time. The SP2 baffle curtain is a windowed baffle curtain intended to spread flow across the entire width of the pond and encourage solids to settle. The curtains should be kept clear of heavy debris that could restrict flow through the windows of the baffle curtain or from debris that could damage either kind of baffle curtain. Any damage should be immediately repaired, and the baffle curtain should be reset at its original location. Curtains are expected to have a 10+ year lifespan and should be replaced when deterioration is sufficient to inhibit proper function.

Diversion Ditches

Diversion ditches route surface runoff away from the System and access road. Ditches should be inspected annually to ensure drainage is directed as shown on the as-built drawing and there is no excessive erosion. Ditches should also be monitored to ensure vegetation or sediment built-up does not back up the water and cause the flow to leave the drainage ditch. Repair ditches and stabilize with equivalent or better channel lining as needed, and remove vegetation and sediment as needed.

O&M Schedule

Weekly (To be performed remotely) – Estimated time to complete: < 5 minutes

- Log into Banner CDS website
  - Check flow at ORBI
    - Average design flow 158 gpm = ~0.45 feet
    - Maximum design flow 367 gpm = ~0.66 feet
  - Verify that both the Fill and Flush valves are working
    - Review water elevations at AFVFP1, 2, & 3 (ORBAF 1, 2, 3)
      - Max water elevation (left axis) should be ≤1941.0
  - Check effectiveness of AFVFPs
    - pH at SP2 ≥ 5.0 (ORBSP2 pH) at Two-Way Flow Splitter
  - Check system effluent
    - pH at SP3 >6.3 (ORBO pH) at SP3
- Schedule a site visit to address any issues if needed.

Monthly (Frequency may be reduced based on system performance and long-term telemetry equipment function)

- Measure and record flow at the flume (ORBI)
- Visual inspection of all components, road, gate, ditches, etc.
- Inspect bar guards at HP, SP1, and SP2, and clean as needed
- Check pH and alkalinity at SP3 outlet
  - pH should always be >6.3 and alkalinity >20 mg/L except when total in flow is in excess of 367 gpm
- Check pH and alkalinity at Two-Way Flow Splitter
  - pH should be ≥5
- Verify that the Smart Drain Systems are functioning as designed.
- Clean and calibrate pH meters at SP2 (Two-Way Flow Splitter) and SP3 (System outlet)
  - During system start-up, upward pH drift was noted between calibration events
- Upload all monitoring data to www.datashed.org

Annually

- Clean and grease stoplogs in all Agri Drain boxes
- At a minimum, during typical high-flow (February – May) collect samples for laboratory analysis at:
  - ORBI, DB, NRD, SRD, JRD, SP2, and SP3 (See Appendix 3, Sheet 1 for sample point locations)
    - Parameters: pH, conductivity, "hot" acidity, alkalinity, iron, aluminum, manganese
    - Measure flow at ORBI, DB, NRD, and SRD, and JRD
    - Upload all monitoring data to www.datashed.org
    - Evaluate total acid load removal
      - Acid load (lb/day) = Flow (gpm) x Concentration (mg/L) x 0.01202 (conversion factor)
      - Measure influent acid load ($Acid_{IN}$): ORBI+RD1+DB+NRD+SRD (inflows)
      - Estimate effluent acid load ($Acid_{OUT}$): Acid at SP3 (ORBO) x Sum of Inflow Flows
        - Effluent acid load should be negative
      - Subtract acid load out from acid load: $Acid_{IN}$ – $Acid_{OUT}$ = Total Acid Load Treated
        - Subtracting negative acid load accounts for excess alkalinity added to Oven Run
- Exercise all valves (fully shut or open as appropriate and return to normal operating position)
  - Dewatering Basin (1X)
  - Jennings-type Vertical Flow Ponds (JVFP1 & JVFP2) (8X)
  - Jennings Rock Drain (1X)
- Verify pH sensor accuracy and replace if needed

As Needed

- Clean stone in AFVFP1, AFVFP2, and AFVFP3
- Draining and stirring treatment media in JVFPs
- Removal and disposal of sediment from SP1, SP2, and SP3 into Dewatering Basin
- Remove vegetation from spillways, channels, pipes, embankments, etc. as needed
- General site maintenance of roads/parking areas, diversion ditch, vegetation, etc.
- Repair/replace sensors and related telemetry equipment
- Replace batteries and other solar-power equipment

AFVFP Smart Drain Programming Instructions

(The following instructions were provided by Agri Drain, Adair, Iowa)
Further information is found in Appendix 2 *(Agri Drain Smart Drainage System Operator's Manual).

General

- You can scroll through the options using the UP and DOWN arrows on the front of the controller (a/k/a "radio").
- You can select an option by pressing the ENTER button.
- You can return to the previous screen by pressing the BACK button.
- Whenever you see a GREEN LED light appear on the right side of the controller, that means that the controller is processing information (updating values, checking if it should open/close the valve, etc.).
- The controller only checks for changes once every minute or so. This means that if you change settings in the registers, such as telling the valve to open, it may take up to a minute before you see the valve open.
- All time settings are based on the clock in the upper right-hand corner of the controller's screen. This clock is in Coordinated Universal Time (UTC) and is five hours ahead of eastern standard time (winter) and four hours ahead of eastern daylight time (summer). Please be sure to keep this in mind when dealing with time settings.
- The only useable values are 1 and 0 except for time durations. All other values are invalid and may offer contradicting information between the system and the user. **Check to verify all setting are either a 1 (ON) or 0 (OFF).**

Registers

- ManualMode (ON/OFF)
  - While ON, the user can open/close the valve by setting the ValveStatus to 1/0 respectively
  - While ON, the controller will ignore any scheduled open/close times
  - While ON, a RED LED light will appear on the right side of the controller
  - While OFF, the RED LED will not be visible
  - 1 = ON, 0 = OFF
- ValveStatus
  - Displays the current status of the valve
  - While ManualMode is enabled, changing the valve status between 1/0 will open/close the valve, respectively
  - While OPEN, an ORANGE LED light will appear on the right side of the controller
  - While CLOSED, the ORANGE LED will not be visible
  - 1 = OPEN, 0 = CLOSED
- Days of the Week (ON/OFF)
  - Set which days of the week the valve should open on
  - When set to ON, the valve will open at the specified StartHour and StartMinute and remain open for the specified Duration
  - When set to OFF, the valve will not open on that specific day of the week
  - 1 = ON, 0 = OFF
- Duration (minutes): The amount of time the valve will stay open for
- StartHour: The hour portion of the time you wish the valve to open
  - NOTE: This is based on the time displayed in the upper right-hand corner of the radio
- StartMinutes: The minute portion of the time you wish the valve to open
  - NOTE: This is based on the time displayed in the upper right-hand corner of the radio
- Battery: The current battery voltage
- Solar: The current voltage from the solar panel

Examples

I want to open the valve right now.

1. Set ManualMode = 1 (ON)
2. Set ValveStatus = 1

I want the valve to be open every Monday, Wednesday, and Friday at 5:30pm for 2 hours.

1. Make sure ManualMode = (0) OFF
2. Set Sunday = (0) OFF, Tuesday = (0) OFF, Thursday = (0) OFF, Saturday = (0) OFF
3. Set Monday = (1) ON, Wednesday = (1) ON, Friday = (1) ON
4. Set Duration = 120
5. Set StartHour = 17
6. Set StartMinutes = 30

pH Calibration Procedure

(The following instructions are taken from Electro-Chemical Devices documents included in Appendix 2)

Remove the pH sensor (probe) from the housing as described in previous section. Use a soft brush to gently clean the probe. Water at the point of monitoring may be used for cleaning purposes. Distilled or deionized (DI) water should NOT be used.

Calibration Example for pH 7 and 4:

Action	Prompt
Double Press any Button	Menu Home, Hold is OFF
Press Hold	Hold freezes 4-20 mA and locks alarms during Calibration
Press Cal (Calibrate)	Is this a new sensor (Yes erases Cal Log In info, No adds to exiting Log)
Press No	Place sensor in Cal solution (use pH 7 buffer)
Press Auto then Cal 1	Stabilizing, 7.00 pH, 7 pH corrected Accept Cal 1?
Press Yes	Cal 1 value 7.00 pH, continue to Cal 2? Move senor to 4.01 pH solution.
Press Yes	Stabilizing, 4.00 pH, 4.00 pH corrected Accept Cal?
Press Yes	Offset: 7.00 pH, Slope: -59.16 mV/pH (Data written to Log)
Press Ok	Calibration Complete
Press Home	Hold is On
Press Hold	Turn Off Hold
Press Exit	Main Display

If communication between the DXM and the pH Meter “flatline” breakers should be flipped and reset at the control box at the pH meter location and communication should be reestablished.

APPENDIX 1

1.5-Foot H-Flume Lookup Table

APPENDIX 2

Equipment Manuals

APPENDIX 3

As-Built Plans

APPENDIX 1

1.5-Foot H-Flume Lookup Table

OPENCHANNELFLOW

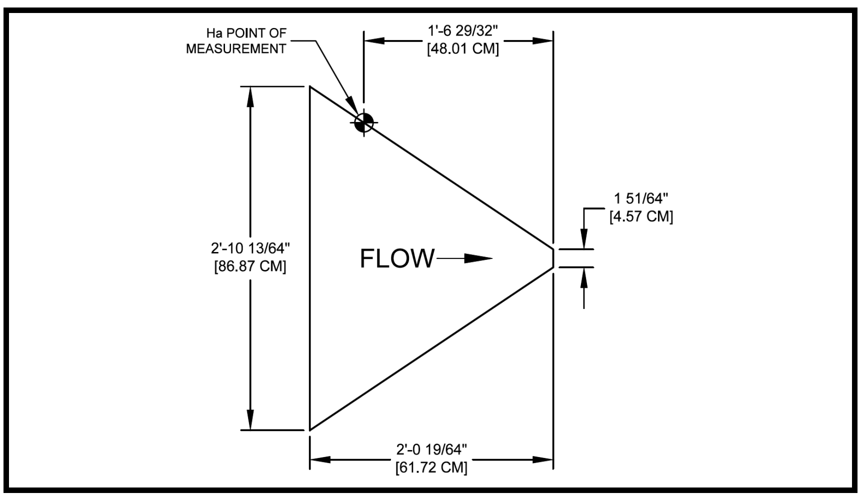
1.5-Foot H Flume Discharge Table

25-30% Submergence Transition ±2-5% Accuracy

Formulas (H in feet): CFS = $-0.00014 - 0.00141\ H_{ft.}^{0.5} + 0.474778\ H_{ft.}^{1.5} + 1.63086\ H_{ft.}^{2.5}$

Formulas (H in meters): L/S = $-0.00396436 - 0.07231968\ H_m^{0.5} + 79.89379128\ H_m^{1.5} + 900.3765227\ H_m^{2.5}$

FEET	INCHES	METERS	CFS	GPM	MGD	L/S	M3/HR
0.01	0.12	0.0030	Excessive error due to fluid-flow properties and boundary conditions				
0.02	0.24	0.0061	0.0011	0.4937	0.0007	0.0312	0.1121
0.03	0.36	0.0091	0.0023	1.032	0.0015	0.0651	0.2344
0.04	0.48	0.0122	0.0039	1.750	0.0025	0.1104	0.3974
0.05	0.60	0.0152	0.0057	2.558	0.0037	0.1614	0.5808
0.06	0.72	0.0183	0.0078	3.501	0.0050	0.2209	0.7948
0.07	0.84	0.0213	0.0103	4.623	0.0067	0.2917	1.050
0.08	0.96	0.0244	0.0131	5.879	0.0085	0.3710	1.335
0.09	1.08	0.0274	0.0164	7.360	0.0106	0.4644	1.671
0.10	1.20	0.0305	0.0200	8.976	0.0129	0.5664	2.038
0.11	1.32	0.0335	0.0237	10.64	0.0153	0.6712	2.415
0.12	1.44	0.0366	0.0276	12.39	0.0178	0.7816	2.812
0.13	1.56	0.0396	0.0319	14.32	0.0206	0.9034	3.251
0.14	1.68	0.0427	0.0365	16.38	0.0236	1.034	3.719
0.15	1.80	0.0457	0.0414	18.58	0.0268	1.172	4.219
0.16	1.92	0.0488	0.0467	20.96	0.0302	1.323	4.759
0.17	2.04	0.0518	0.0523	23.47	0.0338	1.481	5.329
0.18	2.16	0.0549	0.0582	26.12	0.0376	1.648	5.931
0.19	2.28	0.0579	0.0645	28.95	0.0417	1.827	6.573
0.20	2.40	0.0610	0.0711	31.91	0.0460	2.014	7.245
0.21	2.52	0.0640	0.0780	35.01	0.0504	2.209	7.948
0.22	2.64	0.0671	0.0854	38.33	0.0552	2.419	8.702
0.23	2.76	0.0701	0.0931	41.78	0.0602	2.637	9.487
0.24	2.88	0.0732	0.1011	45.37	0.0653	2.863	10.30
0.25	3.00	0.0762	0.1095	49.14	0.0708	3.101	11.16
0.26	3.12	0.0792	0.1183	53.09	0.0765	3.350	12.05
0.27	3.24	0.0823	0.1275	57.22	0.0824	3.611	12.99
0.28	3.36	0.0853	0.1371	61.53	0.0886	3.883	13.97
0.29	3.48	0.0884	0.1470	65.97	0.0950	4.163	14.98
0.30	3.60	0.0914	0.157	70.46	0.1015	4.446	16.00



Notes: Curve fitted equation accurate to within 1.5%
Discharge is calculated to top of flume

Source: Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, U.S. Department of Agriculture, February 1972

OPENCHANNELFLOW

1.5-Foot H Flume Discharge Table

25-30% Submergence Transition ±2-5% Accuracy

Formulas (H in feet): CFS = $-0.00014 - 0.00141\ H_{ft.}^{0.5} + 0.474778\ H_{ft.}^{1.5} + 1.63086\ H_{ft.}^{2.5}$

Formulas (H in meters): L/S = $-0.00396436 - 0.07231968\ H_{m}^{0.5} + 79.89379128\ H_{m}^{1.5} + 900.3765227\ H_{m}^{2.5}$

FEET	INCHES	METERS	CFS	GPM	MGD	L/S	M3/HR
0.31	3.72	0.0945	0.168	75.40	0.1086	4.758	17.12
0.32	3.84	0.0975	0.179	80.34	0.1157	5.069	18.24
0.33	3.96	0.1006	0.191	85.72	0.1234	5.409	19.46
0.34	4.08	0.1036	0.203	91.11	0.1312	5.749	20.69
0.35	4.20	0.1067	0.215	96.49	0.1390	6.089	21.91
0.36	4.32	0.1097	0.228	102.3	0.1474	6.457	23.23
0.37	4.44	0.1128	0.241	108.2	0.1558	6.825	24.56
0.38	4.56	0.1158	0.255	114.4	0.1648	7.222	25.98
0.39	4.68	0.1189	0.269	120.7	0.1739	7.618	27.41
0.40	4.80	0.1219	0.283	127.0	0.1829	8.015	28.84
0.41	4.92	0.1250	0.298	133.7	0.1926	8.439	30.37
0.42	5.04	0.1280	0.314	140.9	0.2029	8.892	32.00
0.43	5.16	0.1311	0.330	148.1	0.2133	9.346	33.63
0.44	5.28	0.1341	0.346	155.3	0.2236	9.799	35.26
0.45	5.40	0.1372	0.363	162.9	0.2346	10.28	36.99
0.46	5.52	0.1402	0.380	170.5	0.2456	10.76	38.72
0.47	5.64	0.1433	0.398	178.6	0.2572	11.27	40.56
0.48	5.76	0.1463	0.416	186.7	0.2689	11.78	42.39
0.49	5.88	0.1494	0.435	195.2	0.2811	12.32	44.33
0.50	6.00	0.1524	0.454	203.8	0.2934	12.86	46.26
0.51	6.12	0.1554	0.473	212.3	0.3057	13.40	48.20
0.52	6.24	0.1585	0.493	221.3	0.3186	13.96	50.24
0.53	6.36	0.1615	0.514	230.7	0.3322	14.56	52.38
0.54	6.48	0.1646	0.535	240.1	0.3458	15.15	54.52
0.55	6.60	0.1676	0.557	250.0	0.3600	15.77	56.76
0.56	6.72	0.1707	0.579	259.9	0.3742	16.40	59.00
0.57	6.84	0.1737	0.601	269.7	0.3884	17.02	61.24
0.58	6.96	0.1768	0.624	280.1	0.4033	17.67	63.59
0.59	7.08	0.1798	0.648	290.8	0.4188	18.35	66.03
0.60	7.20	0.1829	0.672	301.6	0.4343	19.03	68.48
0.61	7.32	0.1859	0.697	312.8	0.4505	19.74	71.02
0.62	7.44	0.1890	0.722	324.0	0.4666	20.45	73.57
0.63	7.56	0.1920	0.747	335.3	0.4828	21.16	76.12
0.64	7.68	0.1951	0.773	346.9	0.4996	21.89	78.77
0.65	7.80	0.1981	0.800	359.0	0.5170	22.66	81.52
0.66	7.92	0.2012	0.827	371.2	0.5345	23.42	84.27
0.67	8.04	0.2042	0.855	383.7	0.5526	24.21	87.12
0.68	8.16	0.2073	0.883	396.3	0.5707	25.01	89.98
0.69	8.28	0.2103	0.912	409.3	0.5894	25.83	92.93
0.70	8.40	0.2134	0.942	422.8	0.6088	26.68	95.99
0.71	8.52	0.2164	0.972	436.2	0.6282	27.53	99.05
0.72	8.64	0.2195	1.002	449.7	0.6476	28.38	102.1
0.73	8.76	0.2225	1.033	463.6	0.6676	29.25	105.3
0.74	8.88	0.2256	1.065	478.0	0.6883	30.16	108.5
0.75	9.00	0.2286	1.097	492.3	0.7090	31.07	111.8
0.76	9.12	0.2316	1.130	507.1	0.7303	32.00	115.1
0.77	9.24	0.2347	1.163	522.0	0.7516	32.94	118.5
0.78	9.36	0.2377	1.197	537.2	0.7736	33.90	122.0
0.79	9.48	0.2408	1.231	552.5	0.7956	34.86	125.4
0.80	9.60	0.2438	1.27	570.0	0.8208	35.97	129.4

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OPENCHANNELFLOW

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Formulas (H in meters): L/S = $-0.00396436 - 0.07231968\ H_{m}^{0.5} + 79.89379128\ H_{m}^{1.5} + 900.3765227\ H_{m}^{2.5}$

FEET	INCHES	METERS	CFS	GPM	MGD	L/S	M3/HR
0.81	9.72	0.2469	1.30	583.4	0.8402	36.82	132.5
0.82	9.84	0.2499	1.34	601.4	0.8660	37.95	136.5
0.83	9.96	0.2530	1.38	619.3	0.8919	39.08	140.6
0.84	10.08	0.2560	1.41	632.8	0.9113	39.93	143.7
0.85	10.20	0.2591	1.45	650.8	0.9371	41.06	147.8
0.86	10.32	0.2621	1.49	668.7	0.9630	42.20	151.8
0.87	10.44	0.2652	1.53	686.7	0.9888	43.33	155.9
0.88	10.56	0.2682	1.57	704.6	1.015	44.46	160.0
0.89	10.68	0.2713	1.61	722.6	1.041	45.60	164.1
0.90	10.80	0.2743	1.65	740.5	1.066	46.73	168.1
0.91	10.92	0.2774	1.69	758.5	1.092	47.86	172.2
0.92	11.04	0.2804	1.73	776.4	1.118	48.99	176.3
0.93	11.16	0.2835	1.78	798.9	1.150	50.41	181.4
0.94	11.28	0.2865	1.82	816.8	1.176	51.54	185.5
0.95	11.40	0.2896	1.86	834.8	1.202	52.68	189.5
0.96	11.52	0.2926	1.91	857.2	1.234	54.09	194.6
0.97	11.64	0.2957	1.95	875.2	1.260	55.22	198.7
0.98	11.76	0.2987	2.00	897.6	1.293	56.64	203.8
0.99	11.88	0.3018	2.05	920.0	1.325	58.06	208.9
1.00	12.00	0.3048	2.09	938.0	1.351	59.19	213.0
1.01	12.12	0.3078	2.14	960.4	1.383	60.60	218.1
1.02	12.24	0.3109	2.19	982.9	1.415	62.02	223.2
1.03	12.36	0.3139	2.24	1005	1.448	63.44	228.3
1.04	12.48	0.3170	2.30	1032	1.486	65.14	234.4
1.05	12.60	0.3200	2.35	1055	1.519	66.55	239.5
1.06	12.72	0.3231	2.40	1077	1.551	67.97	244.6
1.07	12.84	0.3261	2.45	1100	1.583	69.38	249.7
1.08	12.96	0.3292	2.50	1122	1.616	70.80	254.8
1.09	13.08	0.3322	2.56	1149	1.655	72.50	260.9
1.10	13.20	0.3353	2.61	1171	1.687	73.92	266.0
1.11	13.32	0.3383	2.67	1198	1.726	75.61	272.1
1.12	13.44	0.3414	2.73	1225	1.764	77.31	278.2
1.13	13.56	0.3444	2.78	1248	1.797	78.73	283.3
1.14	13.68	0.3475	2.84	1275	1.835	80.43	289.4
1.15	13.80	0.3505	2.90	1302	1.874	82.13	295.5
1.16	13.92	0.3536	2.96	1328	1.913	83.83	301.6
1.17	14.04	0.3566	3.02	1355	1.952	85.53	307.7
1.18	14.16	0.3597	3.08	1382	1.991	87.23	313.9
1.19	14.28	0.3627	3.14	1409	2.029	88.92	320.0
1.20	14.40	0.3658	3.20	1436	2.068	90.62	326.1
1.21	14.52	0.3688	3.27	1468	2.113	92.61	333.2
1.22	14.64	0.3719	3.33	1495	2.152	94.31	339.3
1.23	14.76	0.3749	3.39	1521	2.191	96.00	345.4
1.24	14.88	0.3780	3.46	1553	2.236	97.99	352.6
1.25	15.00	0.3810	3.52	1580	2.275	99.69	358.7
1.26	15.12	0.3840	3.59	1611	2.320	101.7	365.8
1.27	15.24	0.3871	3.66	1643	2.365	103.7	373.0
1.28	15.36	0.3901	3.73	1674	2.411	105.6	380.1
1.29	15.48	0.3932	3.80	1705	2.456	107.6	387.2
1.30	15.60	0.3962	3.87	1737	2.501	109.6	394.4

Source: Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, U.S. Department of Agriculture, February 1972

OPENCHANNELFLOW

1.5-Foot H Flume Discharge Table

25-30% Submergence Transition ±2-5% Accuracy

Formulas (H in feet): $CFS = -0.00014 - 0.00141\ H_{ft.}^{0.5} + 0.474778\ H_{ft.}^{1.5} + 1.63086\ H_{ft.}^{2.5}$

Formulas (H in meters): $L/S = -0.00396436 - 0.07231968\ H_{m}^{0.5} + 79.89379128\ H_{m}^{1.5} + 900.3765227\ H_{m}^{2.5}$

FEET	INCHES	METERS	CFS	GPM	MGD	L/S	M3/HR
1.31	15.72	0.3993	3.94	1768	2.546	111.6	401.5
1.32	15.84	0.4023	4.01	1800	2.592	113.6	408.6
1.33	15.96	0.4054	4.08	1831	2.637	115.5	415.8
1.34	16.08	0.4084	4.15	1863	2.682	117.5	422.9
1.35	16.20	0.4115	4.22	1894	2.727	119.5	430.0
1.36	16.32	0.4145	4.30	1930	2.779	121.8	438.2
1.37	16.44	0.4176	4.37	1961	2.824	123.8	445.3
1.38	16.56	0.4206	4.45	1997	2.876	126.0	453.5
1.39	16.68	0.4237	4.52	2029	2.921	128.0	460.6
1.40	16.80	0.4267	4.60	2064	2.973	130.3	468.7
1.41	16.92	0.4298	4.68	2100	3.025	132.5	476.9
1.42	17.04	0.4328	4.76	2136	3.076	134.8	485.0
1.43	17.16	0.4359	4.84	2172	3.128	137.1	493.2
1.44	17.28	0.4389	4.92	2208	3.180	139.3	501.3
1.45	17.40	0.4420	5.00	2244	3.232	141.6	509.5
1.46	17.52	0.4450	5.08	2280	3.283	143.9	517.7
1.47	17.64	0.4481	5.16	2316	3.335	146.1	525.8
1.48	17.76	0.4511	5.24	2352	3.387	148.4	534.0
1.49	17.88	0.4542	5.33	2392	3.445	150.9	543.1

Source: Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, U.S. Department of Agriculture, February 1972