Constructed Vetiver Wetlands in Jimma, Ethiopia

An evaluation of the effectiveness of the vetiver constructed wetland as a sustainable water treatment solution for the coffee wet mills in the mountains of Jimma, Ethiopia

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Contents

Executive Summary

In the mountains of Ethiopia where an estimated 4000 km^2 of land is dedicated to growing coffee, many farmers are turning to the coffee wet milling process for higher earnings. This water-intensive method creates wastewater effluent high in organic matter and sugars that frequently becomes a pollutant in local waterways.

As an attempt to create an effective, sustainable solution, TechnoServe implemented over 20 vetiver wetlands in 2009 to be operated and maintained by the wet mill cooperatives. TechnoServe has hired me as a volunteer consultant to investigate the effectiveness of these vetiver wetlands in treating and containing the wastewater. The process of understanding the wetland systems required surveying the local farmer cooperatives and assessing the readiness of new and existing vetiver wetlands for the 2012-2013 harvest season. I traveled to many sites in the mountains surrounding Jimma and Sidamo in Western and Southern Ethiopia for 10 weeks from October to December of 2012 to perform the study.

The scientific portion and the community development portion of this research go hand-in-hand. The scientific portion of this research is to assess the success of the wetlands by examining the water quality and water flows entering and exiting the wetlands in order to evaluate and improve the design. This information is used for my Master's project and is found in my Master's report. The community development portion of this research involves the farmer cooperative surveys and site assessments of the new and existing constructed vetiver wetlands. This qualitative data combined with the quantitative data from the water quality characterization and water balance produce a standard operating procedure for the wet mill users and an updated vetiver wetland design to be used by TechnoServe to improve the functionality of the existing wetlands and for the installation of future wetlands. TechnoServe plans to use the results of this investigation to promote the wetlands as a solution to coffee wastewater treatment throughout the regions they work in in Ethiopia and eventually in other countries involved in their coffee initiative, including Latin America and Vietnam.

In order to effectively communicate the project and how it utilizes sustainable community development skills, the following information is described:

1. A brief understanding of and the relationships between the local community, the Government of Ethiopia, and TechnoServe Ethiopia.
2. The significance and effect of the coffee wastewater contamination on the local community.
3. A description of data collection templates for the new and existing wetland site assessments and cooperative leader surveys
4. A summary of works resulting from this investigation to be utilized by TechnoServe in Ethiopia

The deliverables of this research include assessments of the water quality, water balance, maintenance needs, vetiver wetland design improvements, and a standard operating procedure. This information will be taught to the local cooperative members with the desired impact of meeting the government regulations and improving the local waterways during the harvest season.

From this investigation, the effectiveness of the vetiver wetlands as a wastewater treatment method for coffee wastewater is evaluated. It is found that the design is generally good and almost meets requirements, but a few updates and adjustments should be made. The communities demonstrated a

desire and achievement at solving the problems encountered with the treatment systems and are generally hopeful for the success of the wetlands.

Project Overview

Project Description

In the mountains of Ethiopia where an estimated 4000 km^2 of land is dedicated to growing coffee, many farmers are turning to the coffee cherry wet milling process for higher earnings. This water-intensive method creates wastewater effluent high in organic matter and sugars that frequently becomes a pollutant in local waterways.

As an attempt to create an effective, sustainable solution, TechnoServe implemented over 20 vetiver wetlands in 2009 to be operated and maintained by the wet mill cooperatives. The scientific portion of this research is to assess the success of the wetlands by examining the water quality and water volumes entering and exiting the wetlands in order to evaluate and improve the design. The community development portion of this project assesses the operator perceptions of different wastewater treatment systems and the life cycle of the wetland system, providing a standard operating procedure based on these evaluations, and the assessment of the current constructed wetlands, providing action plans to be used to prepare the wet mill cooperatives for use in the upcoming harvest season.

The resulting works of this research include an assessment on the water quality, water volume, maintenance needs, design improvements, and a standard operating procedure. This information will be taught to the local cooperative members with desired impact of meeting government regulations and improving the local waterways.

In order to effectively communicate the project and how it utilizes sustainable community development skills, the following information is described:

1. Brief understanding and relationships between the local community, Government of Ethiopia, and TechnoServe.
2. Understanding of the importance of coffee wastewater contamination on the local community.
3. Description of data collection templates for the new and existing wetland site assessments and cooperative leader surveys
4. Summary of works resulting from this investigation to be utilized by TechnoServe in Ethiopia

Description of Communities

TechnoServe works with hundreds of cooperatives and farmers in Ethiopia and other countries in East Africa. The communities interacted with in this practicum are the ones using wetlands to treat their coffee wastewater and are located in two specific regions of Ethiopia – Jimma and Sidamo. The Jimma communities in the Western mountains of Ethiopia include the 5 larger communities of Jimma, Agaro, Bedele, Bonga, and Limu are broken down into 20 villages represented by the name of the local cooperative working with TechnoServe. Sidamo is another mountainous region toward the Southwest of Ethiopia, near Hawassa. There are 15 new wetlands installed in Sidamo in 2012 by TechnoServe. These wetlands are just becoming established so are planned to be in use for the 2013-2014 harvest season.

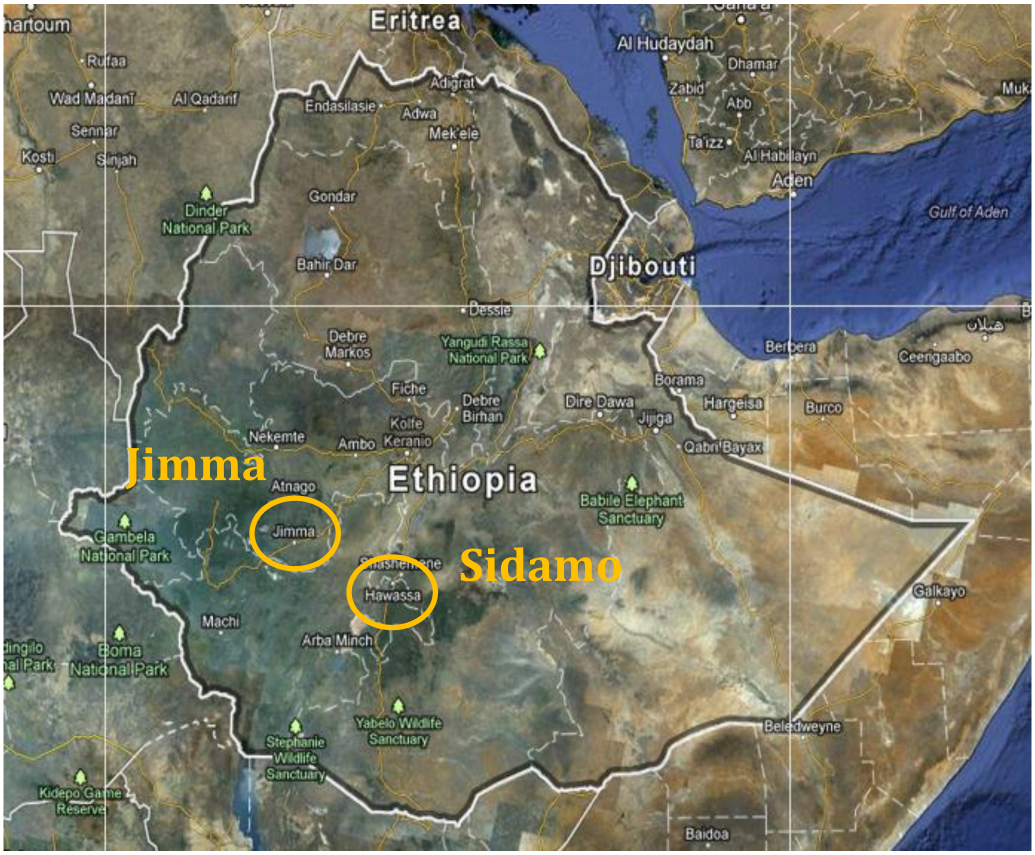

Figure 1: Primary investigation takes place in Jimma but wetlands were evaluated for readiness in Sidamo (Hawassa)

The mountains of Ethiopia are where coffee was first discovered and cultivated. It grows wild as well as planted beneath the forest canopy in these areas. In many cases, the farmers share the coffee lands and harvest the cherries together while others own their own plots. The farmer cooperatives buy the harvested cherries by the kilo and process them. TechnoServe has helped many cooperatives by providing advisers on how to take out a loan and purchase a wet mill in order to receive higher prices for the beans. Once processed, specialty coffee buyers from Europe and North America visit the cooperative wet mill sites to inspect and purchase beans. The buyers and farmers interact to improve the farming and milling practices for better sales.

As a result of the business, financial, and holistic farming advice, farming communities that once were losing members to go beg on the streets of Addis Ababa are now instead seeing their children attend school, according to many TechnoServe workers.

Host Organization Profile

TechnoServe (TNS) is a non-governmental organization that aims to build local capacity utilizing the entrepreneurship of agriculture, agribusiness, tourism, alternative energy, and various small rural enterprises. It was started in 1968 by a businessman and philanthropist, Ed Bullard, who initially focused on helping agricultural cooperatives have a "hand up rather than a hand out" and saw the power of private enterprise[1]. TechnoServe defines its mission as "help[ing] entrepreneurial men and women in poor areas

[1] http://www.technoserve.org/

of the developing world to build businesses that create income, opportunity and economic growth for their families, their communities and their countries."[2] This mission aligns very well with the concept of utilizing businesses to promote a local need, such as "sanitation as a business," but in this case turning a second-rate business into success.

The model TechnoServe uses is to empower entrepreneurs by helping them capitalize on good business opportunities through aiding in building businesses and industries with the outcome of higher wages and local products being bought from the rural poor. As a result, the new income sources and markets are meant to lift the families out of poverty and provide opportunities for the community. TNS works in 30 countries in Africa, Latin America, and Asia and is active in many agricultural sectors including coffee horticulture, dairy, tea, cacao, and cashew. In Ethiopia, TNS works to modernize and rebuild key industries, including coffee.

In the Jimma and Sidamo areas, TechnoServe incorporates these practices by providing teachers and advisers to the farmer cooperatives, particularly in the use of coffee wet mills. The traditional method of coffee processing is dry milling, but wet milling earns $1.00 more per pound for exported coffee. TechnoServe worked with farmers to implement 64 new wet mills from 2009 to 2011. In that time, the Jimma coffee export prices increased 64% and the profits to farmers increased 80%. The wet mills used in the area cost $25,000 but many cooperatives are able to pay off the loan in one harvest season, demonstrating the high earnings of wet milled coffee beans and good business practices.

Maintaining high standards for sustainable coffee production is central to TNS's values[3]. The standards they have developed apply to the smallholder coffee farmers, smallholder coffee enterprises (cooperatives or farmer business groups), estate coffee enterprises (plantations), and coffee service providers (dry mill and exporters) and are focused on production and farm management, social responsibility and ethics, occupational health and safety, environmental responsibility, and economic transparency. Within the standards of environmental responsibility, TNS maintains the mandatory practice of separating wastewater from pulp, containing all untreated wastewater in ponds at least 30 m from any water body and only releasing treated water into water bodies after testing and meeting compliance with national and/or international standards. Additionally, the coffee pulp shall be composted for use as organic fertilizer by producers, water consumption must be tracked by total volume and cherries processed, and water must be conserved by using no more than 2 liters of water per kilogram of cherries. Lastly, an environmental management policy will be developed and shared with all workers. TNS has many more policies not mentioned that do not directly relate to this study.

Country Profile

According to the CIA World Factbook[4], Ethiopia's economy is based on Agriculture, making up 41% of the nation's GDP and 85% of total employment; with coffee as the major export crop. Yet, the agricultural sector faces limitations of poor cultivation practices and frequent drought. The Government of Ethiopia is working with donors to strengthen Ethiopia's agricultural capacity and is seeing success by the decreasing numbers of Ethiopians experiencing starvation. The government is putting forth an effort to achieve development goals focused on agriculture and industry, delineated in the five-year Growth and

[2] (TechnoServe, 2012)
[3] (TechnoServe East Africa Coffee Initiative, 2011)
[4] (CIA Publications, 2013)

Transformation Plan announced in September 2010[5]. As a result, the GDP growth has remained high, but the per capita income is among the lowest in the world[6], with 29.2% of the population below poverty line. Because investment has high impact in Ethiopia, it is one of the Bill & Melinda Gates Foundation's priority countries.

Since Agriculture is Ethiopia's largest provider of GDP and coffee is the largest exported product, the Government of Ethiopia takes an interest in improving and regulating its production. In regards to the environmental contamination and adverse health effects resulting from the popular wet milling process, the government is highly involved in the issue. Wet mill owners must prove they will dispose of the contaminants according to regulation in order to receive the permit of approval to begin working the wet mill for the harvest season. Government workers are out frequently to the sites in the beginning of the season to check for compliance and provide support. The commonly known regulation throughout the wet milling community is for all wet mill effluent to be contained more than 30 meters away from a natural waterway. To meet this standard, many wet mills channel the wastewater into a lagoon or series of lagoons to contain it. This is allowable unless the lagoon is within 30 meters of the waterway. The small size of many of the wet mill sites and close proximity to rivers prevents many wet mills from meeting this standard.

Background Research

In the mountains of Jimma, Ethiopia are thousands of coffee trees ripe with cherries. Farmers grow the fruit and wait for harvest to process them. Once picked, many farmers take their coffee cherries to local wet mills where they are bought by a local cooperative. After hundreds of kilograms of cherries are depulped and soaked in the wet milling process, three end products remain: coffee beans, cherry pulp, and contaminated water. The coffee beans are spread out to dry on parchment tables, the pulp is taken to compost in piles, and the wastewater is dumped. Some wet mill coops release the dark sugary, lumpy water into the closest river. Other coops channel it into lagoons to store for the season, but these lagoons at times overflow into surrounding waterways. Endless disagreement and strife occur between wet mill coops, government workers, and downstream communities.

The disagreement is a result of the high concentration of contaminants in the wastewater. The majority of the pulp is removed and taken to the compost piles, but pieces of pulp and the cherry mucilage remain in the wastewater to be treated. The pulp contains significant amounts of sugars, proteins, and acid, while the sticky mucilage contains proteins and sugars. The sugars are easily fermented leaving organic and acetic acids in the water causing very low pH levels[7] - even as low as 3.8 – and the digested mucilage precipitates out of the solution, forming a thick slime on the surface, clogging waterways and encouraging anaerobic conditions. The result is degraded rivers throughout the mountains each harvest season. The coffee farming practices in the region of Jimma, Ethiopia do not use fertilizers or pesticides, so they are not a concern in the coffee milling wastewater, though they may be in the river from other sources.

The rivers are the main source of water for the local community – including the farmers who sell their coffee cherries to the wet mill cooperatives. They are used for bathing, washing, and even drinking in

[5] (Ministry of Finance, 2013)
[6] (CIA Publications, 2013)
[7] (Murthy, 2004)

some places. In a study performed in the Jimma area of Ethiopia, local communities were surveyed for health effects from the contaminated rivers. Alarmingly, the symptom of “spinning sensation” affected 89% of the population surveyed.

S. no.	Impacts	% Of population affected
1	Spinning sensation (feeling drunk)	89
2	Eye irritation (burning inside)	32
3	Skin irritation	85
4	Stomach problem	42
5	Breathing problem	75
6	Nausea	25

Table 1: Survey report of the health impact on the community residing in the vicinity of coffee processing plant, Jimma Zone, Ethiopia.

As explained earlier, the government is very involved in this issue and works closely with NGO’s like TechnoServe to improve the situation. Since many wet mills cannot meet the primary standard of treating or containing all wet mill wastewater more than 30 meters away from a waterway, communities are seeking alternate solutions to wastewater treatment that may be allowable by the government.

TechnoServe’s Solution:

The Vetiver Grass Constructed Wetland

The solution TechnoServe has developed to treat the wastewater that must be contained within 30 m of a waterway is the constructed vetiver wetland. The goal of the wetland is to contain all water within the wetland and evaporation pond system. Ideally, the processes within the wetland will also filter and biodegrade contaminants.

The wetland functions to treat the wastewater by utilizing settling, filtering, and microbial biodegradation processes to remove the contaminants and uses the volume of the wetland, infiltration, evapotranspiration, and plant uptake to contain the water. Many processes are going on within the constructed vetiver wetlands, centering on the vetiver grass, the soil, and the water. The vetiver grass is ideal to use because it has deep tillering roots[8] to take up water[9], stabilize the soil, and provide oxygen to microbes. The microbes added in the form of effective microorganisms (EM) break down the organic contaminants and ideally fix any nitrogen coming in to prevent it from leaching into the groundwater. The trenches throughout the wetlands allow larger material to settle out of the water, leaving the soil to filter the finer contaminants and allowing water to infiltrate into the ground, and for the soil to store water in its pores. Any excess water flowing out of the wetlands is stored in an evaporation pond.

Description of Activities

As a volunteer consultant for TechnoServe, my roles include visiting all of the wetland sites established in Jimma in 2009 to evaluate their readiness for use and identify 2-4 sites in excellent condition to study; visiting many of the recently established sites in Sidamo to assess their readiness for use; setting up a lab

[8] (Vieritz, 2003)
[9] (Smeal, 2003)

to test the water quality of chosen sites and performing the sample collection and processing; monitoring flow data for the source water meter and setting up and monitoring exit water meter data to understand flows in and out of the system; interviewing local cooperatives and TechnoServe staff to understand the history and outlooks on the wetland systems; suggesting design improvements based on data gathered; and writing a full standard operating procedure for the wetland system based on data gathered.

Deliverables

As a result of the data gathering, interviews, and site assessments, the following deliverables have been agreed on with TechnoServe:

1. Report on Vetiver wetlands status in Jimma and Sidamo and recommended actions
2. Summary and evaluation of test results for water volume and water quality measurements
3. Report on improved vetiver design
4. Assessment of Vetiver wetland construction costs and cooperative perceptions
5. Full SOP on construction and maintenance of the Vetiver wetlands

The deliverables and tasks for the community development portion of this study are the cooperative surveys and wetland action plans used to improve the vetiver wetland design and the standard operating procedure.

Survey Templates

Wetland Cooperative Surveys

The operators and cooperative members of some of the wet mills were surveyed for their understanding and preference for the wetland as a wastewater treatment system. The following questions are the survey template:

Coop Leader/Operator Survey

Preferences

- Do you like the system? Why?
- Does it adequately serve your needs?
- Why do you want a system?
- What system did you use before?
- Are the wetlands better than previous system? How?

Adequacy

- Do you feel trained well enough to run the system?
- What would you do differently?
- Do the wetlands clog?
- Do the wetlands overflow?

Maintenance

- How often do they need to be maintained?
- How difficult are they to maintain?
- Does the rest of the system work? Piping?
- Does the water flow easily to the wetlands?

	How often do plants need to be replaced?
	If a plant needs to be replaced, where do you get the new plant?
	What is the method of harvesting the vetiver grasses?
	How frequently are they harvested?
	What is done with the grasses after harvested?
	Do you have problems with weeds growing vigorously?
	What measures are taken to minimize weeds?
Issues	
	Is there a rainy season in the highlands? Is it possible for a flush of contaminants?
	Have you ever had an upset in which all the plants died? Do you have pest or vector problems? How do you ensure there will not be vectors breeding?
	What soil preparation was done before planting the grasses?
Costs	
	What are capital costs?
	What are operating costs?
	What materials must be bought regularly?

This survey was adapted to accommodate the lagoon site without a wetland that was also surveyed and more questions were asked following up answers to these questions.

Action Plans

The existing wetland and new wetland surveys for readiness for the harvest season were evaluated by the following template:

Vetiver Wetland Action Plan

Wetland Name:		**Zone:**	
Date Visited:		**Year Constructed:**	
Size:		**Overall Condition:**	

Evaluation

Design	
Wetland at least 30 m away from a water body	
Water enters from soak tank at center of wetland?	
Construction	
Banks 50 cm wide, 40 cm tall, vetiver 30 cm apart?	
Vetiver grasses living and planted 40 cm apart?	
Grass planted and growing between vetiver?	
Ground uneven, slope across width?	
1-2 Gravel-filled trenches at entry point?	
Vetiver planted around evaporation pond?	
Maintenance	

Vetiver overgrown and needing to be cut back? Weeds growing? Livestock Grazing? **History:** **Other:**	

From this template, 24 short action plan reports are written. Two sample reports are included in Appendix 1. These reports are distributed to the TNS business advisers to prepare the wetlands for use prior to the start of the harvest season and to decide which wetlands are optimal to investigate further for the study. Before the season it seemed the wet mills placed lower value on preparing the wetlands than the TNS advisers desired. Once the harvest season began, though, the wetlands were functioning and ready for use. It is possible that since the harvest was so late due to bank loans being delayed that the cooperatives' focus and concern was on the bank loans rather than preparing the wetlands, which only takes a couple of days.

Results

The results of this practicum assignment are the deliverables of the Operator Perceptions of Vetiver Wetlands, the Wetland Action Plans, and the Standard Operating Procedure. The deliverable of the Improved Vetiver Wetland Design is the product of the scientific and community development portions of this investigation and is also included.

Operator Perceptions of Vetiver Wetlands

To understand the feasibility of effectively installing, using, and maintaining the vetiver wetland as a sustainable, low-cost solution to treat the contaminated effluent from coffee wet mills, interviews are conducted with key leaders from the local cooperatives. The questions address the general topics of treatment system preference, system and operator adequacy, maintenance, past and current problems, and cost. Cooperative leaders at three established sites in the Jimma area and seven new sites in the Sidamo area were interviewed. One of the interviews is with the cooperative leaders of a site using a lagoon system instead of vetiver wetlands. No interviews are conducted of sites that dump effluent directly into the river, since only TechnoServe sites were visited, though some of them had previously done so. The interviews were conducted in Amharic with bilingual TechnoServe Business Advisers and personnel translating.

Sites formally interviewed: Jawi, Doyo, Duro Mina (Jimma); Bergona Hagarasodicha, Fero, Yitbarak (Sidamo)

Sites informally interviewed: Shegole, Dego Galcha, Ambuye

Preferences

Each cooperative is motivated by three distinct concerns: care for the local environment, health of the local people, and strict enforcement of government regulations; while a couple of the cooperatives are also concerned about earning coffee certifications and setting an example for others to follow. Regarding the environment, in these mountain regions the effluent from the coffee wet mills is the primary source of pollution in the rivers. The coops know that the water is high in sugar and organic matter that is harmful to the health of downstream water users. All of them comment on how the residents of the area use the water for washing and bathing, and in some rivers drinking. Another common motivation for using the wetlands is the repeated visits of the federal government to hound the cooperatives to improve their wastewater treatment. Without proper water treatment facilities, such as a sufficient lagoon or wetland, the government will not approve the loan required by most coops to begin processing for the season. Cooperatives in the Sidamo area confess that they have had many disputes with the local community and government officials about the overflowing lagoons or the dumping of untreated wastewater into the rivers. All cooperatives formally interviewed expressed the concern to meet the government standard of treating the wastewater at least 30 meters away from a waterway.

The wet mill manager at Bergona Hagarasodicha, a site high in the mountains set at the beginning of a river, explains that his cooperative's new wetland is very well-esteemed in the community. Many people used to complain to the coop because the wet mill would release wastewater directly into the river, contaminating the water for downstream users. Since the cooperative buys the cherries from the community's own farmers, the coop deeply desires to take care of them and has recently constructed the wetland to do so. Now the community is proud of this wetland and the wet mill coop and wants to see it succeed. In this area, there are more than 50 wet mills and only 7 are willing to try using the wetlands. Bergo is smaller, newer, and has not seen the same success in profits yet, but they want to lead the way environmentally.

Experience in the treatment of wastewater is varied among wet mills. Of the wet mills with established wetlands, Jawi did not have a previous treatment system; the wetland was installed when the wet milling machine was purchased. Doyo used a lagoon and treated it with effective microorganisms (EM) but the lagoon would fill up and overflow into the river. The cooperative members at the Duro Mina lagoon system are completely satisfied with their own treatment method. They have explored using square versus circle-shaped lagoons and found that the sides of the square-shaped lagoons cave-in so circular lagoons are preferred. Experience may be an important factor in the value and effectiveness of the wetland to the coop depending on how well a prior system functioned and if the government and community had frequently given them pressure to properly manage their waste.

Adequacy

The adequacy of the system is evaluated by whether it is able to contain all of the wastewater and if the cooperative members feel sufficiently trained to operate the system. The Jawi coop does not believe that their system is completely adequate for the amount of wastewater they produce, while the Doyo coop thinks theirs is sufficient. Interestingly, the Doyo wetland has a lot more water flowing out of the wetland into the evaporation pond than the Jawi wetland. The evaporation pond at both sites overflowed by the end of the harvest season. Jawi is looking for ways to contain the water flowing out of the wetlands, including reducing water use and building additional evaporation ponds. As a result, Jawi leaders do not believe they have been adequately trained on how to operate and maintain the wetland system. Doyo leaders received training from the government on how to use vetiver plants and additional training from TechnoServe on how to manage the wetland. Other TechnoServe sites not interviewed have shown their wetlands to not be large enough to accommodate the amount of wastewater produced. The amount of land they have available is frequently not large enough to construct bigger wetlands.

The Duro Mina lagoon site is transferring operations to a new site. The old site has two square lagoons in sequence and the new site has a large, circular lagoon. The coop leaders claim the square lagoons have never overflowed, they have never pumped the water out, and all the water evaporates or is absorbed into the soil. A walk around the square lagoons revealed a series of puddles proceeding from the bank of the lagoon (the new site was to be in operation on the following day, replacing the old site). This site is greater than 50 meters away from a river so this is not seen as a concern.

The new wetlands in the Sidamo area are designed to accommodate the very high amounts of water they use but since they are not yet in use the adequacy cannot yet be determined. All the coop leaders in Sidamo interviewed explain that the lagoon with EM system they had previously used or directly discharging into the river were not adequate solutions. The lagoons overflowed every year and at Fero the leaders had removed a year's worth of pulp from the lagoon before the season began.

Despite any concern the coop leaders have over the adequacy of their system, all of them agree the system they are using meets their goals of preventing the wastewater from getting into the river.

Maintenance

Maintenance is an insignificant concern for each coop. The wetlands require only weeding and cutting back the grass a couple times per year and adding effective microorganisms once a week. The vetiver cuttings are used for mulch or compost so the farmers are benefitting from the small amount of maintenance. At Jawi, the leftover water in the evaporation pond is used to water the vetiver in the off-season. Additionally, the coops interviewed with established wetlands have not needed to replace any vetiver grass yet in the three years of use. Other less successful sites not interviewed have needed to replace many vetiver plants. Vetiver plants in the Jimma area are easily found from the established plants being used to prevent soil erosion and many farmers also grow vetiver. In the Sidamo area, the wetlands are so large and the coops were receiving the vetiver plants from the government, so there was a vetiver shortage. The new wetlands in Sidamo are very large and may require a high amount of weeding, but the work required is insignificant compared with the problems of the old systems. The only maintenance required at the Duro Mina lagoon is to add EM every couple of weeks.

Problems

The coop leaders at Jawi and Doyo do not believe they have had any problems yet— their plants have not died, contaminants have never flushed out through the wetlands, and no vectors are using the wetlands for breeding. A closer look at the trench in the Doyo wetland revealed a large population of numerous larvae species. It is unknown which insects the larvae are from but the area has high mosquito populations, including the malaria-carrying *anopheles*, presenting a concern. In Jawi, they believe the EM they add once per week kills off any larvae. No larvae were seen in their trench. Research does not confirm EM to be effective pest management, but suggests it is a likely possibility. The Dura Mina lagoon leaders believe the acidic pH of the coffee wastewater prevents any vectors from surviving in the lagoon and no larvae were seen in their lagoons.

In regards to the section of the system before the wetland part of the waste treatment, the coop leader at Shegole explained they have had a number of issues arise. If the pulp is not removed immediately from the pulp retention basin then it begins to smell very badly. Workers must continuously move the pulp to the compost piles. Also, the slope of the channel from the wet mill to the basin is not steep enough so the water does not flow easily. A worker has been hired to push the waste down to the pulp retention basin. During high flow, the pulp basin gets blocked and water does not flow out into the wetlands. They installed another exit pipe so it now has two. It is evident that even when problems arise the cooperatives have the capacity to effectively solve them.

In Sidamo, the current problems are all construction-related. One site is full of large boulders where they are attempting to dig out the evaporation pond; another site had trouble leveling the bed of the wetland as these sites are typically on steep slopes; and many sites are not large enough to accommodate the size needed to treat the large quantities of wastewater produced at these coops. The coops and TNS staff have implemented creative solutions, such as the series of two wetlands at Yitbarak to accommodate the slope and space of the site.

Cost

In the set of wetlands constructed in 2009, TechnoServe paid the capital cost and the coops pay for the operating costs. The capital cost is around $2000 and the operating cost is minimal. The common opinion is that wetland costs are very low compared with the advantages of using a wetland system. No materials are needed to be bought regularly, just a worker is paid to weed before the season starts and a guard is paid to watch the entire wet mill site. The Duro Mina leaders believe the capital cost of digging the lagoon is very expensive, at around $50 while the operating costs are minimal. It is unknown if the cooperative leaders know the capital cost of the wetlands and if their opinion on the costs would change.

The cooperative interviews are highly valuable in understanding the capacity of the community to accept, promote, maintain, and respect the vetiver wetland as a coffee wastewater treatment solution.

Action Plans

In addition to surveying the cooperative members, the wetlands were observed and evaluated to meet the previous design criteria, construction, maintenance, and history of operation. The existing wetlands were found to be wide-ranging in regards to readiness for the season. None of the newly constructed wetlands are ready to be used in this season, since the vetiver grass is not established well enough, but will be ready to utilize next season. Two samples of the Action Plan reports are located in Appendix 1.

Standard Operating Procedure

The Standard Operating Procedure (SOP) combines the information gathered from the operator interviews, observations before and during the harvest season, water quality and water flow data gathered, and the wetland design improvements to provide a guide for the wet mill cooperative members and future owners of constructed vetiver wetlands to optimize their construction and use of this point treatment system. This document will be distributed and promoted by TNS to increase environmental accountability throughout Ethiopia. A future goal includes installing these wetlands throughout TNS's coffee initiative countries once the system has been optimized. The SOP is located in Appendix 2.

Improved Vetiver Wetland Design

The water quality characterization and water balance combined with the cooperative surveys and site assessment gathered adequate data to re-design the vetiver wetland wastewater treatment system. The majority of the design is appropriate and effective, but a few small changes will optimize the system. The improved wetland design is the product of the scientific and community development portions of this research. The Improved Vetiver Wetland Design is located in Appendix 3.

Life Cycle Assessment of Vetiver Wetlands

To assess the overall sustainability of the vetiver wetlands, questions must be addressed regarding the whole life cycle of the wetland. These questions include understanding the sustainability of the vetiver plants, the soil, the water, social implications, and costs.

Vetiver grass is proving to be a sustainable form of vegetation to use in the wetlands. The vetiver grass used during initial construction either comes from the government supply or the local farmers. When it needs to be replaced the cooperative purchases some from the local farmers or uses established vetiver already growing on the property. The government supply is in demand and not always available but in Jimma it can be found easily locally. In Sidamo it is not used as widespread and is needed, but may be found locally in the future. Vetiver is a native grass of India, but is found across Africa, including Ethiopia. Due to its ability to grow deep tillering roots and survive droughts, it grows very well. It was chosen for the wetlands because it takes up 7.5 times more water than typical wetland plants, such as *Typha* and for its hardiness. Vetiver additionally has the ability to take up heavy metals, grow in saline conditions, and take up fertilizers and pesticides; though these properties will not be necessary for coffee wastewater. When the vetiver is cut back the cuttings are used for the compost with the cherry pulp. Cattle will eat the cuttings from young plants but not fully established plants, so in the first season the cuttings may be used for animal feed.

The soil in the wetlands and surrounding area is a nitosol, a porous sandy clay common to the mountains of East Africa. In the majority of the sites, the land space used for the wetlands was previously used for the parchment tables to dry the milled coffee beans. A grass is growing on the site, assumed to be found on the wetland area prior to construction. It is unknown the extent of how much the wetland is changing the soil in the area.

The water used in the wet milling process comes from nearby rivers or springs. There are many natural springs in the mountains rendering water quality a larger concern than water quantity. The rivers and springs are a constant source during the harvest season when the water is needed. The rivers have many downstream users, including people bathing, washing, and sometimes drinking, irrigation for agriculture, and animals drinking. Since there are not pesticides or fertilizers used in the coffee growing process they will not be introduced into the rivers through the fields or the wastewater.

The social implications of the wetlands are positive since the wetland is viewed as highly effective. The coffee millers like this solution because operating costs are cheap and TechnoServe pays for capital costs. They also desire to maintain environmental responsibility and value this as an effective solution. The local communities were not interviewed, other than community members in the cooperatives, but they are known to dislike the untreated wastewater and in some areas have demonstrated acceptance and support of the wetlands. The government authorities were also not formally interviewed but when conversed with at the sites they expressed their approval of TNS's work and a preference for the wetlands.

The costs of the wetlands are seen by TechnoServe and the communities as low. One wetland may cost around $2000 to construct, while a lagoon system may cost around $50. For an NGO the $2000 cost is considered an affordable solution. If the cooperatives were paying for it their perception on its value may be different. Operating costs are just to hire a worker to weed and cut back the plants three times a year. No materials must be continually bought unless the wetland is not operating well are requires plants to be replaced. Because of the capital cost of a wetland, it may not be a practical solution in these small farming communities.

The wetlands themselves are sustainable in that they provide a lo-tech solution to treating the wastewater and materials are reused instead of wasted (except for water). Affordable effective microorganisms are used to break down organic material and reduce odor instead of a higher technological process. The excess pulp is brought to compost piles to ferment and be used as fertilizer later on. Neither chemicals nor inorganic fertilizers are introduced at any point in the coffee growing, harvesting, and milling process. By using the wetlands, there is complete monitoring, from beginning to end, of the water used in the coffee process.

Further Thoughts

My role with TechnoServe was primarily an investigative role to provide solutions to immediate needs of their wastewater treatment system. Surveys were used as a tool to understand how the local cooperatives are using the system and should be improved. After compiling this information and improving the design based on user's needs and input, the design will be utilized in the same general area with similar users and environment. This design will possibly be used in TechnoServe's coffee projects Latin America and Vietnam but will need to be adapted to local environmental differences and user preferences. This wetland system was widely accepted by Ethiopian cooperatives using it, but many cooperatives in the Sidamo have not bought into the idea. TechnoServe will use this information to promote it as a wastewater treatment solution that meets local needs and government standards in Sidamo and hopes it will spread. The success will be measured best in future years when its adoption is seen and its effectiveness is evaluated again.

TechnoServe has their own trilingual local staff that performs community teaching sessions and participatory meetings. Volunteers they bring in are to have a skill not met by the local community that they can teach to their staff. As a result, I was not in a position to lead meetings but I was still able to meet with many cooperatives and listen to their concerns and give advice.

Remaining Questions and Conclusion, Next Steps

As a student in the engineering for developing communities program at CU trained in sustainable community development, I am thoroughly impressed with TechnoServe's monitoring and evaluation, transparency, accountability, and creative initiative. As a partner organization they are professional and respectful, and highly value the work of their volunteer consultants. It has been a privilege to work alongside this highly esteemed, effective development organization.

This practicum proved to be an effective way to combine engineering skills and training in sustainable community development with an NGO's program to benefit the larger community. As a result, TechnoServe and I are looking into putting together a proposal for future work together. We would like to conduct interviews of the successful farmers and cooperatives on how they are using their money and in what ways they would like to use their money in the future, including environmental applications. This would ideally tie into a project the specialty coffee buyers would support, since they have made requests for more environmental sustainability measures. We plan to conduct surveys of the coffee buyers to find out which environmental measures they would like to see happen and if they would provide funding.

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Appendix 1: Action Plan Reports

Action Plan: Jimmate

Zone: Limu
Year Constructed: 2009
Date Visited: October 29, 2012
Overall Condition: Excellent

The Jimmate vetiver wetland site is in excellent condition. A mountain spring, plenty of space, and natural slope make the chosen site ideal. It was designed well, since it is not located within 30 meters of a natural water body. There is an irrigation stream diverted from a spring-fed river within a few meters of the wetland but it is not a natural stream.

Additionally, Jimmate has been constructed fairly well. The vetiver looks healthy and well-maintained. It is growing evenly throughout the wetland, suggesting a flat slope across the wetland. There is a trench at the beginning, but it could be dug deeper and filled with gravel and sand to spread the flow out and filter the effluent. The banks are built high at the beginning of the wetland but gradually diminish by the end and there is no trench for the excess flow to follow out of the wetland into the evaporation pit. Overall, the banks and trenches need more definition.

Figure 2: (Left) Trench at entrance to wetland. (Above) Mature Vetiver plants

Jimmate has two evaporation ponds; the first one has vetiver planted around it. Last year the wet mill produced effluent to fill one evaporation pond to the top. This year, the harvest is expected to be smaller so excess effluent may not be an issue.

Figure 3: First evaporation pond

At the time of the visit, this site was very well maintained. The vetiver was cut back, the weeds were removed, and there was no evidence of livestock in the wet mill area. The TechnoServe Business Adviser says there have not been any problems with the Jimmate vetiver wetland.

Figure 4: Very well-maintained site

The only action plan to implement on this site is to dig out a channel and construct a bank at the end of the wetland to direct flow into the evaporation pond. The business adviser for this site already has communicated with the coop to perform this action.

Action Plan: Dembe Zuriya
Zone: Bedele
Year Constructed: 2010
Date Visited: October 25, 2012
Overall Condition: Mediocre – needs a lot of attention

The small wetland at the Dembe Zuriya wet mill site is only in mediocre condition. The first time this site was planted the vetiver grass was choked out by weeds. Currently, the vetiver is patchy: areas are overgrown, areas are newly planted, and areas are lacking any vetiver plants.

Figure 5: The Dembe Zuriya wetland overall.

The construction of this site is very poor. It has lumpy ground; the slope appears to drop off in one corner; no banks are evident on the sides of the wetland; and there is not a trench at the beginning of the wetland. The grass planted between the rows of vetiver is full but brown and should be looked at again once the harvest has started. Additionally, the chosen site is a few meters away from a water body

Figure 6: The wetland is lumpy, missing vetiver plants, and the slope is uneven.

Maintenance is also lacking. The fence around the wetlands is decent but does not appear that it will effectively prevent livestock from grazing on the vetiver plants. Many weeds are growing in the wetland and the evaporation pond is full of them.

Figure 7: The evaporation pond full of tall weeds.

Figure 8: This part of the wetland has decently growing vetiver.

The action items for this wetland include cutting back the overgrown vetiver, replacing the missing vetiver, weeding the entire site, leveling the ground, and constructing a more effective fence around the wetlands.

Appendix 2: Standard Operating Procedure

Standard Operating Procedure

Vetiver Wetland Treatment for Coffee Wet Mill Waste Water

I. Introduction

Purpose: The vetiver wetlands are used to treat the waste water from coffee wet mills to meet government regulations and for the benefit of the surrounding community. The environmental processes utilized in this system to clean and control the contaminants include filtration, biodegradation, plant uptake of water and nutrients, and evapotranspiration. Wetlands have the greatest benefit when the nearest water body is within 30 meters of the effluent treatment site.

Frequency: The vetiver wetlands ideally will be constructed when a new coffee wet mill is installed. The wetlands should be constructed and planted before the rainy season to give the vetiver grass time to become established before the harvest season starts. In the case that the vetiver grass is not ready when the harvest season starts, the former treatment system must be utilized until deemed ready.

Location: The coffee wet mill will be installed on a slope in order to create enough head for the effluent to flow without difficulty into the vetiver wetland. The wetland will be downslope from the wet mill

Responsible Parties: Wet mill cooperative manager and committee, cooperative members, TNS business adviser. In the case of a private owner, s/he will be the primary responsible party.

II. Background

Vetiveria zizanioides is an excellent grass to use in a wetland system due to its deep roots and high uptake of water. The root and stalk system also provide a substrate for a thriving microbial community to break down the organic matter and convert the nutrients for the plants to use. Additionally, the gravel-filled trenches provide a means to spread out the effluent flow while filtering and evaporating the water.

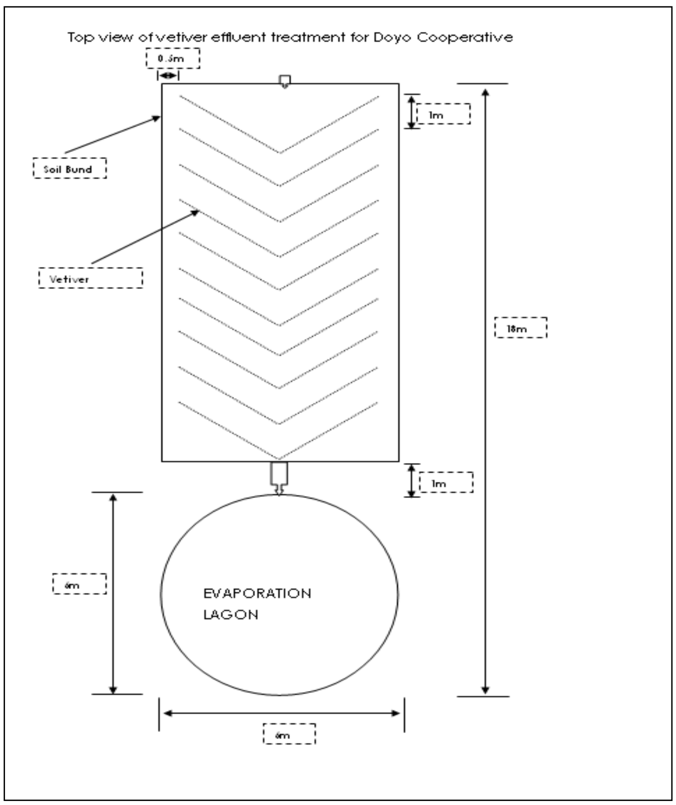
As a result of using older wet mill machinery, high amounts of effluent are produced; the Penagos wet mills use 0.4 liters of water per kilogram of cherries pulped and the Pinhalense use 1.2 liters of water per kilogram of cherries pulped. When the pulp and waste water are channeled into a lagoon, foul odors emanate and the effluent may overflow or leach into local waterways. The lack of an effective waste water treatment system draws conflict with the local community and government officials.

As a means to prevent wastewater overflow into natural water bodies, reduce and treat the waste, the vetiver wetland system provides a natural and effective method of treatment. The pulp is first separated from the water and taken to a compost area where it can be gathered and used by the local farmers. The water then flows through the vetiver wetland where it is treated and used. The organic matter in the effluent remains in the channels between vetiver plants to be broken down by bacteria. Though the wetlands are to be designed to accommodate an expected amount of waste water, any remaining effluent is channeled into an evaporation pond.

III. Physical Characteristics of Vetiver Wetland Systems

Each vetiver wetland system contains a pulp retention basin between the wet mill and the wetland to remove the pulp for composting, a wetland area with 1-3 gravel-filled trenches for spreading the flow, filtering the water, and holding organic matter, and an evaporation pond at the end to catch excess effluent.

1. The wet mill sites within 30 meters of a natural water body should have a wetland built to prevent overflow into the river.
2. A fence should be built around the entire wet mill site to prevent children and livestock from entering.
3. The wastewater from the coffee wet mill should flow easily from the pulp retention basin into the center of the wetland and out of the wetland into an evaporation pond for excess effluent.
4. This example schematic floor plan of the wetland site was used for the Doyo Cooperative in Jimma, Ethiopia.



5. The expected process of wastewater flow throughout the wetland is illustrated below:

Figure 9: Established vetiver wetland ready for the season to start. The pulp retention basin is seen in the bottom right corner and the evaporation pond with concentric circles of vetiver is at the top of the picture.

The pulp is separated from the wastewater in the pulp retention basin. The pulp is taken to compost piles while the wastewater flows into the wetland down the grated hole.

The wastewater will first fill the trench at the beginning of the wetland and then distribute evenly throughout the width of the wetland when the trench fills.

Wastewater will fill the trenches between the vetiver rows and collect there. The water should flow to the end of the wetland and be channeled toward the exit into the evaporation pond.

IV. Required Equipment

The construction and use of the vetiver wetlands require separate materials.

Materials for construction:
1. Shovels and picks
2. Mason's twine and stakes
3. Level and theodolite
4. Vetiver plants
5. Grass turf
6. Gravel for trenches
7. Measuring tape

Materials for vetiver wetland use:
1. Grass cutting tool

V. Preliminary Site Selection and Planning Guidelines

(As adapted from 111014 Sustainability Standard SOP Vetiver Wetlands)[10]

1. For new wet mill sites, plan and map out the location for the wet mill depulping machine and vetiver wetland. Make sure the size of area, slope, and proximity to a natural water body are appropriate. Mason's twine and stakes may be of use to plan the proper dimensions.

[10] (TechnoServe East Africa Coffee Initiative, 2011)

2. Determine how much vetiver will be needed to plant the wetland and identify the source of vetiver plants.

VI. Construction Procedure

(As adapted from 111014 Sustainability Standard SOP Vetiver Wetlands)

1. The chosen site should be leveled and checked with a theodolite to ensure an even slope across and no more than 5% slope downhill. An engineer may be hired to check the slope if theodolite is not available.
2. An earth bank should be built approximately 50 cm wide by 40 cm tall along the border of the vetiver wetland using the soil and materials dug out for the wetland bed. Where the bank has been dug out of the natural slope, it is not necessary to build up a bank. Vetiver should be planted on the banks in rows 30 cm apart.
3. The vetiver grasses should be planted in rows, 40 cm apart. An optional V-shape toward the evaporation pond can be aesthetically pleasing. Within each row, the vetiver should be planted in two triangle-patterned rows 10 cm apart. Between the defined vetiver rows, grass should be planted to stabilize the soil and assist in taking up water. Mark out the vetiver and grass rows with sticks and twine. Prepare the vetiver plants for planting by splitting the clumps into 3-4 tillers and cutting it back to 20 cm high and then plant them.
4. At the entry point, 1-2 gravel-filled trenches should be dug. In the case of larger-sized vetiver wetlands, more gravel-filled trenches can be dug further into the wetland. Deeper trenches can be a benefit to the system to catch and hold more organic matter.
5. The evaporation pond should be built at the far end of the vetiver wetland to capture excess effluent. Pond walls should slope and not be vertical. A circular shape will help stabilize the sides; the sides of square lagoons have been found to cave in. The evaporation pond should also have vetiver planted around it in concentric rows 30 cm apart as a final barrier.
6. Once the pulp retention basin and vetiver wetland are constructed, cement channels and pipes should be built between them to carry the waste water. It is essential to maintain a slope to aid in the ease of water transport. The slope is more important than the overall length of the channel.
7. At the beginning of the harvest season, ensure the waste water is flowing properly into the wetland and the water is spreading evenly through the length and width of the wetland.

Additional Construction Guidelines

(As adapted from 111014 Sustainability Standard SOP Vetiver Wetlands)

1. Vetiver wetlands should be constructed below the wet mill, no part of the wetland or evaporation pond should be closer than 30 m from any water body.
2. The vetiver wetland should be built at least 4-6 months before the start of the harvest to allow plants to establish. If possible, the wetland should be planted just before the rainy season.
3. The required size of a vetiver wetland is determined by the amount of water that is used by the pulping machine during the wet milling process. Table 1 shows the approximate size for a vetiver wetland according to the type of machine and the average number of hours per day the wet mill operated during the harvest. [This table will be reassessed based on study findings in Jimma]
4. The final slope of the wetland should be no more than 5% downhill. There should not be any slope across the width of the wetland to allow the water to spread evenly throughout the wetland.

5. TechnoServe staff (Sustainability BA, Agronomy BA, and Wet Mill BA) can provide technical support or assistance in the construction of the vetiver wetland.

VII. Vetiver Wetland and Evaporation Pond Sizing

To calculate the size of the wetland needed, first estimate the amount of cherries to be pulped per season. This number is multiplied by the assumption that 0.008 m^3 of water is used per kilogram of cherries pulped. The total amount of water for the season is the amount of storage volume necessary for the wetland, if there is no exit effluent. The storage equation is: $V_S = n\ x\ L\ x\ W\ x\ h$ where V_S is the storage volume, n is the porosity of the soil, L is the length of the wetland, W is the width of the wetland, and h is the infiltration depth. These dimensions assume an infiltration depth of 1 m and a porosity of 0.50. From the storage volume equation, the wetland area is found and potential dimensions.

As a safeguard, the evaporation pond should be built to hold 10% of the flow into the wetlands.

Total Cherries per Season (kg)	Wetland Area (m^2)	Wetland Size 1 W (m) x L (m)	Wetland Size 2 W (m) x L (m)	Evaporation Pond r (m) x h (m)
1000	20	2 x 10	4 x 5	0.5 x 2
10000	200	10 x 20	13 x 15	2 x 2
50000	1000	20 x 50	30 x 33	4 x 2
100000	2000	40 x 50	45 x 45	4.5 x 3
150000	3000	30 x 100	50 x 60	5.5 x 3

Table 2: Vetiver wetland sizing according to amount of cherries processed per season.

VIII. Vetiver Wetland Maintenance

The maintenance required for the vetiver wetlands includes the following:

1. Weed the site regularly during the establishment of the vetiver and post-season.
2. Cut the vetiver down to 50 cm after about 6 months to encourage tillering of the roots.
3. In the case that a vetiver plant dies, replace the plant during the following rainy season.

VIII. General Operating Procedure

Employee Operation

1. Cooperative Leader/Private Owner - designation of a Vetiver Wetland Manager (name, address, and telephone number)
2. Responsibilities of Vetiver Wetland Manager
    a. The Vetiver Wetland Manager is to frequently check on the system to see if the water is properly flowing through the channels into the wetland, distributing evenly throughout the wetland, flowing out at the end into the evaporation and not leaking out of the sides of the wetland.
    b. The manager must check to see if any vetiver plants have died and need replacement and identify when the site must be weeded.
3. Signs
    a. Appropriate signs must be placed around the wet mill site to alert people to keep livestock out of the area and prevent the use of wastewater for any purpose.
4. Accessing the facility
    a. The facility should have a paid guard in charge of watching the site

   b. The entrance gate to the site should be kept closed when not in use
   c. A fence should be built around the site to prevent livestock and children from entering
   d. If it is necessary to walk through the wetland, do not step on the vetiver grass, walk down the rows between the vetiver.
5. Sanitation
   a. The workers should be made aware that the effluent is not safe to drink and contains large concentrations of bacteria. In the case of contact with the effluent, they are to wash the affected area and be certain to wash their hands regularly.
   b. After the coffee cherries have been pulped, the equipment and facility must be washed with the clean river water to prevent buildup and bad smells.

Vetiver Wetland Operation

1. The wastewater from the coffee wet mill should flow directly from the pulp hopper to the center of the wetland. If it is obstructed the channels should be cleared.
2. Expect the thick wastewater to fill up the channels and the soil to become saturated.
3. Effective microorganisms (EM) should be added once a week to reduce smell and prevent mosquito larvae from growing. Pour or spray the EM throughout the wetlands, making sure to focus on the first trench. It is recommended to add 1-2 liters of EM per 20 liters of wastewater.
4. Over time parts of the beginning trench may become thick with organic matter. Add EM and stir the trench to mix it with the wash water.

5. A study is currently being performed to see if adding lime to raise the pH of the wastewater is effective at helping the vetiver grass stay healthy longer and soak up more water. Depending on the results, it may be beneficial to add lime in the amount of 3 kg per 1 m^3 of wastewater.

Appendix 3: Improved Vetiver Wetland Design

Improved Vetiver Wetland Design

After observing the constructed vetiver wetlands during the first three weeks of the 2012-2013 harvest season, they demonstrated clear success at meeting the primary goal of preventing the contaminated wastewater from getting into the rivers, yet watching the process over time revealed certain elements that work very well in the system that should be encouraged and others that need additional solutions. The primary concerns are how to manage the high volume of organic matter floating and settling in the wetlands and how to optimize the wetland to use more water to reduce the excess water flowing out into the evaporation pond.

Solutions for Excess Organic Matter

The organic matter is left over from the wet mill process of removing the outer layers of the coffee cherry from the coffee bean. The machine removes the fleshy part, known as the pulp, and then the beans are soaked to dissolve the sticky coating, known as parchment, resulting in large chunks of pulp and high concentrations of dissolved solids serving as a fruity substrate for bacteria. Most of the pulp gets shoveled away to the compost piles and sprayed with effective microorganisms to reduce the fermenting sugar odor. Acidic effluent high in total solids and chemical oxygen demand flows into the wetlands.

Throughout the season the organic matter loading is an increasing concern. In the first couple weeks of the season, the organic matter collects in the trench and the water seeps through the wetlands, depositing suspended solids along the way. By the end of the wetland the water is very low in solids and organic matter, appearing more like lightly steeped tea. As the season continues, the organic matter builds up and spreads between the vetiver rows. When there is enough to fill the wetland the thick organic matter collects at the end of the wetland and may flow into the evaporation pond or just sit in the exit trench. The sites studied seem to have more organic matter than the wetland can handle, since it keeps building up.

Solutions to dealing with the high organic matter loadings must address the odor of fermenting sugar, containing the high volumes of material, and/or aid in breaking down the material. The first solution to be addressed, possibly making the biggest impact, is to install a box before the wetland to serve as a settling basin. Since the trench is currently serving as the settling basin, equalization basin, and biological treatment basin of the system, it quickly fills up and clogs. When this multi-purpose trench fills, the infiltration is blocked and there is no space for settling. Additionally, the pulp retention basin serves as a bar screen, but does not remove all of the larger, more difficult pieces of material to break down. To overcome this, installing a **box with a weir** to encourage settling can remove more of the larger, more difficult to break down contaminants, including excess pulp that is not removed, before even reaching the wetland. This would lessen the strain on the entrance trench, allowing the wetland to filter and biodegrade the finer particles. This box should be made of cement to ensure permanence and have a weir to guide the flow toward the bottom of the box. The floor of the box will slope and drain to one side so the organic matter building up can be flushed out into a small pit to the side of the sedimentation box and be added to the compost piles. Since the system is gravity-fed the water can flow easily through the box, which will be partially underground, and flow into the wetland a little cleaner. Another solution is to install a **fine filter** at the point of inflow into the trench to catch more material for compost. This solution could work complementing the box and weir or instead of it. If it is used instead of the box and weir it will catch more material and need to be cleaned more frequently. In the current situation, most of the trenches are not filled with gravel. When they are filled, the gravel quickly becomes filled with material and is labor-intensive to clean out. With the use of the box and weir and/or filter the amount of material settling into the gravel will be reduced.

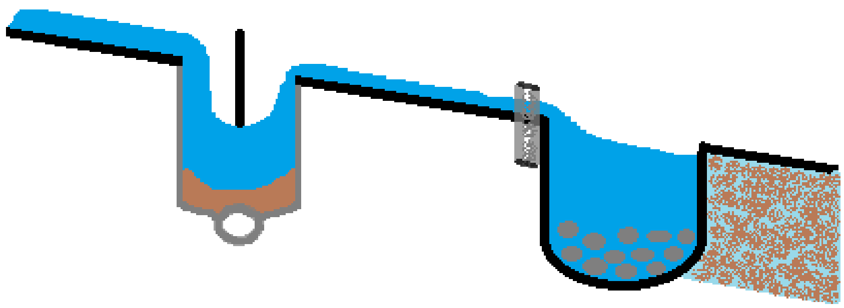


Figure 10: Box and weir acting as simple primary sedimentation. Screen is also shown just before the gravel-filled trench

To address the odor problem, a solution currently being used is to add **effective microorganisms (EM)**; when added more frequently or in larger amounts this also aids in the breakdown of organic matter. It is also possible that adding EM can reduce any risk of vector reproduction in the wetlands[11]. In municipal biological treatment systems the basin is often heated, mixed, and/or oxygenated to activate and encourage bacterial growth. Mixing can easily be achieved by simply using a long stick to **mix the effluent in the trench** to disperse the bacteria among the organic matter substrate while exposing them to more oxygen resulting in an increase in the amount of organic matter broken down. To heat the trench or add oxygen are impractical as they would be too difficult or costly. Another solution is to **add more trenches** across the width of the wetlands to catch and hold organic matter. At the end of the season this material could be shoveled out of the trenches and used as nutrient-rich compost. Another option would be to have a **gate and trench system** allowing the wastewater to flow into the right half of the wetland on one day and the left half on the next day. This may allow time for one side to dry out and the trench to be shoveled out during the off day. The problem with this scenario is that it would be more labor-intensive and require more attention.

Solutions for Excess Water

As the water seeps through the wetland more drains into the evaporation pond than is desired. Totals have not been calculated since the season is not yet finished, but after 11 days at Doyo when 15 m^3 total of water had been put into the wetland system, 5 m^3 had already flowed out into the evaporation pond. To minimize excess effluent, the first step is to **minimize the amount of water** used by the wet mill in pulping and especially washing. In 2011, the Doyo wet mill used 308.5 m^3 of water for pulping and 824 m^3 for washing, combining to 0.0045 m^3 per kg of coffee cherries processed. The Jawi wet mill used 0.0035 m^3 per kg of cherries processed. The coop at Jawi is already water-conscious as a solution and they are further motivated to reduce water use due to the cost of pumping the water. Another simple solution is to add more **variety of plants**. Adding one or two small native trees could positively impact

[11] (Porter, 1993)

the water holding capacity of the wetlands by lowering the water table in the wetlands. At Jawi the wetland soil was already saturated before the season began. The addition of a native tree will not lower the water table to hazardously low levels, just aid in reducing the moisture of the surface soils. A one-year old native *Albizzia sp.* seeding can take up 0.0003 m^3/day[12], which throughout the course of one year is 1.095 m^3. This is not a large amount of water displaced, but if a few trees are planted they can make an impact with time. A one-year old eucalyptus seedling can take up 0.0004 m^3/day[13] but they have become considered a pest and may have adverse effects on the water table. The roots ideally would take up water year-round, leaving more pore space for the effluent. A third solution is to add **lime** to raise the pH. The pH coming in is usually around 4-5. A higher pH could cause less distress to the plants enabling them to take up more water. A study is currently being performed at the Jimmate site to investigate whether pH has an effect on wetland water quality and plant health.

Another issue with the water flow is short-circuiting in the flow through the wetland. Short-circuiting is when the water flow chooses a path that neglects flow through another intended part of the reactor. In the wetlands, the flow generally spreads out but corners have less water until the whole wetland is saturated. The trench at the beginning of the wetland already helps to spread out the flow, but the flow gets moderately short-circuited near the end. **Additional trenches** throughout the wetland can help spread the flow, taking advantage of the full storage capacity of the wetland.

The most significant solution to containing the flow involves ascertaining whether the wetlands have been designed to handle the appropriate amount of daily wastewater flow. Currently, the wetland size at Jawi can only handle the amount of inflow of wastewater for 25 days since water is flowing out and the wetland size at Doyo for only 7 days. Jawi was designed to handle a maximum of 9.60 m^3 of wastewater per day while Doyo was designed for 11.52 m^3 wastewater per day. In the 2011-2012 harvest season, the amount of wastewater (pulp and wash water) flowing into the wetlands at Doyo averaged at 26.98 m^3/day with the maximum at 45.00 m^3/day. This season, Doyo is averaging at 20.6 m^3/day and the maximum so far is 32 m^3/day. The maximum daily water use assumption at Doyo must be reconsidered. Daily water use data at Jawi for past seasons is unavailable, but in the first 30 days of the 2012-2013 harvest season, the maximum daily water flow into the wetlands is 8 m^3/day and the average daily use is 2.5 m^3/day. Even though the actual maximum daily value is lower, the storage capacity at Jawi is still too small.

Jawi is taking up approximately 47% of the water and Doyo is taking up approximately 9% of the water. To address the current state of flows at Jawi and Doyo, the following table gives ideal sizes of the wetlands and how large the evaporation pond must be to maintain the same wetland size, accounting for infiltration, evapotranspiration, and plant uptake.

	Jawi	Doyo
Current Storage Capacity (m^3)	40	80
Current Total Flow (m^3)	67	715
Projected Total Flow (m^3)	85	860
Current Wetland Size (m^3)	10x10x1	10x16x1
Wetland Size Needed (m^3)	10x21x1	40x43x1
Evaporation Pond with same wetland (m^3)	3r x 4h	8r x 8h

[12] (Zahid, 2010)
[13] (Zahid, 2010)

Table 3: How to resize the wetland and/or evaporation pond to accommodate flow.

These numbers are estimated calculated from the source water flow rates. It is assumed all of the water coming out of the source water tank goes into the wetlands. In the case of Doyo, it is unlikely that all of it makes it to the wetlands; it may be sprayed in the grass or be soaked up by the pulp and brought to the compost piles.

It is unrealistic to construct a wetland at these small sites that is 10m x 25m or 40m x 45m. If there is the option to resize the wetland, the following optimizations are more practical, as shown in *Table 2* and *Table 3*.

Jawi	Wetland (m^2)	Evaporation Pond (m^3)
Optimized Solution 1	10x10	3 ponds at r=2.5m x h=2m
Optimized Solution 2	15x15	1 pond at r=3m x h=2m
Optimized Solution 3	14 x 15	none

Table 4: Possible ways to accommodate the flow into Jawi.

Doyo	Wetland (m^2)	Evaporation Pond (m^3)
Optimized Solution 1	10x16	4 ponds at r=7m x h=2.5m
Optimized Solution 2	30x33	4 ponds at r=5m x h=2.3m
Optimized Solution 3	40x43	none

Table 5: Possible ways to accommodate the flow into Doyo.

Since the goal is to contain all of the wastewater, wetland sizes must be calculated that do not expect to have excess flow into an evaporation pond, though one should be built as a safety measure. To calculate the size of the wetland needed, first estimate the amount of cherries to be pulped per season. This number is multiplied by the assumption that 0.01 m^3 of water is used per kilogram of cherries pulped. The total amount of water for the season is the amount of storage volume necessary for the wetland if there is no exit effluent. The storage equation is: $V_s = n\ x\ L\ x\ W\ x\ h$ where V_s is the storage volume, n is the porosity of the soil, *L* is the length of the wetland, *W* is the width of the wetland, and *h* is the infiltration depth. These dimensions assume an infiltration depth of 1 m and a porosity of 0.50. From the storage volume equation, the wetland area is found and potential dimensions. As a safety measure, an evaporation pond should be constructed to hold 10% of the seasonal flow/storage capacity. The storage equation for the evaporation pond is $V_s = n\pi r^2 h$, where *r* is the radius and *h* is the depth of the pond.

Total Cherries per Season (kg)	Storage Capacity (m^3)	Wetland Area (m^2)	Wetland Size 1 W (m) x L (m)	Wetland Size 2 W (m) x L (m)	Evaporation Pond r (m) x h (m)
1000	10	20	2 x 10	4 x 5	0.5 x 2
10000	100	200	10 x 20	13 x 15	2 x 2
50000	500	1000	20 x 50	30 x 33	4 x 2
100000	1000	2000	40 x 50	45 x 45	4.5 x 3
150000	1500	3000	30 x 100	50 x 60	5.5 x 3

Table 6: Wetland Resizing and Dimensions

These wetland sizes may need minor adjustments depending on soil type and infiltration depth. Additionally, they should be an overestimate of what is actually predicted by the amount of cherries due to not all of the used water going into the wetlands and a higher amount of water used per kilogram.