An Application of Baseflow Isolation and Passive Wetland Treatment to Watershed Restoration

Kevin L. Hoover, PG, Terry A. Rightnour, CEP, and F. Roy Zug, III, PE

The project site, located in West Virginia, is a reclaimed wood waste disposal area situated on Pennsylvanian coal strata. Following reclamation of the disposal area, flow in the adjacent stream was observed to have elevated iron and manganese concentrations. The source of the groundwater baseflow entering this portion of the stream appeared to be hydrologically related to the landfill by its close proximity. The source of the metals contamination was not determined, but may be related to percolation from the disposal area into the underlying coal strata. The observable contamination was typical of alkaline coal mine drainage and met the criteria for passive wetland treatment. However, the contaminated baseflow entered the stream along the sides and bottom of the channel at several locations over a 100-meter section and could not be collected for accurate characterization of pollutant loading. Treatment of the entire contaminated stream flow to comply with NPDES permit requirements would have been prohibitively expensive, and insufficient space was available for a treatment facility of adequate size within the narrow stream valley. Given these constraints, it was decided to isolate the contaminated baseflow from the surface flow by construction of a lined stream relocation on top of a gravity-drained collection zone in the existing stream channel. The collection zone consists of a bed of coarse aggregate with a central collection pipe discharging to a submerged outlet, which prevents air from entering the collection zone and minimizes the formation of iron precipitates. The relocated stream channel was formed in place on top of the collection zone with compacted earth, and lined with one layer of polypropylene geomembrane covered by two layers of geotextile. Gabion baskets were then placed on top of the liner for stream stabilization and shaping of the final channel. Accurate discharge characterization at the end of the collection pipe allowed the design of a smaller passive wetland treatment system which treats only the contaminated portion of water in the stream channel while allowing clean runoff water to pass through the project area without contacting the contaminated waters. In addition to cost savings, application of baseflow interception and passive wetland treatment on this site has resulted in a much lower environmental impact than conventional treatment approaches. This remediation approach is also directly applicable to watersheds impacted by non-point source baseflow contamination due to coal mine drainage. Separation of baseflow from uncontaminated surface flow can greatly reduce the quantity of water to be treated and provide accurate treatment system design data. Low maintenance passive treatment is particularly suited to the remote sites typical of coal mining regions, and reliable passive technologies are well documented for applications to acid and alkaline mine drainage and coal combustion byproduct disposal leachate. Coal-related industries and watershed restoration groups are encouraged to consider this approach when addressing non-point source baseflow contamination in stream channels.

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An Application of Baseflow Isolation and Passive Wetland Treatment to Watershed Restoration

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The subject of this watershed restoration project is a 1.8 hectare (4.5 acre) reclaimed wood waste disposal area located in southern West Virginia. It is situated on the side of a narrow mountain stream valley, with the toe of the disposal area ending in close proximity to a small tributary of the Guyandotte River. At the request of the owner/operator, the subject disposal area is referred to herein as the NSB site.

Following reclamation of the disposal area, flow in the adjacent stream was observed to have elevated iron and manganese concentrations. The source of the groundwater baseflow entering this portion of the stream appeared to be hydrologically related to the landfill by its close proximity. The source of the metals contamination was not determined, but may be related to percolation from the disposal area into underlying Pennsylvanian coal strata. The observable contamination was typical of alkaline coal mine drainage and met the basic chemical criteria for passive wetland treatment. However, the contaminated baseflow entered the stream along the sides and bottom of the channel at several locations over a 100-meter section and could not be collected for accurate characterization of pollutant loading. Treatment of the entire contaminated stream flow to comply with National Pollution Discharge Elimination System (NPDES) permit requirements would have been prohibitively expensive, and insufficient space was available for a treatment facility of adequate size within the narrow stream valley.

Given these constraints, it was decided to isolate the contaminated baseflow from the surface flow by construction of a lined stream relocation on top of a gravity-drained collection zone in the existing, eroded stream channel. Accurate discharge characterization at the end of the collection pipe has allowed the design of a smaller passive wetland treatment system that will treat only the contaminated portion of water in the stream channel while allowing clean runoff water to pass through the project area without contacting the contaminated waters.

PROJECT BACKGROUND

The NSB landfill was used from the mid-1970s to mid-1980s for disposal of hardwood wastes from a local sawmill operation, primarily sawdust and tree bark. It was reclaimed with soil cover and vegetation in 1987, and a Closure Plan was submitted to the West Virginia Division of Natural Resources (WVDNR) in 1992. Part of this Closure Plan was a proposal to collect the metals-contaminated baseflow entering the stream near the landfill toe and treat it with a passive wetland system. The proposed collection system consisted of a side-hill stream relocation, a trenched collection zone in the existing stream channel, and several runoff diversion ditches around the collection zone. An initial passive wetland treatment system design contained five narrow vegetated wetland cells arranged in parallel, being the largest system then feasible to construct in the limited project area available adjacent to the landfill. To accommodate flow uncertainties, the system design included individual flow control devices to each cell and an overflow bypass should influent waters exceed the flow capacity of the system.

The Closure Plan and collection-treatment system designs were approved by the WVDNR in 1996, and a draft NPDES permit was issued for the proposed treatment system discharge in 1997. However, because the quantity and quality of the system influent had never been characterized, uncertainty remained as to whether the proposed treatment system would actually be effective. Other regulatory issues, such as the requirement of an NPDES permit for the untreated overflow discharge, also remained to be resolved. For an independent evaluation, Gannett Fleming was asked to develop performance predictions under different influent scenarios. Gannett Fleming identified a number of avenues for improvement in both the collection and treatment systems, and prepared a final design in 1998.

Implementation of the final design required negotiation of a revised NPDES compliance timeframe, as the draft permit stipulated completion of the collection and treatment systems by the end of September, 1998, and attainment of compliance by the end of September, 1999. While it was technically feasible to meet this deadline, there would be no time available to characterize the collection zone discharge and confirm the viability of the treatment system design prior to its construction. Ideally, a year was needed for discharge characterization and design modifications following completion of the collection zone, and a full growing season for vegetative establishment and maturity of treatment functions following construction of the passive wetland system. The WVDNR concurred with this assessment, extending the completion deadline for the treatment system to the end of September, 1999, and attainment of compliance to the end of September, 2000. The final NPDES discharge permit was issued in March, 1998.

DESIGN APPROACH

To meet the completion deadlines imposed by the final NPDES permit, the NSB watershed restoration project was divided into two design/construction Phases. Phase I entailed construction of the collection system, the design for which had been finalized at the time of NPDES permit issuance. This was completed in October, 1998, and monitoring immediately commenced at the collection zone discharge. Phase II was initiated in April, 1999, and monitoring data collected to date used to complete the design of the passive wetland treatment system. Bids were solicited in May, 1999, and treatment system construction began in June, 1999. Construction is expected to be completed by September, 1999. Figure 1 provides an overview of the project site before and after construction.

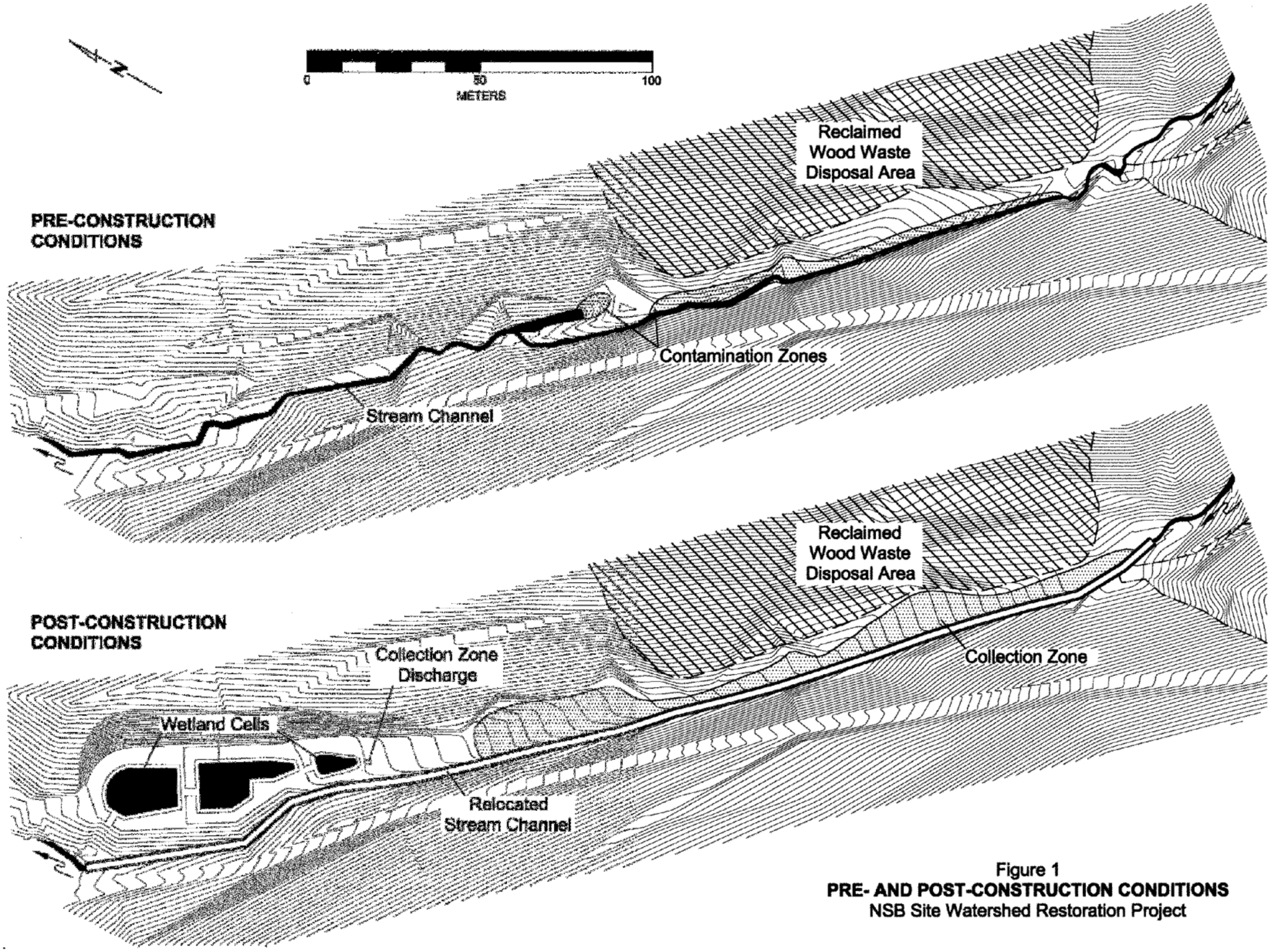

Figure 1
PRE- AND POST-CONSTRUCTION CONDITIONS
NSB Site Watershed Restoration Project

Phase I - Collection System

For the NSB collection system, the baseflow isolation approach was employed for design of the collection zone. Baseflow isolation involves separating groundwater from surface water flow by use of an impermeable layer. This differs from the more common baseflow interception approach, wherein pumping wells are used to create a groundwater flow gradient away from an unlined stream channel, potentially drawing water from the channel itself. Because baseflow isolation eliminates the potential for infiltration from the stream channel, it minimizes the quantity of water that need be accommodated by a treatment system. This was very desirable on the NSB site, where construction space for a treatment system was severely limited. The steep stream channel was also well suited to gravity drainage from a collection zone, and the narrow valley walls allowed reconstruction of the stream channel on top of the collection zone with a minimum of earthwork. Figure 2 shows a typical cross section of the completed collection zone and stream reconstruction.

To allow construction of the collection zone, the surface stream flow was temporarily diverted around the working area, exposing the streambed and contaminated groundwater seeps. The downstream end of the exposed streambed was sealed with a compacted clay berm to prevent contaminant migration out of the collection zone, with a solid polyethylene pipe penetrating it for baseflow discharge. A perforated polyethylene pipe was connected to the solid discharge pipe and laid in the streambed to the maximum upstream point of observed contaminant expression, forming the primary drainage conduit within the collection zone. A bed of coarse aggregate was then spread over the pipe at a level grade perpendicular to the streambed, providing a highly permeable drainage medium over the remainder of the contamination zone. The completed collection zone was covered by a layer of geotextile and compacted earth fill to exclude the majority of surface infiltration.

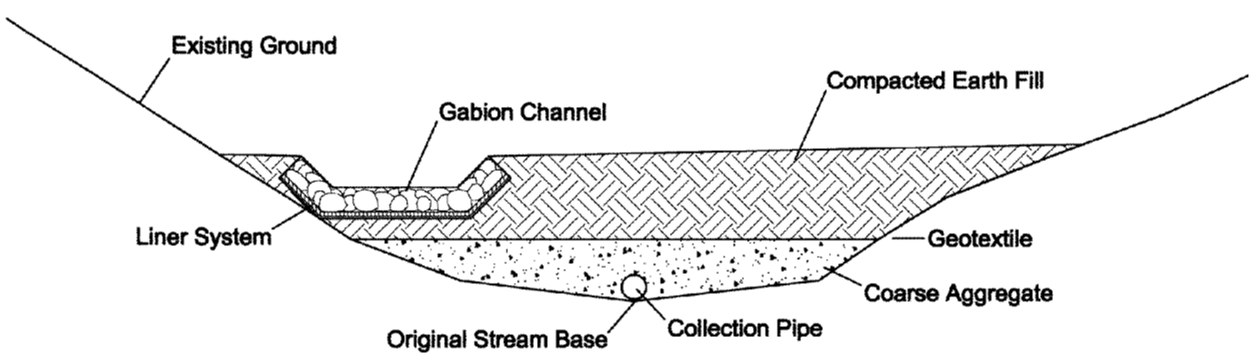

Figure 2
COLLECTION ZONE & STREAM RELOCATION TYPICAL SECTION
NSB Site Watershed Restoration Project

Concurrent with placement of compacted earth fill over the collection zone, a rough channel for the stream relocation was formed along one side of the stream valley, leaving a permanent access route along the other side. The rough earth channel form was covered with a polypropylene geomembrane liner, which was in turn covered by two layers of geotextile for physical protection. Gabion baskets were then placed over the liner system in a trapezoidal configuration to form the final surface of the reconstructed stream channel. Gabions were selected over loose riprap due to the high flow volumes and flow velocities predicted by hydrologic modeling of the stream valley watershed. Final grading of compacted earth fill and topsoil produced positive drainage from the valley sides to the relocated stream channel, eliminating the need for additional runoff diversion ditches around the collection zone. This configuration also minimized the extent to which the stream was offset from its original course. The total length of stream relocation in Phase I was approximately 264 meters (865 feet). Between Phases I and II, the relocated stream channel discharged to a temporary energy dissipater before resuming its natural course.

The final activities of Phase I were construction of an outfall box sump and a small settling basin at the end of the collection zone discharge pipe. The box sump maintained submerged conditions at the pipe discharge, preventing migration of oxygen into the collection zone, where it might otherwise cause precipitation of iron and clogging of the aggregate. Per NPDES permit conditions, flow was monitored at the discharge of the outfall box using a TARCO Model 50H H-flume with a Stevens continuous recorder.

Treatment System Influent Characterization

For the initial 1992 passive wetland treatment system design, it was assumed that influent flow from the collection system discharge to the treatment system would be approximately 2 liters per second (L/s). However, this was not confirmed by any modeling or sampling procedures. Representative surface water and groundwater sampling results showed iron and manganese concentrations averaging 17.94 mg/L and 3.24 mg/L, respectively, and an average pH of 6.89 SU. Again, the baseflow could not be directly sampled, so future system influent concentrations were unknown. In a worst case scenario, these figures equated to influent loadings of iron and manganese of 3,100 grams per day (g/day) and 560 g/day, respectively. The size of the treatment system proposed under the draft NPDES permit was not sufficient to accommodate loadings of this magnitude, and a redesigned system based on this information alone would be substantially larger than the available construction space.

To gather more accurate data prior to construction of the collection system, Gannett Fleming installed flow monitoring and sampling stations upstream and downstream of the contamination area. The difference between upstream and downstream loadings of iron and manganese at these stations was assumed to be the net baseflow contribution from the contamination area. Results from May and June, 1998, indicated an average loading increase of 126 g/day for iron and 36 g/day for manganese. The net flow increase between the two stations for May 1998 through April 1999 averaged 1.2 L/s. These figures were well within the treatment capabilities of a passive wetland system that could be constructed within the site constraints, and confirmed the viability of the passive wetland treatment option.

Following construction of the collection system, the future treatment system influent could be monitored directly, and the final design of the passive wetland treatment system was completed after six months of sampling. The average data from this period are summarized by Table 1 in comparison to NPDES discharge limitations for the eventual treated discharge.

Table 1. Comparison of NPDES Discharge Limitations to Collection Zone Discharge Averages

Monitoring Parameters	NPDES Discharge Limitations	Collection Zone Discharge Average[a]
Aluminum (total recoverable)	748 ug/L Max. Daily	331 ug/L [b]
Biological Oxygen Demand	Monitor and Report	1.86 +/- 1.19 mg/L
Chemical Oxygen Demand	Monitor and Report	64 +/- 65 mg/L
Flow	Monitor and Report	0.88 +/- 0.54 L/s
Iron (total)	1.5 mg/L Max. Daily	2.50 +/- 1.80 mg/L
Magnesium	Monitor and Report	23.24 +/- 19.42 mg/L
Manganese (total)	1.0 mg/L Max. Daily	3.26 +/- 3.24 mg/L
pH	6 to 9 SU	6.30 +/- 0.46 SU
Total Dissolved Solids	Monitor and Report	322 +/- 278 mg/L
Total Suspended Solids	Monitor and Report	7 +/- 5 mg/L
Total Phenolic Compounds	5 ug/L Max. Daily	6 ug/L [b]

[a]Data collected between 10/28/98 and 4/30/99, N = 9
[b]Only one detect for aluminum and total phenolic compounds, remainder non-detect

From these data, it was decided that aluminum would not be a significant design factor, as it is a non-detect parameter in all but one sample analysis and is generally removed with iron in a wetland treatment environment. Similarly, phenolic compounds were detected in only one sample, and no design criteria have been established for this class of parameter. Based on these data, only iron and manganese were expected to average above NPDES discharge limitations in the system influent, and were thus selected as the controlling design parameters for the passive wetland treatment system.

Phase II – Passive Wetland Treatment System

Final design of the NSB passive wetland treatment system was based on Phased Element Removal Technology (PERT^{TM}), which directs the ordering treatment system components in the preferred sequence of contaminant removal found in natural depositional environments (Rightnour and Hoover, 1997). In this case, PERT^{TM} called for a two-stage treatment system, with vegetated aerobic wetland cells targeted at iron removal, followed by a manganese-oxidizing bacterial system (MOBS) unit targeted at manganese removal. For additional confidence in treatment, the vegetated aerobic wetlands were sized to accommodate the maximum loadings for both iron and manganese, as detailed design criteria have not yet been established for MOBS units. The final passive treatment system layout is shown on Figure 3.

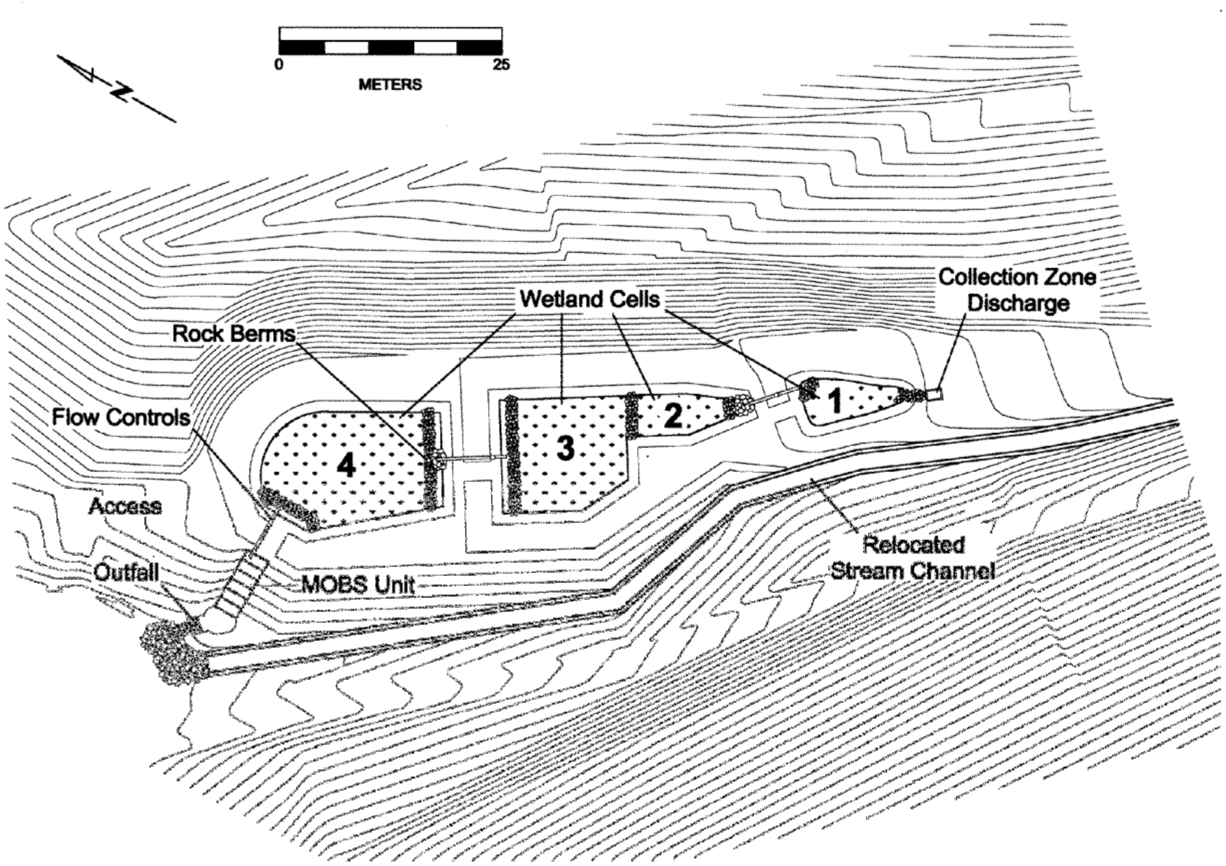

Figure 3
PASSIVE WETLAND TREATMENT SYSTEM
NSB Site Watershed Restoration Project

Vegetated aerobic wetlands constructed to remove iron and manganese are typically sized by surface area for both chemical loading capacity and flow capacity, with the larger of the two requirements setting the size of the wetland treatment cells. Iron and manganese removal rates have been established by Hedin and Nairn (1992) at 10 grams/day-meter^2 (g/day-m^2) and 0.5 g/day-m^2, respectively, when applied to compliance situations. Work by Rightnour and Hoover (1998) indicates that shallow vegetated wetland cells have a flow capacity of approximately 1 L/s per 4 meters surface width (about 1 gallon per minute per foot of surface width).

Ordinarily, at least one full year of influent monitoring data is recommended before sizing a passive wetland treatment system based on maximum observed loadings and flow volumes. In this case, construction timeframes and permit deadlines allowed only six months of data to be collected, so the available information was extrapolated statistically. To give an adequate confidence level that the treatment system could accommodate the maximum chemical and flow loadings to be encountered, three standard deviations were added to the average observed values of iron and manganese loading and flow volume to establish the system design values, as summarized by Table 2.

Table 2. Statistical Derivation of Design Values for the Passive Wetland Treatment System

Parameter	Maximum Observed[a]	Average[a]	Standard Deviation[a]	Design Value (Ave. + 3 S.D.)
Flow	1.45 L/s	0.88 L/s	0.54 L/s	2.50 L/s
Iron Loading	205 g/day	112 g/day	90 g/day	382 g/day
Manganese Loading	185 g/day	87 g/day	47 g/day	228 g/day

[a]Data collected between 10/28/98 and 4/30/99, N = 9

The Hedin and Nairn criteria were then applied to the design values for iron and manganese loading to establish the required surface area for the wetland cells, and the Rightnour and Hoover guidelines applied to the design value for flow to determine the required cell widths, as follows:

Iron Loading:	(382 g/day) / (10 g/day-m^2) =	38 m^2
Manganese Loading:	(228 g/day) / (0.5 g/day-m^2) =	<u>456 m^2</u>
	Wetland Surface Area Required:	494 m^2 (5,320 ft^2)
Flow Volume:	(2.50 L/s) x (4 m/L/s) =	10 m (33 ft) Width

Based on these constraints, a system of four vegetated aerobic wetland cells was designed with a combined surface area of 497 m^2 (5,344 ft^2). The temporary settling basin from Phase I will be filled and vegetated to form one of these cells, as sampling results show that the open water basin has little effect on metals removal. Earthwork constraints and presence of an existing monitoring well prohibited Cells 1 and 2 from being the required 10 meters in width; Cells 3 and 4 were designed at 12 meters in width to compensate. Sizing of the wetland cells for the maximum expected influent flow eliminated the need for an overflow bypass and second NPDES outfall point. Each cell will include an organically-amended planting substrate proven to produce exceptionally rapid and dense vegetative cover, and be planted with cattails and seeded with selected emergent species for initial cover stock. Rock berms will be placed at the inlet and outlet of each cell to aid in flow dispersion across the vegetated surfaces. Internal water levels will be controlled between cells using commercial outfall devices with adjustable stoplogs.

Discharge from Cell 4 will enter a specially designed cascade MOBS unit to effect final manganese polishing. MOBS units, colloquially known as “rock drains,” are based on work by Gordon and Burr (1989) demonstrating that manganese-oxidizing bacteria will colonize most granular surfaces and provide effective manganese removal under circumneutral conditions. MOBS are typically constructed as shallow beds of rock aggregate with water levels controlled at the aggregate surface. In this case, no additional on-site area was available to construct a horizontal MOBS unit after completion of the wetland cells. Instead, a stepped gabion MOBS was designed to form the system outfall, based on a gabion installation geometry developed by Gannett Fleming.

Construction of the passive wetland treatment system will require additional relocation of the stream channel to allow sufficient earthwork area. The stream reconstruction method will be identical to that used in Phase I, with the exception that the channel will not be lined. Approximately 104 meters (340 feet) of additional stream channel will be reconstructed, bringing the project total to 368 meters (1,200 feet). The completed stream relocation will discharge through a permanent energy dissipater before returning to its natural course.

CONCLUSIONS

The NSB restoration project is an excellent example of the efficiency of combined baseflow isolation and passive wetland treatment for stream and watershed restoration. When complete, the system will require no external power and very little maintenance, resulting in long term operational savings. Even at the maximum design value for iron loading, the maintenance cycle for iron sludge cleaning and substrate replacement is predicted to be in excess of 20 years. This is in contrast to a conventional pumping and chemical/ mechanical treatment facility, which requires continuous power and human supervision, resources not readily available at the remote project site. Additionally, passive wetland treatment is more environmentally compatible with its surroundings, producing none of the impacts associated with chemical/mechanical treatment, such as noise, light, and traffic. Reconstruction of the stream channel has also eliminated the ongoing problem of erosion in the stream valley.

This remediation approach is directly applicable to watersheds impacted by non-point source baseflow contamination due to coal mine drainage and similar sources. Separation of baseflow from uncontaminated surface flow can greatly reduce the quantity of water to be treated and provide accurate treatment system design data. Low maintenance passive wetland treatment is particularly suited to the remote sites typical of coal mining regions, and reliable passive technologies are well documented for applications to acid and alkaline mine drainage and coal combustion byproduct disposal leachate. Coal-related industries and watershed restoration groups are encouraged to consider this approach when addressing non-point source baseflow contamination in stream channels. For situations in which regulatory permitting is required, two additional observations from the NSB watershed restoration project should be considered:

1. Sizing of treatment systems, passive or conventional, requires accurate measurement of both influent flow volume and chemical concentrations to determine hydraulic and chemical loading capacities. In the case of diffuse baseflow to stream channels, this information may be difficult or impossible to develop prior to implementation of the collection system. Ideally, at least one full year of data should be collected to assess flow volume and loading variability for the baseflow under all seasonal conditions. Negotiation of NPDES compliance timeframes should include provision for this characterization period when applied to a pollutant source that is not quantifiable prior to collection.
2. Passive wetland treatment systems are biological communities that derive a large portion of their effectiveness from bacterial and vegetative growth activities. It cannot be expected that a passive wetland treatment system will function at optimum levels immediately following construction, as neither the bacteria nor plants are yet fully established. A full growing season following construction is recommended prior to evaluating the ultimate treatment capacity of a passive wetland treatment system, and provision for this establishment period should be included in NPDES compliance timeframe negotiations when employing this technology.

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