Expanding Conservation/Sediment Control Practices in Priority Farm Areas of the Guánica Bay Watershed

Final Comprehensive Report

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Protectores de Cuencas

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2 INTRODUCTION

Historically, the Guánica Bay area was associated with some of the most extensive and healthy reef complexes in Puerto Rico. Unfortunately, coral reefs worldwide have experienced an unprecedented decline over the past 30-40 years, some estimates suggest that in the Caribbean we have lost more than 50% of live coral and over 90% of sensitive and federally listed *Acropora palmata* (elkhorn) and *Acropora cervicornus* (staghorn) species. Meanwhile studies by scientists in Puerto Rico have shown that nutrients and sediment contaminants have increased by 5-10 times pre-colonial levels and several times in the last 40-50 years (Ortiz-Zayas et. al., 2006). 'Coral reefs of Puerto Rico are among the most highly threatened Caribbean reef systems' (Ramos-Scharrón, 2010; Burke and Maidens, 2004). The U.S. Coral Reef Task Force determined that reducing the contribution from land-based sources of sediment was essential in maintaining the long-term stability of coral reefs (USCRTF, 2000). Even though most soils in Puerto Rico have a high to very high vulnerability to water erosion (Reich et al., 2001) and land erosion is recognized to pose a major threat to both freshwater and marine resources (Torres and Morelock, 2002; Soler-López, 2001), limited actions are generally taken to mitigate its effects (Lugo et al., 1981).

The Guánica Bay/Río Loco Watershed (GB/RLW) area was increased historically to bring freshwater to the dry south coast, almost doubling the drainage areas to approximately 151 square miles through a series of reservoirs, tunnels and hydroelectric plants. Subsequently, the GB/RLW watershed encompasses five manmade lakes and associated reservoirs. The watershed includes the urbanized areas of Yauco, a portion of the Lajas Valley agricultural region, and the upper watershed where coffee farming and subsistence agriculture is practiced on steep often highly erodible slopes. The conversion of upland forested lands to agriculture and man-made channels has altered the natural hydrology of the watershed causing upland soil erosion, in-stream channel erosion, loss of lagoons and the downstream transport of sediment (CWP, 2008). Several studies point to dirt roads and sun coffee within farmlands in the upper watershed as some of the major elements that contribute to sediment transport to the Guánica Bay and the nearshore reefs.

A 2016 study conducted by Ramos-Scharrón and Thomaz, concluded that unpaved farm roads may account for over 90% of the sediment lost during erosion processes and eventually reaching waterbodies. Loss of highly erodible soils on steep slopes is clearly a major issue in the Guánica Bay/Río Loco watershed based on GIS analysis, field investigations and data on sediment accumulation in the reservoirs. GIS analysis was used to target the locations of Highly Erodible Lands (HEL) and agriculture, particularly sun grown coffee and other crops being grown at high elevations, and roads and homes on or adjacent to steep slopes. Based on the soil layer, these highly erodible lands were estimated to compose much of the high mountain land areas being used for agriculture in the Lago Lucchetti and Lago Loco drainage areas (CWP, 2008). Furthermore, a study from Ramos-Scharrón in 2010 demonstrated that dirt roads in the upper watershed, particularly in the

Maricao Muncipality, erode at a rate of 100 times faster than soils with significant mulch cover (Ramos-Scharrón, 2010).

As a response to these needs, this project completed the stabilization of 1.7 miles of dirt roads in three farms (using ArcGIS tools) utilizing cost effective BMPs that can be replicable in other locations in the island. The target areas include: San Carlos Farm, Evarista Vélez Farm (Figure 1) and Hacienda Candelaria (Figure 2).

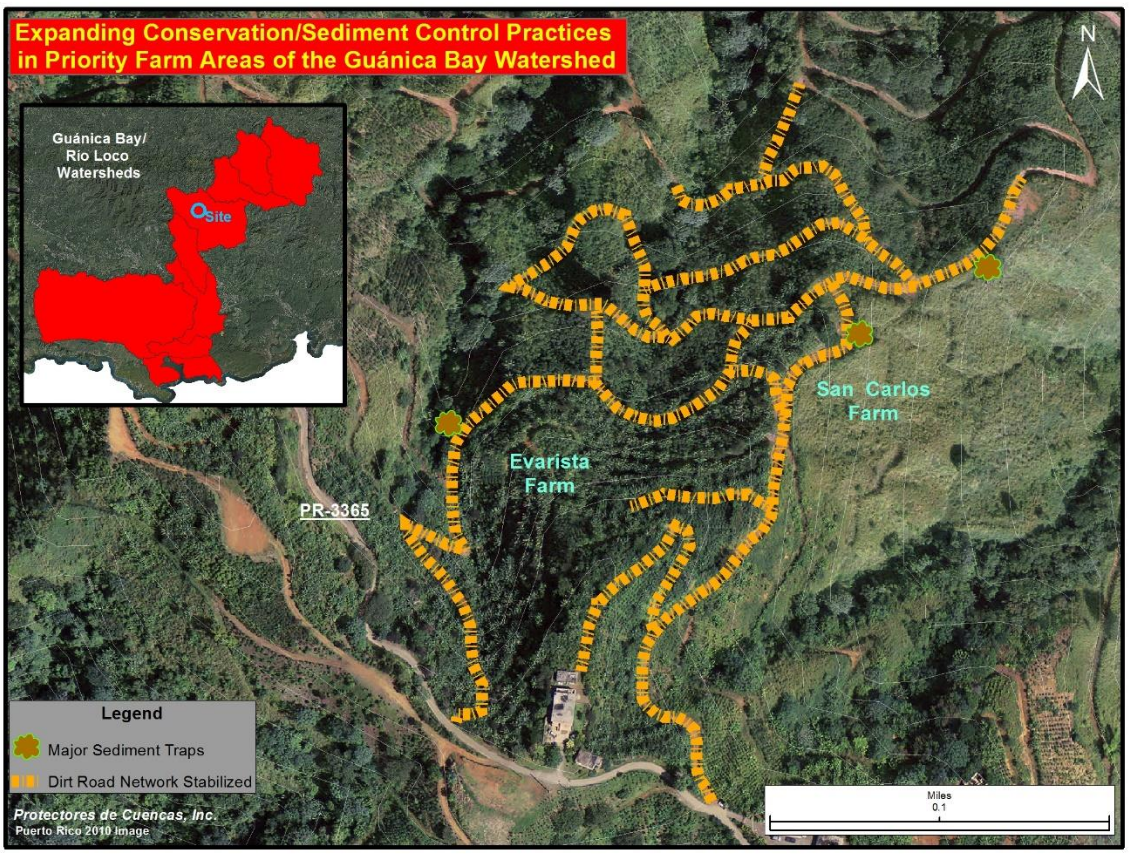
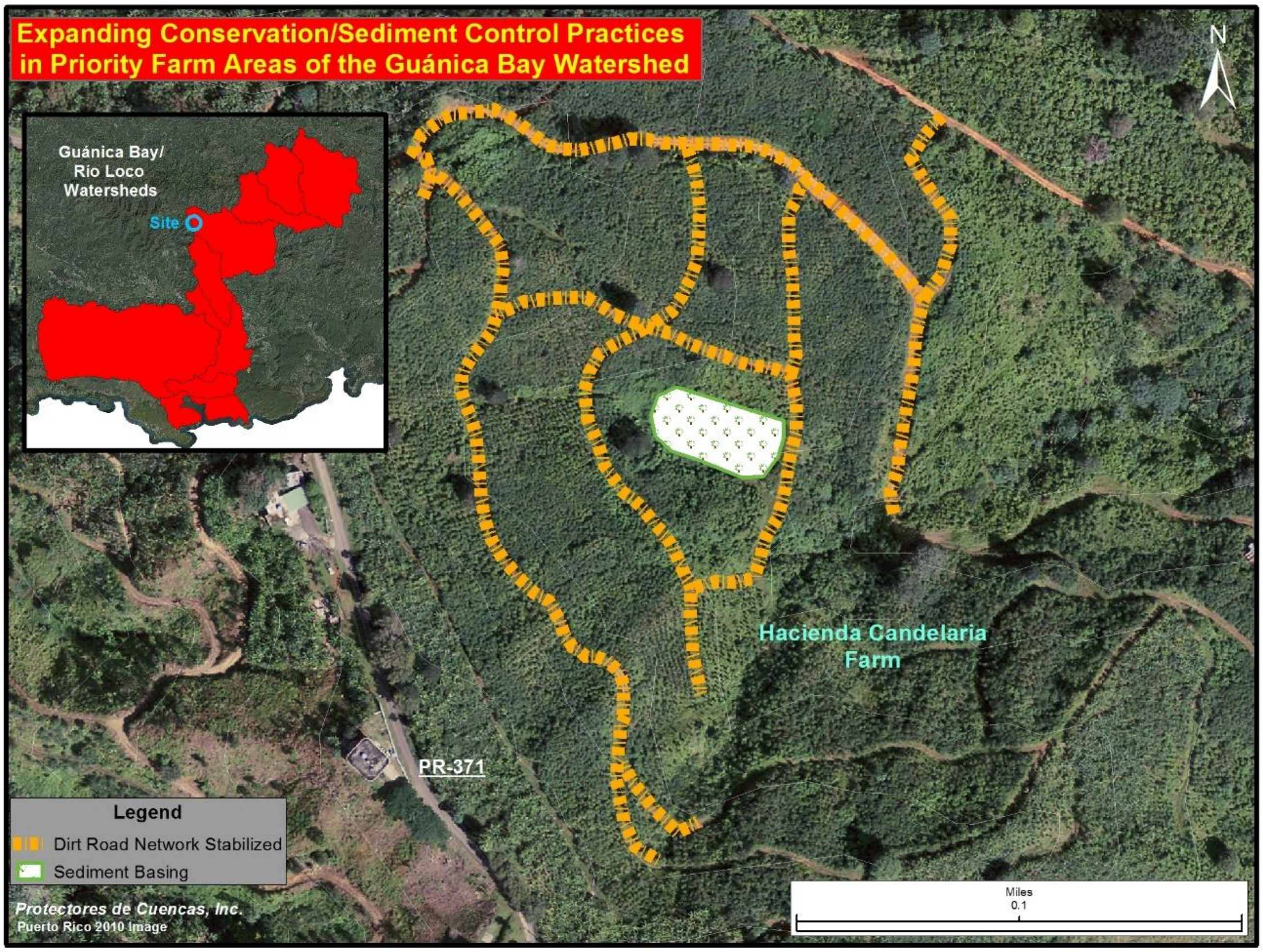


Figure 1. Schematic design of completed project implementation within San Carlos Farm and Evarista Farm.

The project assisted farmers in reducing the need for re-grading dirt roads. We also provided them with guidelines for long-term maintenance. The project worked closely with

Figure 2. Schematic design of completed project implementation within Hacienda Candelaria Farm.



all stakeholders and farm owners to train them in proper installation of temporary and permanent sediment and erosion control practices. We also provided training in construction of stormwater control swales, check dams, creation of infiltration systems with vetiver grass and native trees as well as proper maintenance techniques for Best Management Practices (BMP). By installing these conservation practices, we assisted farmers in reducing the need for re-grading dirt roads that farmers had to do two to three times a year, producing massive sediment runoff. PDC has a partnership with the Natural

Resources Conservation Service (NRCS) on these efforts to address this major threat to coastal ecosystems and to work together on creating a set of standard practices to address runoff from dirt roads in the near future.

As part of our ongoing efforts to maintain communication channels with the partners, we presented in the NRCS State Technical Committee meeting. The meeting was led by the Forestry, Wetland and Wildlife Subcommittee in which we are permanent partners.

This committee recommends actions to the NRCS director as how to allocate funding and policy towards conservation initiatives. This meeting had participation from DNER, FWS, NRCS, National Wildlife Refuges Association, The Breadfruit Institute, the University of Puerto Rico, and another local NGO's (Figure 3). We presented the dirt roads stabilization project accomplishments and put it into perspective of the other state actions needed to advance restoration efforts.

Figure 3. Part of the NRCS State Technical Committee meeting.

3 EVALUATION

The problems of erosion and sedimentation in the Guanica watershed are primarily associated with runoff generated from dirt roads and sun coffee production in the upper watershed farmlands in the central mountain region. Previous studies estimate that highly erodible lands compose much of the high mountain land areas being used for agriculture and these dirt roads in the upper watershed can erode at a rate of 100 times faster than soils with significant mulch cover (Ramos-Scharrón, 2010). A recent study led by Ramos-Scharrón and Thomaz concluded that unpaved farm roads may account for over 90% of the sediment lost during erosion processes and eventually reaching our water resources throughout the watershed. This publication describes the methodology used where rainfall simulations experiments were conducted to quantify runoff and soil erosion. Results indicated that bare soil dirt roads within farms begin to mobilize and transport sediment with less than 0.1 cm of rainfall within 1 to 2 minutes into the simulations, with an average of 69 g of sediment eroded during 30 minutes of simulation.

Based on our field evaluations, recommendations from the farmers and technical assistance from site visits and discussions with DNER, NRCS, the Municipality of Yauco and the farmers, we conducted restoration components that are discussed in detail in the next section of this report. The target farms included: San Carlos Farm, Evarista Vélez Farm and Hacienda Candelaria. These three farmers provided their in-kind contributions which included: meetings participation, aid during project design, provided personnel to assist with labor during BMP implementation. In addition, they provided materials for soil stabilization and water for the trees and plants established in each BMP for road stabilization after project completion.

The following components were implemented at each of the three farms selected for this project:

1. Dirt Road assessment and BMP design
2. Establishment of temporary erosion and sediment control practices
3. Dirt Road Stabilization
4. BMP training sessions
5. Follow up visits to ensure proper maintenance and evaluate functionality
6. Research collaboration

Component details are discussed in the following section.

4 WORK COMPLETED

1 ASSESSMENT AND BMP DESIGN

We conducted various meetings during the months of August, September and October of 2015 to coordinate logistics with farmers and NRCS staff. Following coordination meetings with farmers, NOAA, USFWS, NRCS, site visits were conducted to assess the conditions of the dirt roads at each farm (Figures 4-8). After the dirt road assessment, BMPs were designed for each farm to address specific needs. The project team visited 5 farms and identified 3 best viable options. The three farmers chosen agreed to be part of the initiative, confirmed their match contributions, and agreed on BMPs proposed for each farm. PDC proceeded to purchase materials needed for BMP implementation. BMPs considered during design included: the construction of stormwater control swales, check dams, the creation of infiltration systems using vetiver and native trees, stones and gravel materials to retain soil in place, and sediment traps.

Figure 4. Photo showing the conditions of the dirt roads within San Carlos Farm during assessment visit.

Figure 5. Photos showing the conditions of the dirt roads within San Carlos Farm before BMPs were installed.

Figure 6. Photos showing the conditions of dirt roads within the Evarista Velez Farm before BMP installation.

Figure 7. Photos showing the conditions of dirt roads within Hacienda Candelaria before BMP installation.

Figure 8. Photo showing the conditions of dirt roads within Hacienda Candelaria before BMP installation.

2 ESTABLISHMENT OF TEMPORARY EROSION AND SEDIMENT CONTROL PRACTICES

Before starting any restoration work in the area, we installed a series of temporary sediment and erosion control practices at the current dirt roads of each farm. Sediment control practices included installing silt fences and planting Vetiver grass to redirect runoff to forested areas (Figure 9).

Figure 9. Example of temporary sediment control practices.

3 DIRT ROAD STABILIZATION

The primary goal of this project was to stabilize bare soils in the upper watershed farms to reduce sediment loads to the Guánica Bay. This will protect and build resilience of coral reef ecosystems in this priority area. Prior to stabilization, in most parts of the dirt road network, runoff was running through the center of the road causing erosion forces to transport sediments into our watershed water resources. After completing the installation of temporary sediment and erosion control measures, PDC stabilized approximately 1.7 miles of dirt roads in three coffee farms. Installed BMPs included sediment traps, check dams, swales, regrading, rip-raps, Vetiver grass and paving with granulate fill material and compacting. A brief description of each BMP is provided here to help understand their function and purpose.

Sediment traps serve to detain sediments in stormwater runoff to protect receiving streams, lakes, drainage systems, and the surrounding area. An outlet or spillway is often constructed using large stones or aggregate to slow the release of runoff. Check dams are a commonly used practice constructed across a swale or channel. They are used to slow the velocity of concentrated water flows, a practice that helps reduce erosion. Check dams are typically constructed out of gravel, rock, sandbags, logs or treated lumber, or straw bales. Similarly, swales are designed to manage water runoff, filter pollutants, and increase rainwater infiltration and refers to a vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. As stormwater runoff flows along these channels, it is treated through vegetation slowing the water to allow sedimentation, filtering through a subsoil matrix, and/or infiltration into the underlying soils.

Regrading is commonly implemented as well. It refers to the process of grading for raising and/or lowering the levels of land with the purpose of changing drainage patterns and rerouting surface flow. Land grading is applicable to sites with uneven or steep topography or easily erodible soils, because it stabilizes slopes and decreases runoff velocity.

Rip-rap is a layer of large stones used to protect soil from erosion in areas of concentrated runoff. Riprap can also be used on slopes that are unstable because of seepage problems.

A detailed description of the practices we implemented as well as an analysis of the work completed is presented in the next section of this report.

3.1 Regrading

Approximately 1.7 miles (using ArcGIS tools) of dirt road was stabilized in all three farms to reduce sediment transport to the GB/RL watershed and eventually the marine environment. All the dirt road stabilized was regraded toward the inside of the hillside and runoff was conveyed into a continuous swale with check dams at intervals of approximately 25-30 ft. depending on the slope. The regrading process was conducted using two bulldozers, one provided by the Yauco Municipality and the other by PDC (Figure 10). Grading activities were a bit challenging do to the fact that these roads have been bulldozed so many times in the past decades that the hydrologic conditions desired by the regrading process are very difficult to achieve (Figure 11). Another challenge was that side banks on the roads have vertical slopes and while conducting works part of the slopes falls into the road again. Also, during rain events landslides occur damaging work completed. To overcome these issues in some cases we had to widen roads and a continuous swale was built along the inner side

Figure 10. Dirt road regrading process.

Figure 11. Dirt road showing problems with high banks.

of the road to prevent runoff from getting back into the road again. After regrading activities, the roads where compacted using a small 5-Ton compacting role provided by the Yauco Municipality. We tried using a 15-Ton compacting roll provided by the Maricao Municipality but it was too dangerous to use with the existing slopes (Figure 12).

This practice is highly recommended as it will be very difficult to impossible to implement other BMP without regrading.

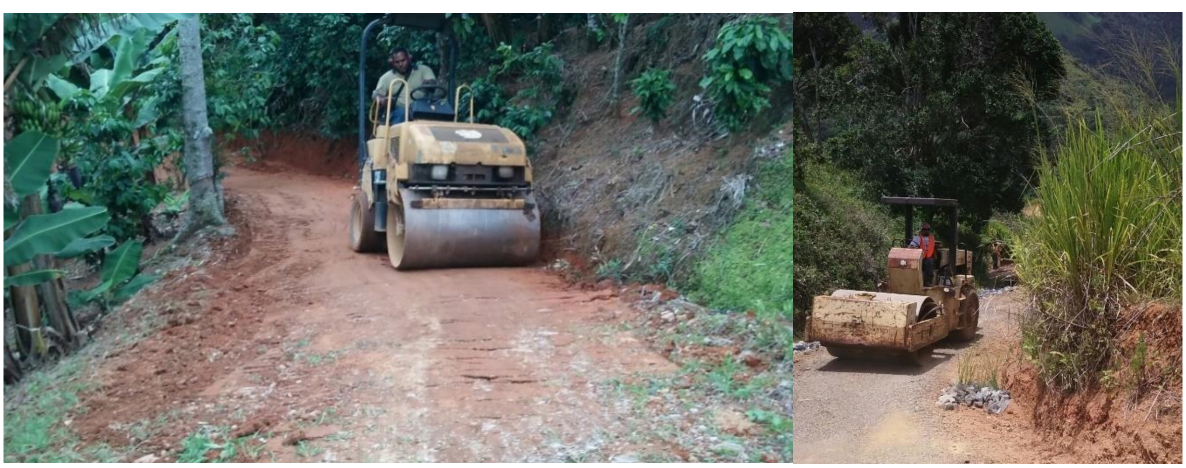


Figure 12. Dirt road during regrading and compaction process.

3.2 Check Dams

Check dams are generally used in concentrated flow sites, such as diches and swales and they can be both a temporary or permanent measurement. They form barriers that prevent erosion and promotes sedimentation by slowing the velocity of water and filtering runoff. Our check dams were implemented in combination with a continuous swale along the inner side of the road. It was almost impossible to cut flow patterns in the swale and get runoff out to forested areas because of the presence of high banks on both sides of the road in many cases and in other instances because of active farmlands that could get affected by the runoff. For this reason, we decided to intersect flow in the continuous swale with the check dams at intervals of approximately 25 to 30 ft. depending on the slope. As stormwater runoff flows through the structure, the check dam catches sediment from the channel itself or from the contributing drainage area. The ones we have built are made from a combination of 8-12 inch stones and Vetiver grass (Figures 13-15).

Figure 13. Implemented check dams in combination with a continuous swale.

They are most effective when used with other stormwater, erosion, and sediment-control measures. Check dams were also installed to help redirect the flow of sediments towards the sediment traps constructed.

One of the challenges encountered with this practice was to find a quarry in the region that had the correct stone size available. The quarry that is closest to the region produces a small percent of the desired stone size therefore we manually selected most of the materials in the quarry or ordered special cuts of the stones. There are other quarries in the Island but far from the site making it not cost effective.

Check dams are another cost-effective technique applicable for the selected work site. For the future, we recommend installing erosion control blankets (if the budget is available) because sediment tends to accumulate fast from the dirt intersections between check dams. If stones are not aligned properly and if poorly maintained, check dams will clog and runoff will redirect again to the center of the road causing erosion and damage to the restored section.

Figure 14. Series of check dams with Vetiver grass constructed.

Figure 15. Examples of completed check dams during this project.

3.3 Sediment Traps

Sediment trapping techniques have demonstrated that work better when constructed with functional redundancy. According to Mekkonen (2015), integrated sediment trapping is the most effective approach to manage sediment migration when compared with individual and combined measures alone. A series of sediment traps were constructed to help filter storm water that was causing erosion problems and discharging sediments (Figures 16-17). The traps were formed by excavating an area across a low portion of drainage swale and berms were constructed and compacted with the small compacting roll. After compacting, the sediment traps where covered with 2-8 inch stones as rip-rap to prevent erosion from the berms and the bottom was punched through with the backhoe to promote infiltration and vetiver half-moons were planted to help trap sediment and promote infiltration and evapotranspiration. A rip-rap overflow was constructed with bigger 1-2 ft. stones to reduce energy of the water. The San Carlos and Evarista Velez Farms

Figure 16. Construction process of sediment traps at San Carlos and Evarista Velez Farms.

are neighboring farms and were worked as a single unit to maximize results and benefits to the watershed. A total of 3 sediment traps were created between these two farms near drainage points. On the other hand, sediment traps were not created at Hacienda Candelaria as this farm already had a space that could serve as a sediment basin so we created a bigger basin that covers most of the drainage area that was stabilized (Figure 18-19). The size of the sediment traps constructed depended on the available space and slopes.

Figure 17. Sediment traps at San Carlos and Evarista Velez Farms.

Figure 18. Construction process of sediment basin at Hacienda Candelaria.

Figure 19. Construction process of sediment basin at Hacienda Candelaria.

3.4 Paving and Compaction

Dirt road stabilization techniques included using fill material to stabilize the steep segments of the roads. Modifications of the stabilization techniques were necessary during the process as the soil of the dirt roads are of very high clay content. The fill material layer used for road stabilization contained small rocks and granulate materials that makes it a good soil mixture for compaction (Figure 20). The road was compacted using a small compacting roller offered in-kind by the Municipality of Yauco (Figures 21). Since this practice was not contemplated when we wrote the proposal the farmers provided the fill material as an in-kind contribution to prevent budgetary increases of the project.

The use of this paving material was one of the most effective practice implemented and it was demonstrated by the research component done in collaboration with Dr. Carlos Ramos from the University of Texas at Austin (a more detailed description can be found at

Figure 20. Fill granulated material piled on the side of the road prior to be applied.

the end of this report). In the future, we recommend using this technique in all of the dirt road network when the budget is available as it is a cost-effective way of preventing road deterioration by rainfall and subsequent runoff and erosion problems.

Figure 21. Dirt road after completed paving and compaction.

3.5 Rip-rap

Rip-Rap consists of a permanent sediment and erosion control practice made with resistant ground cover and the use of large angular stones. It is commonly used to protect slopes, streambanks, channels, or areas subjected to erosion by wave action. Rock rip-rap protects soil from erosion due to concentrated runoff. It is used to stabilize slopes that are unstable due to seepage. It is also used to slow the velocity of concentrated runoff which in turn increases the potential for infiltration. In our case, rip-rap was used to protect sediment trap constructed berms and in overflows. In the sediment traps, rip-rap provided some water quality benefits by increasing roughness and decreasing the velocity of the flow, resulting in better settling of particulates. In other areas, we used rip-rap in existing water ways and it offered an easy-to-use method for decreasing water velocity and protecting slopes from erosion. It is simple to install and maintain (Figures 22-24).

In some cases, we used them for the inlet of the sediment traps and in the sediment basin to reduce the energy of the runoff entering the traps. This practice demonstrated to be an effective technique in the berms and the outflows. In the inlets, they did a great job for the first rain event but it tends to clog rapidly and needs more maintenance so we don't recommend it for the inlet of the constructed traps.

For this practice, we recommend that stones are of good quality, correctly sized, and placed to proper thickness. A filter fabric should be used to cover the soil prior to the installation of the proper size stones. In our case, we did not us it based on budgetary constraints but we don't recommend cutting back on this as it is needed for the long-term effectiveness of the practice. Properly sized bedding or geotextile fabric is needed to prevent erosion or undermining of the natural underlying material. Another recommendation is to use hydroseeding on the areas prior to installing the stones. The rock should be placed as soon as possible after disturbing the site, before additional water is concentrated into the drainage system. Over all, rip-rap is cost effective and easy to install, requiring only that the stones be manually arranged so that they remain in a well-graded mass. Where possible, rip-rap should be combined with bioengineering techniques. In our case, in the areas that was feasible, we intersected rip-rap with lines of Vetiver grass.

Figure 22. Construction process of rip-rap.

Figure 23. Construction process of rip-rap.

Figure 24. Construction process of rip-rap.

3.6 Vetiver Grass

Vetiver grass is a very simple, practical, inexpensive, low maintenance and very effective means of soil and water conservation, sediment control, land stabilizations and rehabilitation, and it also can be used in phyto-remediation practices. When planted in a linear pattern or in half-moons, vetiver plants will form a vegetative mass which is very effective in slowing and spreading run off water, reducing soil erosion, conserving soil moisture and trapping sediment on site. The extremely deep and massively thick root system of Vetiver binds the soil and at the same time makes it very difficult for it to be displaced under high velocity water flows. This very deep and fast growing plant can also tolerate extreme drought conditions as well as moderate soil salinity concentrations with a highly effectiveness on steep slope stabilization. Since we first started using it on coastal restoration projects it has become one of our most common practices implemented due to

Figure 25. Use of vetiver grass during BMP implementation.

its rapid response and tolerance. Now, we are growing our own Vetiver plant material and have developed our own growing and production techniques.

In this effort, we have used it on check dams, sediment traps, rip-rap and on stabilizing soil banks on the side of the dirt road system we have worked on. In combination with other practices such as using proper size stones, it has demonstrated to be the most cost effective technique we have implemented (Figures 25-27). The most commonly available Vetiver plant material comes in small plots, but the best and more rapid results are achieved when plots are transplanted to a 1 gallon pot and grown for no less than 3 months. Because of this technique, planted Vetiver grass, responds more rapidly and adapt to the site's climate condition in a more efficient way with less maintenance period.

Figure 26. Use of vetiver grass during BMP implementation.

Figure 27. Use of vetiver grass during BMP implementation.

3.7 Stone Swales

Gravel and stone beds are called infiltration trenches or stone swales when used as a stormwater control practice. A swale is a small channel that conveys water from one point to another. When planted with grasses or native vegetation, swales can be very useful in collecting stormwater. There are different types of swales and they can serve various purposes depending on the slope, soil type and the pollutants you will be treating. Swales can be made with stones, vegetative cover, concrete or a combination of all them. In our case we build them to cross water from one part of the road to another or when one road intersects to another crossing the waterway.

This practice can also be very cost effective but, on the selected site they tend to clog fast causing more problems than the ones they solve. We do not recommend this practice for the site location. Concrete swales can be a good alternative to implement in future projects. Concrete swales may be more expensive at the short term but on the long run they will be feasible by the savings on maintenance (Figures 28-29).

Figure 28. Constructed stone swales during BMP implementation.

Figure 29. Constructed stone swales during BMP implementation.

3.8 Follow up visit and maintenance

PDC conducted at least 3 follow up visits to the three farms: San Carlos Farm, Evarista Vélez Farm and Hacienda Candelaria. This allowed PDC to provide feedback to farmers and assess sediment and erosion control practices effectiveness, particularly after rain events. Problems encountered were fixed during this period. We also removed any unnecessary temporary measures installed after the site was fully stabilized and restoration activities were completed.

3.9 Final conclusion on BMP's Implementation

Based on our experience implementing BMP's, we can recommend that one practice on its own is not enough to observe an improvement. Instead, it is important to implement a series or combination of BMP practices that are best suited for the location, while taking into consideration other factors such as slope gradients, soil type and composition. The different slope gradients found at each farm will help us compare the effectiveness of the different BMPs implemented on the long term. This information will allow us and farmers to better understand which BMPs are best suited to their particular farms. As PDC continues to implement sediment and erosion control practices, this project will help to develop and standardize cost-effective techniques to reduce sediment loads from the upper Guanica Bay watershed.

During the implementation process of this project, several challenges were faced. A series of landslides happened in the farms that interrupted project implementation. Due to the amount of clearing of dirt roads by the farmers, the incline on portions of the dirt roads are very steep or vertical leading to unstable soil after rain events and frequent landslides. The frequency of rain events in this mountainous area also allowed us to improve and correct certain practices during the process.

Effective stormwater management often occurs by using a holistic system management approach. This approach takes into account the effectiveness of each stormwater practice, the costs of each practice, and resulting overall cost and effectiveness rather than looking at each practice in isolation. Some individual practices may not be effective alone, but when combined with others, it may produce highly effective systems. Our intentions are to continue working towards innovative cost-effective green infrastructure practices that help reduce flows and improve water quality.

5 BMP TRAINING SESSIONS

After BMPs implementation was completed, PDC conducted training sessions at the San Carlos and Evarista farms. For the training, we worked closely with farm owners, UPR-Sea Grant, Department of Natural and Environmental Resources, NRCS and other NGO's and stakeholders to discuss our experience in proper installation of temporary and permanent sediment and erosion control practices such as the construction of stormwater control swales, check dams, the creation of infiltration systems using vetiver and native trees as well as BMP proper maintenance techniques. By installing these techniques, we assisted farmers in reducing the need for re-grading dirt roads. PDC, NRCS and USFWS is discussing the establishment of a partnership to address this major threat to coastal ecosystems and to work together on creating a set of standard practices to address runoff from dirt roads.

The efforts undertaken during this project helped gather information that was ultimately used in deciding the best suitable BMP implementation practices for this type of soils and slopes. The take-away message of the BMP training session was that problems caused by land erosion are reflected on coral reefs. Also, that dirt roads are the biggest erosion problems on coffee farms. Upon completing the exercise, participants exchanged ideas about alternatives to minimize the erosion problems generated by dirt roads. An NRCS article discussing some details of the activity can be found at the following link:

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/pr/newsroom/features/?cid=nrcseprd1291489

Figure 30. BMP training sessions led by Protectores de Cuencas at San Carlos and Evarista Velez Farms.

6 RESEARCH COLLABORATION

These coffee farms are considered heterogeneous landscapes since soil surfaces can be found to have many different surface covers, including cultivated fields with underbrush or weeds, forested hillsides, and uncovered soil. Each type of soil surface has its unique conditions that influence on the amount of erosion generated, such as soil cover, slope, and soil type. It is important to mention that the erosion generated not only impacts on-site but also downstream. On-site impacts typically include soil fertility, infrastructure to work and move within the farm, while downstream impacts are usually observed in the water quality and consequently the health of rivers, reservoirs, coral reefs, and other coastal ecosystems.

A study published in Land Degradation and Development by Ramos-Scharrón and Thomaz in 2016 describes the methodology used during the BMP training sessions (Figure 31) that took place in San Carlos Farm. Rainfall simulations experiments conducted to quantify runoff and soil erosion from different land surface types, including unpaved roads within farms. Water samples were collected to measure sediment concentration levels and compare them to samples taken in other areas of the farm where bare soils are not exposed. Results of the published 2016 study indicated that bare soil dirt roads within farms begin to mobilize and transport sediment with less than 0.1 cm of rainfall within 1 to 2 minutes into the simulations, with an average of 69 g of sediment eroded during 30 minutes of simulation. Authors concluded that unpaved roads account for over 90% of the eroded sediment reaching the watershed.

The research project associated with this effort serves to compare the erosion rates of the different surface covers found at coffee farms. This has helped us identify the surface cover that generates the most erosion and therefore focus our efforts on one specific type of surface. Preliminary data from the rain simulation experiments and sediment traps indicate that bare dirt roads are the primary generator of erosion. To control the erosion and ultimately the water quality, management efforts should focus on the dirt roads. Therefore, it is important to work with all stakeholders to continue with the design, implementation and maintenance of sediment control practices that are focused on farm dirt roads.

Figure 31. Rain simulation experiments during BMP training sessions at San Carlos Farm.