Micro-Hydroelectric Power Facility Using Mine Drainage

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Abstract: With a combined flow rate ranging from about 63 to 126 lps (1,000 to 2,000 gpm), the treated effluent and seasonal untreated overflow at a conventional mine water treatment plant are being used to generate electricity. Two micro-hydroelectric turbines, individually rated at 20 kW, were installed in 2012 at the Antrim Acid Mine Drainage Treatment Plant. The Babb Creek Watershed Association has operated the plant since 2001 and the onsite generation of electricity will defray operation and maintenance costs in order to help assure sustainable treatment. This is the first project in Pennsylvania to use treated and untreated AMD to generate electricity with impulse (Turgo) turbines. In addition to furnishing the power needs of selected treatment components at the plant, the intention is to connect to the local electric utility or "the grid". The complex terrain coupled with the utilization of both the treated effluent and seasonal untreated overflow created some unique design and construction challenges. This is a case study on the design, permitting, construction, and startup of a micro-hydroelectric power facility located in the bituminous coal fields of north-central Pennsylvania within the Susquehanna River Basin.

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INTRODUCTION

During the 20th century, medium-volatile bituminous coal was extensively mined in the North Central Coalfields of Tioga County in northern Pennsylvania. As a result, metal-laden, acidic mine drainage (AMD) from some of the historic surface and underground mining operations degraded the receiving streams. Over the past few decades, the Babb Creek Watershed Association (BCWA) has been able to successfully treat or mitigate many of these discharges (Barr 2004). The Antrim Acid Mine Drainage Treatment Plant (Plant), operated by the BCWA, is a conventional facility utilizing waste lime as an alkaline reagent to treat some of the most pollutive AMD in the watershed. The Plant is located within the town of Antrim, Duncan Township, Tioga County (Figure 1). The Pennsylvania Department of Environmental Protection (PADEP) oversees the operation and maintenance of the Plant.

There are two sources of AMD conveyed to a collection pond, which feeds the Plant. Both discharges issue from abandoned underground mines. A drainage ditch conveys discharge BI-14, which is located within the town of Antrim, and a 6-inch gravity pipeline conveys discharge BI-16 (Backswitch Discharge), which is located 1.6 km (1 mile) from the Plant. The combined flow rate ranges between 32-252 lps (500-4,000 gpm) and averages 95 lps (1,500 gpm). The Backswitch Discharge has considerable less flow, 5.7 lps (90 gpm), but the water is more significantly degraded. Table 1 provides the median water quality data for both of the discharges and the treatment Plant effluent (009). From the collection pond, the combined discharges are conveyed to and through the Plant via a 30-cm (12-in.) PVC pipe (Main Line). A 30-cm (12-in.) valve within the Main Line controls the flow to the Plant. Waste lime is pulverized by two ball mills to create lime slurry that is injected into the Main Line. The raw water and slurry are mixed in a static mixer, before being conveyed to an 18-m (60-ft.) clarifier. The treated water is decanted from the clarifier and is then conveyed via a 41-cm (16-in.) PVC pipe to a 1.8-m (6-ft.) diameter outlet structure, which in turn discharges to an unnamed tributary to Bridge Run. During seasonal high-flow periods, the Plant is unable to treat the entirety of the AMD and the excess untreated water discharges from the collection pond directly into the unnamed tributary. During these periods, additional lime slurry is injected into the Plant effluent in order to provide excess alkalinity to treat the by-passed raw water in-stream.

In 2008, due to an economic downturn, the sustainability of the trust fund that supplied the funding for the operation and maintenance for the Plant was in question. To offset operation and maintenance costs and potentially generate revenue, BCWA working with the PADEP considered building a micro-hydropower facility. BCWA then applied for, and was awarded, a $430,000 Energy Harvest Grant in 2009 to fund the project. BioMost, Inc. was selected to design and to install the micro-hydropower facility.

The design considerations for the Antrim Micro-Hydropower Project (AMHP) included: (1) utilization of both the treated AMD and the periodic raw water overflow, (2) maximum utilization of the available change in elevation at the site, (3) protection of vital parts of the turbines from potentially aggressive water, (4) management of potential scaling issues in the penstock, and (5) installation of facilities to enable the sale of excess electricity to the local utility.

Table 1. BI-16, BI-14, 009 Water Quality (median values)

Location (collection period)	**Flow** cfs (gpm)	**pH** s.u.	**Alkalinity** mg/l	**Acidity** mg/l	**Iron** mg/l	**Manganese** mg/l	**Aluminum** mg/l	**Sulfate** mg/l
BI-16 (n=16) (1993-2008)	126 (2,000)	3.00	0	208	6.3	8.3	17.5	414
BI-14 (n=14) (1992-2008)	5.7 (90)	3.10	0	248	25.7	23.5	16.4	720
009 (n=197) (1996-2006)	114 (1,800)	8.85	66	0	0.3	3.6	0.8	675

BI-16 Antrim Discharge; BI-14 Backswitch Discharge; 009 Antrim Acid Mine Drainage Treatment Plant Discharge; Total metals; *source - Babb Creek Watershed Association*

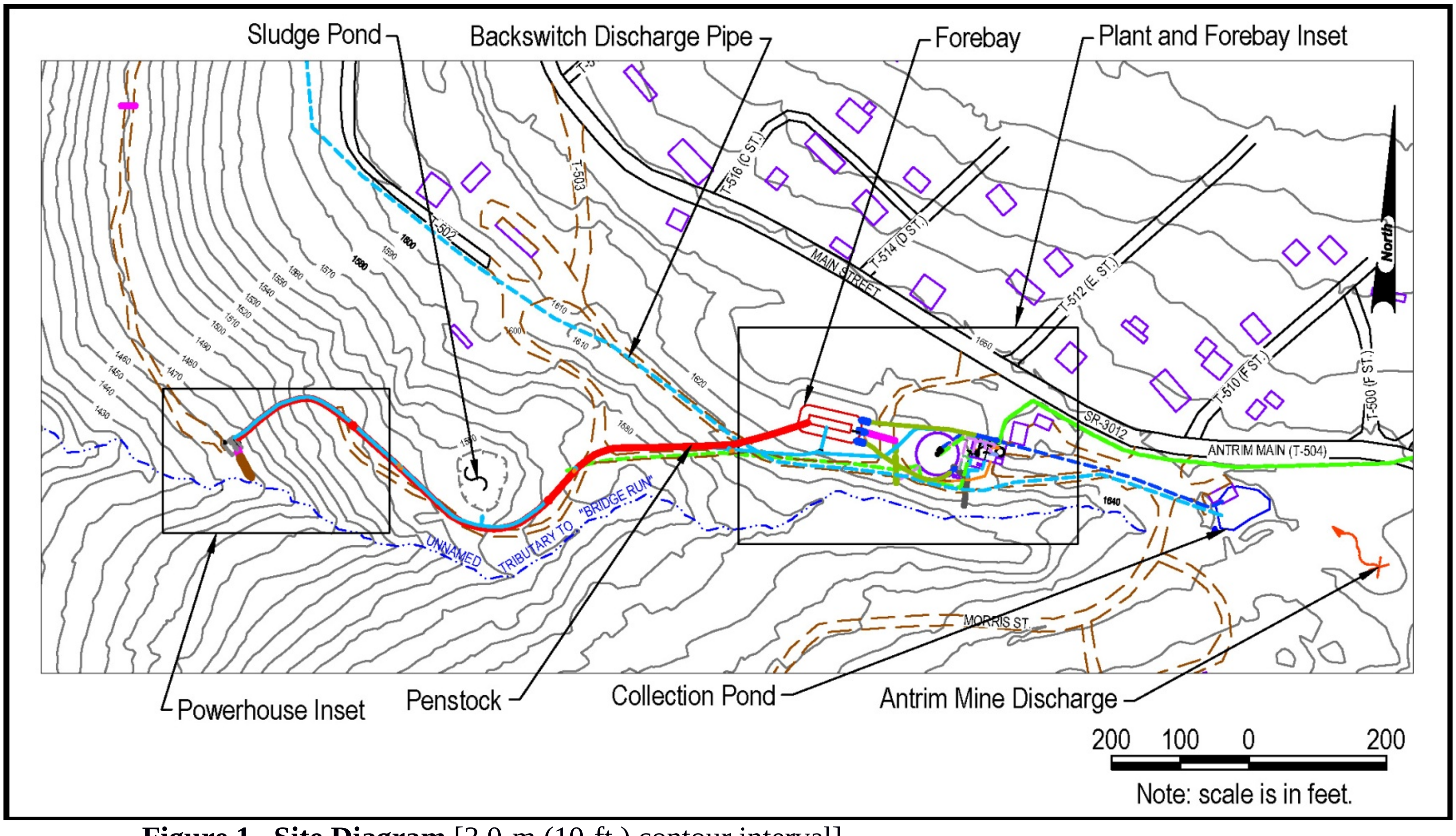

Figure 1. Site Diagram [3.0-m (10-ft.) contour interval]

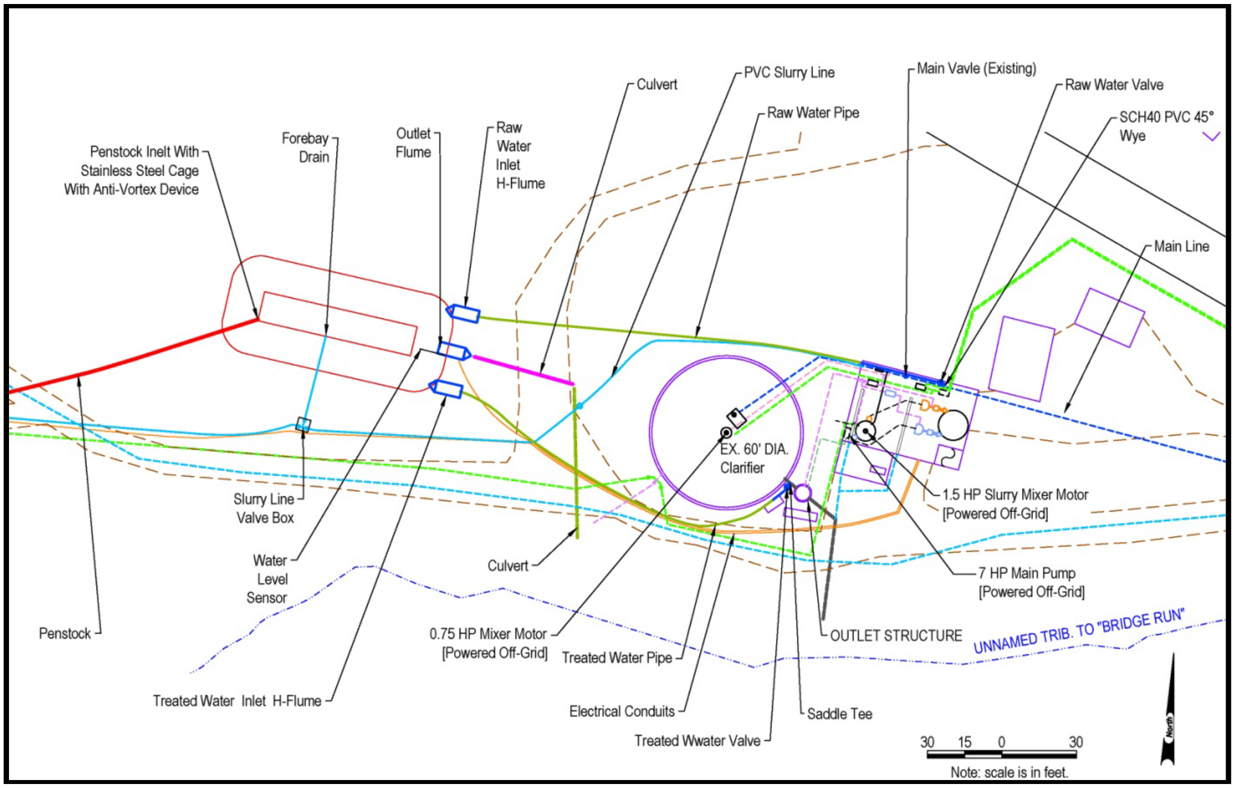

Figure 2. Plant and Forebay Inset

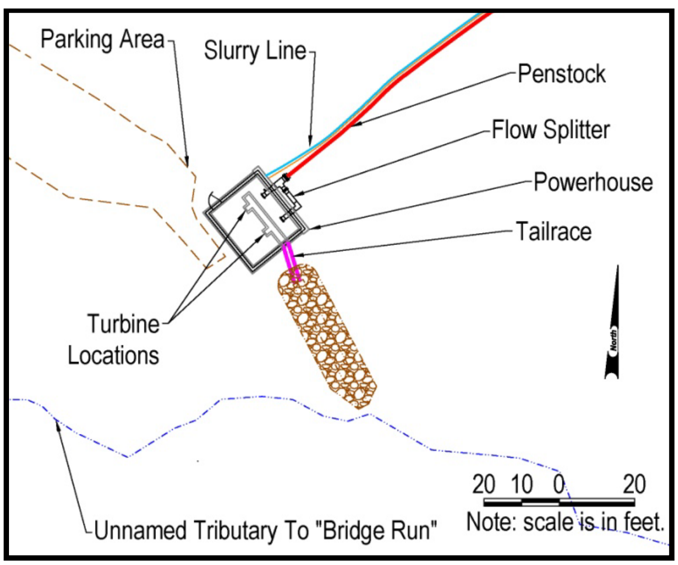

Figure 3. Powerhouse Inset

FEDERAL ENERGY REGULATORY COMMISSION APPROVAL

In addition to state and local permits and notifications relating to earth disturbance and building construction, one of the design criteria for the AMHP was for the facility to be connected to the local utility company (grid) in order to sell the excess energy generated by the turbines. Connecting to the grid, however, is considered to be affecting foreign and interstate commerce; therefore, the AMHP falls under the jurisdiction of the Federal Energy Regulatory Commission (FERC) (16 USC 817, 2012). To obtain FERC approval, there are three licensing tracks and two exemption tracks (exemptions considered licenses) (FERC 2004). If a project does not connect to the grid, the project does not fall under the jurisdiction of FERC, but a Declaration of Intent (DI) must be completed and approved to confirm that the project does not need to obtain a license (18 CFR 24.1, 2012).

The three licensing tracks are Traditional, Integrated and Alternative. All licensing tracks have a time-line that, on average, are approximately two years or longer, which extended beyond the Energy Harvest Grant period. The two exemption tracks are the 5MW and Conduit. The time-lines for the exemptions are similar to the regular licensing tracks, but with elimination of certain sections. The time-lines of the Conduit and 5MW Exemption tracks are less than one year and about a year, respectively (FERC 2004). The Conduit Exemption was not applicable for the AMHP, and, even with the shortened time-line for the 5MW Exemption, the time needed to obtain the approval and construct the AMHP exceeded the grant period.

To ensure that the project was going to be built within the required grant period, the decision was made for the AMHP to be an off-grid facility until FERC approval is received. The off-grid configuration required completion of a DI, with an average approval time-line of about two to three months. This allowed for a longer construction period for the AMHP. In the design change, select motors in the Plant that run continuously were to be segregated from the grid and powered solely by electricity generated by the AMHP.

CONSTRUCTION

In the context of this paper, the construction phase, which was completed in the spring of 2012, is divided into different sections, which are not chronologically ordered. The different sections are the Plant, Forebay, Penstock and Powerhouse.

Plant

To utilize the maximum flow rate, as feasible, two pipes were extended from existing facilities to direct both the treated and untreated water to the forebay.

Treated Water

To redirect the treated water to the forebay, a connection to the existing pipeline between the clarifier and outlet structure was installed. (Refer to Figure 2.) The added plumbing consists of a 41-cm x 30-cm (16-in. x 12-in.) saddle tee, 30-cm (12-in.) knife-gate valve (Treated Water Valve), and 30-cm (12-in.) pipe (portions SCH40 PVC and DR32.5 HDPE). The Treated Water Valve in the open position directs the water to the forebay and, in the closed position the water is directed to the outlet structure for discharge through the pre-existing effluent piping. The added plumbing was also installed in a manner to maintain the water level within the outlet structure as a small portion of the treated water is continuously transferred by means of a 7 hp pump (Main Water Pump) to the Plant for use as process water.

Raw Water

In order to utilize the majority, if not all, of the excess raw AMD during high-flow periods, a 30-cm (12-in.) 45° wye was connected to the existing Main Line above the valve that controls the flow to the Plant. A 30-cm (12-in.) stainless steel gate valve (Raw Water Valve) was installed in the piping (Raw Water Pipe) that was extended from the wye to the forebay. The configuration of the added plumbing allowed excess raw water to be directed to the forebay without affecting the functionality of the Plant. Portions of the Raw Water Pipe are SCH40 PVC and DR32.5 HDPE. When the Raw Water Valve is closed, overflow water will discharge from collection pond spillway.

Forebay

A forebay was installed in order to utilize both the treated water and the periodically bypassed raw water. The forebay for the AMHP is a 12-m x 28-m (40-ft. x 91-ft.) pond, 2.1-m (7-ft) in depth, that stabilizes and controls the flow of water before entering the penstock. The Raw Water Pipe discharges in the northeast corner and the Treated Water Pipe discharges in the southwest corner of the forebay. The overflow outlet of the forebay is located between the inlets from the Plant. To measure the flow entering the penstock, the forebay inlets and the outlet include 0.6-m (2.0-ft.) H-flumes with 117-cm x 122-cm x 305-cm (46-in. x 48-in. x 120-in.) concrete approach channels. Any flow in the forebay outlet can be subtracted from the combined inlet flows in order to calculate the flow rate into the penstock. The inlet for the penstock in the southeast corner of the forebay is protected with a trash rack/anti-vortex device. The custom-fabricated, 304 stainless steel, trash rack/anti-vortex device is a cubic cage topped with a 2.67-mm x 305-mm x 457-mm (0.105-in. x 12-in. x 18-in.) 304 stainless steel plate designed to prevent objects >15 cm (6 in.) from entering the penstock and to prevent the penstock from drawing air via a vortex.

Penstock and Other Pipe/Conduits

Penstock

A penstock over 335 m (1,100 ft.) in length was installed in order to utilize the 49-m (160-ft.) change in elevation. The penstock conveys water, under pressure, from the forebay to the turbines. For discussion purposes, the penstock is divided into five sections: inlet, upper, middle, lower and flow splitter. The inlet section of SDR35 PVC pipe extends from the forebay to the beginning of the HDPE pipe. The SDR35 PVC inlet section connects to the DR26 upper section of the penstock with a 46-cm (18-in.) flexible coupler. Flange connections join the upper section with the middle and lower sections, DR17 HDPE and DR11 HDPE, respectively. A flange connection is also used to join the lower section of the penstock to the DR11 HDPE flow splitter immediately upgradient of the powerhouse.

Electrical

A 10-cm (4.0-in.) electrical conduit was used to house the four, 4/0-gauge, aluminum wires that extend from the powerhouse to the Plant. The four wires convey electricity generated by the turbines to the Plant. Three #4 and one #2 THHN copper wires from the Plant convey high-voltage power from the grid to the powerhouse for the lights, controls and other electrical components. A 2.5-cm (1.0-in.) electrical conduit houses shielded, twisted-pair, communication wire from the water level sensor control box in the Plant to the water level remote display in the powerhouse. Electrical risers with above-grade junction boxes, installed along the conduits, allowed the wire to be pulled through the sections. A separate 2.5-cm (1-in.) electrical conduit houses coaxial communication wire that runs from the water level sensor to the water level sensor control box located in the control room of the Plant.

Slurry Line (Acid Recirculation Line/Forebay Drain)
The slurry line was installed to serve the following three main functions: 1) to enable supplemental water treatment in the tailrace at the powerhouse; 2) to enable acid-washing of the penstock; and 3) to enable the forebay to be drained to the sludge pond. For simplicity, this pipe and related connections are referred to as the slurry line. There are 15-cm (6-in.) PVC cleanouts with threaded caps located approximately every 91 m (300 ft.) along the length of the slurry line.

The primary function of the pressure-rated, 15-cm (6-in.), SCH40 PVC slurry line is to allow lime slurry from the Plant to be dispensed into the combined untreated and treated AMD in order to provide supplemental alkalinity after power generation in the tailrace prior to entering the receiving stream. The utilization of the lime slurry for supplemental treatment was selected, in part, due to the pre-existing availability from the Plant. Within the powerhouse the slurry line is extended to the tailrace by installation of a 7-cm (3-in.) PVC pipe with ball valve. Note that if lime slurry were added at the forebay, the non-reactive material (grit) in the lime slurry may have accumulated in the forebay and been conveyed through the penstock which would have resulted in damage to the turbines.

The slurry line can also be used to drain the forebay or to acid-wash the penstock. A 15-cm (6-in.) perforated riser and solid lateral, connected to the slurry line by a 15-cm (6-in.) knife gate valve, allows the water from the forebay to drain to either an existing sludge pond via a 7-cm (3-in.) PVC ball valve or to the tailrace. If needed to remove scale, acid can be circulated within the slurry line and penstock via a 5-cm (2-in.) PVC pipe with ball valve installed in the powerhouse.

Powerhouse

The powerhouse is the building the where turbines, electrical equipment and other components are located. The features discussed in this section are the penstock flow splitter, powerhouse penstock components, turbines, overspeed controllers, and tailrace.

Penstock Flow Splitter
The penstock flow splitter (PFS) is comprised of 46-cm & 30-cm (18-in. & 12-in.) HDPE piping that splits the flow to the two turbines. The main section of the penstock is connected to the PFS immediately upgradient of the powerhouse with a flange connection. The PFS includes an 46-cm x 46-cm x 30-cm (18-in. x 18-in. x 12-in.) reducing tee with a 46-cm x 30-cm (18-in. x 12-in.) reducer on the primary leg. The 30-cm (12-in.) HDPE pipes extend through a 0.6-m (2-ft.) thick, steel reinforced concrete wall. A 45° bend in each leg of the PFS, cast into the concrete

wall, helps the wall to act as a thrust block for the PFS.

Powerhouse Penstock Components

Each turbine has the same components. From the PFS, there is a 30-cm x 20-cm (12-in. x 8-in.) reducer followed by a 20-cm (8-in.) butterfly-type shutoff valve. This valve is for shutoff purposes only and not intended to control the quantity of flow to the turbine. A 20-cm (8-in.) expansion joint is located between the butterfly valve and the Turbine Flow Splitter (TFS). A TFS is installed downstream of the expansion joint and directs the flow to the two spear valves. A pressure gage with a range of 0.0 - 0.6 MPa (0 - 87 psi) is located on the TFS.

Figure 4. A portion of the powerhouse penstock components

Turbines

The impulse, Turgo-type, turbines (Figure 5) installed are designed to operate at 1,800 rpm and generate 240v at 60 Hz using approximately 16 to 57 lps (250 to 900 gpm). Due to the possible aggressive nature of the water, turbine components in contact with water were coated with high phosphorus, electroless nickel (EN), plating. The EN plating is approximately 2 to 3 mils thick and provides a high level of corrosion and abrasion resistance. Each turbine has dual adjustable spear valve nozzles. These spear valve-type nozzles provide precise flow control and allow the operator to adjust the amount of generated power provided to the off-grid components in the Plant. The water flows through the nozzles directed at the runner causing the runner to rotate. The runner is attached to the generator shaft, which when the runner is turning, the generator produces electricity. Each turbine has a three-phase 138V/240V 20 kW (appx. 27 hp) generator.

Figure 5. Installed turbines

Overspeed Controllers

Each turbine has an overspeed control that uses a 420 VME-D-2 Bender Relay that activates mechanical contacts connected to the dump loads (electric heaters submerged in the tailrace). If the rpms for a turbine runner increases, the voltage and frequency (Hertz) increases, which causes the dump loads to engage. The engaged dump loads increase the electrical demand, which slows the generator. The relay, programmed to automatically check the voltage and frequency, disengages the dump loads once the voltage and frequency fall within the specified range. The overspeed control protects the turbine from spinning too fast and prevents over-generation of electricity. Excessive voltage can damage the electric motors in the Plant.

Tailrace

The tailrace is used to convey the water from the turbines to the discharge location. The AMHP tailrace is comprised of three sections: the trough, the culvert pipe and an outlet channel. The trough is located in the powerhouse floor and is cast-in-place reinforced concrete. The 46-cm (18-in.) HDPE Type-S (dual-walled) culvert pipe conveys the water from the powerhouse to the outlet channel. The outlet channel is an open channel lined with 46-cm x 10-cm (18-in. x 4-in.) riprap (approximately R-5) that conveys the water to the receiving stream.

DISCUSSION

Currently, the project is operating in the off-grid configuration and is providing electricity to run three segregated motors within the Plant. In this configuration, only 21 lps (330 gpm) are needed to produce the 6.9 kW (9.25 hp) requirements. Not all of the flow is being utilized and significant electricity generation potential (over 200,000 kWh per year) is being lost. By supplying the electricity to operate the three motors, the AHMP has reduced the cost of operating the Plant by about $5,000 a year. Once the project is licensed, operating at full capacity and selling electricity back to the local utilities, the payback period is projected to be approximately 10 years. In the future, application for a FERC license, via the 5MW Exception track, will be completed for the AMHP.

The AMHP was one of the first of its kind and provided significant obstacles to overcome; however, the project serves as an example of turning an environmental liability into an environmental asset. This project demonstrates that micro-hydroelectric power generation utilizing AMD is potentially applicable at numerous sites throughout the Appalachian region where post-mining discharges require active treatment.

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