Partnering for Reclamation of Coal Refuse in Raccoon Creek Watershed, Ohio

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Note: See full illustrated version of this document at http://www.ohiou.edu/geology/facstaff/stoerpag.html

Acid mine drainage and erosion from abandoned minelands continues to plague streams in Ohio. Addressing mineland problems is costly and technically difficult, owing to the size and hydrogeochemical complexity of the systems, whether they are underground mines complexes or large valley-fill refuse piles. Equally challenging is the political dimension of the problems, involving many stakeholders (including the public) with overlapping interests and jurisdiction. The many stakeholders create an opportunity for pooling resources and joining forces, in the hands of an entrepreneurial watershed group with vision and the capacity to sustain and convey that vision. The development, maintenance and functioning of partnerships for mineland reclamation is the topic of this paper, illustrated through two case studies of refuse pile reclamation.

The Raccoon Creek Watershed

Raccoon "Creek" is more correctly a river: Its large 683.5 mi^2 drainage basin encompasses portions of Athens, Hocking, Vinton, Jackson, Meigs and Gallia counties in Southeastern Ohio (Figure 1). Raccoon Creek discharges into the Ohio River below Gallipolis, Ohio, and is 112 miles long. The Pennsylvanian stratigraphy of geologic formations in the watershed is generally consistent with cyclical sequences of clay, coal, shale, limestone and sandstone. The principally mined coal seams include the Brookville, Clarion, Lower and Middle Kittanning. Most mining occurred before Ohio's 1972 reclamation law, so most of the watershed's 21,550 acres of surface mines were never backfilled or resoiled. Underground mining affects another 25,610 acres, causing subsidence and AMD problems. Raccoon Creek's water quality reflects the legacy of mining and other land uses: Known causes of impairment in the watershed include pH, organic enrichment/ dissolved oxygen, metals, ammonia, siltation, flow alteration, brine, and thermal modifications (OEPA 1996). Eighty-five miles (31.5%) of the 269 stream miles surveyed in the Biological and Water Quality Study of The Raccoon Creek Basin (1995) fully attained the warmwater habitat (WWH; 20.5%) or limited resource water-acid mine drainage (LRW-AMD; 11%) biocriteria benchmarks (OEPA 1997).[1] About 140 miles (52%) partially attained these targets, while 44 miles (16.5%) did not attain them. The leading cause of impairment to Raccoon Creek where limited, partial or non-attainment of targets is noted (79.5% of all surveyed streams) is acid mine drainage.

The goal of restoration is upgrading stream conditions such that all stream miles attain warmwater habitat benchmarks. The task is admittedly daunting. We argue that a vision of fishable, swimmable streams that is sustained and articulated by the Raccoon Creek watershed coordinator, and

[1] The WWH designation defines the "typical" warmwater assemblage of aquatic organisms for Ohio streams. It is the principal restoration target for the majority of water resource management efforts in the state. The LRW-AMD designation applies to streams and rivers that have been subjected to severe acid mine drainage pollution from abandoned mine lands or gob piles and for which there is no immediate prospect for reclamation.

shared by individuals and public managers with a stake in the watershed, will provide the incentive for pooling resources and overcoming obstacles to reach the goal.

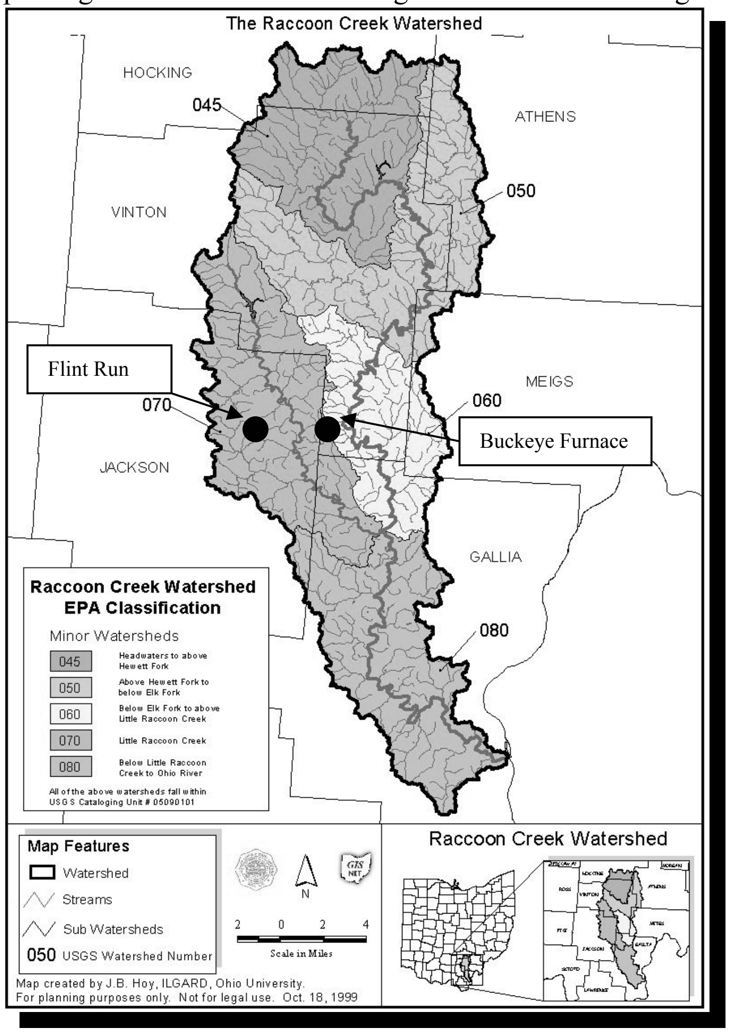


Figure 1. Raccoon Creek Watershed.

Partner roles

Partners include public managers (agency employees or elected officials at all levels of government, or anybody supported by public funds), the community, the watershed coordinator, the private sector (businesses), and universities. Some of the partners are likely to have functioned independently to restore or protect the watershed long before the watershed partnership formed. The roles of the various partners in the Raccoon Creek partnership are described in the following sections.

Public Managers

Research from government agencies (USGS, ODNR and OEPA) has contributed crucial data on water quality and biological resources, describing the extent of acid mine drainage, its effects, and methods for restoration (e.g. Wilson 1985, 1988; Sedam 1993; OEPA 1983). Starting in 1978, Ohio Department of Natural Resources Division of Mineral Resources Management (ODNR-DMRM) completed projects costing several million dollars to reclaim mineland in the watershed. At the time, the agency’s mandate was protection of public health and safety, rather than water quality.

The Ohio Environmental Protection Agency (OEPA 1997, 2001) collected water-quality, fish and macroinvertebrate data that was the backbone of later plans written by the partnership. The dominant fish species found throughout the watershed is the pollution tolerant creek chub (Figure 2). The other dominating species such as the longear sunfish, bluegill sunfish, green sunfish, bluntnose minnow and white sucker are all moderately to very tolerant of pollution. The species found in the smallest numbers are those that are very pollution sensitive, such as the black redhorse and the mimic shiner.

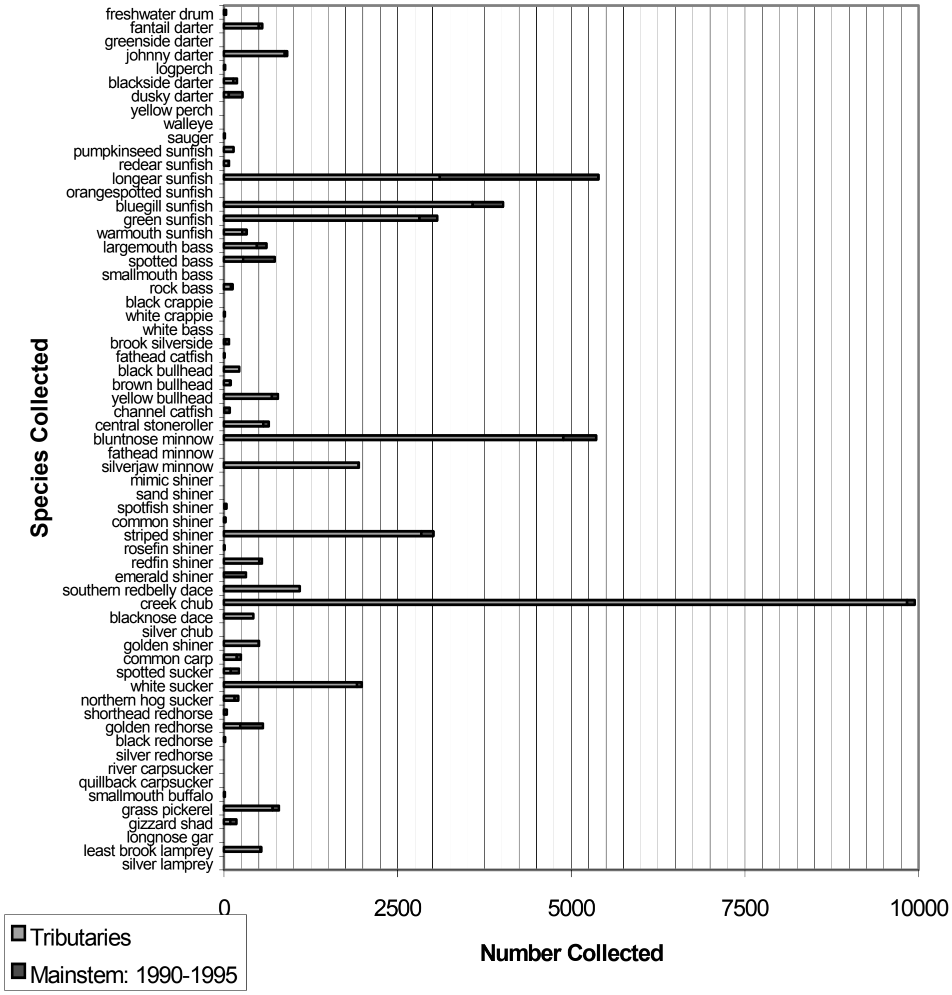


Figure 2. Total fish abundance in Raccoon Creek watershed, 1981-2000 (OEPA).

Among macroinvertebrates (Figure 3), Diptera is the most common order, comprising primarily pollution-tolerant species. In Raccoon Creek as a whole, EPT (Ephemeroptera, Plecoptera and Trichoptera) species account for about 30% of the overall taxa, but constitute a much lower percentage among mining-impacted reaches. Overall, the OEPA data show that the northern part of the watershed, namely the headwaters, experiences a poor biological community performance because of acid mine drainage. Middle and lower portions of the watershed, however, range from fair to good in supporting aquatic life. The OEPA data are important in diagnosing stream conditions, including seasonal integration of conditions not possible with intermittent water-quality data. The data also serve as a benchmark for measuring and documenting changes (hopefully, improvement). The importance of documenting improvement cannot be overstated when public funds have been invested, both for justifying expenditures and for building political support for future investments in water quality.

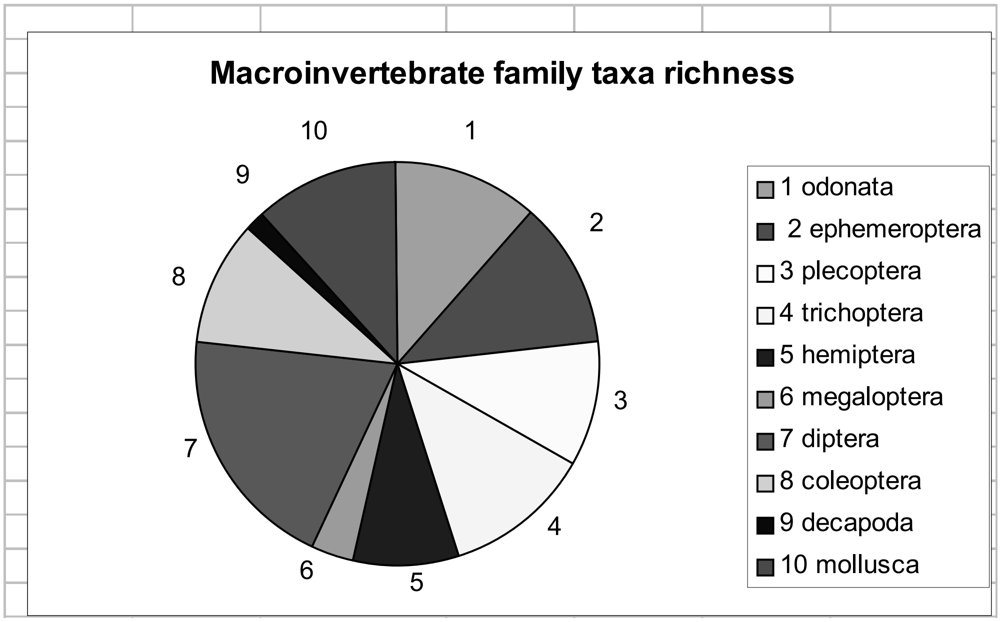


Figure 3. Macroinvertebrate family taxa richness in the Raccoon Creek Watershed. (From OEPA, Division of Surface Water, Ecological Assessment Section, unpublished findings 1981-2000.

Public managers have the capacity for building public support for an agenda of creating public value through stream restoration, but pushing an agency into new territory is risky (Moore, 1995). In fact, visionary individuals within agencies may succeed in changing agendas, but often at the cost of their jobs. The partnership serves the crucial role of keeping public managers "upright," confident, and on the right course. An effective partnership includes not only supporters but also people from the ranks of stakeholders that hold opposing views (Moore, 1995). Landowners, the private sector, and especially coal companies must be represented to ensure that powerful values other than clean water (i.e., property rights, free enterprise, and energy) are not sacrificed. Balance and win-win solutions are key, but finding these requires having all interests represented at the table.

OEPA completed a federally mandated Total Maximum Daily Load (TMDL; USEPA 2002) study of Raccoon Creek (OEPA 2002). In a good example of a win-win solution, the partnership provided much of the data used to estimate AMD loadings, alleviating some of the workload OEPA is under in developing statewide TMDL reports.

Community Role

Community involvement is perhaps the most important element in successful watershed restoration. Scientific experts can analyze water samples and agency officials can help make project decisions, but without public support these efforts will have little effect. As critical as it is to clean up polluted waterways, it is equally necessary to educate and involve community members in the goals and activities that will improve their quality of life, partly for building political support and partly for ensuring sustainability of the restoration.

Interest in restoring Raccoon Creek first began nearly two decades ago. The Raccoon Creek Improvement Committee (RCIC) is a grassroots watershed group that formed in Gallia County in the 1980s in response to the degraded condition of the creek. The group started with small projects, such as trash pickups and logjam removal, but members quickly realized the problems reached much farther than the borders of their county and would take more technical expertise and funding than the group could muster. They called their public managers for help. Constance White from ODNR Division of Soil and Water Conservation with assistance from Natural Resources Conservation Service (NRCS) drove the development of the Little Raccoon Creek Management Plan (USDA 1994). That plan spawned the formation of a Technical Action Committee (TAC) to include public managers from ODNR DMRM, Vinton and Jackson Soil and Water Conservation Districts, Ohio Valley Resource Conservation and Development (RC&D), the NRCS, and citizens from the six counties in which Raccoon Creek flows. The TAC had the task of tackling some of the objectives established in the Little Raccoon Creek plan. Included was the arduous grant-writing task, to establish funds to get the projects activities from concept to on the ground conservation. The first Raccoon Creek EPA 319 grant included funding for a coordinator.

Coordinator's Role

The quest for funding tapped state and federal watershed programs (see Funding Mechanisms section) to support particular watershed projects, but also yielded critical funds for project coordination. The first watershed coordinator, Chip Rice, was advised by the TAC, and had the task of working with partners to set goals, calling on partners' resources, and bringing in new partners and additional resources. The coordinator started out leading small grant-funded activities like trash pickups and tree plantings, but with time and funded mandates the position evolved to include fieldwork, water sampling, planning, grant-writing, communicating with stakeholders through public meetings and newsletters, bringing forward residents' concerns, and managing a flexible partnership. The coordinator helped write AMDAT (Acid Mine Drainage Abatement and Treatment) plans to qualify the headwaters (Rice et al. 2002) and Little Raccoon Creek (Laverty et al. 2000) for state AMD set-aside funds (see Funding Mechanisms section). In the last five years, coordination has split to two positions, the Watershed Coordinator and the Watershed Projects Manager, both of them managing the many activities associated with eight large AMD projects, testimonial to both the demands and need for the coordinator's role.

The flexibility of the partnership has been a cornerstone of success. The partnership lacks a formal structure such as a memorandum of understanding. Guidance and input are accomplished through an ongoing series of public meetings, focus groups centered on specific issues of concern (e.g., AMD), a Leadership Review Board, and the monthly Raccoon Creek Forum. The Leadership Review Board is a group of 18 state and community leaders who met twice to help shape and edit the 2002 Watershed Management Plan. The Raccoon Creek Forum meets monthly to discuss project activities and new initiatives, and includes public managers and representatives of local businesses who provide advice, funds, and technical expertise for ongoing projects. The Raccoon Creek coordinator calls and moderates the Forum.

At the monthly forum, open to anyone, partners meet to discuss activities. Some discussion focuses on current activities and the identification of tasks and how they might be accomplished. The Forum is also an opportunity for partners to bring new ideas, opportunities, or barriers to success to the table for group thought. Various partners, with an understanding of their organizations' missions and resources, may offer financial or technical assistance. The partnership relies on a shared vision of a healthy Raccoon Creek, a goal that overlaps with partners' organizational or program missions. More than anything, the coordinator articulates that vision as often as necessary.

University role

Universities, including Ohio University in Athens and Hocking College in Nelsonville, Ohio have provided assistance through talent, experience, and a commitment to public service. The Voinovich Center at Ohio University in Athens houses the Institute for Local Government Administration and Rural Development (ILGARD) and the Appalachian Watershed Research Group (AWRG). ILGARD provides grant-funded assistance with GIS, planning and public interaction; AWRG provides grant-funded assistance with basic and applied research, much of which can be described as watershed characterization (flow, water chemistry, geology, numerical modeling, aquatic ecology, etc.). The flexibility of the partnership extends to the University, where talent can be tapped on an *ad hoc* basis. The Voinovich Center provides a mechanism for one-stop shopping, so that GIS specialists, political scientists, biologists, geologists, geochemists and engineers can be accessed through a single grant. The University in many cases does the grant writing in a win-win solution where the watershed coordinator brings the research opportunities and the power of the partnership (property access and contacts, for example), and the University writes the grant and does the needed research.

One of the most valuable roles of ILGARD was to apply for and receive a watershed coordinator position for Raccoon Creek through a multi-agency grant program (See Funding Mechanisms section). This position solidified support for the coordinator, and freed funds from an existing grant to hire Brett Laverty to manage certain implementation projects. ILGARD also applied for and received a Non-Point Source 319 grant (see Funding Mechanisms) to develop the 2002 Watershed Management Plan.

Graduate theses and some undergraduate projects have helped define projects and treatment techniques for many of the AMD-impacted tributaries. Many of these outline the effects on both water quality and aquatic life throughout specific tributaries and sub-basins in the watershed. Student work on the condition of Raccoon Creek water bodies and remediation problems has been continuously underway since 1995 (e.g., Hughes et al. 1996, Last 2001, Laverty 2017, Prim 1999, Shimala 2000) Ohio University graduate students wrote theses for both the Buckeye Furnace and Flint Run Reclamation Projects described at the end of this paper.

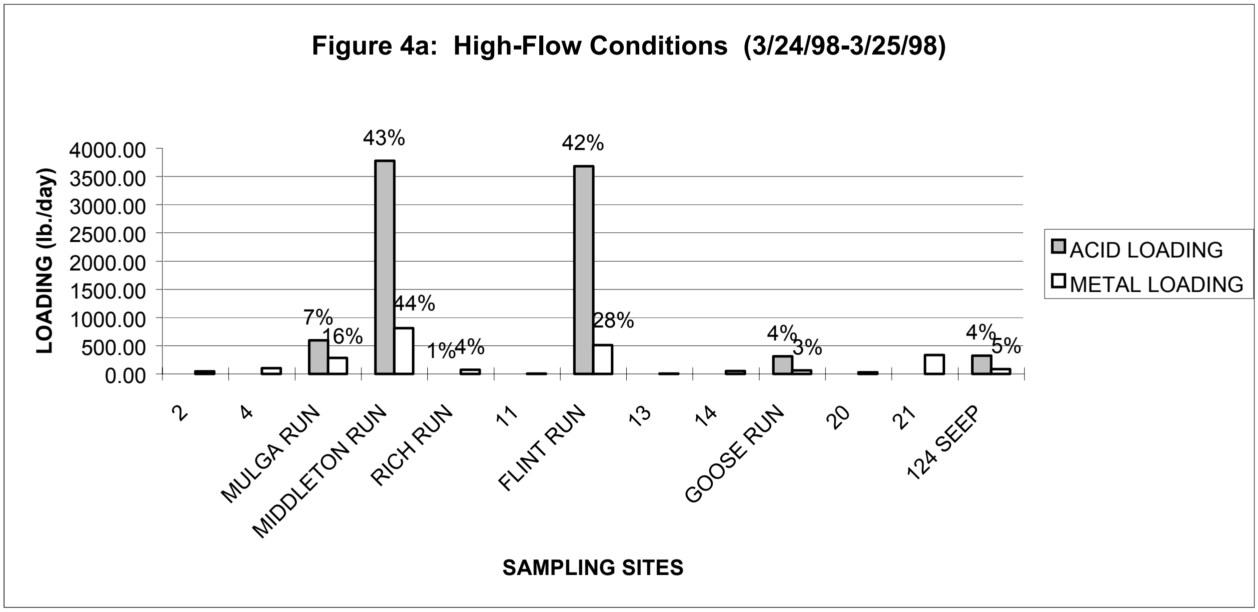
Goal Setting

The 2002 Management Plan showed that acid mine drainage was the number one issue of concern both for the public and for public managers. The watershed group has outlined a strategy to reduce the effects of acid mine drainage in the 36 impaired stream segments with the goal of achieving warmwater habitat designation. Toward that goal, the following objectives were identified:

- Complete 100% of the projects proposed in the AMDAT and TMDL Plans, averaging 2 projects every 3 years.
- Implement a long term monitoring plan for water chemistry (quarterly) and biology (semi-annually).
- Develop a research agenda to further the Raccoon Creek partner's knowledge of AMD impacts on streams.
- Explain benefits of reclamation to the local community; evaluate two completed projects biannually and write case studies for wide distribution.
- Educate the local population about stream degradation from AMD through three public presentations per year.
- Develop by 2005 a partnership with three additional public or private funding programs.

To meet the first objective, as well as to satisfy AMDAT funding requirements, potential projects had to be prioritized. Prioritization was based mainly on loading, so Chip Rice and Brett Laverty (then an OU student) undertook the enormous task of measuring loading in every seep and stream in Little Raccoon Creek, where AMD is most severe. Of the 12 tributaries studied, six contribute 99% of the total acidity to Little Raccoon Creek (Laverty et al. 2000). Acid load varies from 8700 lbs/day during high flow (March, 1998) to 1000 lbs/day during low flow (June, 1999). These six priority subwatersheds show elevated levels of acidity, conductivity, total dissolved solids (TDS) and metals, and low levels of pH and alkalinity, during both high- and low flow periods. The six priority subwatersheds are all located in northeastern Jackson County, where coal mining was most active (Figure 4a and b).

While the relative role of tributaries under different flow regimes varies (Middleton Run has the largest acid load under high-flow conditions, but contributes a negligible amount under low-flow conditions), Flint Run is consistently the largest source of acidity, and ranks as the number one priority for remediation. Buckeye Furnace, formerly the watershed's third largest contributor of acid loading, based on earlier data, was reclaimed at the time of the AMDAT investigation.



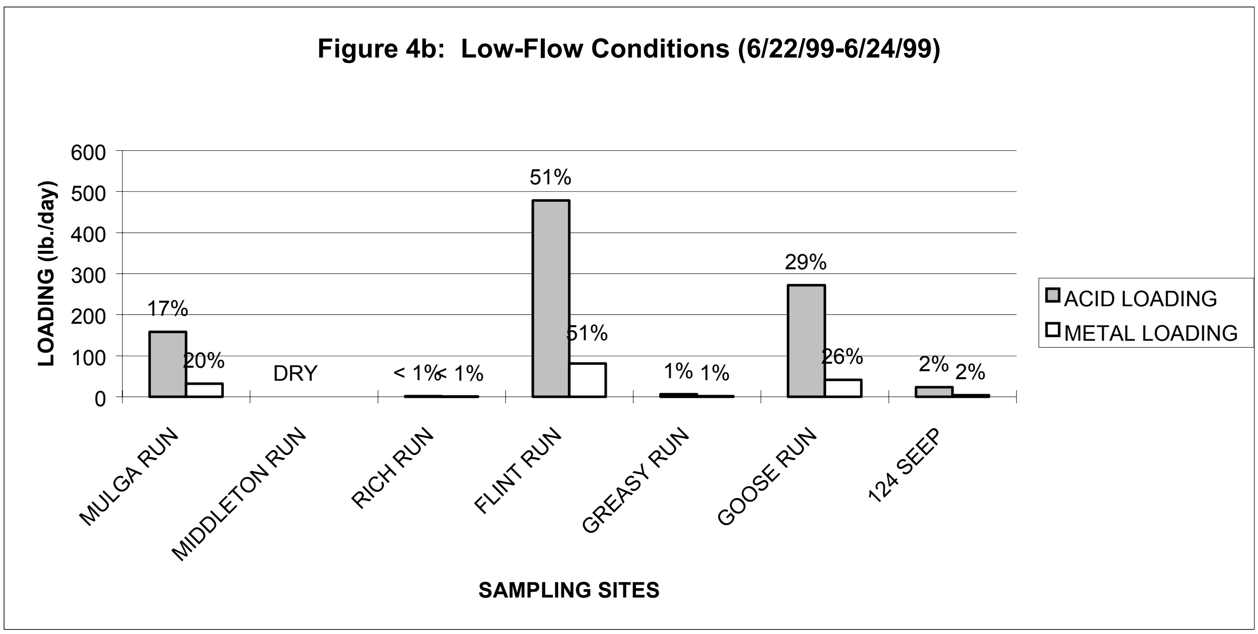


Figure 4. Acidity and metal loading to Little Raccoon Creek under (a) high-flow and (b) low-flow conditions. Labels show percentages of the total load to Little Raccoon Creek.

Prioritizing potential projects requires setting water-quality goals consistent with the objective of achieving warmwater habitat in receiving stream segments. Net alkalinity was successfully modeled for the Raccoon Creek headwaters by OEPA as a surrogate for other water-quality parameters such as pH, and a goal of 20 mg/l net alkalinity (alkalinity minus acidity) in the Raccoon Creek mainstem was selected as an initial goal (Figure 5). The model shows that when stream segments meet this target, other listed parameters (metals and pH, for example) will meet standards commensurate with warmwater habitat: pH 6.5 – 9.0, Fe <1 mg/l, Al < 750 ug/l, Mn < 2 mg/l, and TDS < 1500 mg/l. Ohio EPA is currently developing more refined water quality endpoints for Raccoon Creek. The net-alkalinity model, in the meantime, allows the target to serve as a goal for both pH and metals as causes of impairment on OEPA's 303(d) list. The model indicates that the standard for pH is met when the acid concentration reduction (or net alkalinity target) is met. The Total Acid Mine Drainage Loading Model (TAMDL) being refined by National Mine Land Reclamation Center at West Virginia University should prove, in the near future, to be a welcome addition to the prioritization of water quality end-points in restoration projects such as the one underway in Raccoon Creek.

Net Alkalinity				
STREAM SEGMENT	**Existing Conditions**	**CUMULATIVE CONC. (mg/l)**	**TARGET (mg/l)**	**DEVIATION FROM TARGET (mg/l)**
EAST BRANCH RACCOON CREEK	**reach end**	**-59.0**	**20**	**-79.0**
WEST BRANCH RACCOON CREEK	**reach end**	**-20.2**	**20**	**-40.2**
MIDDLE SECTION BRUSHY CREEK	**reach end**	**-6.1**	**20**	**-26.1**
BRUSHY CREEK	**reach end**	**-13.2**	**20**	**-33.2**
MIDDLE SECTION LAKE HOPE	**reach end**	**12.0**	**20**	**-8.0**
HEWETT FORK	**reach end**	**-33.0**	**20**	**-53.0**
MIDDLE SECTION BOLINS MILLS	**reach end**	**-9.5**	**20**	**-29.5**

Figure 5. Stream segment end net alkalinity targets and deviations for Raccoon Creek headwaters.

Support from Public Managers

Completing large AMD projects in Raccoon Creek has required pooling resources from a variety of sources, summarized here.

The Ohio legislature established the AMDAT (Acid Mine Drainage Abatement and Treatment) fund in March 1995. The Division transfers up to 10% of the annual federal Abandoned Mine Land (AML) grant into the AMD "set-aside" fund (recently about $500K-600K per year). In March 1999 the Ohio DMRM received authority to grant money from the AMDAT fund directly to watershed groups, provided that a watershed group meets certain criteria. The group must be a charitable organization as defined in RC 1716.01; it must provide matching funding (including in-kind) for 50% of the cost of the proposed project; it must use the funds only for (a) data collection and analysis to qualify the watershed as a "hydrologic unit", (b) monitoring of water quality changes resulting from an abatement project, or (c) engineering design and construction costs for a priority reclamation project in the qualified hydrologic unit. Two of the three AMDAT modules for Raccoon Creek have been funded in this way.

The state-funded AML (Abandoned Mine Land) Program addresses environmental problems associated with abandoned mines affected prior to April 10, 1972. The program is funded through state severance taxes on coal and other minerals that generate approximately $1,000,000 annually. Funds can be disbursed through direct negotiated contracts with private landowners, universities and mining companies, and in the past were limited to projects addressing public health and safety. As a result of the US Office of Surface Mining's incentives to provide for other avenues to abate acid mine drainage than the AMD set-aside program, formalized with the 1994 signing of the Appalachian Clean Streams Initiative (OSM 1995), states now have more flexibility in the use of AML funds, and can also use them to address acid mine drainage problems under a "General Welfare" clause. State AML funds are used in Raccoon Creek to leverage other funding sources for design and construction and for studies and research. Local mine operators have utilized the "no-cost" AML program to reclaim abandoned mined lands adjacent to their permits.

The ODNR Division of Soil and Water Conservation, in partnership with OEPA, ODNR Division of Mineral Resources Management, OSU Extension, and the Ohio Coastal Management Program developed the watershed coordinator grant program to provide funds for organizations and agencies to hire watershed coordinators. These competitively funded positions allow for planning and water-quality improvement on a watershed basis. ILGARD applied for and received funds to support the Raccoon Creek Watershed Coordinator.

Recognizing that remining can offset costs of restructuring and material placement needed to mitigate AMD problems, ODNR DMRM will examine the potential for remining, offering incentives to encourage it where it is technologically and economically feasible. Though remining permits have been issued in the watershed, no AML funds have been used to supplement the process.

The EPA's Non-Point Source (319) Program provides an important source of funds for alleviating non-point source pollution from mining. Funds are disbursed competitively through District Offices of the OEPA. Funds from this program have, with DMRM resources, formed the backbone of the planning, design and construction remediation for AMD in Raccoon Creek. These funds also support education, capacity building and other conservation programs in Raccoon Creek.

OEPA also provides technical assistance through biologic sampling, analysis and TMDL reports. OEPA completed the TMDL report for Upper Raccoon Creek (OEPA 2002).

The National Mine Land Reclamation Center at West Virginia University provides important technical assistance in watersheds funded by the ACSI program.

Restoration

Site characterization, project design and construction, and post-construction monitoring are all part of the restoration phase. As demanding as this phase is, much of the overall effort was invested earlier, in partnership building, watershed characterization, priority setting, and funding. Up-front effort is well invested, and the same is true in the restoration phase itself. Site characterization is critical to effective engineering and eventual success. Similarly, follow-up assessment is an important feedback loop as well as a tool for building support of the broader restoration effort. Two case studies will illustrate the importance of characterization and follow-up monitoring.

Characterization: Flint Run Case Study

The overall watershed survey found that Flint Run (Figure 1) contributed 42-51% of the total acidity load to Little Raccoon Creek. Mean annual loadings (1997-1999) are 3000 lb/day acidity, 400 lb/day Fe, 140 lb/day Al, and 11,000 lb/day sulfate. The source of these extreme loads is 240 acres of pyrite-enriched coal refuse from a former coal-preparation facility and mine-refuse dump in the headwaters of Flint Run. Mead Paper Co. purchased the land for timber reserves and began reclamation in

1984, including grading, re-routing drainage, and applying paper-mill sludge for revegetation. Work was completed in 1987. Five measurements made during reclamation may not reflect pre-reclamation water quality, but convey the magnitude of the problem at Flint Run before Mead's work: Mean annual loadings (1985-86) were an astonishing 21,000 lb/day acidity, 2000 lb/day Fe, 520 lb/day Al, and 29,000 lb/day sulfate.

Despite loading decreases of 62 to 86% of 1985-86 values, Flint Run remains a clear priority. How to mitigate the problem was less clear. Careful site characterization was deemed important, to ensure that the engineering design would have a high chance of success. Characterization was done by Mead Corporation, by OU student Brett Laverty, working with coordinator Chip Rice, by an OU hydrogeology class as a project, by the U.S. Geological Survey, and by R.D. Zande & Assoc., consulting engineers, all with help from ODNR DMRM.

After many field trips and after initial data were collected and scrutinized, hypotheses emerged to explain the exceptionally poor water quality and the plumbing of the pile with respect to both air and water. It was hypothesized that strip pit lakes surrounding the pile recharge the pile; alternatively, rainfall infiltration into the pile could be the main recharge source. The high acidity could be due to long water residence times in the pile, or it could be due to oxygen availability. Oxygen inflow was hypothesized to a flowpath that included emergence of water at seeps followed by infiltration of seepage back into the pile downstream. Alternatively, rapid flow was observed through the pile, causing a dynamic water table and the possibility of oxygen entry between events. Geomorphic pipes that developed in the cohesive weathered material seemed to play a role. Convective airflow through permeable layers was postulated.

The hydrologic and geochemical mechanisms operating in the pile are important because the dominant process implies a preferred engineering solution. Water control is almost always the preferred goal of AMD projects, because loadings from mines and coal refuse are commonly found to be directly proportional to discharge. (With many other contaminants, dilution at high discharges may result in a more uniform loading.) If infiltration is the primary recharge mechanism, capping is implied. If on the other hand lake recharge is important, drainage of the bordering lakes is implied. Air entry is as important as water entry. If convective airflow is important, capping is implied; if seep emergence and sinking is dominant, re-grading and stream diversion are implied.

Testing hypotheses involved establishing the pile geometry and its relation to underlying geologic features, determining the permeability of the materials, and estimating a water budget. The pile geometry was measured with a careful topographic survey, a resistivity survey, drilling, and core analysis. Monitoring wells were installed to measure hydraulic head and hydraulic conductivity. A rain gage was installed. Probes with dataloggers were installed in the lake and in wells to measure dissolved oxygen (DO) and pH.

An OU class made a water budget of just the upper part of the refuse, which is divided more or less into an upper and lower valley (Welch et al. 2002), separated by a compacted old railroad embankment that may act as a hydraulic dam. Based on their water budget, recharge (precipitation minus evapotranspiration) to the pile can account for all the visible upper valley discharge of 1.3 million ft^3/yr without invoking any recharge from the strip pit lakes. The lakes have a water surplus of 2.7 million ft^3/yr, but no surface connection to the pile. They may be connected to the pile by subsurface flow: Measuring hydraulic conductivity and gradients, the flux from the lake into the pile is from 2 to 11 million ft^3/yr, an uncertain but significant amount. It appears that the pile is an important lake outlet, but not all of the flow is accounted for in the upper valley discharge. The students sought another way to account for the missing water. Based on the geology, the lake may discharge in the lower valley through both refuse and underlying fractured shale. Rock core analysis and the resistivity survey (corrected for topography) show that a highly fractured shale unit that outcrops down valley may provide the needed hydraulic linkage (Figure 6), despite the haul road dam. The sandstone has high feldspar content, leading to low conductivity when the feldspar weathers to clay.

Connection between the lakes and the pile causes a sustained flow even in dry weather. However, rainfall still plays a role. During a heavy rain event, DO levels in a monitoring well dropped to 0 mg/l, and the pH rose to neutral. The interpretation is that the layer of infiltrating water created a barrier to airflow. Oxidation reactions in the waste shut down temporarily. This finding indicates the importance of airflow, and suggests that capping the pile to limit air entry as well as water entry would be effective. On the other hand, limiting recharge from the lakes is likely to yield a greater load reduction.

Armed with the information from the partners and confirmatory data of its own, R. D. Zande & Assoc. produced an engineering plan that called for phased construction, to begin in 2004 with draining of the lakes and construction of passive treatment facilities. Monitoring after each phase will guide the next step, if any, depending on how the understanding of the system mechanics changes. Funding for the restoration of Flint Run will likely come from a combination of EPA 319 funds, ODNR DMRM and ACSI funding sources.

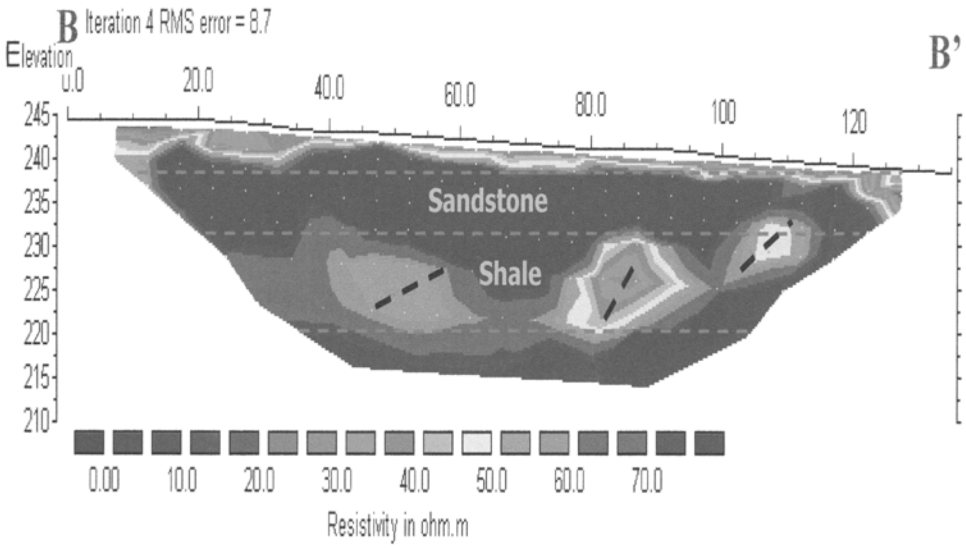


Figure 6. Resistivity image of the material between the lake and pile, showing conductive areas interpreted as fracture zones in the shale.

Characterization is a step that must precede design for the remediation to be effective. Phasing construction and making measurements to either confirm or adjust the “model” of how the system works will reduce uncertainties in site characterization and add to the general understanding of these complex systems. Bringing many partners into the characterization phase is helpful, because it pools experience and creativity, and divides the workload. Having students help with the characterization, and passing that information on to engineers may also reduce costs.

Design and Follow-up Assessment: Buckeye Furnace Case Study

Follow-up assessment at every phase of construction, and to monitor system performance over time, is an important feedback loop to increase partners’ knowledge of AMD-generating systems. Monitoring is also needed to show public managers or other funding entities, and also the public, what the funds accomplished. Success breeds success, and this feedback helps build support of the broader restoration effort.

The Buckeye Furnace Reclamation Project in Jackson County, Ohio, combined source control measures and passive treatment methods to reduce erosion and acid mine drainage (AMD). Prior to reclamation, this 65-acre complex of abandoned coal mines and refuse piles contributed over 3700 lb/day of acidity to Buffer Run, which drains 1275 acres. Erosion of refuse increased flooding in Buffer Run and adjacent roads. Average metal loads were 790 lb/day iron and 273 lb/day aluminum. Source-control reclamation consisted of 1) regrading the refuse, 2) installation of two retention ponds, 3) capping the refuse with a low-permeability clay cover to reduce infiltration, 4) adding soil and paper sludge (Mead

BYPRO) as an organic rooting layer, and 5) removing three ponds serving as major upland recharge sources. Additionally, passive treatment systems for AMD were built, including 6) open limestone channels to stabilize constructed channels and add alkalinity, 7) an anoxic limestone drain (ALD), 8) a successive alkalinity-producing system (SAPS) to capture numerous underground mine seeps, and 9) steel slag leach beds. During construction, OEPA granted a permit to install (PTI) for the addition of 1750 tons of steel slag (calcium silicate, from a Mingo Junction, Ohio steel mill). This strongly alkaline material was placed in an alkaline recharge system (ARS) of ponds.

ODNR DMRM directed the project in partnership with WVU's NMLRC, Raccoon Creek Partners, and private-sector engineering consultants and contractors. The total project cost was $1,090,530.79.

A follow-up study of data collected mainly by the coordinator and OU was done by OU (Davis 2002) to determine the effectiveness of the different components (Figure 7) and of the reclamation as a whole.

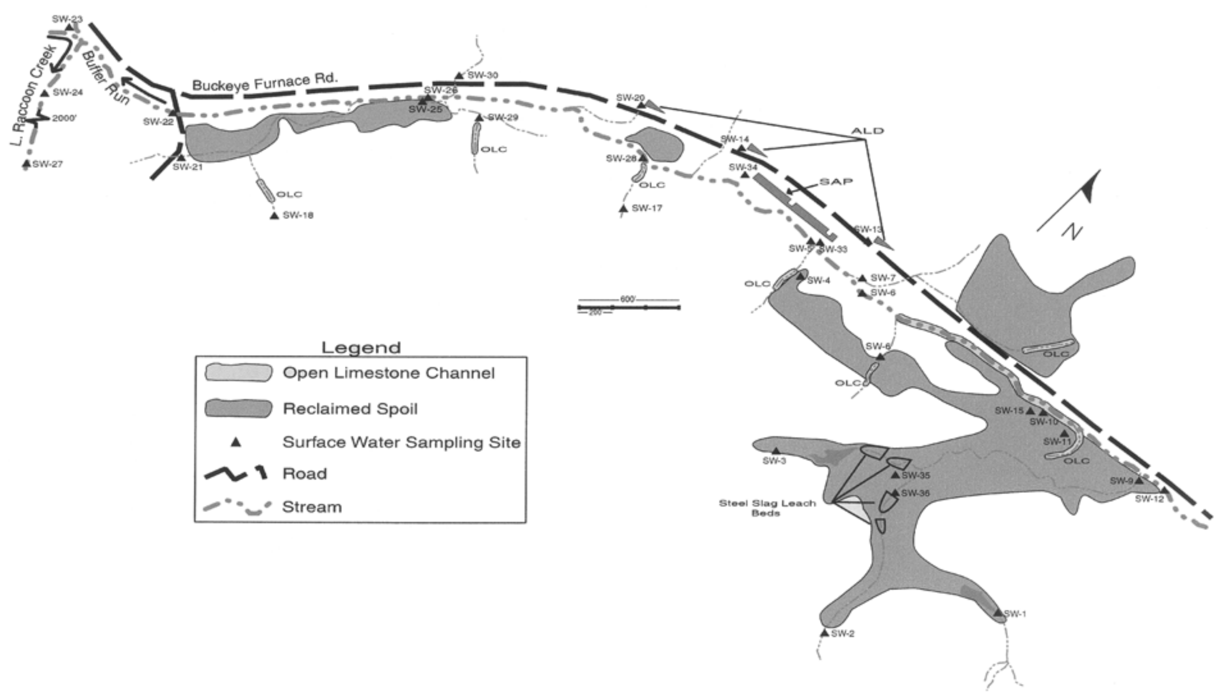


Figure 7. Location of reclamation components.

Water samples were collected and analyzed quarterly beginning February 1996 by private-sector consultants. The sampling stopped during the actual construction phase and resumed again September 1999. The coordinator and OU did most of the follow-up sampling. Flow measurements were taken at select locations, but were not taken at every sampling site or date. Unfiltered water samples were collected in 250 milliliter sterile polypropylene bottles and treated with 5 milliliters of 20% HNO_3 to preserve the ions and prevent further precipitation of metals. Although samples were not filtered at the time of collection, the water appeared clear. An additional sample was collected in a 1-liter soft-sided cubitainer and not acidified. Airspace was minimized to reduce the dissolution of oxygen. Labeled samples were packed in ice and sent to the ODNR state laboratory in Cambridge, Ohio, for chemical analysis. Most flows were measured with a portable flume, but smaller flows from pipes were measured with bucket and stopwatch, and larger flows were measured using pygmy meters and wading rods.

The Mann-Whitney test was used to test the hypothesis that the mean values of the parameters before and after reclamation (or upstream and downstream of the reclaimed area) are unequal, indicating a change in water quality. Generally, the t-test for normal distributions is used to test the equivalency of two samples. To avoid the undue influence of extreme flows on the mean value, the Mann-Whitney test substitutes loading *rank* in a combined data set for loading *magnitude*.

Post-reclamation data indicate an accomplishment of the project goals: the reduction of flooding and AMD pollution in Buffer Run and its receiving stream, Little Raccoon Creek. Statistically significant decreases in overall loads were achieved (Figure 8), including acidity (89%), aluminum (90%), and iron (88%).

Component	**Acidity**	**Alkalinity**	**Alum.**	**Mang.**	**Iron**	**SO_4**	**pH**
Overall	-89% Yes	NA	-90% Yes	-64% No	-89% Yes	-50% No	NA
ALD	-67% Yes	NA	-76% Yes	-20% No	Incr. No	NA	NA
SAPS	-99% Yes	+ ∞ Yes	-96% Yes	Neglig. No	-94% Yes	Incr. No	NA
Capping	-91% Yes	NA	-92% Yes	-73% Yes	-88% Yes	-71% No	NA
Slag bed	NA	+99% Yes	NA	NA	NA	NA	+46% Yes

Figure 8. Performance of each component. Statistical significance (α=0.05) is given (Yes/No).

To quantify the overall loading reduction, mean values could be used but may be biased by high flow events or rainfall differences between the years. An alternative is to compare the relationship between loading and flow before and after reclamation. The change in the slope (Figure 9) shows the dramatic loading reduction due to reclamation. The mean annual flow of Buffer Run is about 2 cfs (1 cfs/mi^2) or about 900 gpm. The corresponding mean annual load reduction is 1600 lb/day (2000-400).

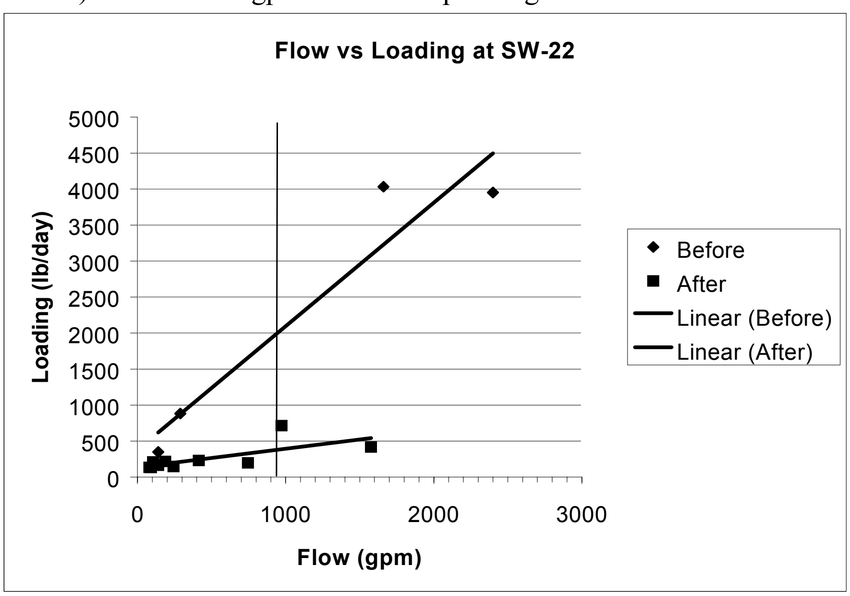


Figure 9. Acidity loading vs. flow before and after reclamation. Vertical bar shows mean annual flow.

The reduction in load can be apportioned by treatment, with the exception of the steel slag leach beds, which were combined with the capping due to the absence of measurable flow in them. Capping and leach beds accounted for 71% of the improvement, the ALD accounted for

5%, the SAPS for 4%, and unknown factors (including OLCs) for 20% (Figure 10). The follow-up monitoring is important because it shows what can be expected of different technologies. The variation in natural flow is a challenge, but can be overcome using non-parametric statistics and the method of graphical analysis in Figure 9.

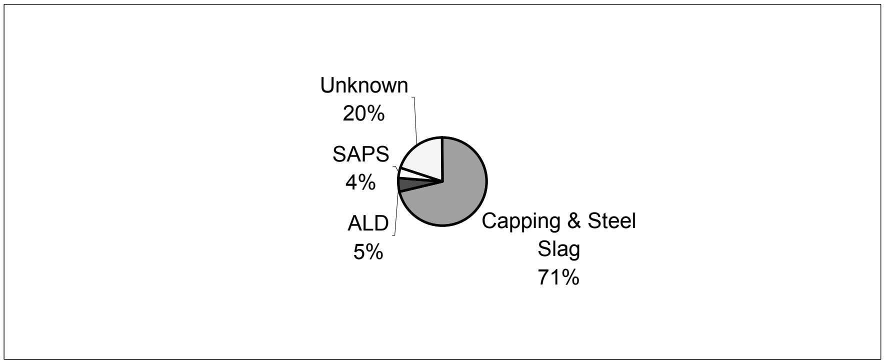


Figure 10. Contributions of reclamation components to overall acidity load reduction.

Conclusion

The partners are involved in various capacities at all stages: community involvement, team building, gathering political support, planning, grant writing, data collection, goal setting, project prioritization, funding, site characterization, project design and engineering, construction, post-construction monitoring, and technology transfer. Keeping partners on board and engaged is critical to restoration success, because no single partner has sufficient resources for the job. The keys to successful partnerships appear to be:

- Early involvement of all stakeholders to ensure that all values are represented;
- Flexibility;
- A watershed coordinator to call partners together and to focus efforts ;
- A shared vision or goal consistent with every partner's goals, clearly and frequently articulated by the Coordinator;
- A regular forum, open to anyone, to air concerns and bring partners together to solve problems and find win-win solutions;
- A rational (e.g., loading-based or alkalinity goal-based) approach to setting priorities;
- Careful characterization of problems to guide the design phase;
- Monitoring of water quality and aquatic health before and after project completion to gage success in order to build political support for later projects.

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