DESIGN CONSIDERATIONS AND CONSTRUCTION TECHNIQUES FOR SUCCESSIVE ALKALINITY PRODUCING SYSTEMS[1]

by

G.A. Skovran[2] and C.R. Clouser[3]

Abstract. Successive Alkalinity Producing Systems (SAPS) have been utilized for several years for the passive treatment of acid mine drainage. The SAPS technology is an effective method for inducing alkalinity to neutralize acid mine water and promote the precipitation of contaminating metals. Several design considerations and construction techniques are important for proper system function and longevity. This paper discusses SAPS design, water collection and introduction to the SAPS, hydraulics of SAPS, construction, operation and maintenance, and safety, and found that these factors were critical to obtaining maximum alkalinity at several SAPS treatment sites in Southwestern Pennsylvania. Taking care to incorporate these factors into future SAPS will aid effective treatment, reduce maintenance costs, and maximize long term effectiveness of successive alkalinity producing systems.

Additional Key Words: acid mine drainage treatment, passive treatment systems

Introduction

Coal mine drainage may be classified into two categories: net alkaline or net acidic. In most cases, net alkaline discharges can be treated by providing adequate detention time for natural precipitation of most contaminating metals. In water where acidity is greater than alkalinity, alkalinity must be generated to cause the formation of metal hydroxides and precipitate the metals from the water.

Passive Treatment Systems for the remediation of acid mine drainage (AMD) have incorporated the Successive Alkalinity Producing System (SAPS) technology (Kepler and McCleary 1994) as an effective method of providing alkaline addition to acidic mine water. The SAPS technology may fail to function as planned or be short lived if not properly designed or correctly constructed. The design and construction of SAPS at Oven Run Site D, Oven Run Site E, Jenners Passive Treatment System and Friedline Mine Project between 1995 and 1997 has provided valuable information for improving the performance and longevity of SAPS.

Site Descriptions

Oven Run Site D consists of seven cells, two of which are SAPS treating a discharge of approximately 379 L/min (100 gpm). The discharge emanates from a series of seeps captured in an open channel and conveyed to the first cell of the system. Oven Run Site E is also comprised of seven cells with two SAPS treating approximately 379 L/min (100 gpm). The water is piped 503 m (1650 ft) from an abandoned deep mine discharge to the treatment area. The Jenners Passive Treatment System incorporates three cells, which includes one SAPS, to treat a 379 L/min (100 gpm) discharge flowing from a contaminated, abandoned well, previously used as a public water supply. The passive treatment system at the Friedline Mine Project captures approximately 38 L/min (10 gpm) from an abandoned deep mine and utilizes eight cells, two of which are SAPS. Though each site is unique, all four incorporate certain design considerations and construction techniques that ensure effective treatment, maximize the longevity of the SAPS, and minimize maintenance.

SAPS Design

Prior to any passive treatment system design, extensive water quality and quantity data must be collected and analyzed monthly, for a minimum of one year, to determine the proper configuration and size of the components needed for the desired level of treatment. The mean flow rate determines the size of each individual treatment component, while the water

[1]Paper presented at the 1998 Annual Meeting of the American Society for Surface Mining and Reclamation, St. Louis, Missouri, May 16 - 21, 1998.

[2]George A. Skovran, P.E., Project Engineer, USDA, Natural Resources Conservation Service, Somerset, PA 15501

[3]Christopher R. Clouser, Director of Technical Services, Southern Alleghenies Conservancy, Bedford, PA 15522

Proceedings America Society of Mining and Reclamation, 1998 pp 235-242
DOI: 10.21000/JASMR98010235
https://doi.org/10.21000/JASMR98010235

chemistry dictates the number and types of components needed for treatment. Mine waters which are net acidic, contain ferric iron or high levels of aluminum (>3 mg/l) normally require a SAPS or a series of SAPS as part of the passive treatment system for effective remediation. Passive treatment systems of this type generally consist of three components; aerobic wetlands, SAPS, and settling basins (Figure 1). These components are configured and may be repeated as dictated by the water chemistry to reach the desired effluent.

Cattails (Typha latifolia) are established in aerobic wetlands and provide limited removal of iron and suspended solids. The wetlands produce an annual source of leaf litter for the downstream SAPS. The cattail biomass can generally provide a sustainable supply of oxidizable organic matter to the SAPS in excess of the needs of the microbial communities, basically eliminating the need to replenish the compost layer of the SAPS (Kepler and McCleary, 1994). Wetlands are generally designed for approximately six to eight hours detention time with a desired water depth of 7.6 cm - 15.2 cm (3 in. - 6 in.). On sites where cattails are prevalent, they should be salvaged and transplanted into the newly constructed wetlands.

The wetland is followed by the SAPS component which can effectively treat discharges high in ferric iron and/or aluminum concentrations and is capable of removing 150-300 mg/L acidity (Kepler and McCleary, 1994). The acidity level in the raw mine water and desired effluent determine the number of SAPS required in a given system. Water containing high acidity levels are treated by using a series of SAPS to achieve a net alkaline outflow. SAPS consist of a 0.9 m - 1.5 m (3 ft - 5 ft) deep body of water maintained above a 15.2 cm (6 in.) layer of organic mushroom compost and a 0.6 m - 0.9 m (2 ft - 3 ft) layer of high quality limestone (Figures 3 and 4). The mine water flows vertically through the compost and rock layers and exits through a series of perforated pipes placed on the bottom of the SAPS. The depth of freestanding water is necessary to provide adequate hydraulic head and limit oxygen diffusion into the compost layer. The high biological oxygen demand (BOD) of the compost reduces the ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}) by creating an anoxic zone preventing the coating of the underlying limestone. By removing the dissolved oxygen in the compost layer prior to the water contacting the limestone, the SAPS effectiveness is not limited by ferric iron (Fe^{3+}) in the mine water. As the limestone dissolves, alkalinity is added to the water. The size of the SAPS is based on the detention time of the water within the stone. Water should remain within the limestone for a minimum of twelve hours to provide maximum alkaline generation (Kepler and McCleary, 1994). For stone sizes typically placed in SAPS, a porosity of 50% can be used to compute the required water storage volume. On all four of the study sites, the design stone volume was doubled, providing equal amounts of production and maintenance stone for an approximate 20 year life. Oven Run Site D, Oven Run Site E, and Friedline Mine Project have acidity levels that are near or exceed 300 mg/L, therefore two SAPS were constructed at these sites. The mine water entering the Jenners Passive Treatment System is slightly acidic, requiring only one SAPS.

Settling basins are constructed downstream of the SAPS component to promote the precipitation of

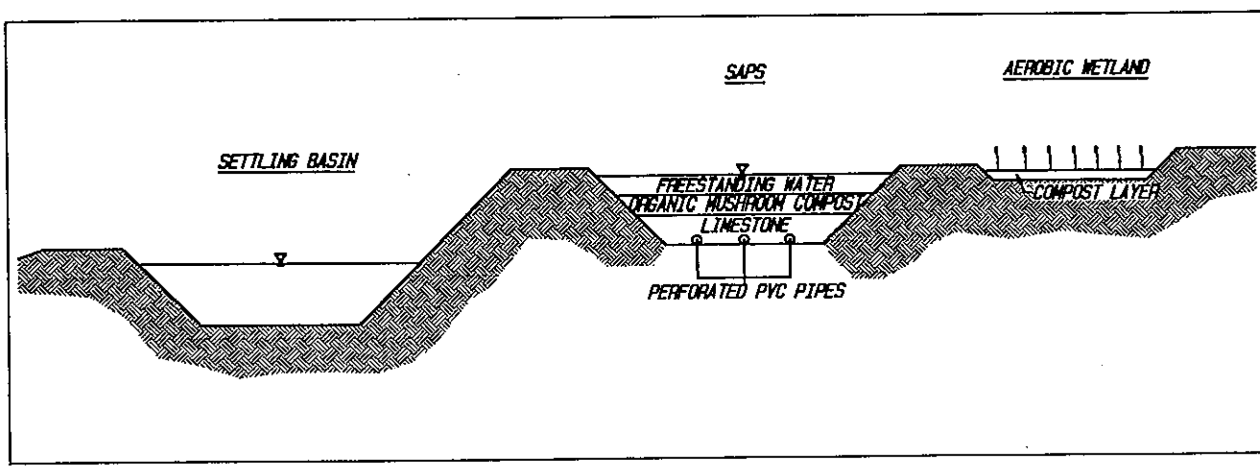

FIGURE 1. TYPICAL CROSS SECTION OF PASSIVE TREATMENT SYSTEM INCORPORATING SAPS TECHNOLOGY

iron, aluminum, and the partial precipitation of manganese. Settling basins should be sized as large as possible to provide storage volume for the precipitated metals with a minimum designed detention time of 2.8 days (Central Environmental Services, 1981).

Water Collection and Introduction to the SAPS

The method of collecting the mine water for treatment is critical to ensure that the maximum amount of contaminated water is conveyed to the treatment area. It is also important to divert all clean surface and storm water to avoid overloading or flushing the system.

The discharges at the four study sites are the result of either a direct discharge from a mine opening or a series of scattered seeps.

At Oven Run Site E and Friedline Mine sites, the mine opening discharges were captured by exposing the openings and installing perforated PVC pipes in the mines (Figure 2). The pipes were sized based on the maximum anticipated flow rates, with an allowance for iron and sediment accumulation to ensure that the water flows freely from the mine. Sandstone bedding and drainfill were used around the pipe to capture the discharge and minimize iron accumulations within the stone. River gravel, if readily available, may also be used for this purpose. To ensure that all of the mine water enters the pipe, a concrete cutoff wall was installed at Oven Run Site E and a clay cutoff barrier was constructed at the Friedline Mine site.

Scattered seep discharges were collected at Oven Run Site D by constructing 229 m (750 ft) of open earth channel immediately downslope of the seeps. The channel, oversized to allow for iron and sediment accumulation, diverted the mine water to a rock channel which conveyed the discharge to the first cell of the passive treatment system. Properly sized limestone was used to stabilize the channel and to add additional alkalinity to the mine water.

At the Jenners Passive Treatment System, the mine water discharges directly from an abandoned well. A containment dike was constructed around the well and is incorporated as part of the first treatment cell.

Diversions and waterways were constructed on all four sites to exclude as much surface and storm water runoff as possible. Limestone was also used in all surface water rock channels to add additional alkalinity.

Hydraulics of SAPS

For SAPS to function, the water must be forced vertically through the compost and rock layers before exiting from the pond bottom. Establishing and maintaining the desired water elevation in the SAPS is perhaps the most critical component of the system design. Topography and space limitations will dictate the type of pipe discharge system used to convey the water from the SAPS to the next treatment component, usually a settling basin.

Oven Run Site E utilizes inline water level control structures with removable weir boards to regulate water surface elevation in the SAPS (Figure 3).

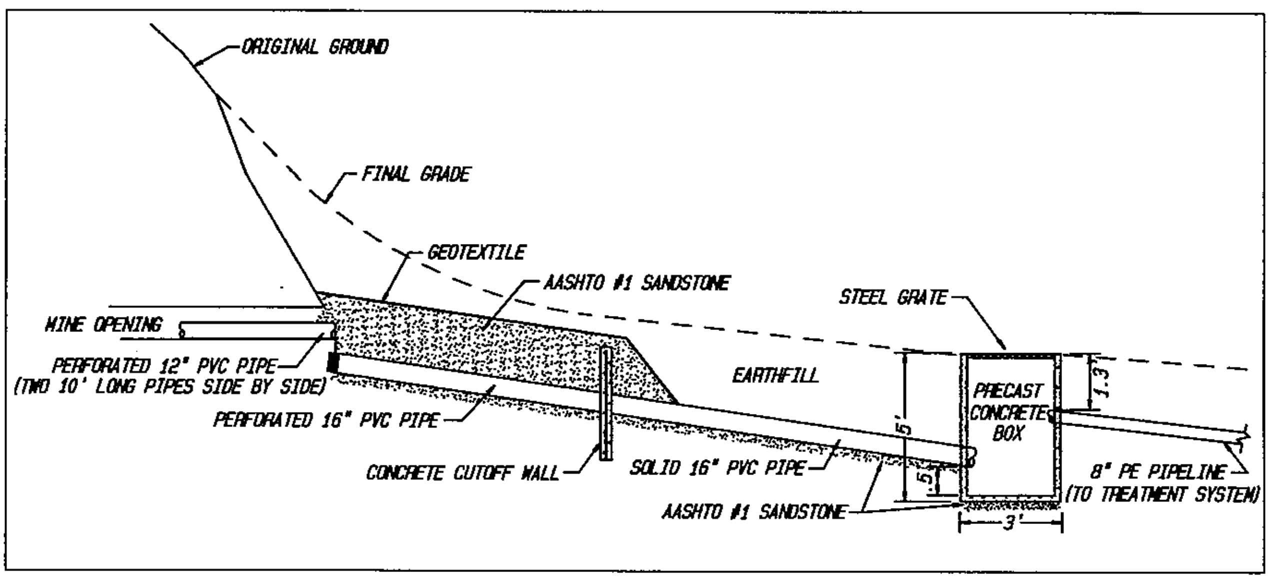

FIGURE 2. MINE WATER COLLECTION SYSTEM AT OVEN RUN SITE E

The structures extend the entire depth of the SAPS and outlet above water surface elevation in the settling basin. This system not only regulates water surface elevation but allows for "flushing" or completely draining the SAPS for maintenance. If possible, this type of outlet configuration is recommended. Where elevation drop is limited between the SAPS and settling basin, an alternate piping system is needed to convey the water. On Oven Run Site D and the Jenners Passive Treatment System, the three 15.2 cm (6 in.) PVC pipes in the bottom of the SAPS were extended through the embankment and outlet above water elevation in the settling basin (Figure 4). In this system, a minimum of three feet potential hydraulic head is necessary to ensure that flow will enter the settling basin and not go through the emergency spillway. The water elevation in the SAPS is regulated by adjusting the pipe outlet elevation. As the water falls from the discharge pipes into the settling basin, oxygen is induced which facilitates the precipitation of the iron, aluminum and manganese.

Construction

When constructing earth embankments for SAPS or passive treatment cells, embankment top widths, side slopes, soil compaction, cut off trenches, freeboard, anti-seep collars, and emergency spillways must be properly sized or incorporated to ensure stable and impervious structures. For example, treatment components at the four study sites were designed according to the Pennsylvania Soil and Water Conservation Technical Guide.

Prior to design, soil investigations were performed to determine that suitable quality and quantity of embankment material was present. Embankment material met the requirements of the Unified Soil Classification System, ML, CL, or CH. More pervious material when used, was placed on the downstream side of the embankments. Three of the study sites contained large volumes of iron deposits within the proposed treatment areas. This material is not suitable for embankment fill and was placed in a designated disposal area. Embankments were constructed with 2H:1V inside slopes, 3H:1V outside slopes and 2.4 m - 3.0 m (8 ft-10 ft) top widths. The top widths of the embankments allowed the use of common construction equipment on the embankments, simplified the installation of the components, and will allow for system maintenance. Cutoff trenches were installed along the centerline of all embankments to a depth determined by the quality of foundation material encountered. All fill was compacted using a sheepsfoot roller or compactor in approximately 20.3 cm (8 in.) lifts to ensure impervious structures. Compaction within 0.9 m (3 ft) of all pipes and the water level control structures was accomplished by using small manually-driven compaction equipment. Anti-seep collars were installed where needed to eliminate potential seepage along pipes. All embankment heights were overbuilt to allow for settlement. Though watershed areas above the treatment systems were minimal, emergency spillways were constructed to maintain system integrity in the event of a pipe restriction or act of vandalism. Also, a minimum of 0.3 m (1 ft) of freeboard was provided above design high water.

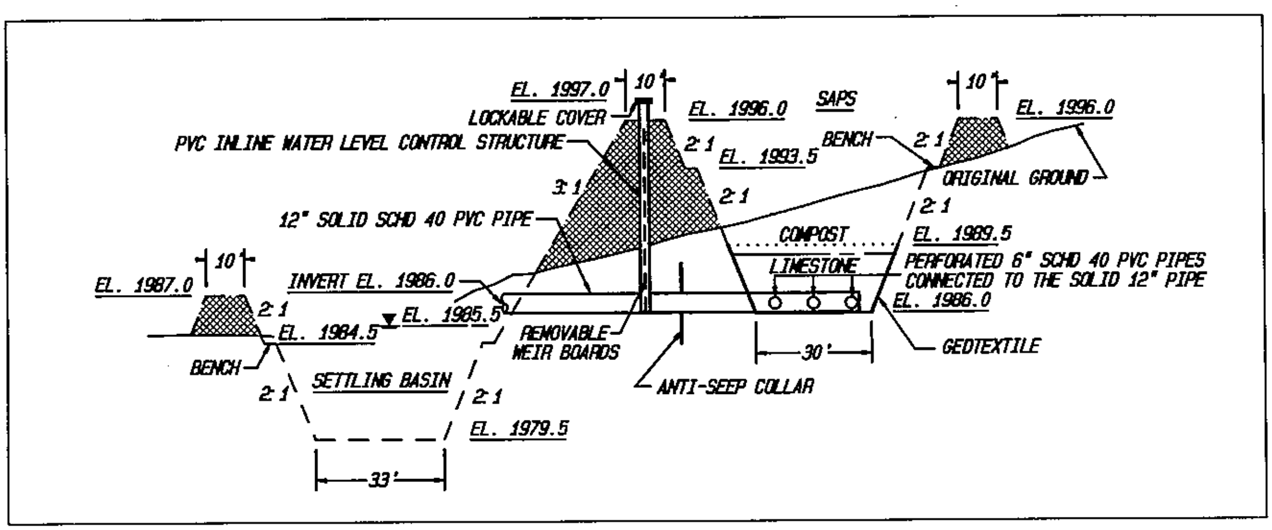

FIGURE 3. SAPS OUTLET USING WATER LEVEL CONTROL STRUCTURE AT OVEN RUN SITE E

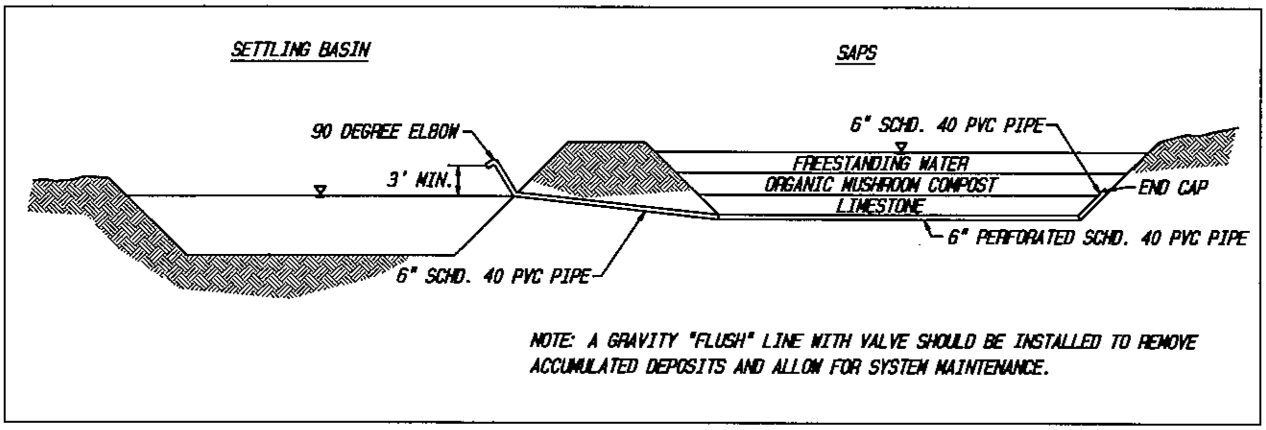

FIGURE 4. TYPICAL PROFILE OF SAPS OUTLET USING PIPE TO CONTROL WATER ELEVATION

Erosion and sedimentation plans were developed for all project sites in cooperation with the local county conservation district and implemented on each site to minimize sediment loads in the receiving streams during construction.

Operation And Maintenance

Properly designed and constructed SAPS require only minimal maintenance, however some periodic maintenance is needed to ensure long term, effective performance.

During the first five to ten days of system operation, the effluent will contain high levels of BOD until the compost stabilizes (Seibert, 1995). Discharges into quality streams may require short term aeration or other means to reduce BOD levels to comply with local regulations.

A monitoring program should be set up to acquire flow rate and water chemistry data at specified sampling points to assess the efficiency and performance of the system (Figure 5). Flow rates can be monitored by installing flumes, or weirs at the discharge points or using a bucket and stopwatch on smaller flows. Points should be sampled quarterly after the system reaches equilibrium, approximately six months after initial start up. The following parameters should be analyzed by a qualified laboratory using standard chemical testing procedures: pH, Acidity, Alkalinity, Total Iron, Ferrous Iron, Aluminum, Manganese, Sulfates, Specific Conductance (Seibert, 1994).

Maintenance plans should be developed to outline the responsibilities of the project manager and include a sampling plan map (Figure 6) and inspection checklist for all components of the passive treatment system. The inspection checklist, as a minimum, should address maintaining desired water levels in the SAPS and wetlands, annually flushing the SAPS to remove iron and aluminum deposits, cleaning precipitant from pipes and open channels when volume is reduced by 50%, removing precipitate from the settling basins when volume is reduced to 50%, and checking embankments and structures for damage.

Most SAPS are designed to be effective for a life of 20 to 25 years, dependent on the rate of limestone consumption. Limestone and compost will need to be replaced when the stone has dissolved to a level that no longer produces the desired effluent.

Average performance at Oven Run Site D is shown in figure 7. This system has effectively treated over 4.39×10^8 L (1.16×10^8 gal) of mine water. In the first two years of operation, this system has removed 15,000 kg (33,000 lb) of iron and 680 kg (1,500 lb) of aluminum and has generated over 60,780 kg (134,000 lb) of alkalinity as $CaCO_3$ (Watzloff, 1997).

Safety

Passive treatment systems incorporating SAPS, wetlands and settling basins pose a potential risk of drowning or injury, especially to young children. Installing shallow bench areas around SAPS and settling basins, as constructed on Oven Run Site E, can reduce the hazard of falling into deep pool areas. The benches, when densely established in cattails can be beneficial by discouraging people from entering the cells while also enhancing system operation. When passive treatment systems are constructed near populated areas, a chain link fence, as installed around the perimeter of the Jenners Passive Treatment System, should be considered to limit access. Warning signs, life buoys and ropes can be placed near potential hazard areas.

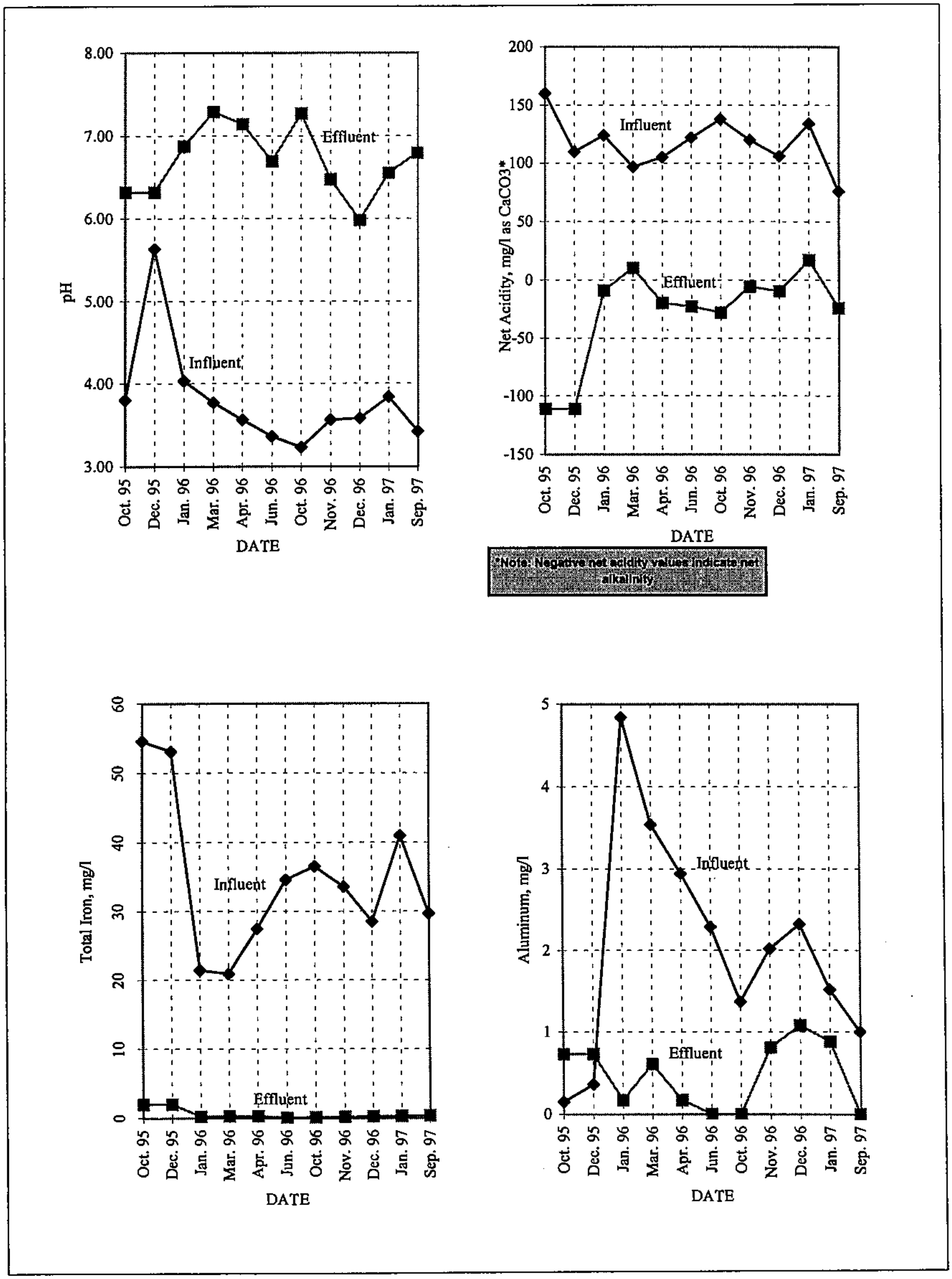

FIGURE 5. MONITORING DATA FROM OVEN RUN SITE D (U.S. BUREAU OF MINES)

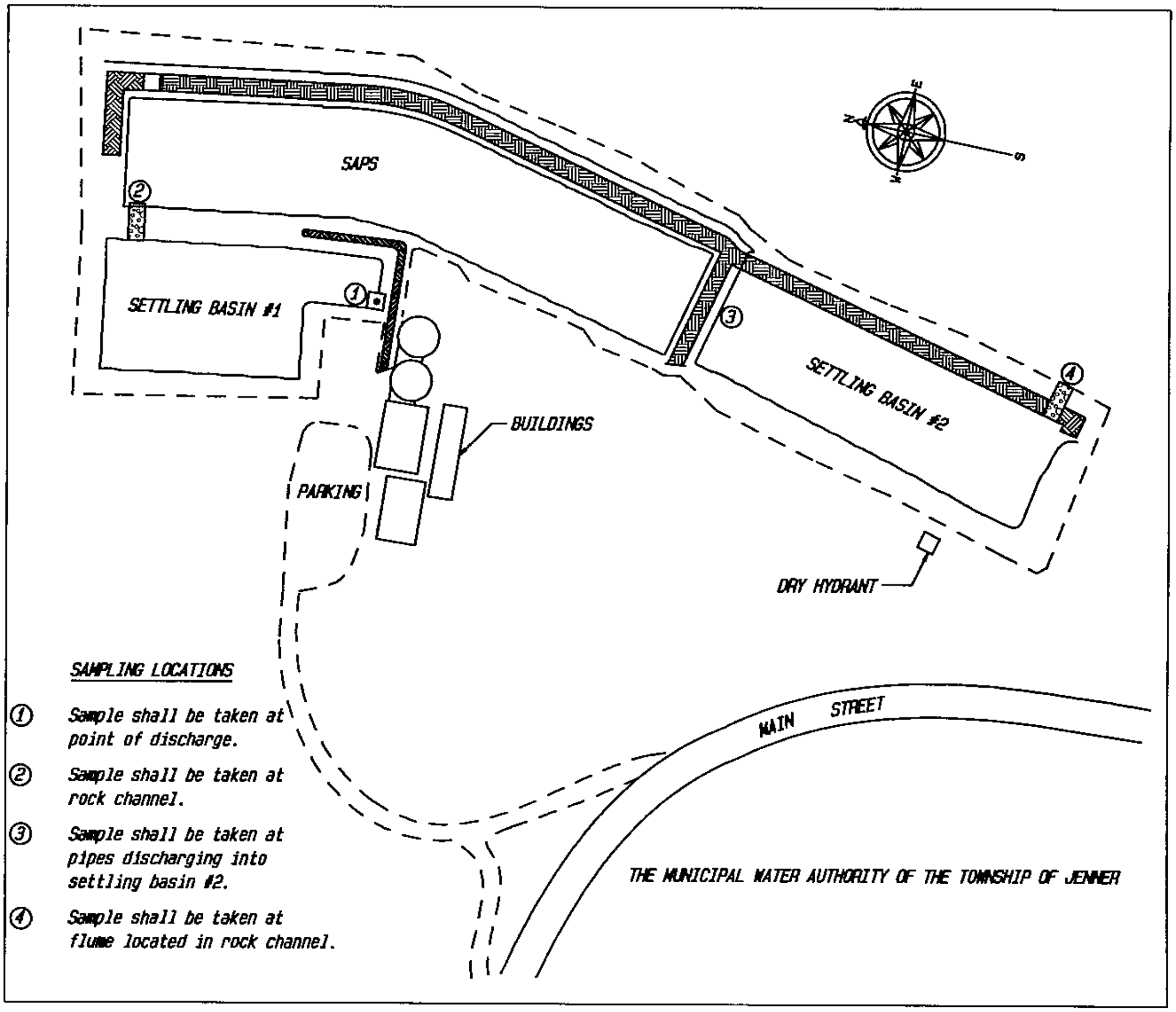

FIGURE 6. SAMPLING PLAN MAP FOR THE JENNERS PASSIVE TREATMENT SYSTEM

PARAMETER	INFLUENT	EFFLUENT
pH, STANDARD UNITS	3.8	6.7
IRON, mg/L	34.6	0.39
ALUMINUM, mg/L	2.0	0.40
NET ACIDITY/NET ALKALINITY, mg/L AS $CaCO_3$	177 (NET ACID)	22 (NET ALKALINE)
FLOW, L/min	407	407

FIGURE 7. AVERAGE WATER QUALITY DATA, 1995-1997, OVEN RUN "SITE D" (U.S. DEPARTMENT OF ENERGY)

Literature Cited

Central Environmental Services. 1981. Mine Water Discharge Analysis, Kovalchic RAMP. p.4.

Kepler, D.A., and E.C. McCleary. 1994. Passive Wetland Treatment System Design, "Site D", Oven Run Watershed, Somerset County, Pennsylvania. 22 p.

Kepler, D.A. and E.C. McCleary. 1994. Successive Alkalinity Producing Systems (SAPS) for the Treatment of Acidic Mine Drainage. p. 195-204. In Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage. Volume 1 of 4. (Pittsburgh, PA, April, 1994)
https://doi.org/10.21000/JASMR94010195

NRCS. 1992. Pennsylvania Soil and Water Conservation Technical Guide (Section IV), Pond Standard and Construction Specification 378.

NRCS. 1995. A Handbook of Constructed Wetlands. Volume 4. p. 25-26.

Seibert, D.R. 1995. personal observations.

Seibert, D.R. 1994. Oven Run, "Site D", Operation and Maintenance Plan. 4 p.

Watzlaff, G.R., U.S. Bureau of Mines. 1995-1997 Water Quality Testing Data at Oven Run "Site D".

Watzlaff, G.R., U.S. Department of Energy. 1997. Summary of first two years of system operation at Oven Run "Site D".