Bioremediation in the Campesino Community of Cordillera Blanca, and other areas of the Three Watersheds Municipal Commonwealth

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CONTENTS

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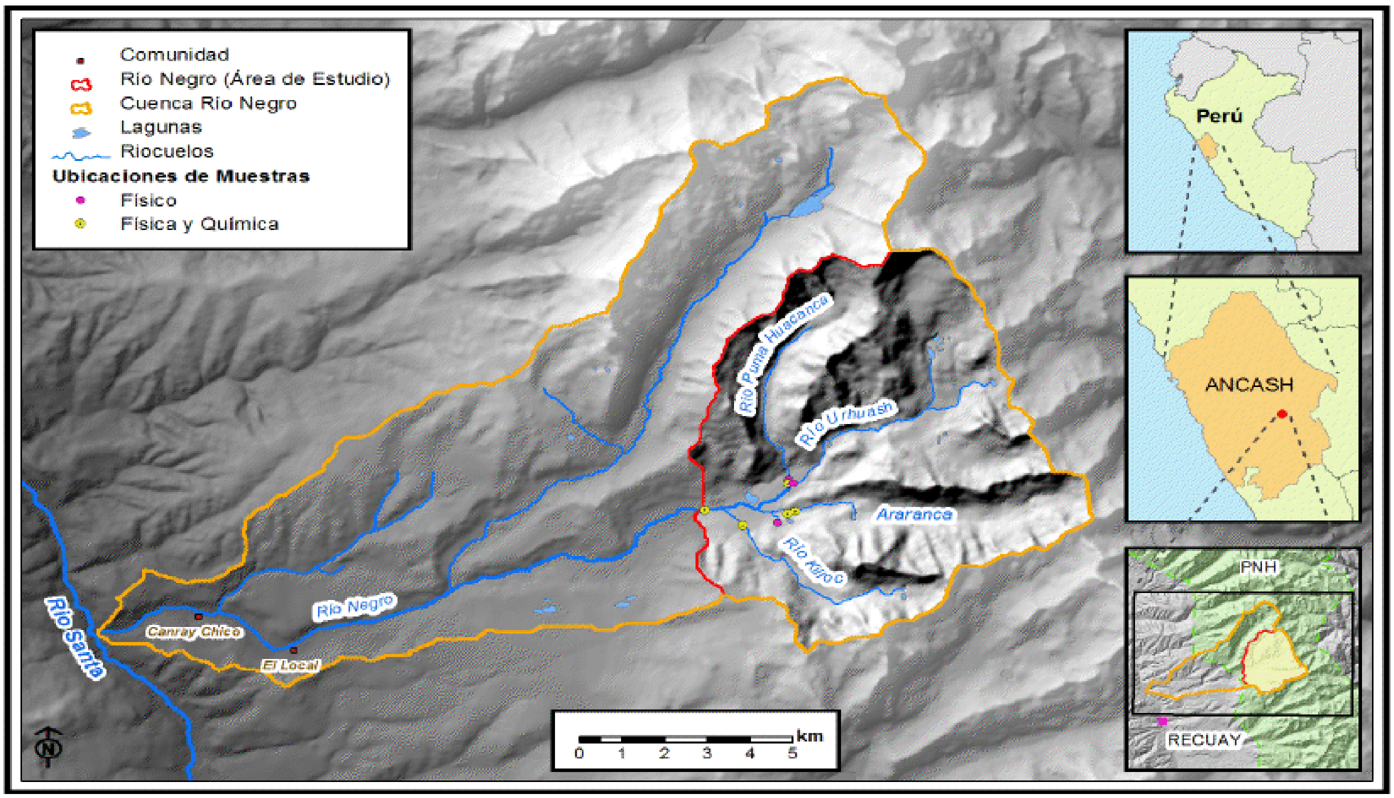
I. Introduction

a. Water Contamination in the CC Cordillera Blanca

i. Background

The Campesino Community of Cordillera Blanca (Canrey Chico), located in the Municipal Province of Recuay in the Department of Ancash, is home to 332 people[1] and is a community based almost entirely on agriculture for consumption and sale. The community's economic wellbeing is reliant on quality harvests, healthy livestock and high agricultural productivity – all of which are in turn dependent on a quality source of water.



Canrey Chico receives its water from the Rio Negro, a glacially-fed tributary of the Rio Santa which flows through the entire length of the community's land. Originating in the peaks of the Cordillera Blanca, the river passes through high altitude grazing areas before descending through fields used for agriculture and eventually passing alongside the town of Canrey Chico itself on its way to the Rio Santa. Given poor relations with the

[1] INEI, Censos Nacional de Peru 2007 - Población y Vivienda, 2007.

neighboring community of Canrey Grande (located on the northern side of the Rio Negro), the Rio Negro is Canrey Chico's only source of fresh water aside from a few natural springs, which do not provide nearly enough water to meet the community's needs.

Beginning shortly after the massive earthquake of 1970, the community of Canrey Chico has been experiencing increasing contamination in the Rio Negro. This massive seismic event, in addition to killing thousands of people in the region, caused huge avalanches in the area and radically altered much of the geography, changing the paths of streams and rivers, adding metals into many water sources such as the Rio Negro. While the contamination began abruptly as a result of the earthquake, it has continued and indeed accelerated in recent decades as a result of natural contamination from receding glaciers, a process accelerated by the rising temperatures associated with climate change. As glaciers recede and expose rocks that for millions of years have been covered in ice, concentrated deposits of metals in these rocks enter the glacial meltwater passing over them, and enter the water stream. This meltwater enters tributaries which then empty into major rivers; in this case, the Rio Negro. While metals are present in all natural water sources, the amount of metals present in newly exposed rock are so highly concentrated, that what would normally be very pure glacial melt water quickly becomes extremely acidic or basic, discolored and non potable. This "natural contamination" poses a major threat to agricultural communities downstream that depend on clean water to feed their animals, use for irrigation and of course for personal consumption.[2] While natural contamination is to some extent unavoidable, the speed at which it is occurring in the Peruvian Andes has been pushed far beyond normal rates due to the effects of climate change.

One of the most common forms of natural contamination is iron contamination. In addition to discoloring the water and riverbed with an orange hue, the high iron levels make the water very acidic – harmful to humans, animals, and plants. This is the major type of contamination present in the water of the Rio Negro, pictured below along with canals carrying the Rio Negro's water around the community of Canrey Chico.

[2] "Climate Action | Adaptation to Climate Change." *European Commission*. N.p., n.d. Web. 04 Sept. 2012.

Current levels of metal contamination in the Rio Negro are so high that the community must severely limit its use of this abundant water source. The Rio Negro is now used solely for irrigation of community pastures (high altitude grasslands used for animal grazing). Other crops in the community, such as potatoes, maize, wheat, and oats, are watered by seasonal rain only.[3] For all other uses (bathing, washing clothes, and human and animal consumption), the community must use water from collection tanks that have been built around two natural springs in the community (pictured below).

These natural springs have become Canrey Chico's *only* source of potable water, and as the community has grown in size its water needs are now far in excess of what the springs can provide. This is especially true now that a sewage system has been put into place in town, which heavily taxes the water supply. Every night, the community shuts off the tanks to collect enough water for use the following day meaning there is no water at night. In the dry season, these conservation methods are often not sufficient, and water shortages for days and weeks on end are not uncommon.[4]

[3] Cruz, Alejandro, and Rolando Salvador. "Interview with Canrey Chico Community Members." Personal interview. 28 Aug. 2012.
[4] Cruz, Alejandro, and Rolando Salvador. "Interview with Canrey Chico Community Members." Personal interview. 28 Aug. 2012.

ii. Testimony of Community Members

Over the past 4 decades, members of Canrey Chico have observed a multitude of negative effects resulting from the contamination in the Rio Negro. These range from large die-offs of trout in the river (shortly after the 1970 earthquake), changes in the smell of the water and of course a gradual change in color. Of greatest concern to the community, however, are the effects on human, animal, and plant health.

Detailed studies into the health of the people of Canrey Chico, or studies into the growth rates and health of the community's crops and livestock have not been performed – so describing the effects of the contaminated river water must come from personal interviews with members of the community. Interviews were carried out with various members of the community. The interviewees, Alejandro Cruz, Rolando Salvador, Fermin Cruz and Vilma Tamara gave insightful accounts from different perspectives of community life; Alejandro from an agricultural perspective, Rolando from agriculture and from his work as a member of the Comite de Investigacion Agropecuario Local (CIAL), and Vilma from the women's perspective using water to cook, bathe children and use for household work.[5]

From the agricultural perspective, Alejandro and Rolando emphasized that crops irrigated with water from the Rio Negro grow significantly slower than plants irrigated by water from the natural springs in the community. Not only do they grow slower, but they reach a limit in size significantly less than their counterparts not receiving contaminated water. The highland pastures in Canrey Chico, which are still watered by the Rio Negro, grow much slower and to a shorter height than they did just a few decades ago, and the plants themselves are often discolored.

One of the most important uses of potable water aside from human consumption is animal consumption. For a community entirely dependent on agricultural production, the health of livestock is critical. Unhealthy animals produce lower quality milk and meat, greatly impacting the income of the community. Alejandro and Rolando discussed that while the community's livestock now primarily drinks water from the natural springs, during times of water shortages they are forced to allow them to drink from the

[5] Cruz, Alejandro, Rolando Salvador, Fermin Cruz, and Vilma Tamara. "Interview with Canrey Chico Community Members." Personal interview. 28 Aug. 2012.

Rio Negro. More importantly, the animals continue to graze on pastures irrigated by the Rio Negro, and these highland grasses on which they graze naturally accumulate metals. Thus, very high amounts of metals are entering the animals though their diet. These metals pass on to the animal's meat and milk – which are in turn consumed by the community. Interviewees mentioned that both the quality and quantity of milk from cattle has been consistently declining over the years, as has the general health and weight of cattle and sheep. Production of meat has declined and general quality of meat from all livestock is significantly worse than just a few decades ago.[6]

Members of the community have also experienced various health problems in the years and decades since river water began to be contaminated. All the interviewees mentioned that many members of the community began to complain (and still complain) about recurring stomach ailments and headaches which were non-existent when the Rio Negro was clean.

From the women's perspective, the contamination of the Rio Negro has had other effects. Aside from consumption, iron levels in the water are now so high that it cannot be used for washing clothes. The iron content stains and discolors any clothes that are cleaned with it and thus the limited fresh water from the springs must be used for these purposes. Water from the tanks is of acceptable quality for drinking, washing, and other household tasks, but there is often not enough of it and certain tasks cannot be done, especially during the dry season.[7]

b. Contamination Data for the Rio Negro

Having a detailed scientific understanding of the exact nature of the contamination of the Rio Negro is a critical prerequisite to planning any strategy to address the contamination. Initial monitoring of water conditions in the Rio Negro was performed by TMI but this task is now the responsibility of the people of Canrey Chico. Since 1998, as part of its Punas-Agua project, TMI has helped create the "Comite de Investigacion Agropecuario Local" (CIAL). The "Comite" is a group of community

[6] Cruz, Alejandro, Rolando Salvador, Fermin Cruz, and Vilma Tamara. "Interview with Canrey Chico Community Members." Personal interview. 28 Aug. 2012.
[7] Cruz, Alejandro, Rolando Salvador, Fermin Cruz, and Vilma Tamara. "Interview with Canrey Chico Community Members." Personal interview. 28 Aug. 2012.

members who have been trained in the basics of water monitoring and taught how to operate monitoring equipment. The following data (a consolidation of data taken by the CIAL and other TMI members over time) provides a picture of the quality of water in the Rio Negro and its tributaries during the past year. It also indicates how far these levels are from accepted norms for potable water. Metal levels (in mg/L of H2O) significantly above the potable water limit are highlighted in yellow:

Site	Aluminum	Arsenic	Cadmium	Mercury	Iron	Lead	pH Level
Rio Negro (Bajo)	1.655	.126*	0.012	.192*	5.275	0.197	3.57
Rio Quilloc	0.1	.115*	0.0185	.192*	0.44	*.017	7.025
Rio Araranca	0.195	.112*	.003*	.120*	0.45	0.2915	7.49
Rio Negro (Union of Urhuash and Puma)	2.1	.15*	0.038	.251*	7.15	0.3405	3.57
Rio Urhuash	x	x	X	X	x	x	3.59
Rio Pumahuacanca	x	x	X	X	x	x	3.52*
Acceptable Maximum Levels (mg/L H20)	0.2	0.01	0.003	0.001	0.3	0.001	6.5-8.5

*dry season only
x = no data

Given this information, it is clear that the Rio Negro suffers from various types of contamination. Data at the union of the Urhuash and Pumahuacanca Rivers indicates that these two tributaries are the source of high levels of aluminum, arsenic, cadmium, mercury, iron, and lead observed downstream at the Rio Negro “Bajo” site, closest to the town of Canrey Chico. The water entering the Rio Negro from the Araranca and Quilloc is not far from acceptable pH levels due to its relatively low iron content, but it does contribute significantly to high levels of arsenic, cadmium, mercury and lead.

c. Effects of Metal Contamination

It is important to have an understanding of the effects that each type of metal contamination has on humans/animals/plants. As will be discussed later in the report, given the various constraints this project may encounter, particularly financial restraints, the most feasible approach may be to create a partial bioremediation which only removes some metal contaminants. In this case, it will be necessary to prioritize which metal contamination should be addressed first when designing the bioremediation system.

Lead Contamination **–** The effect of Lead (Pb) on crop production depends on the concentration, type of salts and plant species involved. There are greater effects at higher concentrations and durations of exposure to Pb, but in some cases, lower concentrations might stimulate metabolic processes. The major processes affected are seed germination, seedling growth, photosynthesis, plant water status, mineral nutrition, and enzymatic activities.[8] Scientific studies show that Pb does not readily accumulate in the fruiting part of vegetable and fruit crops; higher concentrations are most likely to be found in leafy vegetables and on the surface of root crops. Lead accumulates in the upper 8 inches of the soil and is highly immobile. Pb^{2+} is not biodegradable and once soil has become contaminated, it remains a long-term problem.[9]

Lead contamination in the environment exists as an insoluble form, and the toxic metals pose serious human health problems like brain damage and mental retardation. Lead is very toxic and has chronic health implications even at very low concentrations. Ingestion of Pb can cause colic anemia and renal diseases. Lead replaces Ca in bones, and over a long term exposure this cumulative effect can inhibit the synthesis of hemoglobin , adversely affect the central nervous system, the peripheral nervous system, and the kidney.[10]

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[8] Voijant Tangahu, Bieby, Siti Rozaimah Sheikh Abdullah, Hassan Basri, Mushrifah Idris, Nurina Anuar, and Muhammad Mukhlisin. "A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation." *Hindawi Publishing Corporation*. International Journal of Chemical Engineering, 3 June

[9] Patra, Manomita, Niladri Bhowmik, Bulbul Bandopadhyay, and Archana Sharma. "Comparison of Mercury, Lead and Arsenic with Respect to Genotoxic Effects on Plant Systems and the Development of Genetic Tolerance." *Science Direct*. Environmental and Experimental Botany, 26 Feb. 2004.

[10] OKORONKWO, NE, JC IGWE, and EC ONWUCHEKWA. "Risk and Health Implications of Polluted Soils for Crop Production." *Academic Journals*. African Journal of Biotechnology, 15 Sept. 2005.

***Arsenic Contamination* –** The effects of Arsenic (As) toxicity on crops is harmful because As can remain in the environment for an extensive period, allowing the metal to accumulate to levels that harm the physiochemical properties of soils and lead to loss of soil fertility and crop yield. Scientific studies have found that as the concentration of As increases in soils the production of crops decreases. Arsenic, when not detoxified, may trigger a sequence of reactions leading to growth inhibition, disruption of photosynthetic and respiratory systems, and stimulation of secondary metabolism.[11] Plants vary considerably in their tolerance to high levels of arsenic; crops like wheat and maize tend to be much more sensitive.[12]

Arsenic can have serious long term effects on human health. Bioaccumulation of arsenic in plants can be hazardous to humans and animals because of its relationship to cancer, arteriosclerosis and chronic liver disease. The edible portions of plants rarely accumulate dangerous levels of arsenic because phytotoxicity occurs before toxic levels are reached. The highest concentrations of As are found in plant roots, intermediate levels in vegetative tissue, and the lowest levels in reproductive tissue.[13] Toxicity to animals or humans is usually from the consumption of surface residues of arsenic on plant material or long term exposure in drinking water. Chronic effects of As exposure via drinking water include skin lesions, neurological effects, hypertension, peripheral vascular disease, cardiovascular disease, respiratory disease, diabetes mellitus, and malignancies.[14] Other health problems include increased risks of skin cancer as well as other skin lesions such as hyperkeratosis and pigmentation changes.

***Aluminum Contamination* –** Aluminum (Al) toxicity is a major agricultural problem around the world because Al is one of the primary factors that reduce plant growth on

[11] Garg, Neera, and Priyanka Singla. "Arsenic Toxicity in Crop Plants: Physiological Effects and Tolerance Mechanisms." *SpringerLink*. Springer Science Business Media, 27 Mar. 2011.
[12] Walsh, Leo M., Malcom E. Sumner, and Dennis R. Keeney. "Occurrence and Distribution of Arsenic in Soils and Plants." *Environmental Health Perspectives*. N.p., Aug. 1977. Web.
[13] Walsh, Leo M., Malcom E. Sumner, and Dennis R. Keeney. "Occurrence and Distribution of Arsenic in Soils and Plants." *Environmental Health Perspectives*. N.p., Aug. 1977. Web.
[14] Yoshida, Takahiko, Hiroshi Yamauchi, and Gui Fan Sun. "Chronic Health Effects in People Exposed to Arsenic via the Drinking Water: Dose–response Relationships in Review."*Science Direct*. Toxicology and Applied Pharmacology, 1 Aug. 2004. Web.

acid soils, like the soil at Canrey Chico. Although it is generally harmless to plant growth in pH-neutral soils, plants grown in acid soils have reduced root systems and demonstrate many nutrient-deficiency symptoms due to Al solubility at low pH levels. Inhibition of root and shoot growth is a visible symptom of Al toxicity, where roots are inefficient in absorbing both nutrients and water. Young seedlings are more susceptible than older plants. Although Al does not interfere with seed germination, it does impair the growth of new roots and seedling establishment. The consequence is an overall decrease in yield.[15]

Although there is little evidence that normal exposure to aluminum presents a risk to healthy adults, some studies point to risks associated with increased exposure to the metal. Aluminum in food may be absorbed more than aluminum from water, and because aluminum competes with calcium for absorption, consuming aluminum in increasing amounts can be a factor that contributes to the reduced skeletal mineralization (osteopenia) observed in preterm infants. A small percentage of people are allergic to aluminum and can experience contact dermatitis, digestive disorders, and vomiting if they are in contact with or ingest products containing Al. For people without allergies, other heavy metals are much more toxic unless consumed in excessive amounts. Scientific evidence has shown that exposure to Aluminum has been linked with the development of Alzheimer`s disease. Elevated brain aluminum concentrations have been found in post-mortem examinations of victims and affects several neurophysiological processes, responsible for the degeneration characteristic of Alzheimer`s disease, but research in this area has been inconclusive; aluminum accumulation may be a consequence of the disease rather than a causal agent.[16]

***Cadmium Contamination* –** Excessive amounts of Cadmium (Cd) in soil causes many toxic symptoms in plants. These negative symptoms include: reduction of growth (especially root growth), disturbances in mineral nutrition and carbohydrate metabolism, deleterious effect in photosynthetic processes, and therefore can significantly reduce

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[15] Mossor-Pietraszewska, Teresa. "Effect of Aluminium on Plant Growth and Metabolism." *Acta Biochimica Polonica*. N.p., 4 Sept. 2001. Web.

[16] Costa Ferreira, Pricilla, Kamila De Almeida Piai, Angela Maria Magosso Takayanagui, and Susana Inés Segura-Muñoz. "Aluminum as a Risk Factor for Alzheimer's Disease."*Revista Latino-Americana De Enfermagem*. Sci-Flo Brasil, Jan.-Feb. 2008. Web.

biomass production. Although plants do not require Cd for growth or reproduction, plants can accumulate relatively high levels of cadmium. Much of the Cd taken up by the plant is retained in the root, but a portion is transported to the aerial part of the plant. The amount of Cd accumulated and translocated in the plant depends on the plant`s genotype, which differs between crop species. Visual symptoms from Cd toxicity include: browning of the root system, leaf necrosis, and chlorosis, the reddish-brown discoloration of the leaf blades.[17]

When taken up by plants, Cd concentrates along the food chain and ultimately accumulates in the body of people eating contaminated foods. Once absorbed, Cd irreversibly accumulates in the human body in kidneys and other vital organs like lungs and liver. Cd is also a highly toxic metal that can disrupt a number of biological systems at doses much lower than other heavy metals. Short term effects from the intake of cadmium-contaminated food include acute gastrointestinal problems, such as vomiting and diarrhea. Long term effects are associated with the accumulation of Cadmium in kidneys, where it damages filtering mechanisms. This causes the excretion of essential proteins and sugars from the body and further kidney damage. Other problems caused by long term exposure to Cd include: bone fractures, reproductive failure, damage to the central nervous system, damage to the immune system, psychological disorders, and possible DNA damage or cancer development.[18]

Mercury Contamination – Plants are not generally sensitive to the harmful effects of mercury (Hg) compounds; however, Hg is known to affect photosynthesis, oxidative metabolism and reduce plant water uptake. Acidic waters, like the Rio Negro in Canrey Chico can contain significant amounts of mercury. Polluted water leads to mercury laced fish, meat, and vegetables. In aquatic environments or soil microorganisms can convert inorganic mercury to methyl mercury, a substance that can be absorbed quickly by most organisms and is known to be very harmful. This transformation makes mercury more prone to bio magnification in food chains. Populations with traditionally high dietary

[17] Grant, C.A., W.T. Buckley, L.D. Bailey, and F. Selles. "Cadmium Accumulation in Crops."*Agronomy Section*. Canadian Journal of Plant Science, 6 Aug. 1997.
[18] Bernard, A. "Cadmium & Its Adverse Effects on Human Health." *Indian J Med*. Department of Public Health, Catholic University of Louvain, Belgium, 2 Apr. 2008. Web.

intake of food originating from fresh or marine environments are at the highest risk for exposure to mercury.[19]

Mercury and its compounds are toxins and in small quantities are hazardous to human health. The major effects of mercury poisoning manifest as neurological and renal disturbances as it can easily pass the blood-brain barrier and effect the brain. Effects of mercury consumption include: Disruption of the nervous system, DNA damage and chromosomal damage, allergic reactions, resulting in skin rashes, tiredness and headaches, negative reproductive effects, such as sperm damage, birth defects and miscarriages, and damage to brain functions. Damaged brain functions can cause degradation of learning abilities, personality changes, tremors, vision changes, deafness, loss of muscle coordination and memory loss.[20]

Iron Contamination –Excessive amounts of Iron (Fe) in anaerobic and acidic soils may lead to Fe toxicity which can result in crop yield reductions from 12 to 100%. Overabundance of Iron can be extremely toxic as it reacts with oxygen and catalyzes the production of free radical species. It can also result in lower uptake of other essential nutrients, either due to the barrier created by the Fe coatings or due to chemical interactions in the soil. Iron, even at low concentrations, can also cause algae blooms, which create biological oxygen demand, can kill fish, smother aquatic plants and produce potent neurotoxins.[21]

Although Iron is an essential mineral, large amounts can have detrimental effects to human health. The ingestion of large quantities of iron can damage blood vessels, cause bloody vomitus/stool, damage the liver and kidneys, and even cause death. Other effects include: depression, rapid and shallow respiration, coma, convulsions, respiratory failure, and cardiac arrest. Diseases of aging such as Alzheimer's disease, other neurodegenerative diseases, arteriosclerosis, diabetes mellitus, and others have also been linked to excessive iron intake.[22]

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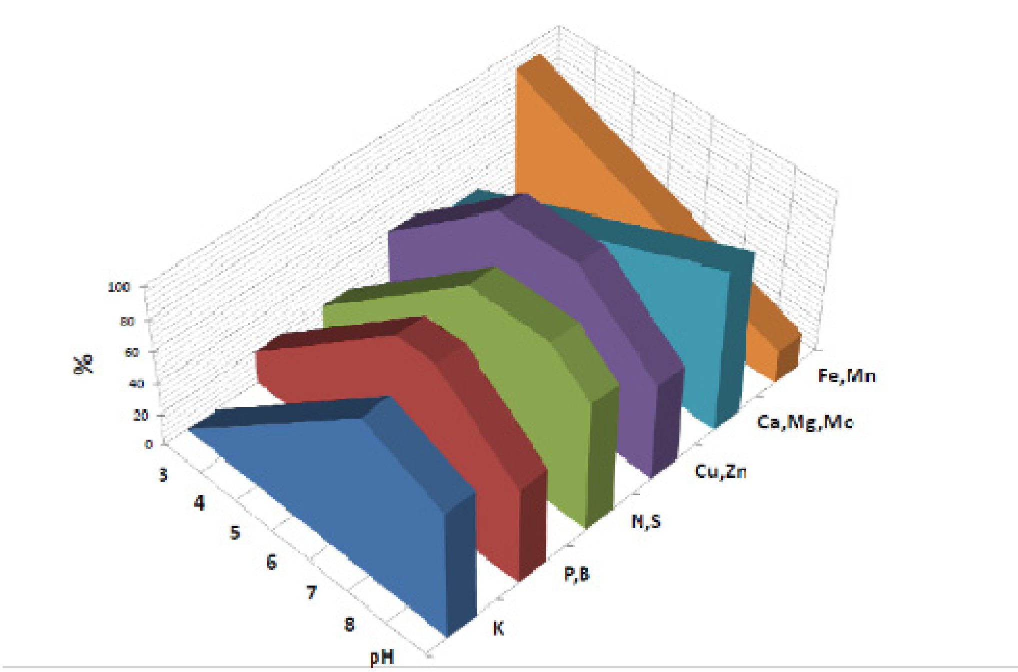
[19] Zahir, Farhana, Shamin J. Rizwi, Soghra K. Haq, and Rizwan H. Khan. "Low Dose Mercury Toxicity and Human Health." *Science Direct*. Environmental Toxicology and Pharmacology, Sept. 2005. Web.
[20] "Chemical Fact Sheets -- Mercury." *Wisconsin Department of Health Services*. N.p., Mar. 2000. Web. 16 Aug. 2012. <http://www.dhs.wisconsin.gov/eh/chemfs/fs/mercury.htm>.
[21] "Iron (For Private Water and Health Regulated Public Water Supplies)." *SaskH2O*. Government of Saskatchewan, Dec. 2007. Web.
[22] "Iron in Drinking-water." World Health Organization, 2003. Web.

***Highly Acidic Soil* -** High acidity levels in the Rio Negro and the tributaries Pumuhuacanca/Urhuash are caused by oxidation of iron in the water. The levels of iron in these two tributaries, combined with their high flow rates means that water at the lower part of Rio Negro (Bajo) maintains this very high acidity. This high acidity is likely the most critical and harmful contamination component present in the Rio Negro. Plants grown in acid soils can experience a variety of symptoms including aluminum (Al), hydrogen(H), and/or manganese(Mn) toxicity, as well as potential nutrient deficiencies of calcium (Ca) and magnesium(Mg). Manganese, like aluminum becomes increasingly more soluble as pH drops, and Manganese toxicity symptoms can be seen at pH's below 5.6. Mn is an essential plant nutrient, so plants transport manganese into leaves. Classic symptoms of manganese toxicity are crinkling or cupping of leaves.[23] The following chart shows the solubility of vital nutrients and different pH levels:



Nutrients needed in large amounts by plants are referred to as macronutrients and include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Elements that plants need in trace amounts are called trace nutrients or

[23] Brady, N. and Weil, R. The Nature and Properties of Soils. 13th ed. 2002

micronutrients. Trace nutrients are not major components of plant tissue but are essential for growth. They include iron, (Fe), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), molybdenum (Mo), and boron (Bo). Both macronutrient and micronutrient availability are affected by soil pH. In slightly to moderately alkaline soils, molybdenum and macronutrient (except for phosphorus) availability is increased, but P, Fe, Mn, Zn Cu, and Co levels are reduced and may adversely affect plant growth. In acidic soils, micronutrient availability (except for Mo and Bo) is increased. Nitrogen is supplied as ammonium (NH_4) or nitrate (NO_3) in fertilizer amendments, and dissolved N will have the highest concentrations in soil with pH 6-8. Concentrations of available N are less sensitive to pH than concentration of available P. In order for P to be available for plants, soil pH needs to be in the range 6.0 and 7.5. If pH is lower than 6, P starts forming insoluble compounds with iron (Fe) and aluminum (Al) and if pH is higher than 7.5 P starts forming insoluble compounds with calcium (Ca).[24]

It is clear that there are a plethora of risks to human, animal, and plant health given current contamination levels in the Rio Negro. Iron is likely the most harmful contaminant to plant growth and health, while arsenic, mercury, and cadmium are all very harmful to animals and humans. Removal of iron, which would make the water safer for irrigation in addition to lowering the solubility of other metals would be a necessary part of any bioremediation system, particularly a pilot project. However, **a full-scale bioremediation system in the community should seek to eliminate ALL of the aforementioned metals** that currently exist at toxic levels.

II. The Use of Bioremediation to Treat Water contaminated with heavy metals

a. A Brief Background of Bioremediation and Passive Treatment

For a community of very limited financial resources and human capital to devote towards activities other than the constant work required in an agricultural community, realistic and affordable options for improving water quality in the Rio Negro are limited.

[24] Sparks, Donald; Environmental Soil Chemistry. 2003, Academic Press, London, UK

Bioremediation is an attractive option for poor, rural communities like Canrey Chico to deal with water contamination. Mechanical water treatment facilities, in addition to being far too expensive for most communities to afford, are relatively complex structures which require at least a basic understanding of engineering to properly maintain. Repairs and replacement of grates, pipes, and other components is also expensive, time-consuming, and frequently requires the assistance of outside actors. A bioremediation system is significantly cheaper, but most importantly requires little to no skilled maintenance.

The United States Environmental Protection Agency defines bioremediation as a natural process in which microbes (or biological organisms in general) remove contaminants from water and release them in form of water and/or carbon dioxide.[i] Bioremediation encourages the rapid growth of these biological organisms by providing the right growth conditions (i.e. oxygen, fertilizer, etc). This innovative approach has generated a great deal of buzz among the environmental community for its inexpensive, environmentally-friendly, and low maintenance requirements. Throughout the last few decades, it has been used to clean up oil spills and treat contaminated soil and water, particularly around abandoned mines where acid mine drainage (AMD) or acid rock drainage (ARD) threaten the surrounding inhabitants.[25]

"Bioremediation" encompasses a wide variety of treatment designs – one approach, referred to as "passive treatment" would likely be the most practical and effective in a situation like Canrey Chico's. Nearly 35 years ago, a group of researchers at Wright State University observed water quality improvements in a natural Sphagnum bog in Ohio that received low pH, metal laden water. In another independent investigation, researchers at West Virginia University observed similar results at the Tub Run Bog. These documented results laid the foundation for subsequent work on developing a technology to treat AMD or ARD.[26] The technology came to be known as "passive treatment" and is considered a bioremediation system because it uses natural organisms to remove pollutants from water. James Gusek, a bioremediation specialist with Golder Associates, an American environmental services firm, defines passive

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[25] "Environmental Inquiry - Bioremediation." *Environmental Inquiry - Cornell University*.
[26] Gusek, James J. "Passive Treatment 101: An Overview of the Technologies." 2008 U.S. EPA/National Groundwater Association's Remediation of Abandoned Mine Lands Conference. Denver. Lecture.

treatment as "a process of sequentially removing metals and/or acidity in a natural-looking, man-made bio-system that capitalizes on ecological and geochemical reactions. The process requires no power and no chemicals after construction and lasts for decades with minimal human help".[27]

Passive treatments vary widely depending on characteristics of the water they are designed to treat. Factors such as the temperature, altitude, surface area, access, and treatment goals influence the design of the system. For example, some passive treatments may need to be combined with lime-dosing active systems to create a "hybrid system" that can treat highly acidic water (Canrey Chico would require this). While there are no single passive treatment recipes for treating contaminated water, every experiment with these systems has resulted in better understanding of the mechanisms involved. The following examples present previous cases in passive and hybrid treatments.[28]

b. Case Studies

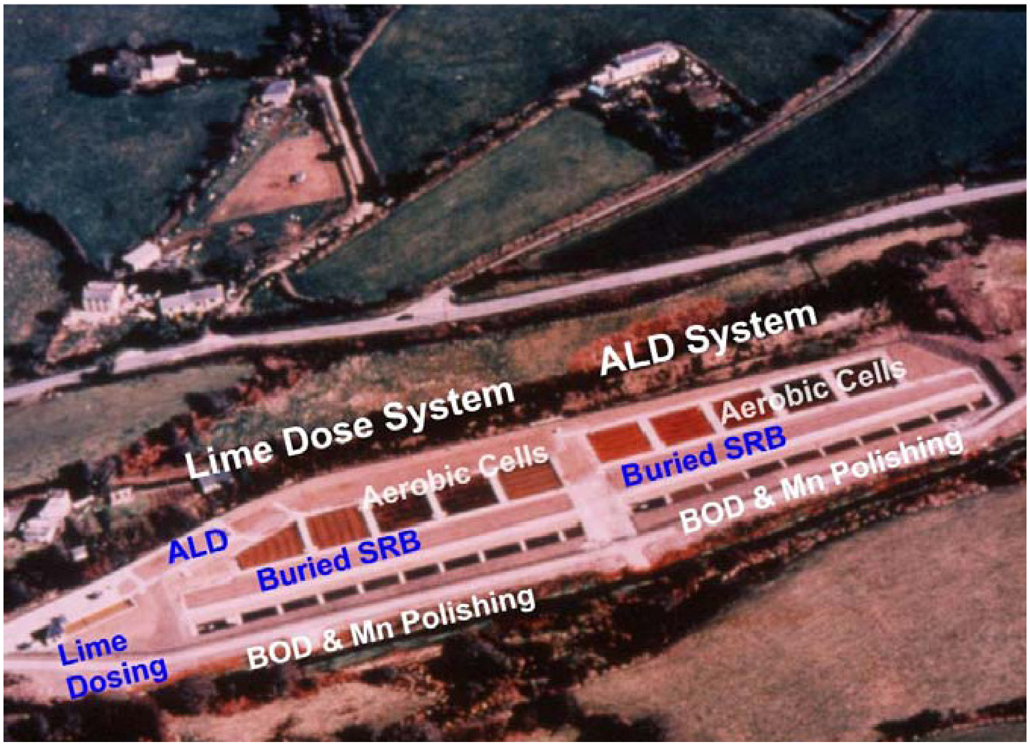
Wheal Jane Mine, Cornwall, UK

Wheal Jane Mine was abandoned in March 1991 when dewatering ceased and the mine flooded. Subsequent failure of an adit plug in 1992 resulted in the release of nearly 30,000 cubic meters of acidic, metal rich minewater into the Carnon River, prompting the UK's Department of the Environment to fund three pilot passive treatment systems by 1994. Each system comprised the same main treatment stages, each containing five aerobic reed beds, an anaerobic cell and an aerobic rock filter. Two of the treatments were completely passive, one incorporated an anoxic limestone drain (ALD) to add alkalinity. The third included a pre treatment stage in the form of lime dosing followed by a sulfate reducing bioreactor and an aerobic polishing cell (hybrid system). With pH level of 3.8, the water contained high levels of Al, As, Cd, Cu, Fe, Mn, Pb, and Zn. The goal of the treatment was to raise the pH to levels that allowed passive iron removal in the downstream aerobic cells while containing the amount of conventional iron hydroxide sludge that would be produced as a result of the treatment. Research and results of the three pilot projects suggested that the Fe removal efficiency observed in ALD was identical to that of the hybrid system but the passive system composed of ALD,

[27] Gusek, James J. "Passive Treatment 101: An Overview of the Technologies." 2008 U.S. EPA/National Groundwater Association's Remediation of Abandoned Mine Lands Conference. Denver. Lecture.
[28] Gusek, James J., and Kevin W. Conroy. *Hybrid Treatments for Very Acidic Mining Influences Water*. Rep. N.p.: n.p., n.d. Print.

performed better at removing metals and treating acidity. However, due to land area constraints, the hybrid system was preferred for the final project.[29]

Wheal Jane Mine Site Aerial Photo (Gusek)



III. Selecting the Right System Design for Canrey Chico

Research on passive treatment suggests a variety of methodologies for choosing and building a system. However, all approaches should incorporate the following steps for ensuring an effective, efficient, and sustainable system:

1- Determine the physical and chemical characteristics of the stream to be treated
2- Review treatment goals
3- Examine advantages and limitations of different treatment systems
4- Ensure maintenance

Our research found two useful approaches to choosing the right treatment for the Canrey Chico Community. The first approach, developed and published by Penn State

[29] Gusek, James J., and Kevin W. Conroy. *Hybrid Treatments for Very Acidic Mining Influences Water*. Rep. N.p.: n.p., n.d. Print

University in the United States, suggests two broad treatment categories while the second, documented by Jim Gusek, focuses on three general passive treatment types.

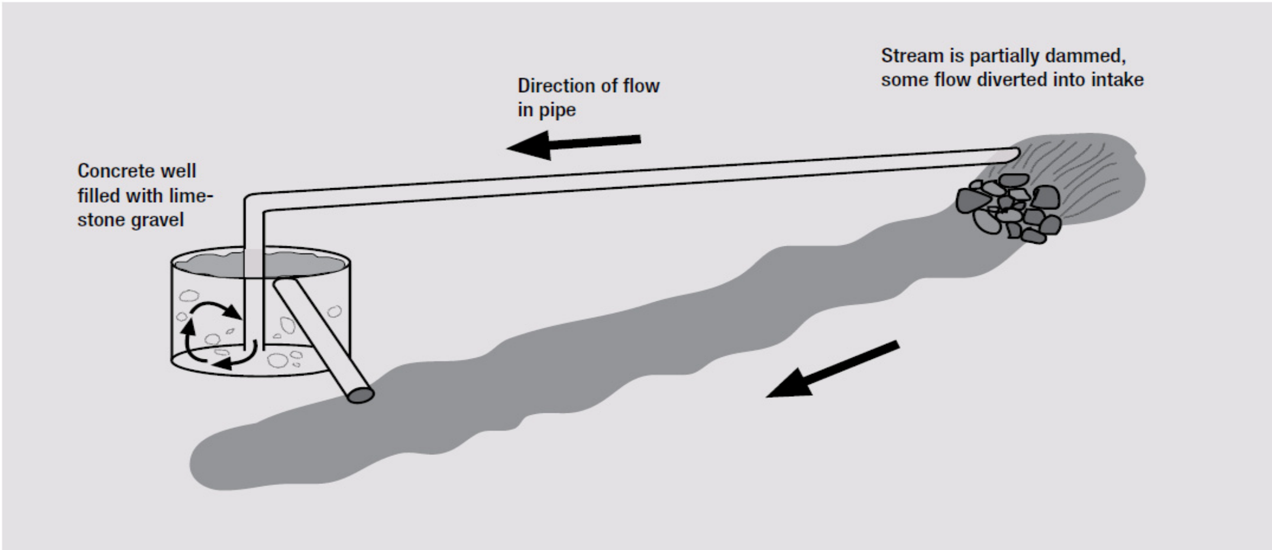
a. Penn State Methodology

The Penn State University research recommends a two category approach to treating water contaminated with heavy metals. Category I treatments seek to neutralize acidity by raising the pH levels while Category II treatments increase the pH level to facilitate removal of metals from the water.

<u>Category I Treatments:</u>

Most often used to treat water that has been affected by acid rain and may be used in combination with another Category I treatment. Treatment types include:

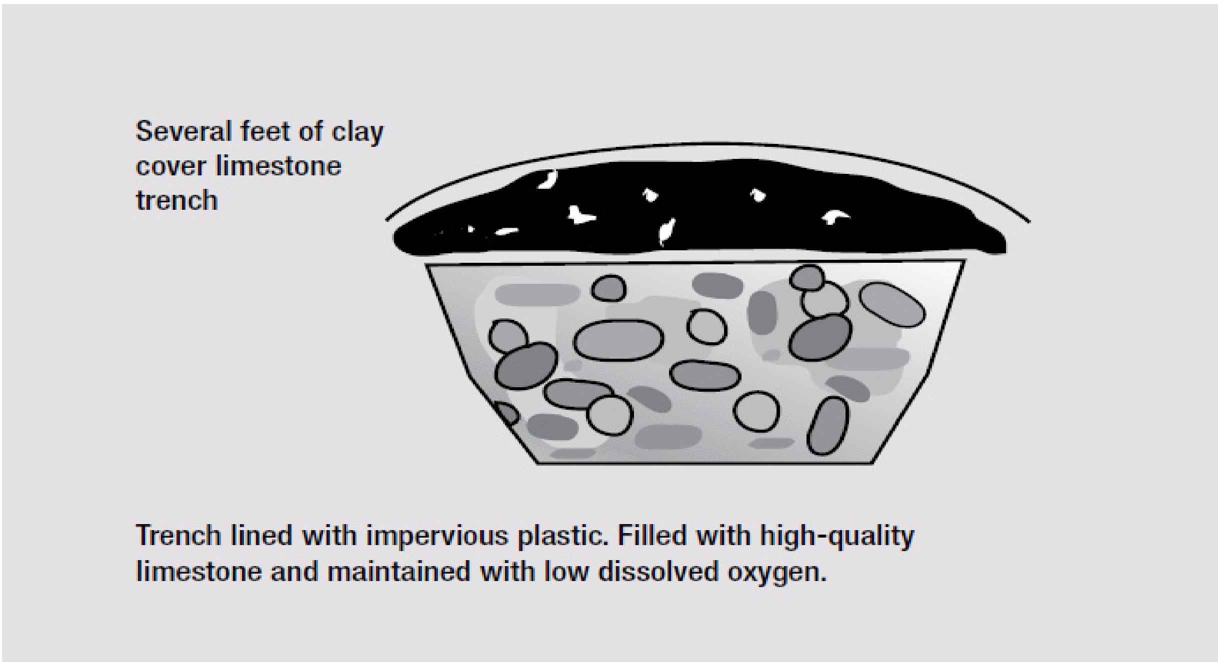
- Watershed liming
- Wetland liming
- In-stream limestone sand:
    - Sand is placed directly into the stream bead and dissolves as it spreads downstream; it increases the PH level by adding CaCO3 and reducing the aluminum concentrations
    - Requires sufficient flow and stream gradient to carry the sand downstream
    - Limitations: inconsistent improvement in the water quality, contradictory formulas recommending the amount of sand needed to treat the water, effectiveness reduces with time, in case of high concentrations of aluminum it could result in precipitation of aluminum
- Alkaline groundwater addition wells
- Limestone diversion wells:
    - A concrete circular casing is placed next to the stream. A small intake dam is constructed upstream from the well to create an elevation difference. The treated water then exits through an overflow pipe back into the stream. Below is a cross-sectional diagram of limestone diversion well:



- Limitations include: potential for aluminum to precipitate in the system; treats small flows and is unlikely to be successful in varying flow systems; requires weekly maintenance and frequent intake repairs; requires access for delivery of limestone

- Anoxic Limestone Drains (ALD)
  - ALDs are buried trenches of limestone that increase alkalinity in an anoxic environment
  - The net alkaline drainage then enters a constructed wetland or settling pond where the metals will oxidize and settle at the bottom
  - ALDs are not suitable for treating drainage that contains high levels of dissolved oxygen (DO)
  - Most effective in treating water with the following characteristics:
    - pH less than 6 with net acidic of less than 300 mg/L
    - Low concentrations of aluminum and ferric iron (Al and Fe^{3+}) - less than 1 mg/l
    - Moderate concentrations of iron in ferrous form (FE2+ may be greater than 20 mg/L)
    - Low dissolved oxygen levels (D.O. less than 1 mg/L)
  - Advantages include: great pretreatment option (especially in combination with the wetland treatment), possible in significantly smaller treatment area

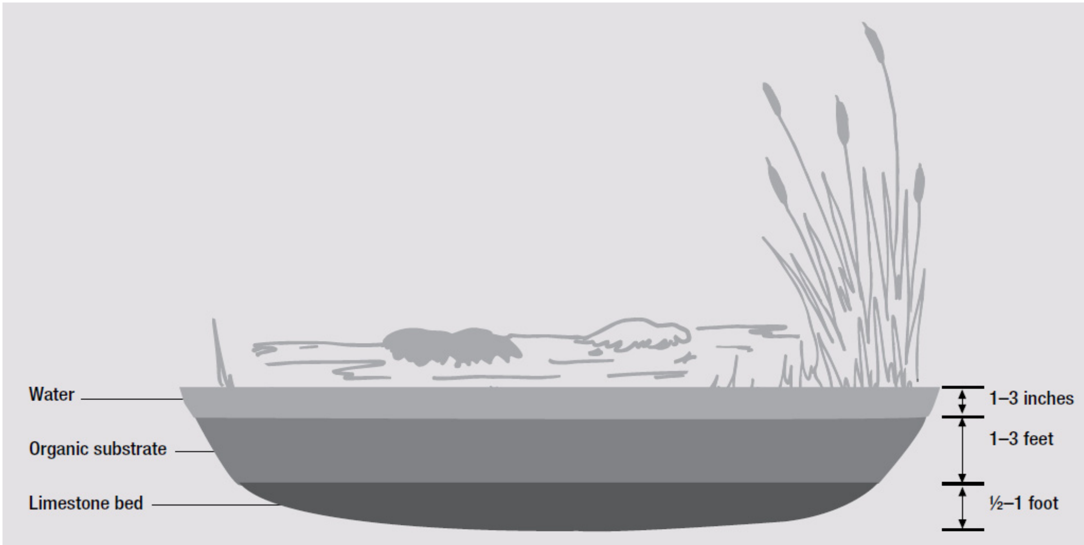
- Limitations: inconsistent levels of alkalinity achieved, treatable effluent limited to low oxidized metal concentrations for aluminum and ferrous iron



(Anoxic Limestone Drain(ALD))

<u>Category II Treatments:</u>

- Aerobic Wetlands
    - Used to treat net alkaline streams (pH greater than 5.5); their purpose is to remove low to medium concentrations of metals (iron, aluminum, and manganese) through oxidation and hydrolysis
- Anaerobic Wetlands
    - They increase the pH levels
    - Are similar to aerobic wetlands in design but “have a thick, permeable, organic substrate that is either mixed with limestone or placed over a limestone bed”.
    - Consist of 1-3 inches of water on top of the substrate that is 2-3 feet thick
        - most common substrate is spent-mushroom compost combined with limestone
    - Limitations: they may not survive in highly acidic environments: net acidic in the range of 300-500 mg/l, low to moderate flow rate and pH around 4; in highly acidic environments, they may be used in combination with sandstone treatments, inconsistent metal removal rates (esp. at higher metal concentrations), requires a large area, and has limited effective life



- Successive Alkalinity Producing Systems (SAPS)
    - Similar to anaerobic wetlands constructed on top of limestone drainage beds
    - Designed to treat water with dissolved oxygen content btw 2-5 mg/l and medium to high metal concentrations
    - Can generally treat water with: acidity levels ranging from 300-500 mg/l, moderate to high levels of ferric and ferrous iron (Fe 3+, FE 2+ greater than .25 mg/l), aluminum, dissolved oxygen (greater than 5 mg/l), and flow rates of low to moderate (<.12 cubic ft/sec)
    - Advantages: smaller treatment area is required, can treat poor quality water
    - Limitations: produces noxious odor (hydrogen sulfide) near the treatment area, limited by high levels of aluminum and ferric iron

b. Gusek Methodology

James Gusek, a bioremediation expert who specializes in designing passive treatment systems in the United States, describes three kinds of passive treatments:

1. Abiotic, limestone-based that treats net-acidic water
2. Semi-biological methods that condition the water for subsequent limestone dissolution
3. Biologically-facilitated components:
    a. Biochemical reactors (BCRS) that treat high acidity and a wide range of metals
    b. Aerobic cells containing cattails and other plants

Abiotic Components	Semi-Biological Components	Biological Components
Anoxic limestone drains (ALDs)	Successive/ Reducing alkalinity producing systems (SAPS)/(RAPS)	Aeration & settling ponds
Open limestone channels (OLCs)		Aerobic wetlands
Limestone Up-flow ponds		Sulfate reducing bioreactors (AKA Biochemical Reactors – BCRs)
Limestone beds		Limestone beds (manganese removal)
Diversion wells		
Limestone sand (semi-passive)		

Component	Function/Situation	Advantages	Disadvantages
Aeration & settling ponds	Oxygenate MIW exiting from ALDs, SAPS/RAPS, or biochemical reactors; settle total suspended solids/clarify	Easy to build, long lasting; iron precipitates can be harvested for beneficial use	Must be periodically cleaned
Aerobic wetlands	Oxygenate MIW to precipitate iron oxy-hydroxides, co-precipitate arsenic, re-oxygenate effluent from BCRs; moderate alkalinity additions; precipitation of manganese oxide facilitated by algae and other biota	Easy to build, very cost effective, low maintenance; iron precipitates can be harvested for beneficial use	Cells subject to freezing; seasonal turnover may create temporary metal (e.g., Fe) spikes as root zone geochemistry fluctuates between oxidizing and reducing conditions
Biochemical Reactors – BCRs	Reducing environment conducive to de-nitrification, selenium reduction, cyanide destruction, metal sulfide precipitation; uranium oxide precipitation; adds biologically derived alkalinity; hardness and organic concentrations increase which affect metals toxicity; effluent typically can be commingled with by-passed MIW to effect additional treatment	Simple to build, cost effective, effective in a wide variety of climates and MIW chemistry from net acidic to net alkaline; can treat high levels of aluminum without plugging; infrequent maintenance on the order of decades; temporary overloading survivability good if designed properly	Ineffective for manganese; may release Mn on startup; effluent may have elevated biochemical oxygen demand; effluent is low in dissolved oxygen and needs polishing with aerobic wetlands or equal; required BCR cell surface area is a function of acidity – high acidity MIW may require pre-treatment in hybrid configuration to fit in restricted space sites. Not efficient for nitrate levels greater than 50 mg/L
Limestone beds (manganese removal)	Microbial facilitated precipitation of manganese oxide	Simple to build, cost effective, low maintenance	Iron levels must be low – aerobic wetland upstream

Mechanisms used in passive treatments generally include:

1. Sulfide and carbonate precipitation due to sulfate-reducing bacteria (SRB) in anaerobic environments
2. Hydroxide and oxide precipitation due to bacterial activity in aerobic zones
3. Filtering of suspended material
4. Metal uptake by live roots and leaves
5. Adsorption and exchange with plant, soil, and other biological materials

Sulfate Reducing Bioreactors (SRB)

Research has shown that chemical reactions facilitated by the bacteria *desulfovibrio* contribute significantly to the removal of dissolved heavy metals in sulfate-reducing bioreactors:

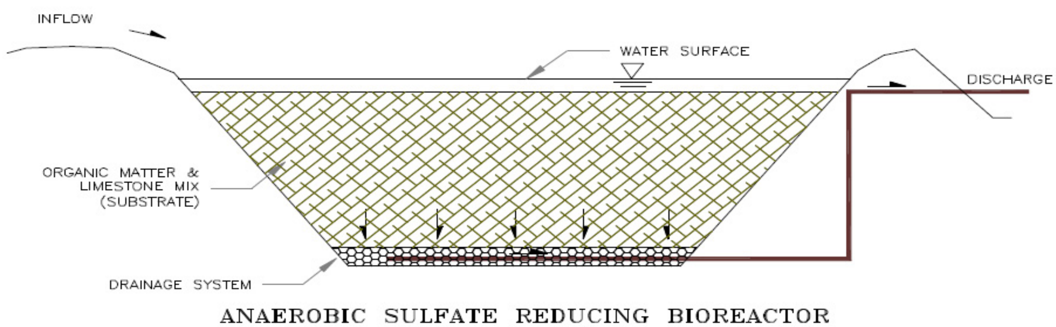


Figure X: Typical sulfate reducing bioreactor

The bacterial reactions involve the generation of:

1. Sulfide ion (S-2), which combines with dissolved metals to precipitate sulfides
2. Bicarbonate (HCO3 -) which raises the pH of the effluent

Required conditions for SRB:

1. pH of 5.0, achieved through the bicarbonate reaction and/or the presence of limestone sand
2. Presence of a source of sulfate

3. Organic matter (CH2O from the substrate)

Advantages:

1. No aluminum plugging
2. Ability to handle low flow net acidic water or high flow net alkaline water
3. Use of organic materials
4. Resilient to loading and climate variations
5. Consumes sulfate, capable of treating selenium
6. Generates more net alkalinity in effluent
7. Burial to minimize vandalism
8. Opportunities for community involvement in organic procurement

IV. Proposed Full–Scale System Design(s) and Pilot System Design

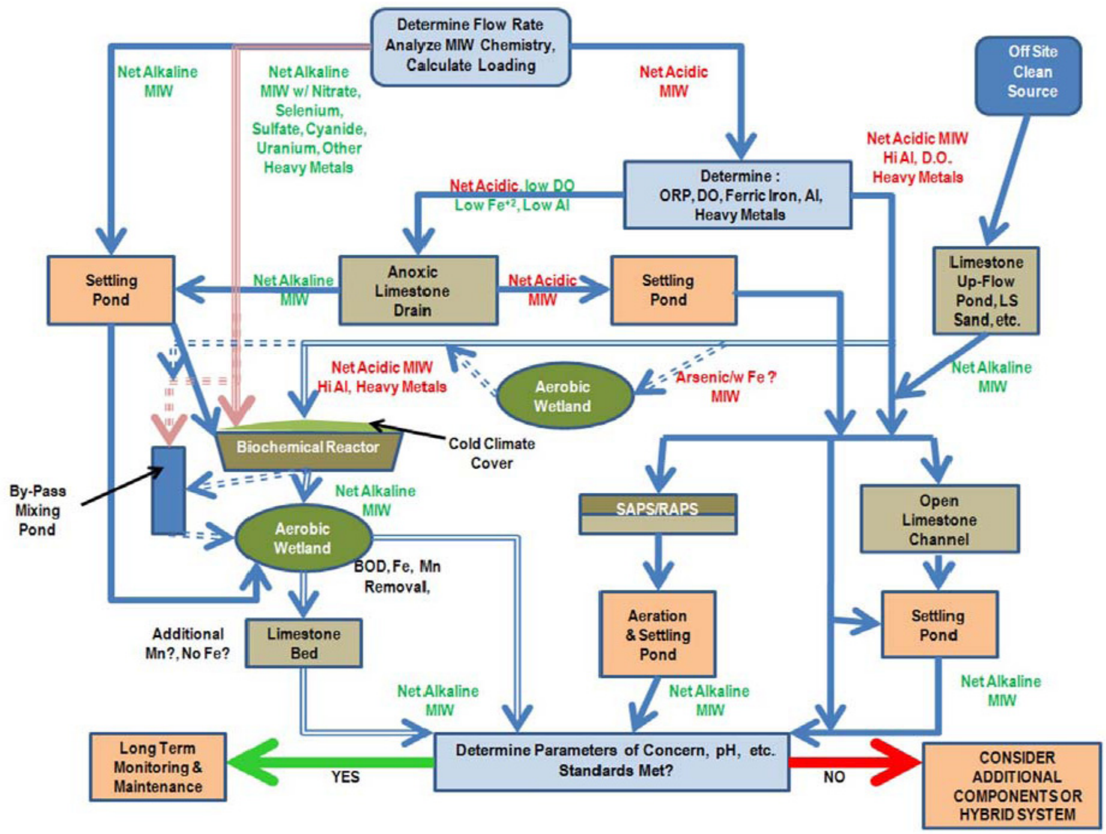
As mentioned above, the first step in choosing the right treatment and designing the most effective bioremediation system would be determining the physical and chemistry of the water to be treated. The following table presents the characteristics of water during both dry and rainy season in Canrey Chico water resources:

Parameter	Source 1		Source 2		Source 3		Source 4	
	Rain season	Dry Season	Rain Season	Dry Season	Rain season	Dry Season	Rain season	Dry season
pH	6.26	7.79	7.09	7.89	3.92	3.52	3.76	3.38
Conductivity	35	39	31	62	126	667	176	870
Temp***	9.8	7.5	12.4	6.9	10.5	7.36	10.1	9.6
Flow (Liters/sec)								
Source type (river, seep, mine adit, etc.)	Glacial Water	Glacial Water	Glacial Water	Glacial Water	Glacial Water	Glacial Water	Glacial Water	Glacial Water
Al (dissolved)	0.070	0.13	0.280	0.110	0.710	2.600	1.850	2.350
Fe (dissolved)	0.180	0.700	0.750	0.150	4	6.550	6.300	8.000
As (dis.)	<0.050	0.115	<0.050	0.112	<0.050	0.126	<0.050	0.150
Mn (dis.)								
Hg (dis.)	<0.025	0.192	<0.025	0.120	<0.025	0.192	<0.025	0.251
Pb (dis.)	<0.010	0.017	0.520	0.063	0.370	0.024	0.660	0.02
Cd (dis.)	0.006	0.031	0.003	<0.002	0.002	0.022	0.002	0.07

*** Temp measured in Celsius
Source 1: Rio Quilloc, Source 2: Rio Araranca, Source 3: Rio Negro (Bajo), Source 4: Rio Negro – Union de los Ríos Urhuash y Pumahuacanco

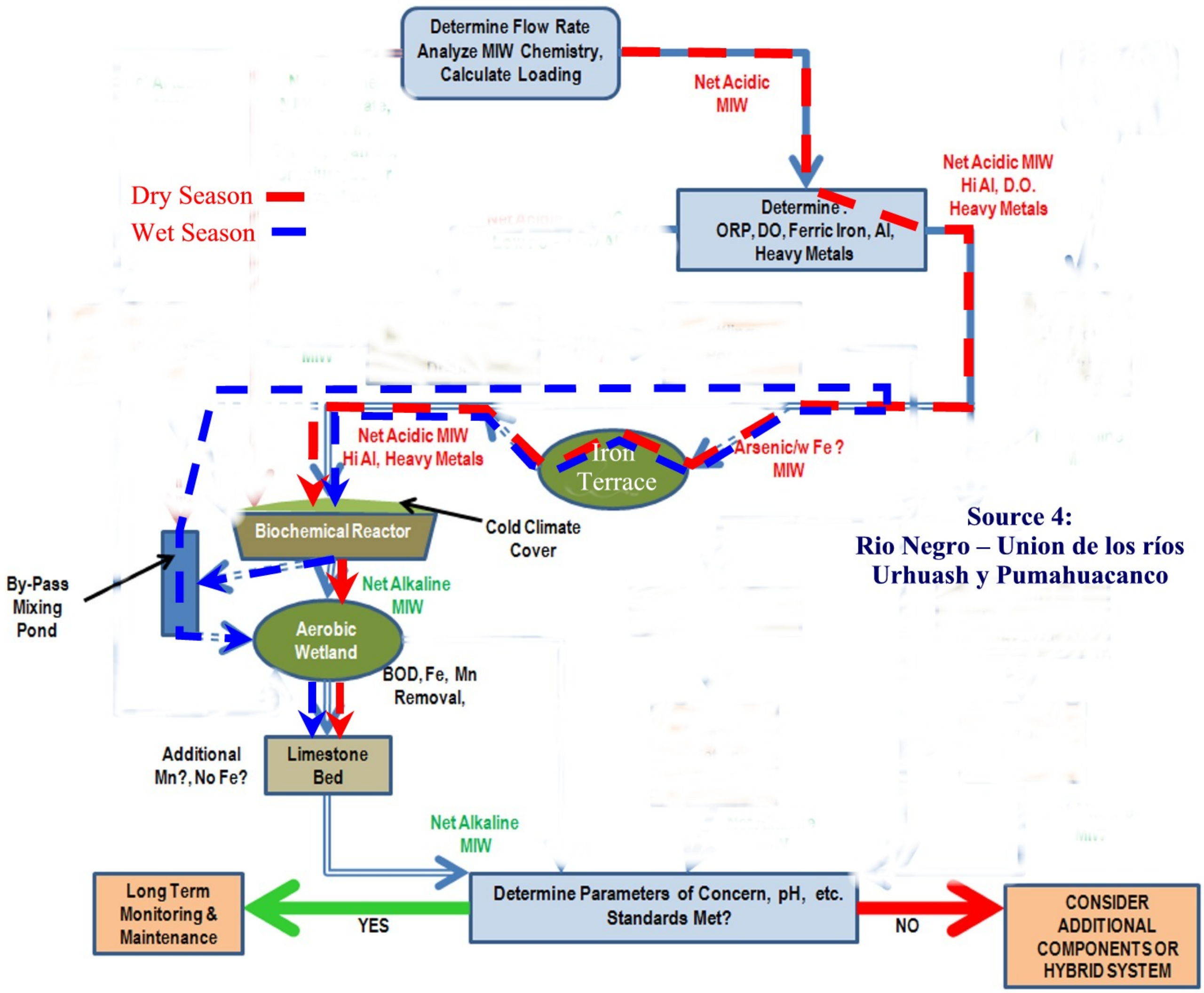
Using both the Penn State and Gusek methodologies, we can use the above information and the following flow charts to arrive at potential treatment designs for raising pH levels and removing the metals from the Rio Negro.

Passive Treatment of Mining Influenced Water (MIW) Decision Tree[30]



[30] Gusek, James J. "Passive Treatment 101: An Overview of the Technologies." 2008 U.S. EPA/National Groundwater Association's Remediation of Abandoned Mine Lands Conference. Denver. Lecture.

Decision Tree, modified for Highly Acidic MIW w/high levels of dissolved heavy metals, e.g. Rio Negro[31]



Given the characteristics and levels of contamination present, the above chart represents the most effective type of system design for the Rio Negro. The proposed system would function as follows:

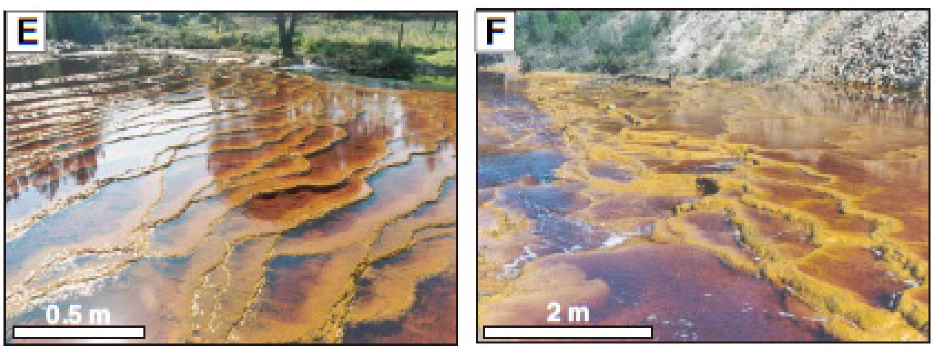
1. The first component of the passive treatment system would be an **iron terrace** – which would serve to remove iron from the water and reduce the very high acidity. An iron terrace, or terraced iron formation (TIF) is a naturally occurring or man-made structure which consists of a series of very small

[31] Gusek, Jim. "Correspondence with Jim Gusek, Golder Associates, Engineers Without Borders." E-mail interview. Sept. 2012.

(centimeter-scale) waterfalls, over which iron contaminated water passes. These waterfalls oxygenate the water and thus allow iron to precipitate out of the water as solid Iron Oxide, which collects on the iron terrace. This removal of iron results in a sharp reduction in acidity, and is a necessary first step so that other metals can be removed later in the system.[32]

   a. Sizing of the terrace would probably be based on a guess of 10 m^2 of terrace surface area per gram of iron loading per day. Thus, if you were trying to treat 10 Liters per second of Source 4 water, the terrace would need to be 10 L/sec * 3600 sec/day = 36000 liters per day x .0068 grams Fe/liter = 244.8 grams/day * 10 m^2/gram/day = 2448 m^2 or about 0.25 hectares.

<u>Natural Terraced Iron Formations</u>[33]



2. The second component of the system is the **<u>sulfate reducing biochemical reactor, or BCR</u>** (Described and pictured in section III(b)). The effluent from the iron terrace would feed the BCR, <u>which would remove copper, zinc, cadmium, lead and mercury as sulfides and aluminum as a hydroxy-sulfate compound</u>. **Properly designing the BCR is one of the most important steps to creating an effective system**, and a gradual scaling up process should be used to reach the best final design in the most cost-effective manner:

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[32] Espana, Javier S., Esther S. Pastor, and Enrique L. Pamo. "Iron Terraces in Acid Mine Drainage Systems: A Discussion about the Organic and Inorganic Factors Involved in Their Formation through Observations from the Tintillo Acidic River." *Geosphere* 3 (2007): 133-51. Print.

[33] Espana, Javier S., Esther S. Pastor, and Enrique L. Pamo. "Iron Terraces in Acid Mine Drainage Systems: A Discussion about the Organic and Inorganic Factors Involved in Their Formation through Observations from the Tintillo Acidic River." *Geosphere* 3 (2007): 133-51. Print.

a. *"Proof of Principal" Testing*

i. Typically, locally-available and plentiful candidate substrate materials for BCR systems are evaluated in the laboratory, involving "proof of principle" testing, utilizing about 30 to 60 grams of different substrate materials in culture bottles immersed in MIW samples. The tests take about six to eight weeks. Aerobic testing is typically conducted simultaneously by monitoring effluent behavior over time under aerobic conditions (algae inoculum) without substrate. Typical algae inoculum may include pond scum or algae growths from natural wetland sites near the project (**Laguna Coyota**). Indicative measurements during proof of principal testing include pH, oxidation reduction potential (ORP), conductivity, substrate/water color and odor.

ii. Proof of Principle studies are static rather than flow-through experiments and are intended to:

1. Test the suitability of the candidate substrate materials or inoculum in a passive treatment component (typically a BCR)
2. Determine whether removal of a contaminant by microbial processes in a wetland with a known substrate composition is possible.

Proof of Principle Testing Setup

b. *Bench Scale Testing*

   i. Next, bench scale tests (see image below), utilizing about 200 pounds (100 kg) of substrate, are operated in the field for at least three months, preferably through a period with a typical range of dissolved metals concentration. These tests constitute a low-cost field demonstration of the principles developed in the laboratory. This approach begins to simulate the typical kinetic chemical reactions that might occur at a larger scale. Site specific loading factors and substrate hydrology/permeability characteristics are determined during bench scale testing.

<u>Bench Scale Testing Setup of Five BCR Mixtures</u>

c. *Pilot Scale Testing*

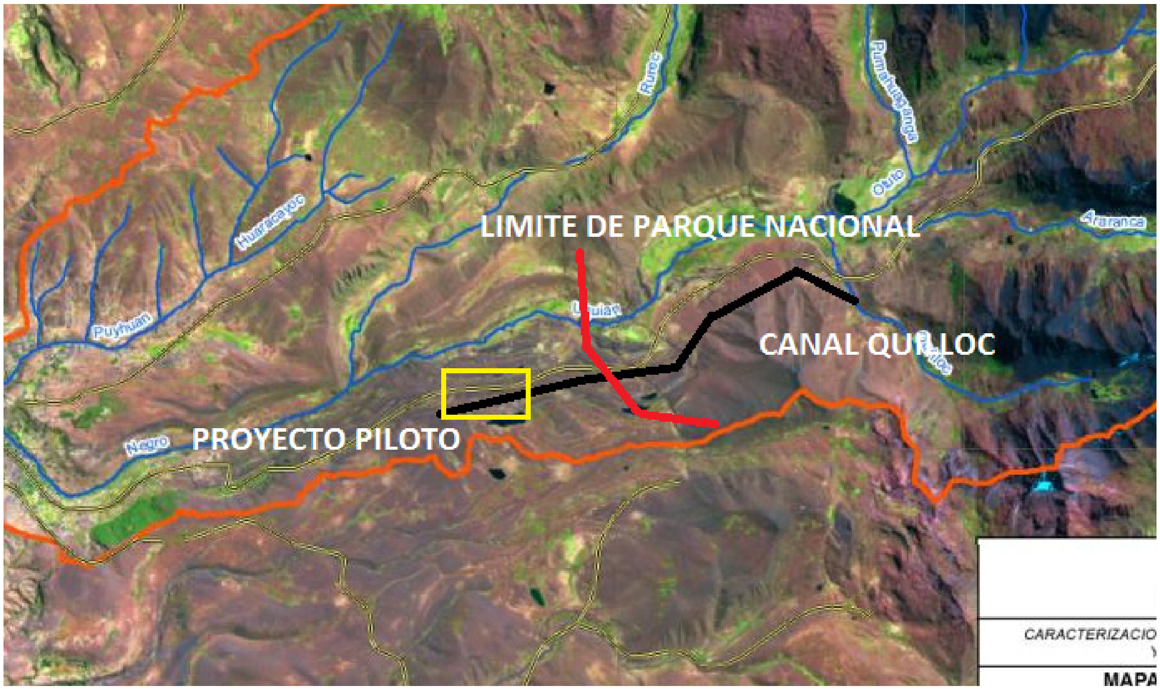
   i. Successful bench scale testing supports the construction of pilot scale systems utilizing tons of substrate. These systems are typically operated for at least a year before full scale system design is finalized. If possible, pilot system cells (pictured below) are sized to be integrated into the overall passive system design. It is important to note the importance of the laboratory tests to characterize “unique” MIW sources, substrate and their interactive results. A multitude of substrate candidates can be evaluated cost effectively in proof of principle scale testing. Bench scale testing allows cost-effective determinations of loading factors and system dynamics and thereby improves the likelihood that pilot scale designs will function as expected. This phased approach minimizes risk in determining the applicability of this technology for treating MIW in a wide variety of situations.[34]

Pilot Scale BCR Testing Setup

d. As mentioned previously, determining the size of the full-scale BCR is dependent on flow rates and contaminant levels from each source, from both wet and dry seasons.
e. **A pilot BCR system and/or just a pilot Iron Terrace could be placed along the currently unused Quilloc irrigation canals.** These canals can divert water from the Quilloc southwest and out of the National Park. Using these canals to divert water towards a pilot system outside the park would remove the hassle of obtaining

[34] Gusek, James J. "Passive Treatment 101: An Overview of the Technologies." 2008 U.S. EPA/National Groundwater Association's Remediation of Abandoned Mine Lands Conference. Denver. Lecture.

permission from the park and would also provide the pilot system with a consistent, low flow source of water. The canal's location are indicated on the below map in black:



3. The next part of the system would typically be an <u>**aerobic wetland or marsh**</u>. The wetland serves to remove remaining Iron and lower the elevated Biological Oxygen Demand (BOD) of the BCR treated water. The wetland can be man made or an existing area could be used, such as <u>Laguna Coyota in the case of Canrey Chico.</u>
4. The final step of the system would be a <u>**Limestone Bed**</u>, which concludes the remediation process <u>by removing Manganese from the water</u>.

It should be clear after reading this outline that a full-scale bioremediation system is complex, and <u>that the process of testing and evaluation to create the most effective system for the given situation requires *at minimum* a year and half</u>, in the absence of unforeseen delays.

a. Obstacles to Implementation

Determining the location, design specifics, and scale of this proposed system requires knowledge of the available financial resources for the project, and must take into consideration a variety of other challenges that could affect the progress of the project. The previous section of this report has outlined the design of a full-scale bioremediation system that would remove *all* of the harmful metals currently present in the Rio Negro. This multi-stage system is by necessity a large and (relatively) complex system which would require significant financial resources to construct. If successful, it would turn the highly contaminated Rio Negro into a water source which could be used for all purposes by the people of Canrey Chico. The treated water would be of sufficient quality for irrigation, animal consumption, and most importantly, human consumption. However, there are various obstacles which could force the project to scale down. Such obstacles include:

Regulations on Construction Within the Huascaran National Park

A significant obstacle that comes with the creation of a bioremediation system (full-scale or pilot) is the fact that the most convenient locations for construction (relatively flat spaces where the flow rate of the river is not too fast and treatment cells could be built with minimal difficulty) are all located high in the Puna of Canrey Chico. Much of this part of the community lies within the Huascaran National Park. Naturally, regulations of the National Park prohibit most types of construction projects, so to understand better the regulations involving construction within the boundaries of the park, I consulted with the Park Director, Martin Salvador. Construction within the park is divided into two types – construction as part of a scientific investigation and infrastructure. **Creating a small-scale pilot system in the park would be classified as a <u>scientific investigation,</u> but a full-scale system would be categorized as an <u>infrastructure project</u>.**

The process of securing permission to conduct a scientific investigation is described in the National Park Service's *Texto Único de Procedimientos Administrativos* (TUPA), number 3 –

3. Entry clearance to conduct scientific research in a Protected Natural Area SINANPE, for a period of up to one (1) year (including investigations that require temporary collection of biometrics, position transmitters or marking that does not damage wildlife)

Requirements:

- *Application addressed to Manager of Natural Protected Areas*
- *Research plan in Spanish*
- *Data sheet from scientific institution or sponsoring organization, and due accreditation in the case of foreigners*
- *Include in the development of the research at least one Peruvian researcher and an attached cover letter indicating the scientific institution to which he belongs or university of origin*
- *Recieve in writing the permission of native communities for researchers to visit or stay on their land*
- *Receipt of payment for processing fee*

Processing fee:

- Tax Unit (ITU) 15%

Where you start the process: *INRENA Window*

Authority approving the procedure: *Manager of Protected Areas*

Authority to resolve the administrative appeal: *Manager of Natural Protected Areas (Reconsideration), Head of INRENA (Appeals)*

Securing permission for an infrastructure project (full-scale bioremediation system) is a more complex and less formulaic process, which requires a formal report and proposal to be submitted to the Park offices for review. Martin Salvador emphasized the importance of having detailed plans for the plant along with full data for the water being treated. The project must be demonstrated to cause minimal damage to the park and not be a risk of further contaminating water sources. The benefits of the project must be demonstrated to be significant enough to outweigh the damage to the geography of the park caused by construction, and the plant (pilot or full-scale) should be enclosed so as not to pose a danger to grazing animals nearby. Finally, a successfully executed pilot project would be necessary to have any chance of approval for a full-scale bioremediation system.[35]

[35] Salvador, Martin. "Interview with Director of Parque Nacional Huascaran, Martin Salvador." Personal interview. 2 Oct. 2012.

Interference with Community Grazing Areas

The aforementioned flat valley located in the park, where the 4 tributaries join to the Rio Negro, is also an area heavily used by the members of Canrey Chico to graze their animals. While a basic pilot project would not take up much of this grazing space, a larger full-scale system would. In the event that this project were to successfully make it past the pilot stage, the community would have to determine another place to move these animals for grazing – as the bioremediation system would have to be fenced off and the amount of land in this area available for grazing would decrease significantly.

Financial Restrictions

Depending on the amount of financial support which can be secured from domestic or international sources, the potential scale of the project may change. If not enough funding can be obtained, a full-scale system designed to fully remediate the Rio Negro may have to be scaled down to a smaller, less complex system that only partially remediates the water to levels useful for irrigation, but not for animal or human consumption.

b. Possible Implementation Strategies

Single Bioremediation System on Rio Negro

Implementing a single, full-scale system on the Rio Negro which would address all contaminants presently in the water, would be the ideal strategy with the greatest positive impact for the people of Canrey Chico. This strategy would also be the most ambitious and likely the most costly, but the end result of a Rio Negro that can be used for human consumption and irrigation would be a massive boon to the severely strained water resources of the community. The outline for this single system makes up most of this report and is described in section IV.

Smaller Treatment Systems at One or Two Tributaries

In the event of limited financial resources available to devote to the bioremediation project, it would be possible to create a smaller system on one or two of the most contaminated tributaries to the Rio Negro (the Urhuash and Pumahuacanca). Project designs that seek to individually treat the tributaries of the Rio Negro would be cheaper than a full scale system (see section IV(d)), but would still require the same exhaustive design and testing process before they could be functional; ie a small scale system will require the same amount of time to implement as a full scale system, aside from slightly less construction time. This approach will improve the overall quality of the Rio Negro, but because other contaminated tributaries are not being treated, the water at the point of use for Canrey Chico will still be significantly contaminated. While quality might be improved to the point that it could be safely used for irrigation, it will not be of sufficient quality for human or animal consumption.

A "Partial" Bioremediation system on individual tributaries or the Rio Negro

Another way the project could be scaled down would be to create a system (or multiple systems) designed to only remove one or two metal contaminants from the Rio Negro or its tributaries.

Such a system might include only the first component of the outlined full-scale system in Section IV – <u>perhaps only the Iron Terrace</u>. The utility of such a system would be questionable however. Although removal of iron would make the water less acidic, remove the orange hue and make it slightly safer for use in agriculture, various other harmful metals would remain in the water. Arsenic and lead, whose harmful effects on humans are described in section I(c), would remain in the water at very unsafe levels, along with cadmium, aluminum, and mercury – also very harmful at their current levels. For human and animal consumption, the Rio Negro would remain off-limits.

c. Community Capacity to Construct and Maintain System

One of the most important factors when discussing the creation of a bioremediation system is analyzing in advance the labor necessary to construct the system and maintain it – and more importantly analyzing the ability of the local community to organize and ensure that this maintenance does indeed occur. The creation of infrastructure projects, whether it be an electricity grid or a sewage system or a bioremediation system, all require maintenance, and if a community does not have the will and ability to organize and devote time and resources to the projects maintenance, it will undoubtedly end in failure. When discussing the project during interviews with community members, support was very high. However, given how many preliminary steps must be performed before an appropriate system is designed and confirmed to function, it is not possible at this time to know how much labor would be required and what kind of maintenance will be necessary. These issues are entirely dependent on what design and strategy is settled upon prior and during the testing stages. **However, regardless of system design, the amount of maintenance needed will be quite low**. As Gusek describes in his brief history of passive treatment systems:

"A well-designed passive system should function for many years without a major retrofit to replenish construction materials, periodic visits to conduct "flushing" events, and be able to function without using electrical power.

Passive treatment system longevity is believed to be limited by the steady effects of metals accumulation and the depletion of key materials/nutrients. ***Some aerobic components (e.g., aerobic wetlands) could last virtually indefinitely*** *as long as provisions are made to periodically remove and dispose of accumulated iron hydroxides and other precipitates.*

BCR designs to date take advantage of the observation by Thomas and Romanek (2002) that the consumption of their limestone-buffered organic substrate (LBOS) [a.k.a. organic BCR substrate] progressed from the top-downward in their top-fed columns. Thus, BCR substrate longevity can be extended with increasing cell depth/mass. The oldest BCR known, the West Fork system in Missouri, reached its 12-year milestone this summer. While it does not appear to be running out of "fuel" nor plugging with metal precipitates, it may require some maintenance. Estimates involving typical BCR cell loading, carbon content and dimensions suggested that ***a typical BCR cell could last about 30 years without the addition of fresh organic material."***[36]

d. Projected costs

Using a program called *AMDTreat*, widely used amongst passive treatment specialists in the United States and worldwide[37], preliminary estimates on the costs of passive treatment systems can be made.

PROJECTED COSTS

Biochemical Reactor Testing and Design Process

Pilot-Scale Iron Terrace on Quilloc Canals
Pilot-Scale Biochemical Reactor on Quilloc Canals

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[36] Gusek, James J. "Passive Treatment 101: An Overview of the Technologies." 2008 U.S. EPA/National Groundwater Association's Remediation of Abandoned Mine Lands Conference. Denver. Lecture.
[37] Gusek, Jim. "Correspondence with Jim Gusek, Golder Associates, Engineers Without Borders." E-mail interview. Sept. 2012.

Pilot-Scale System Total

Full-Scale Iron Terrace on Rio Negro
Full-Scale Biochemical Reactor
Full-Scale Limestone Bed
Full-Scale Bioremediation System Total

V. Including an Educational Component

To ensure sustainability of the designed bioremediation system and transfer knowledge to the future generations of Canrey Chico, The Mountain Institute believes that if a full-scale bioremediation is pursued, it should include an educational component. The educational strategy will consist of three main stages:

1. Communication
2. Evaluation
3. Knowledge Sharing

1. Communication

It is imperative that the community is involved in every step of this project and demonstrates sufficient capacity to take ownership of the system. The issue of water contamination was brought to our attention by the community members themselves, and we are confident that given the positive impact this project would have on the overall health of the community and its potential to increase economic productivity, the community members will enthusiastically engage with us on this project as they have done in the past. We have identified the following platforms for community engagement with this project:

Community Meetings

On the first day of every month, the members of Canrey Chico community gather together to discuss issues relevant to their community. The Mountain Institute regularly participates in these meetings to inform the community of their projects. These meetings are then followed by smaller meetings with individuals or community leaders are actively involved with the supervision or operation of those projects. TMI would use these regular meetings as a platform to inform the broader community on the goals of the project and the basic science, technology and methodology of the proposed bioremediation system.

Choosing a Supervisor, Maintenance, and Construction Personnel

Prior to construction of the plant, TMI will organize a meeting to be attended by community leaders and members of the community interested in being involved in the construction and maintenance of the system. One community resident will be chosen by the community leaders and TMI to serve as the Bioremediation System Supervisor. He/She will be further trained on the details and mechanisms of the system and will take an active role in monitoring the efficiency of the system. He/She would also serve as a liaison to communicate potential problems occurring in the system with TMI staff. The supervisor would be trained and provided with the tools to measure the quality of water on the regular basis and keep concise records of findings. Following the selection of the Supervisor, a small group of personnel (2-3 people) responsible for basic monitoring and maintenance of the system post-construction would be selected. Finally, the largest but most important group of community members willing to help with actual construction would be selected (they would be compensated for their labor).

Bioremediation Workshops

TMI will hold at least three workshops (before, during, and after construction is completed) to meet with all community members involved in plant construction. These meetings will be compulsory for the Supervisor and Maintenance Personnel, but the entire community will be invited and encouraged to attend. These workshops, which will facilitated by TMI staff, but also attended by TMI partners at UNASAM specializing in environmental engineering and bioremediation, will provide community members with a more in-depth understanding of the mechanisms involved in the bioremediation system. A member of the TMI team will explain the operational requirements of the system and advise on potential challenges of the design, along with foreseeable challenges in the maintenance of the system once construction is complete.

Incorporating water sanitation practices into school curriculum

Through experience, we have learned at TMI that educating the younger members of the community plays a critical role in educating the broader community on an issue. We plan to engage with the staff at XXXX school in Canrey Chico and develop a curriculum that teaches the students about the importance of clean water and ways to prevent its contamination. Oftentimes, local community members unknowingly dump their garbage into the water or wash their clothes on the riverbeds using chemical detergents. By educating students about the impacts of such contaminations, they will in turn encourage their parents to find alternatives for behavior that damages the water resources of the community and the region as a whole. We would like to put in place monthly workshops in the school for students of all ages to learn about these issues, so that the subject is a constant in the curriculum and can make a true impact on the students.

2. Evaluation

Community Reports

Once construction of the plant has been completed and it has begun to process water, the Bioremediation System Supervisor and other involved community members (with the help of our staff) will produce a one page report every six months (dry season and rainy season) detailing the water quality measurements. TMI will review these reports and report back on the effectiveness of the system during an annual community "update meeting", during which TMI and members of Canrey Chico will:

- Review the results achieved by the system
- Identify the challenges that remain
- Resolve any potential errors in the design of the program

Bioremediation Site Visits

Every year, for the first three years, and every other year thereafter, TMI will accompany an environmental scientist to the bioremediation site to evaluate water quality and review the measurements recorded by the supervisor throughout the year. The findings will be reported back to TMI to evaluate the effectiveness of the system and address any required changes in the design. These findings will also be shared with project funders and community leaders.

Community/School Visits

Every year, TMI will visit the community during a monthly meeting to understand the real impacts of the project: In what way have they benefited from cleaner water? Are the crops increasing? Is their livestock healthier? Additionally, we will visit the school to converse with the students to evaluate their understanding of issues that impact their water resources. The staff member will then report on her/his findings during these visits.

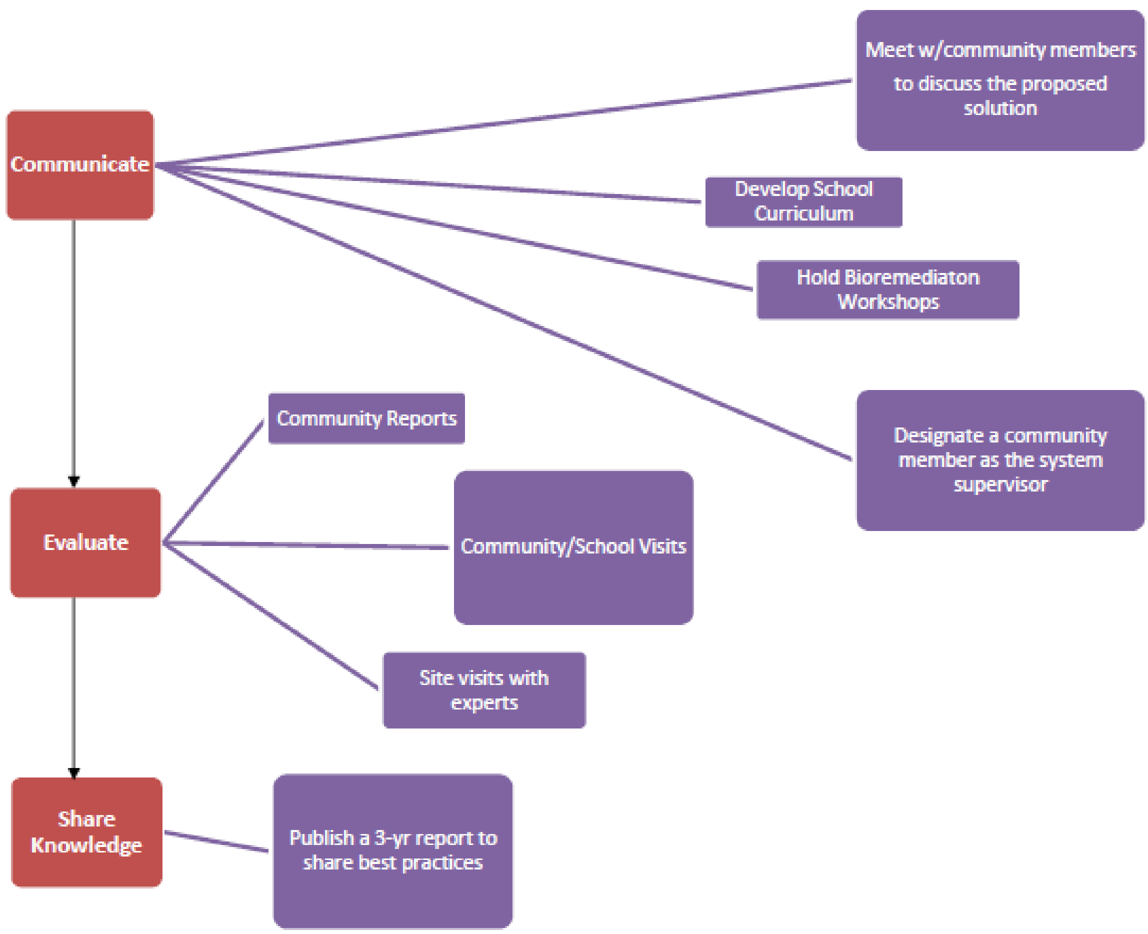
3. Share Knowledge and expand the use of Bioremediation to other communities in the Three Watersheds Municipal Commonwealth (MMTC)

Three years from the start date of the bioremediation project, TMI will publish a report detailing the design and results of the first bioremediation project in the high mountains to share its findings with other organizations and communities worldwide. The report will include:

- Pre-design considerations
- Involved mechanisms
- Pilot projects and their results
- Final project cost/benefit analysis
- Design and construction of the final project
- Improvements observed after 1st, 2nd, 3rd year
- Challenges faced throughout the life of the program
- Remaining challenges
- Community involvement
- Overall evaluation of the system

The importance of using the Canrey Chico bioremediation project as a pilot for future expansion to the entire Three Watersheds Commonwealth cannot be stressed enough. If bioremediation can be demonstrated as a low cost, low maintenance, but effective water treatment method, the multitude of communities within the

Commonwealth dealing with water contamination will be significantly more likely to invest in such a system. Given meager financial resources on the local level, mayors are much more likely to direct available funds towards more visible and proven investments. A successful project in Canrey Chico would make investing in water treatment much more viable and likely destination for local investment. The Commonwealth's various sub-committees and groupings ensure that documentation of the progress and experience gained in Canrey Chico will be made available to all members of the MMTC, so that similar projects can be undertaken in other communities with an informed knowledge of the process and the costs involved in implementing such a system.



VI. Possible Funding Sources for Pilot and/or Full-Scale System

a. International Funding

The following international organizations offering grant support for water quality projects have been identified:

Name of the Grant	Application Deadline	Description	Source
EPA		Currently no opportunities but check site regularly for updates- they fund clean water projects around the world	http://www.epa.gov/oia/grants/index.html
Deutsche Bank Americas Foundation	Ongoing basis	Deutsche Bank works in partnership with local nonprofit organizations to provide distressed communities and disadvantaged individuals with opportunities for safe and affordable housing and economic advancement- they have previously given grants to water projects in Latin America	https://www.db.com/usa/content/en/1066.html
The Coca Cola Foundation	Ongoing basis- Online application	Water wardship support access to clean er and sanitation, ershed protection in er-stressed regions, zation of water for duction and or multiple systems that do more provide clean drinking er, education and reness programs that mote water conservation in communities and ustry	http://www.thecoca-colacompany.com/citizenship/application_guidelines.html
Blue Moon Fund	Ongoing	blue moon fund works to build human and natural resilience to a changing and warming world. We use natural,	http://www.bluemoonfund.org/grantmaking/applying/

		social, and financial capital to implement new models in high-biodiversity regions around the world.—would be eligible under climate change mitigation/adaptation grant	
Canadian International Development Agency	Non currently-check periodically		http://www.acdi-cida.gc.ca/acdi-cida/ACDI-CIDA.nsf/eng/ANN-93015497-R99
Caterpillar Foundation	Ongoing online application	Caterpillar supports the philanthropic efforts of the Caterpillar Foundation. Founded in 1952, the Caterpillar Foundation has contributed more than $500 million to help make sustainable progress possible around the world by providing program support in the areas of environmental sustainability, access to education and basic human needs.	http://www.caterpillar.com/cda/layout?m=401496&x=7&f=467266
Finland Ministry for Foreign Affairs			http://formin.finland.fi/public/default.aspx?culture=en-US&contentlan=2
Foundation Ensemble	Ongoing	Water and sanitation, sustainable development, animal biodiversity, these three areas of activity reflect the founders' wish to fight poverty issues, whilst working towards long-term environmental protection.	http://www.fondationensemble.org/amicprog_crit.php
Ford Foundation	Ongoing	Should apply under their "economic fairness: expanding livelihood for poor households" initiative	http://www.fordfoundation.org/regions/andean-region-and-southern-cone/for-grant-seekers
Global Environment Facility	Ongoing	The GEF funds a broad array of project types that vary depending on the scale	http://www.thegef.org/gef/who_can_apply

		of GEF resources, the project needs and the issue addressed. In order to be approved, each project follows a specific project cycle.- the project must be approved by the country rep.	
Minor Foundation for Major Challenges	Ongoing	The proposal requires an education/political component: The board grants support to the projects they believe have the greatest impact on influencing public opinion and increasing political support for cutting green house gas emissions. We are looking for innovative and experimental projects with high impact, and we are willing to bear the risk that such projects entail.	http://www.minor-foundation.no/apply-for-a-grant
Monsanto Fund	January1-Feb 29	Meeting critical needs in communities by supporting nonprofit organizations that help with things such as food security, sanitation, access to clean water, public safety and various other local needs	http://www.monsantofund.org/grants/international/
Oak Foundation	Ongoing	Oak Foundation commits its resources to address issues of global social and environmental concern, particularly those that have a major impact on the lives of the disadvantaged.	http://www.oakfnd.org/node/4036
OPEC Fund for International Development	Ongoing	OFID's grant program includes technical assistance for small-scale social schemes, sponsorship for research and other	http://www.ofid.org/PROJECTSOPERATIONS/Grants/GrantApplication.aspx

		intellectual pursuits, and humanitarian aid. In addition, OFID has set up special grant accounts that respond to the urgent and unique challenges presented by HIV/AIDS, Palestine and, most recently, Energy Poverty.	
Peru Opportunity Fund	Ongoing	We are looking for grantee partners who work with small scale farmers to help them overcome barriers to producing more from their land and earning more from their crops. Specifically, we are looking for projects that: 1) Bring relevant information to small farmers that will help them improve their yields and increase their incomes; and 2) Provide access to appropriate environmentally-friendly technologies that increase productivity	http://www.peruopportunity.org/application-process.html
USAID			http://peru.usaid.gov/frequently-asked-questions
Veolia Environment Foundation	Quarterly-January 1st	The Foundation enables Veolia Environment employees to get involved with the associations or international outreach organizations.	

Waterloo Foundation	Ongoing	TWF believes that improving an individual's ability to access a high-quality education; and supporting communities to have access to clean drinking water, sanitation and hygiene are both key to achieving this objective. These form TWF's two main themes of interest in our World Development program, and each is described in more detail below.	http://www.waterloofoundation.org.uk/Applications.html

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