ACID MINE RECLAMATION IN SPOTSYLVANIA COUNTY, VIRGINIA, USA: USING WATER CHEMISTRY AND VEGETATION RE-ESTABLISHMENT AS A MEASURE OF SUCCESS[1]

Robert G. Sobeck, Jr.[2], James E. Perry, Allen Bishop, and Edward Epp

Abstract: In watersheds of the mid-Atlantic region of the US where sulfide spoils occur from mining operations, geochemical reactions develop additional acids in the soil and water supply. The resulting condition lowers ambient pH to very low values (2 to 4 SU). The low pH impairs the soil chemistry and water quality to the extent that native flora and fauna can not survive on the site. This work presents the design and evaluation of remedial work implemented to abate acid mine drainage from a sulfide mine (Valzinco Mine) in the Piedmont Provence of Virginia, USA. Water quality conditions were measured before and after the remediation work, and documented the re-establishment and abundance of native wetland and aquatic vegetation within the site. Data showed that average pH increased from 3.4 to 5.1 and a decrease in total dissolved solids (Fe, Al, Zn, Pb, Cu, Cd, and SO_4^{2-}) over the study period. Initial wetland vegetation, both planted and volunteer, quickly colonized the site with an average ground cover of >74% after five years. Aquatic vegetation cover averaged >50% after 2 years and many plots had coverage >100%. Composition, species richness, and abundance of the new vegetation communities was similar to that of near-by reference (un-affected by mine activities) wetland (>75%, 6.0 spp. m^{-2} vs. 5.5 spp. m^{-2}, average cover 74% vs. 67%, respectively). Two amphibians (southern leopard frog, pickerel frog) and two aquatic reptiles (brown water snake and northern water snake) were captured on the site during the fifth year, indicating a return of herpatifauna to the wetland and aquatic communities. We conclude that the increase in pH, decline in total dissolved minerals, success of the re-vegetation of the site, and return of the reptiles to the site, is a strong indication that the remedial work successfully restored the soil and water chemistry closer to pre-mining conditions. Therefore, we suggest that the successful restoration of this site was based on sound hydrological and biogeochemical principles that can be applied to restoration efforts in other acid damaged watersheds in the mid-Atlantic region.

The reader is also directed to another paper in this volume by Seal et al which presents additional material on this project. The geologic setting, mine location, geochemistry and water quality sampling data are published there.

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Introduction

Knights Branch watershed (~7.8 sq. miles or 20.2 sq. km.) is part of the York River drainage system (2674 sq. miles or 6625 sq. km.) which discharges to Chesapeake Bay. As a Virginia Piedmont headwater catchment, Knights Branch and Music Branch combine to create Northeast Creek which discharges to North Anna River. Knights Branch exhibits water quality characteristics which develop from acid mine drainage (AMD) such as increased acidity and increasing levels of dissolved metals. The pH in Knights Branch remains low (2-4 SU) until the flow mixes with Music Branch to form Northeast Creek. Northeast Creek recovers to neutral conditions (Fig. 1).

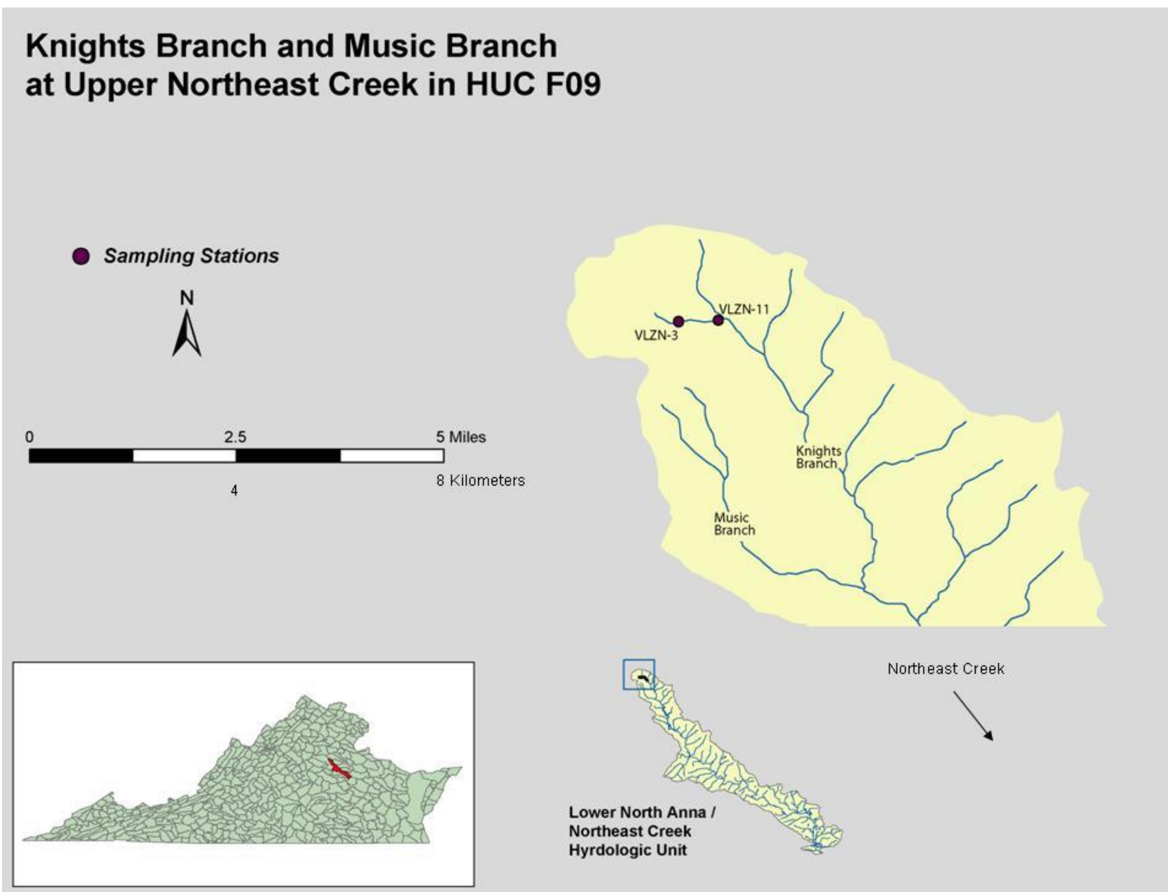

Figure 1. Valzinco Mine at VLZN-3 and Mitchell Mine occurs at VLZN-11 in Hydrologic Unit F09 in Virginia.

The primary causes of AMD in the northwest tributary of Knights Branch are geochemical and microbial reactions occurring throughout the local soils and upper spoils deposited from the operations of a World War II (WWII) lead-zinc mine known as Valzinco (Seal et al, this volume). Another mine was developed downstream in Knights Branch at the confluence of the western and northwestern headwater tributaries to extract gold. The downstream mine site is older than Valzinco, probably pre-Civil War, and is known as the Mitchell Mine (VLZN-11 in Fig. 1, Sweet et al, 1989). The occurrence of a gold mine in a Virginia watershed typically raises the added concern of Hg potentially occurring in watershed sediments as this element was used to combine and capture the Au.

Both mine sites have been surveyed and evaluated through the Orphaned Land Program of Division of Mineral Mining (DMM), in the Virginia Dept. of Mines, Minerals & Energy (DMME), and published as Inventory No's. 8831 and 8828. The mines were ranked with priority ratings of "A" (High) for reclamation. Water quality in Knights Branch was surveyed in 2000 from the Valzinco site to approximately one-half mile downstream of the Mitchell site. The pH remained low (2-4 SU) the entire length of the channel while pH of background waters varies between 4.5-6.5 SU (Seal et al, this volume). Both mine sites have deposits of spoils occurring in the floodplain of Knights Branch, and in the reach at Valzinco the spoils actually comprise the channel and floodplain of the tributary. The occurrence of spoils in the respective floodways has enabled mine spoils from both sites, under fluvial forces, to move through the downstream reaches of Knights Branch and presumably into Northeast Creek.

Reclamation activities began in 2001 and proceeded in two significant phases through 2005. The first phase closed mine entrances and re-established ecological conditions normal to this location in Piedmont Virginia. Valzinco Mine included construction of a dam across the drainage channel of the valley. The greatest mass of spoil rests behind the dam and fills the original drainage channel. The second phase established riparian structures at the dam and downstream wetlands cells to return the channel of Knights Branch to its original location. This alignment is where ground water seeps collect and move to discharge from the northern and southern lands of the watershed.

The mass of acids developed over the decades has dissolved metals mined at Valzinco (Pb, Zn) as well as metals occurring in the saprolite of the watershed (Al, Fe). The rocks in this region of the Piedmont in Virginia are represented schematically in Fig. 2. Sulfide zones, as well as other lithologies, occur in relatively narrow widths along a west-to-east transect. Due to the variation in mineralogy, the more general term of saprolite is used to describe the soft, decomposed rock and clays resident over the basement parent rock.

This paper is primarily concerned with design of elements in the watershed, as altered by the abandoned ore processing facilities at Valzinco Mine, in order to: a.) preclude AMD, b.) re-establish the geomorphology and ecology of Knights Branch watershed, and c.) close Valzinco Mine shafts. Furthermore, the project had to be completed with limited funds which meant that a significant mass of spoils had to be left in place behind the dam constructed for ore processing. Those spoils reside in riparian lands of the watershed and represented the greatest challenge for this project.

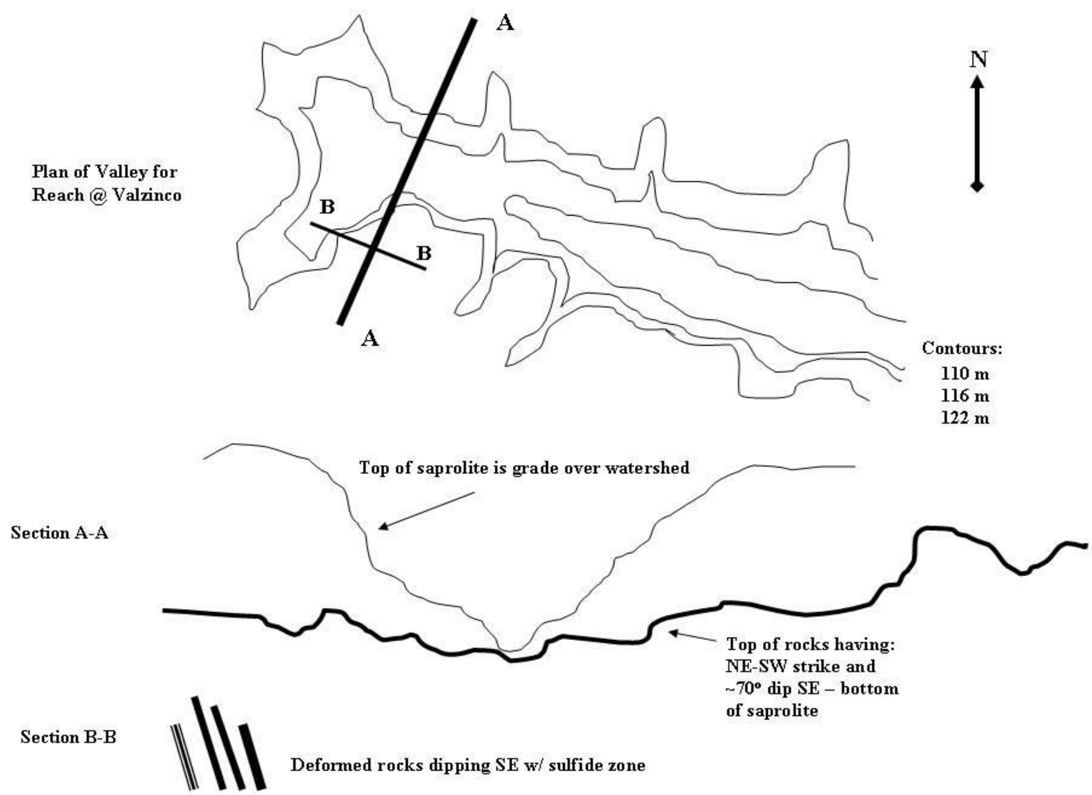

Figure 2. Arrangement of saprolite in Knights Branch at Valzinco Mine.

Valzinco Mine and Knights Branch Watershed

Valzinco Mine

The mine was started to supply metals to support the US in WWI; however, ore was not processed within the watershed until mine operations during WWII (Sweet, et al, 1989) and a processing plant was constructed on-site. Processing operations sent mine spoils and waste processing chemicals to a pond created with a dam constructed across the incised channel and floodplain of the valley. Failure of the dam spillway has enabled fluvial transport of mine wastes down the watershed although a substantial mass of spoils remains on the upstream side of the dam. The dam is substantial and could not be removed. The dam was constructed with a spillway at the north end to force Knights Branch in that direction thereby slowing flow to settle the waste sediments into the former channel of Knights Branch.

<u>Knights Branch</u>

Figure 3 is a spectral photograph of the Valzinco site that relates certain wavelengths of light energy to acid conditions along the riparian parts of the stream. The aqua-blue color of the photograph correlates to low pH of water in the vegetation and soils of the watershed (Anderson, 1999). The white areas, transecting the light blue valley in the center of the figure, represent the approximate alignment of the constructed dam at Valzinco.

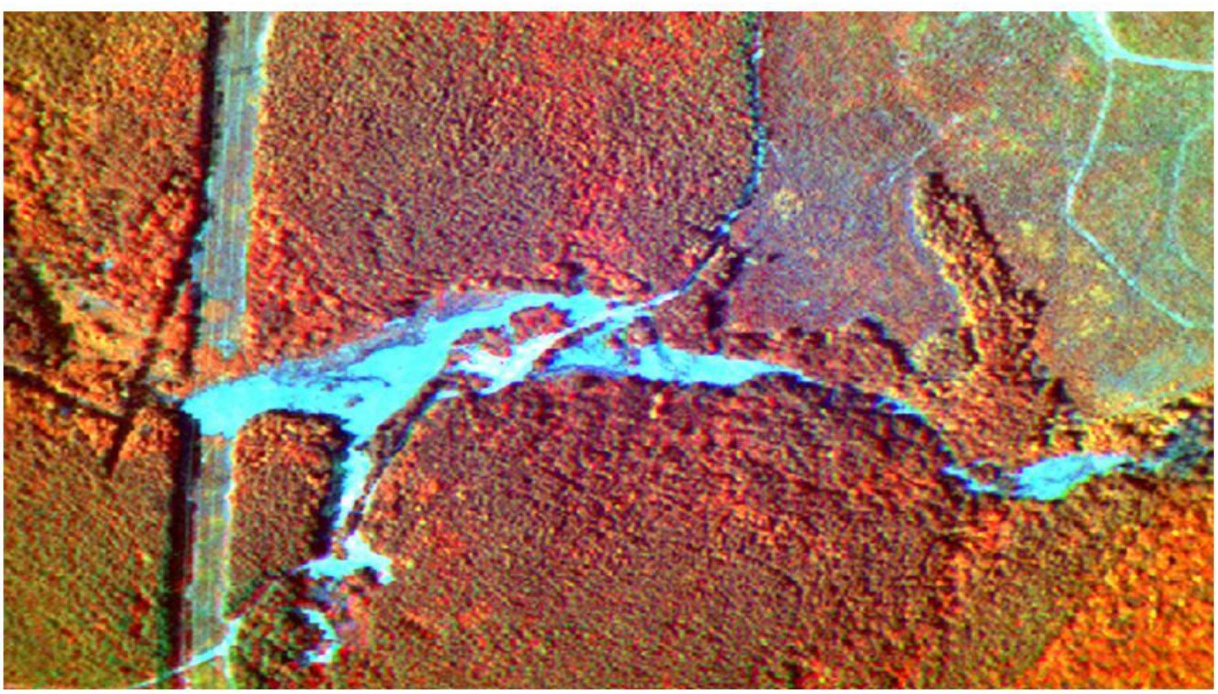

Figure 3. Aqua-blue in the spectral reflectance photo represents AMD effects in Knights Branch.

From a geomorphic perspective, once mine spoils are transported into fluvial segments of a watershed, watershed sediments and spoils intermingle and move as a composite mass. Understanding the fate and transport of the sediments mixture becomes a more important part of reclamation activities conducted downstream of the original mine site. The maximum sediment mass typically transports under bankfull flow regime which recurs between 1.5 years and 2.5 years depending on the hydrological characteristics of a watershed system. At Valzinco, the abandonment of the mine site occurred at the close of WWII and Phase I reclamation occurred in 2001 – a 56 year interval. Assuming an average bankfull flood every two years would imply between 25 and 30 significant floods capable of transporting mine sediments through the watershed with saprolitic material. Furthermore, two significant hurricanes, Camille and Agnes, created significant floods through the entire York River basin at the approximate midpoint between abandonment and reclamation ensuring mine waste transport through the Knights Branch watershed. Therefore, the reclamation at Valzinco necessarily encompassed restorating geomorphic conditions suitable to this region of Virginia.

Finally, the background ambient conditions of Virginia Piedmont, acid precipitation and lack of alkaline geologic materials, indicate that any significant additions of acid to the watershed will lower the pH of the waters below acceptable water quality criteria set forth in the Virginia Administrative Code (9 VAC 25-260-50). As mine spoils erode and deposit through the watershed, the development of AMD spreads. Hydrological trends of precipitation, and resulting hydraulic regimes, transport acids from the saprolite of the watershed to the discharge carried by the incised channels. Water quality modeling is beyond the scope of this paper, however, the authors measured higher masses of dissolved metals under transport during times of elevated flows

Methods

Stream flows were measured using stream gaging and computation methods of the US Geological Survey (USGS) as published by Rantz (1982). The geologic setting, geochemistry and detailed results of decade-long water quality sampling are presented in a companion paper published by Seal et al (this volume).

A simple ground water model was constructed using stream data collected under drought conditions through the summer of 1999 (Bear, 1979). Seepage through the dam face and along Knights Branch was measured with a current meter at various locations in the channel. The drought ensured base-flow conditions occurred in the stream and the assumption was made that local stream measurements quantified additions of ground water between measurement sites through the valley. The model and measurements indicated the surcharge of spoils, and the dam structure constructed for the former tailings pond; ensure an upward seepage of ground water directed into the former incised channel draining the watershed. Figure 4 is a graphic representation of the location of spoils in Knights Branch. The incised channel of the valley (blue lines) was the discharge for local ground water and surface drainages. Additional data and analysis concerning trends in ground water flow through the valley are presented in the Reclamation Design section of this paper.

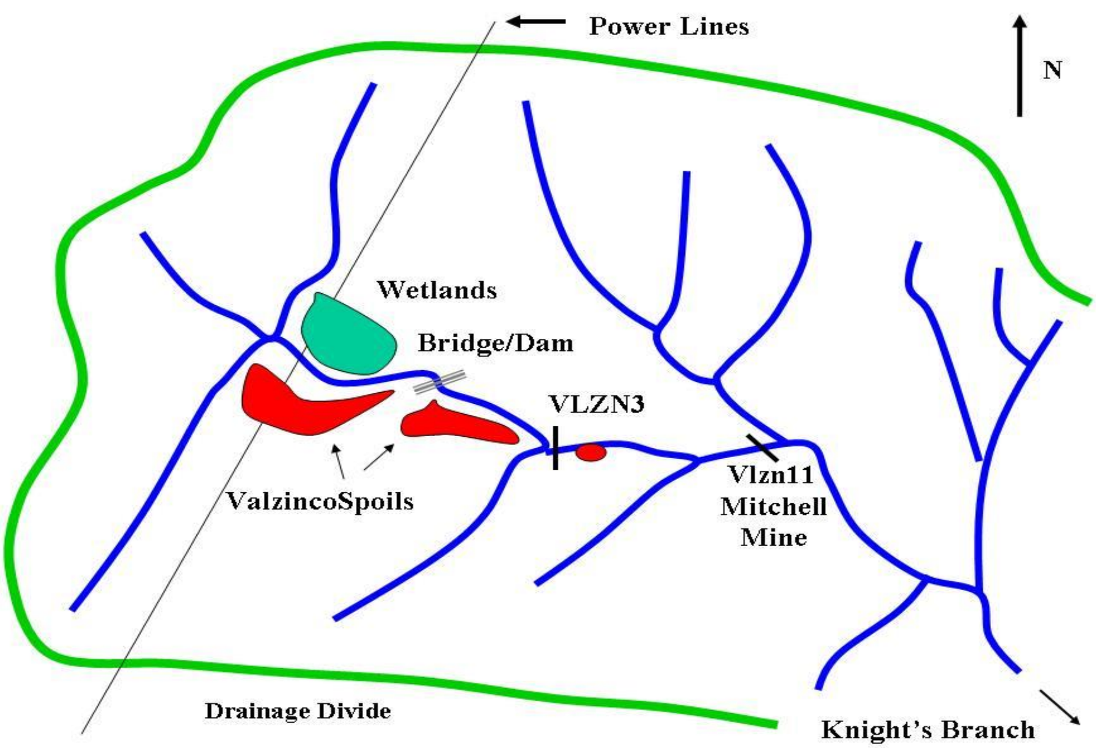

Figure 4. Arrangement of mine spoils in upper Knights Branch watershed (USGS, 1983).

Upstream water quality was used to evaluate changing environmental conditions before and after reclamation efforts (see Seal et al, this volume). At Valzinco, wetlands had developed on saturated spoils along Knights Branch and that ecology was expanded to reclaim the riparian lands.

Geomorphic characteristics of the valley and incised channel below the dam were studied and characteristic measurements taken. Sediment transport modeling techniques (Sobeck, 2000) were used to assess how mine spoils were eroding and depositing through the valley. This material was also used to design geomorphic elements of the Valzinco reclamation and return the patterns of erosion and deposition to conditions more representative of weathering saprolite in Piedmont Virginia. A recovery model for sulfate sediments and AMD drainage was used from another tributary in the North Anna River basin (Movall, 1986) to formulate the conceptual design at Valzinco. However, the design at Valzinco included a concept to preclude development of excessive AMD and dissolved masses of metals discharging to the drainage basin.

For post-restoration data, vegetation was sampled along line transects in the three restored cells. Each transect began at a random distance along an established baseline at each cell and ran from south to north. For pre-restoration, 10 random plots were sampled in the existing wetland. A 1m X 1m square quadrat was used on both sample dates: placed at a random point at 10m intervals along transects for post restoration, and random along a baseline in the pre-restoration sample. Individual species coverage (including bare ground as a species) and water depth were measured in peak season (mid-August) (Perry and Atkinson, 1996; Perry and Hershner, 1999; DeBerry and Perry, 2004) of 2002, 2005, and 2007. Only the data from 2007 will be presented in this manuscript. Relative cover and relative frequency was used to calculate Importance Value (IV) (Perry and Hershner, 1999). Dominant species identified as those species that had an IV equal to, or greater than, 20%. Data from Beal (1977) was used to determine pH average and pH range of wetland and aquatic species. No pH data was available for upland species. All plants were identified to species level according to Fernald (1950), Radford et al. (1968), Gleason and Cronquist (1991), Weakley (2002), and the Flora of North America Association (2002). Nomenclature followed the Flora of North America Association as cited in the USDA, NRCS (2005).

Results and Discussion

Pre-reclamation Conditions in Knights Branch

Knights Branch has been monitored for hydrology, water quality, and sediments, from May 1998 to the present, prior to and after phased reclamation construction (Phases I and II). Monitoring continued after reclamation construction for existing parameters as well as ecological indices pertinent to the expanded wetlands (Seal et al., 2008). The data developed from the February 2000 sampling event, as excerpted in Table 1, indicates characteristics of the impaired water quality conditions in Knights Branch as AMD mixed with the receiving waters. While seasonal variations in the watershed altered the flows and metals concentrations in the receiving waters, the February 2000 data is representative of the ongoing degradation. Again, the metals are dissolved out of the residuals left from ore processing and from naturally occurring saprolite of the Piedmont such as aluminum in clay minerals.

The data was used to calculate mass-flow conditions in Knights Branch for each constituent and relate the impairment to the pH as shown in Fig. 5.

Table 1. Flow and water quality conditions in Knights Branch, upstream and downstream of Valzinco Mine, prior to reclamation in February 2000.

Location	Flow L/s	pH	Alkalinity	Calcium	Lead	Zinc	Aluminum
Upstream	7.5	5.6	1.6 mg/l	1.7 mg/l	0.007 mg/l	0.085 mg/l	0.15 mg/l
Downstr.	21.2	3.9	None	1.5 mg/l	0.18 mg/l	2.9 mg/l	0.83 mg/l

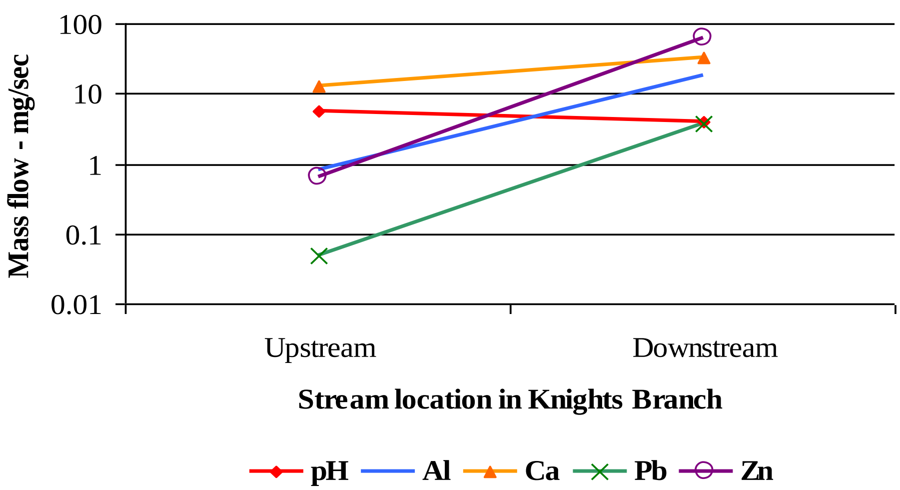

Figure 5. Instantaneous mass-flow of selected metals in Knights Branch, upstream and downstream of Valzinco Mine, prior to reclamation.

The following summary statements are supported by the data collected prior to reclamation:

a. Water quality was impaired in Knights Branch from Valzinco to a point downstream of Mitchell Mine until the confluence with Music Branch;

b. Acidity increased from Valzinco through the length of the northwest tributary of Knights Branch and downstream in the mainstem channel to VLZN11;

c. The increased acidity dissolves heavy metals and other constituents from the mine spoils and saprolite resident in the floodplain and mainstem channel of Knights Branch;

d. Water flowing through the site was impaired and not meeting specific water quality standards of Virginia. The pH of the receiving water flowing through the mine site fluctuated between 2 and 4 SU. Concentrations of Pb in the water column were reported in excess of 1 mg/l, or 2 orders of magnitude above the standard for drinking water and 1 order of magnitude above the maximum fresh water chronic criteria (~ 0.08 mg/l);

e. No woody vascular plants were able to survive at Valzinco, more than likely due to impaired soil and water quality;

f. The main stem channel through the Valzinco site and the entire reach of western tributary in Knights Branch maintained a discharge through the 1998-99 drought; flow in August 1999 was essentially a base condition for the tributary at the close of the drought;

g. Flows out of the Valzinco valley vary from less than 3 Lps (Aug. 99) to greater than 184 Lps following a 4-year storm event (Sept 99),

h. Under all flow regimes, the bulk of the metals occurring in the water column were dissolved forms; and

i. Mass transport of dissolved metals was highest when flows were high although concentrations of metals were low and pH raised.

<u>Mass Transport of Sediments</u>

The transport of mine waste out of Valzinco valley has created similar environments at locations where sediments deposit through downstream reaches of Knights Branch. As Knights Branch flows through the Valzinco valley, it begins to pick up sediment load from the remainder of the watershed in addition to the mine waste spoils transported below the dam. Bankfull flow is the primary mechanism of sediment transport (Leopold, 1994); precipitation capable of producing that channel flow regime primarily determines the arrangement of spoils from Valzinco. Figs. 6, 7 and 8 indicate the development and propagation of AMD and spoil transport within the fluvial regime of Knights Branch.

Figure 6. Valzinco mine spoils and saprolite sediments above the dam in Knights Branch.

Figure 7. Valzinco mine spoils and saprolite sediments transported below the dam in Knights Branch towards sampling station VLZN-3.

Figure 8. Mass transport of Valzinco spoils and watershed sediments out of Valzinco valley.

Pre-Existing Vegetation

As can be seen in Figs. 6-8, vegetation was sparse to non-existent. Small pockets of soft rush (*Juncus effusus* L.) and golden club (*Orontium aquaticum* L.) occurred along the periphery. Only the golden club, an aquatic plant that inhabits running water, appeared to occur in a perennial state while the soft rush did not occur in the same spot from year to year. On the northwest edge of the restoration site (see Fig. 6, left) was a small wetland area dominated by cotton grass (*Eriophorum virginicum* L.), an acid-loving plant listed as a species of special concern in Virginia (Townsend, 2007) and rice cut grass (*Leersia oryzoides* (L.) Sw.). Southern-bog cranberry (*Vaccinium oxycoccos* L.), also an acid-loving plant listed as a species of special concern in Virginia (Townsend, 2007). Woody species rarely survived for more than a year on the spoils and were usually represented by only their standing-dead remains (see Figs. 6-8).

Reclamation Design at Valzinco

The reclamation design for Valzinco Mine incorporated desirable elements of the ambient conditions in the watershed and alter those conditions that were objectionable.

The positive attributes of the mine site are:

a. Wetlands had developed on spoils which were saturated with ground water;

b. A dry pit on site served as a suitable landfill for excavated mine spoil;

c. The surrounding land is well vegetated which minimizes runoff peaks during significant storm events;

d. Music Branch introduces alkalinity at the confluence with Knights Branch and water quality recovers in the main stem channel to neutral pH; and

e. Knights Branch discharges under dry and wet periods maintaining saturated conditions in the soils of the Valzinco valley.

The most significant processes to alter in Knights Branch, which impaired the water quality, were as follows:

a. The geochemical and microbial oxidation-reduction reactions, within exposed spoils and sediments at Valzinco, increase the acidity of Knights Branch water supply. This occurs through repeated wetting and percolation of resultant acids through the exposed spoils and sediments;

b. Periodically, mine spoils are fluvially transported, through the existing channel at Valzinco, downstream in the Knights Branch watershed to depositional environments;

c. The acidity that develops at Valzinco increases the dissolution of certain elemental species, such as aluminum, present in the naturally occurring sediments and rock of Knights Branch watershed; and

d. The country rock in Knights Branch watershed appears devoid of alkalinity.

The pre-mine location of Knights Branch is filled with spoils and spent chemicals from processing ore as depicted in Figs. 9 and 10.

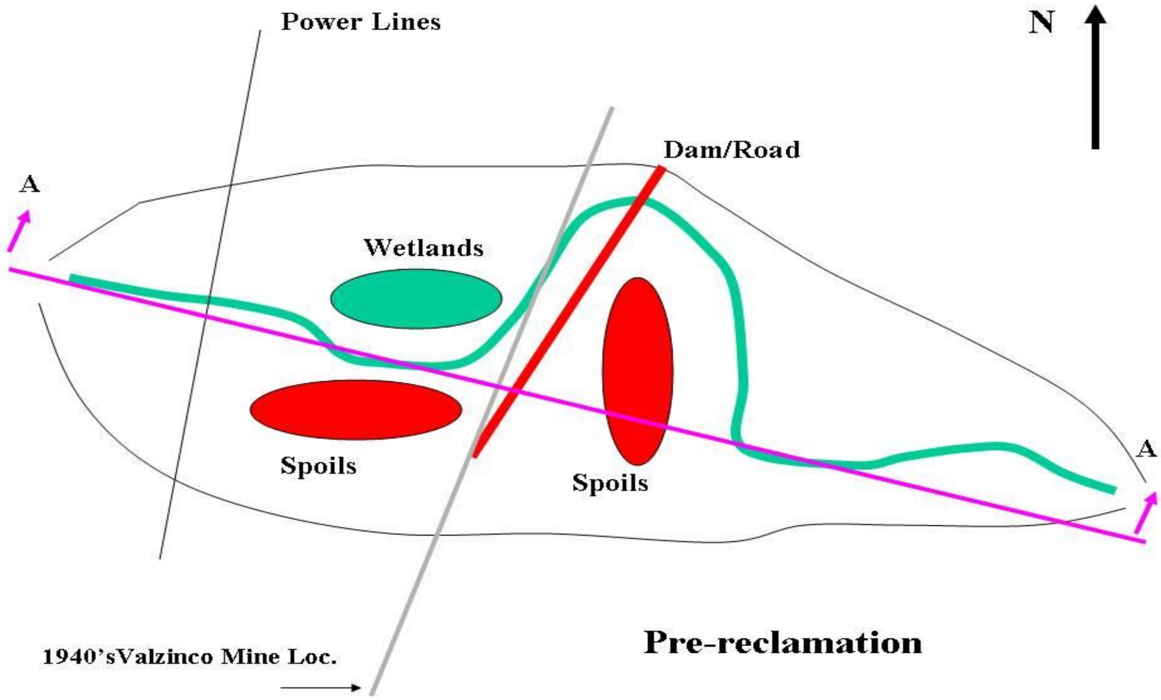

Figure 9. Position of stream channel after mining operations ceased at Valzinco.

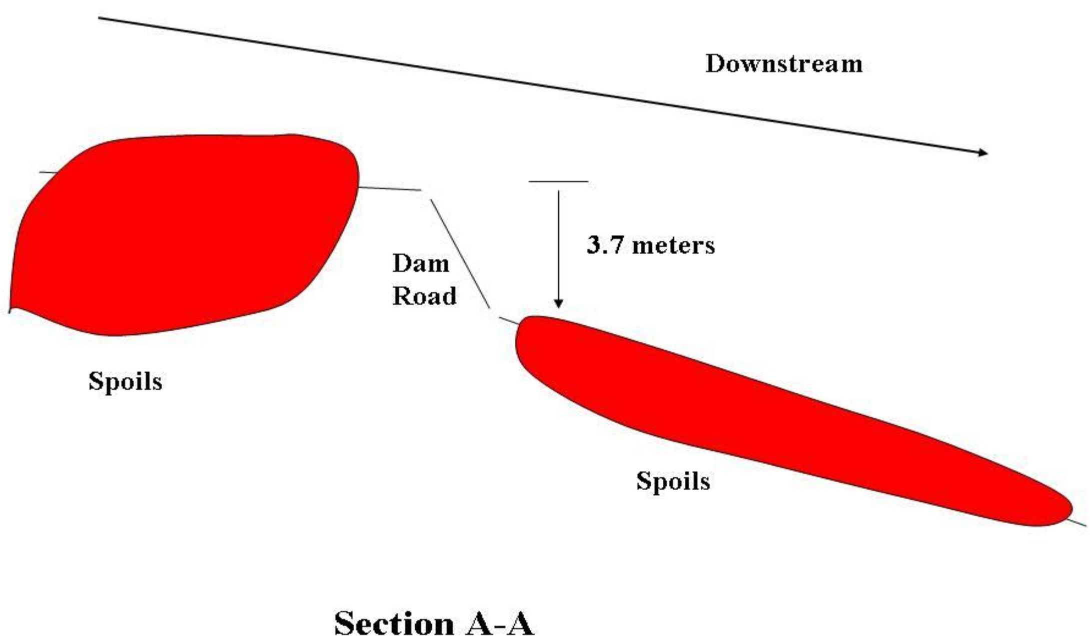

Figure 10. Depth and extent of spoil mass along Knights Branch in Valzinco valley.

As depicted in Figs. 9 and 10, the spoils mass was greater than 3 meters deep on the upstream side of the dam at Valzinco and the downstream spoils were typically above the water level of Knights Branch when flows were below bankfull-stage. The environmental objectives of reclamation design at Valzinco were as follows and shown conceptually in Fig. 11:

a. Separate the occurrence of the free oxygen interface from the mine spoils;

b. Promote the expansion of wetlands over the saturated spoils and provide a temporary source of alkalinity until naturally occurring alkalinity develops in the anoxic zones of the sediments;

c. Reduce the uptake of metals by vegetation in wetlands;

d. Reduce fluvial transport of mine spoils downstream in the Knights Branch watershed; and

e. Alter ground water chemistry occurring near the surface of the floodplain at Valzinco to promote anoxic conditions.

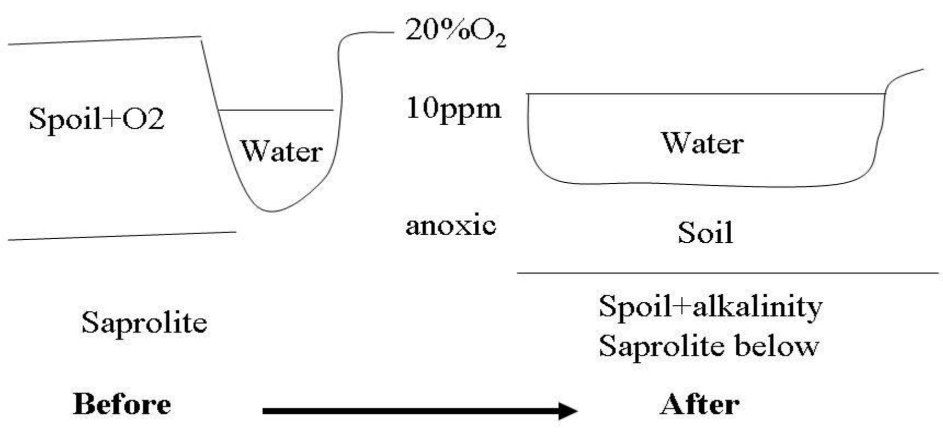

Figure 11. Conceptual design for the conditions in Knights Branch watershed at Valzinco above and below the dam site.

Re-establishing Knights Branch geomorphology with the Valzinco dam

As noted in Table 1, flow across the valley increased approximately by a factor of three. During the drought period of 1999 (pre-reclamation), the lead author measured a channel flow over the dam of 0.3 Lps and a channel flow of 0.7 Lps at the downstream limit of the valley (Sta. VLZN3 in Fig. 4). At the same time, seepage flows accumulating at the southeast toe of the dam measured 0.17 Lps. Similarly, at the close of the drought in October 1999, an approximate 4-year precipitation event developed a channel flow of 98.8 Lps at the dam (north end) and the discharge of the channel at the downstream limit of the valley was 185 Lps at VLZN3. Therefore, it was evident that significant amounts of ground water and surface water were developing from the south side of the valley below the former spoils dam. That is, spoils in the former incised channel acted as a significant source of seeps that discharged through the dam face.

Fluvial forces are the most efficient mechanism of sediment transport (i.e., mine spoils) through a watershed. The objective of reversing the biogeochemical processes developing AMD had to be achieved while accommodating the naturally occurring discharge of Knights Branch under flood conditions. The reclamation design completed by the authors at Valzinco accomplishes the following (see Figs. 12 and 13):

a. Excavated spoils to a depth 0.6 meters below finished grade in all planned wetlands cells;

b. Capped all spoil masses, within planned wetland cells and all other locations, with 0.6 meters of clean soil and vegetation;

c. Shifted the location of the anoxic zone into the clean soil cap that supports the wetlands and moved the oxic zone into the water column;

d. Initiated the test of a bacteriacide over 2 spoil landfills which are subject to wetting fronts from percolation of precipitation through their caps;

e. Maintained the subsurface hydrologic regime and ground water levels as currently established while diffusing prior channel flow (depths of 1.83 to 3.05 meters) across the dam and back to the location of the former incised channel carrying the stream. This maintained saturated conditions in the soils supporting the wetlands while reducing fluvial transport under flood;

f. Added alkalinity throughout spoil masses through the use of submerged, sacrificial, aggregate limestone (85% reactive) beds;

g. Planted vegetation, over sloped areas subject to highest velocities, capable of withstanding 2.1 to 3.05 meters-per-second velocities developed by surface water flows during floods;

h. Promoted low-profile aquatic vegetation in the wetlands cells to avoid uptake of dissolved metals as root growth remains within clean soil cover;

i. Decreased slopes to reduce erosion potential;

j. Confined spoils to small areas in landfills and decreases percolation of precipitation; and

k. Established ground water monitoring wells throughout the valley, above and below the dam, to monitor ground water quality discharging to Knights Branch.

As stated previously, this design altered the overall site to preclude AMD from developing. This was accomplished in saturated riparian lands by shifting the oxidation-reduction potential above and within spoil masses to favor reducing conditions. Buried limestone was sacrificial alkalinity for promotion of vegetation. As reducing conditions develop in anoxic sediments of the wetlands, the biogeochemical cycles yield alkalinity and preclude oxidation of the various metal complexes within the spoils (Herlihy, 1984, Moval, 1986). The geomorphic elements of the design control flood waves and promote normal transport of watershed sediments (see Figs. 18 through 20). The two landfills confined spoils to a small "footprint" and have developed vegetation over the soil caps.

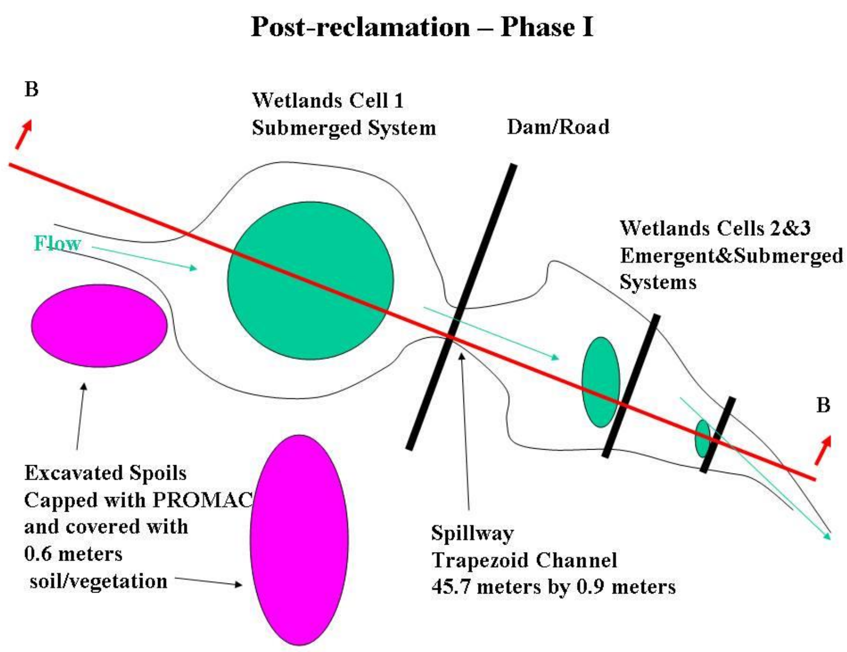

Figure 12. The surface design for reclamation of Valzinco Mine and restoration of Knights Branch.

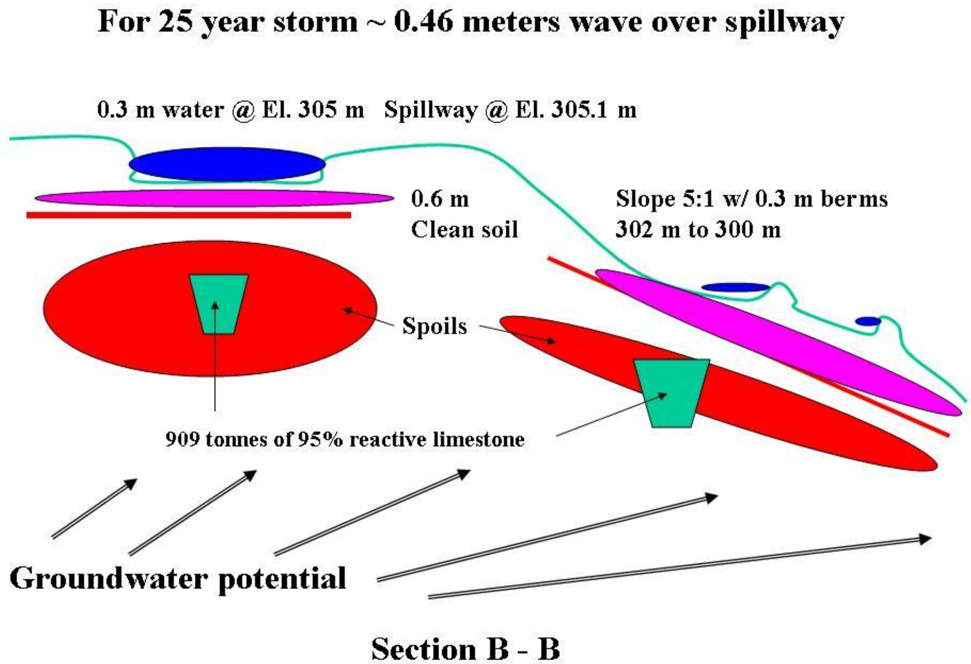

Figure 13. The subsurface aspects of the reclamation-restoration design in Knights Branch.

The reclamation construction for Phase I was completed in 2001-2002 as shown in Figs. 15 through 18.

Figure 14. Covered spoils under soil cap contiguous to Knights Branch approaching Wetlands Cell 1.

Figure 15. Soil cap over landfill containing wet-excavated spoils with microbial inhibitor applied.

Figure 16. New 46 meter spillway cut into dam structure and regarded dam face with vegetation mat on 5:1 slope.

Figure 17. Berm 1 is in foreground forming Wetlands Cell 2; the new spillway over the dam shows in the background.

Phase I was completed during drought conditions and stream flows measured during pre-reclamation were abnormally low. Phase II was completed after studying the geomorphic characteristics of Knights Branch and measuring the hydrologic conditions under various floods. Figure 19 shows conditions at the close of Phase I construction, the close of the drought and as ground water is accumulating in the three wetlands cells. It was necessary to allow flood conditions to develop over the site to re-establish erosional features after Phase I reclamation activity. This was especially important in the altered riparian lands since cover soil was placed over spoils under saturated conditions and continuous channel flows.

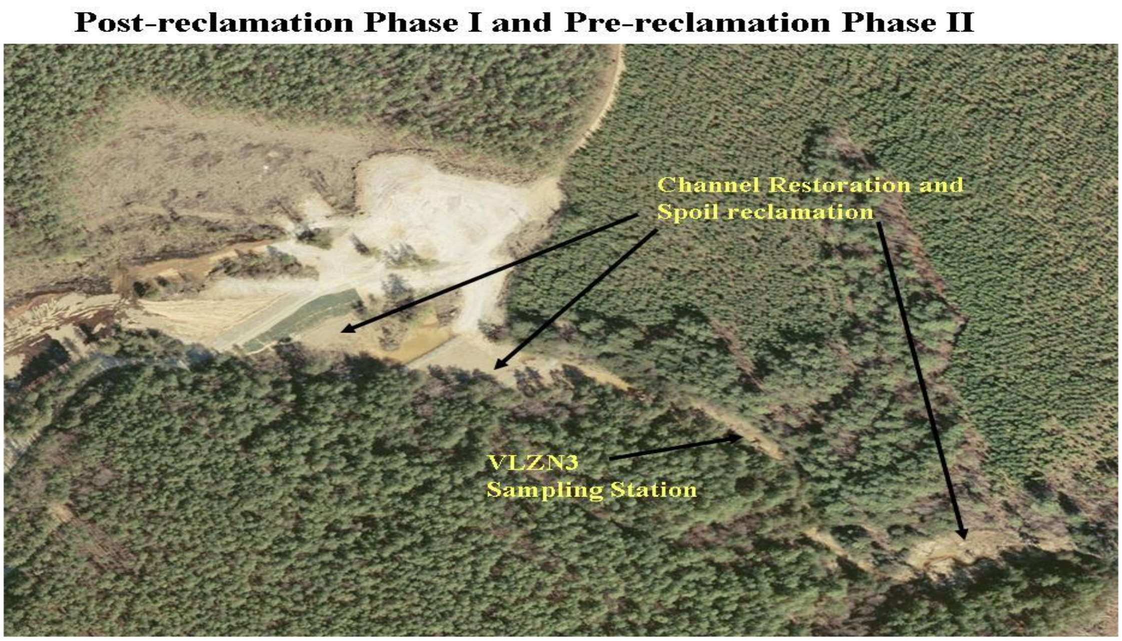

Figure 18. Phase II establishes a southern channel for Knights Branch from the dam through Wetlands Cell 2.

The bankfull stage for the stream channel was established and an equivalent channel designed and constructed on the downstream face of the dam and at the discharges of the wetland cells (ends of arrows). Figure 19 represents the final design details for completing Phase II in Knights Branch. In this phase, the channel was reconstituted along the southern side of the valley in the location of the former incised channel prior to the construction of the dam. Periodic flood waves over the dam caused erosion on the downstream face, over the location of the pre-mine channel, as indicated in Fig. 20.

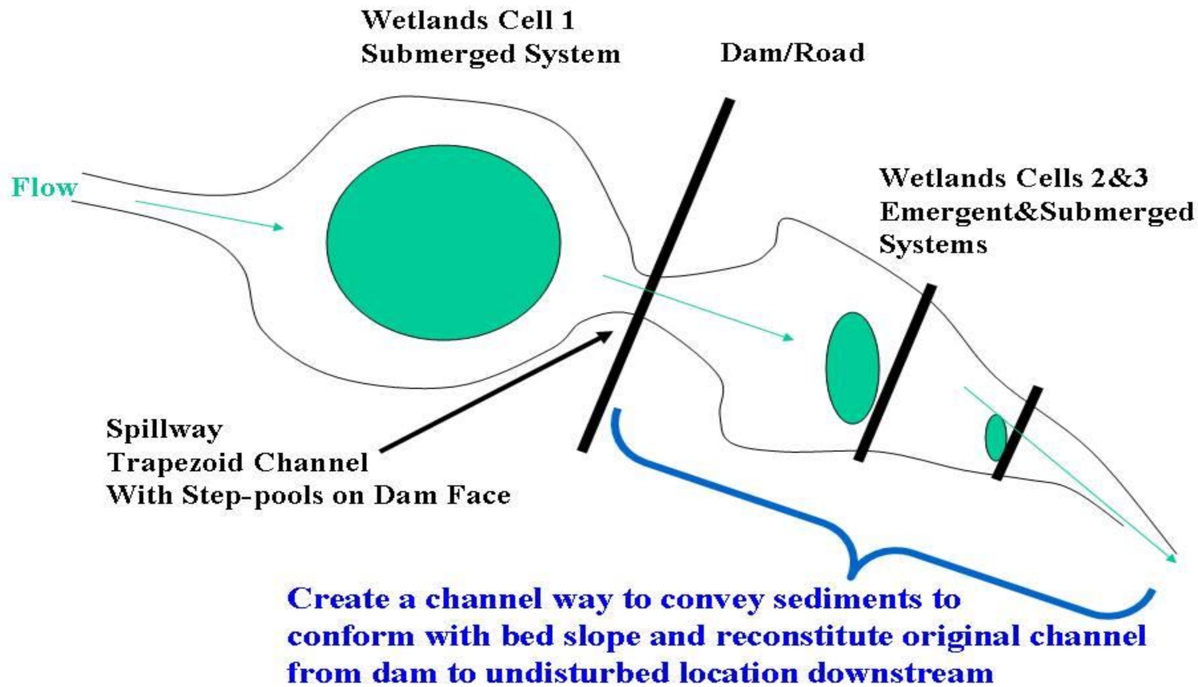

Figure 19. Added design features along Knights Branch to match hydrology to the geomorphic features of the valley.

Figure 20. Channel development over the dam (2003) along the south side of the watershed and location of Phase II step-pool structure.

Phase II construction completed in Knights Branch at Valzinco continued to promote the development of vegetation and increased the alkalinity of the surface and ground water to support restoration objectives in the watershed.

Post-reclamation Conditions in Knights Branch

Three water quality sampling events were completed in Knights Branch since Phase I reclamation construction (Seal et al, 2008). As noted above, mass-flow of dissolved metals was highest when flows in Knights Branch were elevated. To evaluate performance of the reclamation designs, water quality characteristics should be compared under similar hydrologic conditions at the same location. Hydrology and water quality at a remote site such as Valzinco are measured as discrete samples since a flow gage and composite sampler were beyond the financial budget for this project. Water quality characteristics in Knights Branch at Sta. VLZN3 are presented in Table 2 and Table 3 for dissolved and total forms for each parameter. Knights Branch was flowing under approximately equal hydraulic conditions and the results represent pre- and post-restoration. However, the water temperature in February 2000 was much lower than the water temperature in June 2007 during the sampling events.

Table 2. Water quality at Station VLZN3, February 3, 2000 (water temperature equal to 1^{o}C).

Feb 2000	pH	Alkalinity	Aluminum	Calcium	Lead	Zinc
Dissolved	3.9	none	0.83 mg/l	1.5 mg/l	0.18 mg/l	2.9 mg/l
Total	3.9	none	0.83 mg/l	1.5 mg/l	0.19 mg/l	2.9 mg/l

Table 3. Water quality at Station VLZN3, June 6, 2007 (water temperature equal to 26^{o}C).

June 2007	pH	Alkalinity	Aluminum	Calcium	Lead	Zinc
Dissolved	5.1	2.45 mg/l	0.079 mg/l	12.4 mg/l	0.002 mg/l	1.32 mg/l
Total	5.1	2.45	0.369 mg/l	12. mg/l	0.034 mg/l	1.33 mg/l

Flows were measured at Sampling Station VLZN3 during the sampling events noted in Tables 2 and 3 and equaled 600 Lps and 586 Lps, respectively. Therefore, instantaneous mass-flows for the various constituents may be calculated for February 2000 and June 2007 using dissolved forms for each constituent as indicated in Table 4.

Table 4. Dissolved mass-flow of various metals at Sampling Sta. VLZN3 before, and after, reclamation.

Date	Temp ^{o}C	Alkalinity	Aluminum	Calcium	Lead	Zinc
Feb 3 ‘00	1	0 mg/s	17.6 mg/s	31.8 mg/s	3.8 mg/s	61.5 mg/s
June ‘07	26	50.7 mg/s	1.64 mg/s	257 mg/s	0.03 mg/s	27.3 mg/s

The calculations presented in Table 4 indicate the masses of dissolved metals are decreasing with time in Knights Branch as a trend resulting from restoration of Valzinco valley. Noting the difference in temperatures for the two sampling events, and the general condition that warmer waters dissolve greater masses of ions, the data indicate the effects of Valzinco spoils over the valley are diminishing and the biota are returning to more naturally occurring forms. The soils of the watershed will require some period to elutriate and find an equilibrium condition representative of the Piedmont.

Flora and Fauna

Figures 21 through 24 show the continued development of vegetation and channel flood plains through Phase II reclamation construction.

Figure 21. Former spoils area upstream of the dam and surrounding Wetlands Cell 1.

Figure 22. Former location of Knights Branch channel at northern end of dam.

Figure 23. Knights Branch below the dam and reconstituted channel to the right.

Figure 24. Downstream limit and wetlands of the Valzinco valley below the dam

The vegetation community of Cell 1 was dominated by spike rush (*Eleocharis obtusa* (Willd.) Schult., IV = 25.1) and bladderwort (*Utricularia gibba* L., IV = 22.2) (Figures X1-X2, Table 5). Where water was greater than 10cm deep, bladderwort coverage often exceeded 100%. Average cover for the cell was 74.7%. The annual weakstalked bulrush (*Schoenoplectus purshianus* (Fernald) M.T. Strong) was seasonally common with in the cell (IV = 10.6). This was a surprising find as it is usually found in alkaline systems with a mean pH of 7.1 and range of 6.7 to 8.3. Bare ground, treated as a species in our cover data, was also dominant with IV = 29.0.

Table 5. Vegetation coverage of quadrats from each cell. (WD = water depth, SD = standard deviation). Running mean square (Mueller-Dombois and Ellenberg, 1974) was used to determine minimum number of quadrat samples needed.

	Coverage Cell 1 (%)	**WD-1 (cm)**	**Coverage Cell 2 (%)**	**WD-2 (cm)**	**Coverage Cell 3 (%)**	**WD-3 (cm)**
	118.5	**1**	**76**	**5**	**90.2**	**5**
	163.1	**50**	**40**	**15**	**95**	**15**
	168.1	**50**	**81.1**	**5**	**75**	**5**
	27	**10**	**90.1**	**10**	**43.6**	**10**
	40	**15**	**90.1**	**1**	**70.1**	**1**
	57.5	**10**	**80.2**	**10**		
	52	**10**	**80.1**	**10**		
	7.5	**15**	**107**	**10**		
	64	**10**	**50.1**	**10**		
	50	**5**	**62**	**0**		
Average	**74.8**	**17.6**	**75.7**	**7.6**	**74.8**	**7.2**
SD	**52.9**	**17.6**	**19.9**	**4.7**	**20.3**	**5.4**

The bulrush and spike rush dominated the vegetation community of Cell 2 (IV = 27.3 and 23.9, respectively) (Fig. 23, Table 5). There was less standing water on the site compared to Cell 1. Average cover for the cell was 75.7%. Bare ground was also dominant with IV = 24.9. Many woody shrubs were established within the cell (although, not encountered in our quadrats) and included such species as buttonbush (*Cephalanthus occidentalis* L.), highbush blueberry (*Vaccinium corymbosum* L.), spice bush (*Lindera benzoin* (L.) Blume), and hazel alder (*Alnus serrulata* (Aiton) Willd.). Several trees, including American sycamore (*Platanus occidentalis* L.) black willow (*Salix nigra* L.), river birch (*Betula nigra* L.), and red maple (*Acer rubrum* L.), had reached an age of 2 to 3 years old and appear to be healthy and robust.

Spike rush dominated the vegetation community of Cell 3 (IV = 29.8) (Figure 25, Table 5). As with Cell 2, there was less standing water on the site compared to Cell 1. Average cover for the cell was 74.8%. Bare ground was also dominant with IV = 27.3. Again, many of the same shrubs and tree species were volunteering in the cell. Due to recent regarding work on the cell, few of these were greater than a year old. However, those present appeared to be healthy and robust.

A total of 16 species were encountered in our quadrats (Table 6). All of these are considered broad ranging species found in habitats with a pH usually ranging between 4 and 8. Two species (*Cyperus odoratus* L. and *S. purshianus*) are usually found in more alkaline habitats (i.e. pH >7).

Table 6. Mean pH and range for all species encountered in quadrats. Data was calculated from Beal (1977). NA = data not available, * = data for that specific species not available but calculated from similar members of that genus. ** = plants that occurred in near-by undisturbed wetland.

Species	Mean pH	ph Range
Bidens cernua* L.*	**NA**	**NA**
Cyperus odoratus* L.*	**8.5**	**NA**
Dichanthelium scoparium* (Lam.) Gould*	**NA**	**4.0-7.5***
Dulichium arundinaceum* (L.) Britton*	**4**	**4.8-7.5**
***Eleocharis obtusa* (Willd.) Schult.**	**6.8**	**4.1-8.7**
Juncus acuminatus* Michx*	**6.8**	**4.2-8.3**
Juncus effusus* L.*	**6.8**	**4.8-8.2**
Leersia oryzoides* (L.) Sw.*	**6.9**	**5.1-7.9**
Leersia virginica* Willd.*	**8.5**	**NA**
***Lespedeza cuneata* (Dum. Cours.) G. Don**	**NA**	**NA**
***Polygonum pensylvanicum* L.**	**NA**	**4.5-8.5***
***Schoenoplectus purshianus* (Fernald) M.T. Strong**	**7.1**	**6.7-8.3**
Sparganium americanum* Nutt.*	**6.2**	**4.9-7.2**
***Utricularia gibba* L.**	**5.1**	**4.8-7.0**

Ten plant species were encountered in our quadrats within the near-by undisturbed wetland. All ten species were also found in the restored cells (Table V2). Therefore, the two sites were very similar with a Simpson's Index = 76.9% (note: any SI >50% considered similar). Species richness from the Valzinco site was slightly higher a 6.0 spp. m^{-2} vs. 5.5 spp. m^{-2}, for the undisturbed wetland. Mean cover of the Valzinco cells was also slightly higher (74% vs. 67%).

Summary

In summary, the vegetation communities of the restored cells were similar to near-by wetlands. Species coverage, composition, and richness were similar to a natural system. The occurrence of numerous woody trees greater than one year old indicates that woody vegetation can now survive on the site.

It is important to note, that although no organized effort was made to gather data on the herpatifauna, several specimen of reptiles and amphibians were captured and/or noted in the cells. These included two southern leopard frogs (*Rana sphenocephala*), five pickerel frogs

(*Rana palustris*), one brown water snake (*Nerodia taxispilota*), and three northern water snakes (*Nerodia sipidon*). All four of these species are usually found in wet and/or aquatic habitats (Martof et al. 1980). Their presence indicates that the restored site now provides habitat for herpatifauna, a point that needs further study since herpatifauna are renowned for their sensitivity to acidification.

Mine operations resulted in large masses of spoils and spent chemicals deposited in the riparian lands of Knights Branch. This project returned the position of Knights Branch channel to its pre-mine location. It also precludes the development of AMD by inhibiting the mixture of ambient oxygen with spoils. Furthermore, geomorphic principles were used to incorporate mine residual elements and structures, such as the dam used to settle spoil masses, in the design. The design has re-established the biogeochemistry and ecology representative of this part of Virginia Piedmont.

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