Measuring the effectiveness of an erosion control practice for watershed management: The case of Hydroseeding

Photo by Protectores de Cuenca Inc.

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Yasiel A. Figueroa Sánchez, SUNIA Intern

Lisa Vandiver, ERT, NOAA Restoration Center

Dave Eslinger, NOAA Office for Coastal Management

Shan Burkhalter, TBG, NOAA Office for Coastal Management

Rob Ferguson, IMSG, NOAA Coral Reef Conservation Program

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Abstract

The goal of this project was to determine the effectiveness of the hydroseeding practice in reducing Land-Based Sources of Pollution (LBSP), with special emphasis on erosion and sediment control, at the hydroseeding sites and downstream of the hydroseeding sites. This goal was achieved using the Open-Source version of the Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT), a tool developed by the National Oceanic and Atmospheric Administration Coastal Services Center (NOAA-CSC) that examines the relationship between land cover, nonpoint sources of pollution, and erosion. This tool was used to compare the difference in surface water runoff, sediment, nitrogen and phosphorus loadings between a baseline landscape (i.e. pre-hydroseeding) and a managed landscape (i.e. post-hydroseeding) and subsequently to determine the reduction of sediment, surface water runoff, nitrogen and phosphorus loadings due to the hydroseeding practice.

Methods included geo-referencing the hydroseeding sites in the field and digitizing their boundaries using a combination of Geographic Information Systems (GIS) and Google Earth. Geospatial data were acquired from NOAA's Office of Coastal Management, and clipped to the extent of the GB/RL watershed. Finally, using OpenNSPECT an analysis comparing pre and post- hydroseeding sites was performed. This analysis was done for six hydroseeding sites, from which five are within the RL/GB watershed. Results presenting the reduction of sediment, runoff, nitrogen, and phosphorus loadings both at the practice and downstream of the practice were produced and are presented in this report. According to OpenNSPECT changing an area from bare land to grassland reduces sediment loadings and runoff at the practice by approximately 83% and 73% respectively.

Background

Erosion caused by the loss of highly erodible soils on steep slopes, particularly in the coffee growing regions of Yauco, P.R., was identified in the Guánica Bay Watershed Management Plan (WMP, 2008) as one of the critical issues affecting the integrity of the Rio Loco/Guánica Bay (RL/GB) Watershed. The impact of this LBSP translates to high sediment accumulation in reservoirs, high sediment transport along streams and rivers, and high turbidity in the near shore coral reefs and in the areas surrounding the Guánica Bay. The stabilization of highly erodible lands (HEL) is a priority for the management of the RL/GB watershed, and the implementation of the hydroseeding technique was recommended to address this issue.

Ridge to Reefs and Protectores de Cuencas have tested and defined a set of methods and techniques, including hydroseeding, to stabilize bare soils. Since 2012 approximately 20 acres of bare soils have been stabilized in the RL/GB watershed using the hydroseeding practice. During this time the hydroseeding techniques have been tested and executed using multiple formulations (i.e. different mixtures of plants, bonding agents, hydromulch, fertilizer, etc.) with the objective of determining the best practices in terms of cost and effectiveness. However, no efforts have been directed to measure the impact of the hydroseeding technique in terms of LBSP's reduction. This project evaluates the effectiveness of hydroseeding to reduce LBSP, with special attention to erosion and sediment control. The primary objectives of this study were to: (1) evaluate pollutant removal efficiency (e.g. runoff, sediment, nitrogen, phosphorus) of the hydroseeding practice at the site and (2) to determine what proportion of those reductions were translated downstream within the RL/GB watershed.

Methods

OpenNSPECT was used to compare pre- to post-hydroseeding scenarios to determine changes in runoff, sediment, and pollutant loadings. These comparisons provided estimates of the effectiveness of the hydroseeding practice at the site and downstream of the site. In general, the following steps were followed; first, the hydroseeding sites were assigned the bareland classification to generate results for a baseline scenario (i.e. pre-hydroseeding). Secondly, the hydroseeding sites were classified as grassland, simulating the vegetative cover that the hydroseeding practice establishes when it is effective, and results for a modified scenario (i.e. post-hydroseeding) were generated. Finally, the baseline and modified scenario outputs were compared using OpenNSPECT's Compare Outputs Tool (see the OpenNSPECT section of this report for detailed information of the Compare Outputs Tool). The results presented in this report are derived from the values presented in the grids produced by the compare outputs tool. A more detailed description of the methods is provided below.

The Open-Source Nonpoint Source Pollution and Erosion Comparison Tool

The Open-Source version of the Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT) works as a plug-in for the open-source and free GIS software package MapWindow. OpenNSPECT examines the relationship between land cover, nonpoint sources of pollution, and erosion and it can be used with any watershed as long as the user has access to the required data. Comparing differences in water quality between baseline landscapes and managed or disturbed landscapes is OpenNSPECT's primary focus. Therefore, the tool's outcomes have the potential of informing and empowering resource managers to make well-versed decisions on land-based issues affecting water quality and nearshore ecosystems.

OpenNSPECT uses three established, widely-used models to predict runoff, pollutant, and sediment production. The Soil Conservation Service (SCS) Curve Number Technique uses precipitation and hydrologic soil groups to determine the infiltration capacity of the soil and assigns a water retention factor to land cover types. Event Mean Concentration (EMC) estimates mean concentration of pollutants in runoff using coefficients based on each land cover type. The Universal Soil Loss Equation (USLE) uses soil, elevation, slopes, and land cover parameters to identify sources of erosion and estimate total sediment yield. The Modified Universal Soil Loss Equation (MUSLE) predicts erosion from a rainfall event, while the Revised Universal Soil Loss Equation (RUSLE) predicts annual erosion.

As a decision-making tool OpenNSPECT's capabilities are very diverse and follow more than a few approaches to produce several types of outputs. In order to perform and carry out its functionalities OpenNSPECT requires the following data:

- Elevation data (raster format Digital Elevation Model (DEM))
- Land cover data (raster format)
- Rainfall data (raster format)
- Soil data (vector format)
- R-factor data (raster format)
- Local pollutant coefficients (tabular format)

Appendix A presents a table containing the datasets used as inputs for the hydroseeding analysis. The datasets presented in appendix A cover the extent of Puerto Rico and are projected to Universal Transverse Mercator, North American Datum, Geodetic Reference System. Using OpenNSPECT these datasets were clipped to the extent of the RL/GB watershed border layer.

All raster data had a 30 meter resolution. Also, as there are no local pollutant coefficients derived for the RL/GB watershed the default pollutant coefficients OpenNSPECT provides were used in the analysis.

OpenNSPECT produces three primary types of data outputs. These are as it follows:

- Local Effects – estimates of the amount of runoff (liters) pollutant (units of mass), or sediment (units of mass) coming from a particular location (i.e. a single cell). For a site that consists of multiple cells, the values from the cells can be summed to determine total runoff (liters) and pollutant mass. Figure 1 presents an overview of this process.
- Accumulated Effects – estimates of the total runoff (liters), pollutant (units of mass), or sediment (units of mass) load delivered through a particular location (i.e. a single cell). Accumulated effects values include contributions from both, the cells upstream and the cell in question.
- Concentration – estimates of the average concentration at a particular location (i.e. a single cell) taking into account what is flowing in from upstream. These are reported in concentration units (mass/volume).

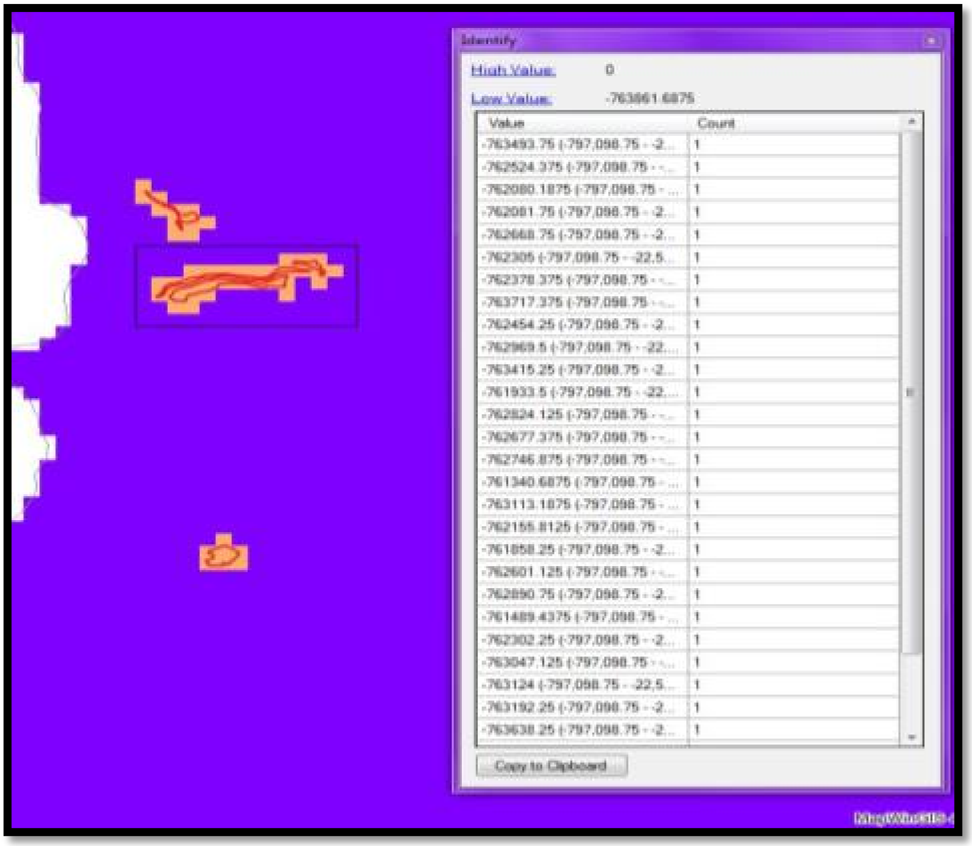

Figure 1. Example of the reported values for runoff and pollutant loading changes at the practice. The values of the light brown cells contained within the black box are summed. The product of the sum is the reported value.

The output layers display estimations of runoff, pollutant loads, pollutant concentration, and total sediment loads. These output types are produced and displayed in the Map Window legend automatically once the model performs its analysis. Below are some of OpenNSPECT's capabilities and the process by which the model produces the outputs:

Estimating runoff volume

The Soil Conservation Service (SCS) Curve Number Technique is used to quantify the volume of runoff. Generally, the SCS Curve Number Technique uses land cover and hydrologic soil groups to determine the infiltration capacity of a particular area, which is quantified as the SCS curve number. Appendix C presents a table that lists the SCS curve numbers. The curve number combined with precipitation data allows for the calculation of runoff depth, which is then quantified as runoff volume by multiplying runoff depth by the area of the cell. Also, using spatial elevation data, flow direction and flow accumulation throughout a watershed are determined with the purpose of deriving a stream network.

The following outputs are produced after the analysis is completed:

- Runoff volume (L)

Estimating pollutant loads and concentrations

Using land cover as a proxy OpenNSPECT estimates pollutant loadings and concentrations. Coefficients representing the contribution of each land cover class to the expected pollutant load are applied to the land cover dataset, and then by incorporating a runoff volume grid the model is capable of estimating pollutant loadings and concentrations. These coefficients are similar to event mean concentrations and were derived from published studies provided throughout the nation (see Appendix B). Ideally, pollutant coefficients should be developed locally for the studied watershed but oftentimes this can be cost prohibitive, as was the case for this study. It is important to note that the procedure to estimate pollutant concentration does not take into account duration or intensity of rainfall. OpenNSPECT has the ability to produce estimates for a number of pollutants including user-specified pollutants, but for this project we focused on nitrogen and phosphorus.

The following outputs are produced after this analysis is completed:

- Accumulated Pollutant (kg)
- Pollutant Concentration (mg/L)

Estimating sediment loads

OpenNSPECT uses the Revised Universal Soil Loss Equation (RUSLE) (USDA-NRCS, 1986) to estimate annual rates of erosion. The Revised Universal Soil Loss Equation is as follows:

$$A = R * K * L * S * C * P$$

Where:

A = average annual soil loss	S = slope steepness factor
R = rainfall/runoff erosivity factor	C = cover management factor
K = soil erodibility factor	P = supporting practices factor
L = length-slope factor	

The R-factor and K-factors are provided in rainfall and SSURGO datasets that can be acquired from NOAA's Office of Coastal Management. The LS factor is calculated from the Digital Elevation Model data. The C-factor is derived from default values associated with land cover classification (Appendix C). The P factor is not included in the current version of OpenNSPECT. RUSLE estimates gross erosion but it does not estimate how much of the eroded soil is actually being transported through the stream network, for this sake, OpenNSPECT calculates a Sediment Delivery Ratio. The Sediment Delivery Ratio is the ratio of sediment leaving a model cell to the total sediment eroding within the cell, it accounts for sediment movement and redeposition within the cell of origin. This is calculated based on drainage area, the relief-length ratio, and the SCS curve number (Williams, 1977). Finally, multiplying the product of RUSLE and of the Sediment Delivery Ratio produces an annual sediment yield.

The following outputs are produced after this analysis is completed:

- Sediment loss (Kg)

- Accumulated sediment yield (1000’s of Mg) Mg = Metric Tons

Comparing Outputs

The compare outputs tool calculates the absolute change and percent change between two different OpenNSPECT runs. This means that OpenNSPECT has the ability to compare the results from a baseline scenario and a modified or management scenario, and to produce output grids that present the difference in the values from the two selected scenarios. This tool has the capability of comparing the outputs of local effects, accumulated effects, and pollutant concentration. The approach followed to produce the compare output grids is a simple mathematical approach, it is presented below:

- Direct Comparison (Management – Baseline) – a grid presenting the difference between the values of the modified and baseline scenario is produced in units of the original data. A value of zero is interpreted as no change, while positive numbers represent an increase and negative numbers represent a decrease in the measured variable.
- Percent Change (100*(Management-Baseline)/Baseline) – a grid presenting the relative difference between two scenarios is expressed as a percentage change from the original values. A value of zero is interpreted as no change, while positive percentages represent an increase and negative percentages represent a decrease in the measured variable.

Model Limitations and Appropriate Use

OpenNSPECT, like all models, makes some assumptions and has some limitations. In this case, some of the major assumptions are:

1. This is a surface water flow model; there is no ground water tracking and no storm water diversions included. Water simply flows downhill.

2. Erosion modeled with the Universal Soil Loss Equation is sheet and rill erosion and does not account for mass land movement such as landslides.
3. There is no time-dependency in the model. As a result, processes such as downstream sediment redeposition or nutrient uptake are not simulated. Therefore, the actual values produced by OpenNSPECT are probably overestimates for what would be measured in the field for a receiving water body. They should be considered worst-case values.

OpenNSPECT's greatest strength is in comparisons between the effects of different land-use scenarios while holding all these assumptions constant. Therefore, looking at the relative changes that land-use changes create should be fairly accurate, although the actual quantities estimated may not be very accurate. In other words, OpenNSPECT is best for looking at relative changes under a set of simple and constant assumptions. It does give quantitative results, but they must be interpreted within the scope of the assumptions that were used in the model.

Processing Issues and Data Adjustments

As it is usual for this type of analyses there were some initial errors and issues that required some tuning and modification for OpenNSPECT to process data and produce more reliable results. Below the principal issues with its corresponding alternative are presented:

Hydroseeding sites size-resolution issue

The raster datasets used as data inputs have a resolution of 30 meters. That means that the actual size of every cell or pixel measures 30 meters wide and 30 meters long (30x30) which represents an area of 900 square meters (900 m^2) . Following this, 900 m^2 equates to 0.2 acres; and the size of the hydroseeding sites ranged from 0.3 – 5.4 acres. Therefore, OpenNSPECT was not able to estimate values for some of the hydroseeding sites due to the resolution of the input datasets. In short, the dataset's cell size were too big in comparison with the hydroseeding sites and the model is not able to produce results under these conditions (i.e. resolution of the input datasets were too low).

In order to deal with this issue the hydroseeding sites were expanded applying a 25 meter buffer; Figure 1 presents an overview of the process carried out to deal with the polygon size issue. Once the hydroseeding sites were buffered the analysis was repeated and OpenNSPECT produced results for all the sites. By applying a buffer, the area of the hydroseeding sites was enlarged which resulted in the overestimation of the runoff and pollutant change values (i.e. unadjusted value) estimated by OpenNSPECT. Therefore, the runoff and pollutant change values had to be adjusted for every site.

To adjust the values the difference between the actual and buffered area of the hydroseeding sites was taken into account. An actual to buffer ratio was calculated for every site by dividing the actual area of the site by the buffered area of the site (Equation 1, Table 1). Then, the actual to buffer ratio was multiplied by the estimated buffer change value (i.e. unadjusted value) to produce the estimated actual value (i.e. adjusted value) (Equation 2, Table 1).

For the downstream of the practice results section, in which the results are presented by sub-watershed, there is a slight change in the way the actual to buffer ratios were calculated for those sub-watersheds that have more than one hydroseeding contributing site (e.g. Rio loco at Presada Loco Dam sub-watershed). In this case the actual to buffer ratio was calculated by dividing the sum of the actual area of the contributing sites by the sum of the buffered area of the contributing sites. All subsequent results will be provided for the 'Estimated Actual Change' value only.

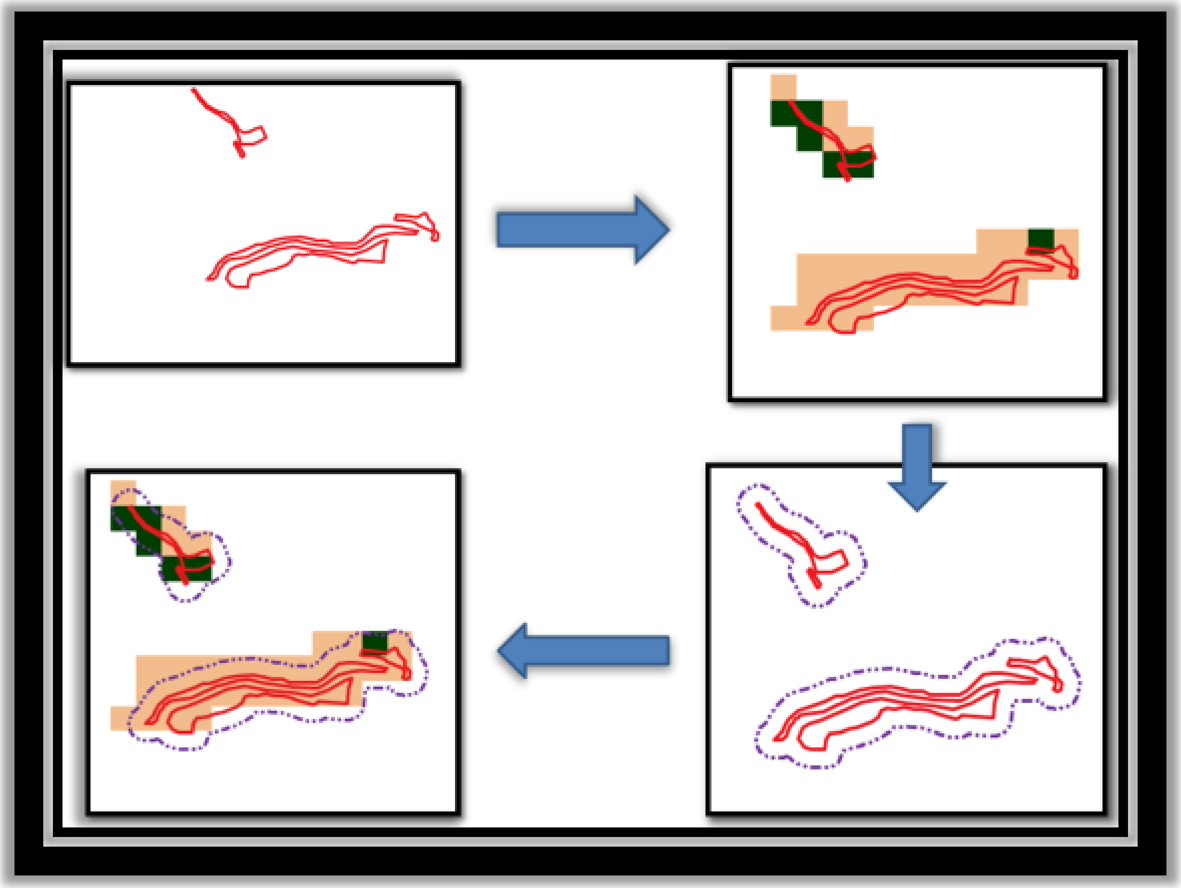

Figure 2. Overview of the steps followed to fix the hydroseeding sites polygon size-resolution issue.

Equations:

(1) $$\frac{Actual\ Area}{Buffered\ Area} = Actual\ to\ Buffer\ Ratio$$

(2) $$Estimated\ Buffer\ Change \times Actual\ to\ Buffer\ Ratio = Estimated\ Actual\ Change$$

Table 1: Data adjustments carried out for each site including the actual area, buffered area, and actual to buffer ratio for every site as well as the estimated buffer change value and the estimated actual value using the runoff results as an example.

Site	Actual Area (acres)	Buffered Area (acres)	Actual to buffer ratio	Estimated Buffer Change (millions of Liters)	Estimated Actual Change (millions of Liters)	Percent change (%)
Montelejos 2	0.3	1.6	0.2	-5.7	-1.1	-56.0
Montelejos 1	1.8	9.1	0.2	-31.3	-6.2	-59.5
María Bonita	0.5	1.6	0.3	-5.3	-1.7	-72.0
Hacienda La Paz	2.5	4.9	0.5	-12.5	-6.4	-71.5
Santa Rita	5.4	15.6	0.3	-26.0	-9.0	-85.0
Fabres	2.5	25.4	0.1	-59.7	-5.9	-74.5

Results

Site description

The OpenNSPECT model was run for six hydroseeding sites five of which are located within the RL/GB watershed limits. Figure 3 presents a map of the RL/GB watershed limits, with its respective sub-watersheds, and the six hydroseeding sites. Sites Montelejos 2, Montelejos 1, and María Bonita are situated in the upper watershed, while sites Hacienda La Paz and Santa Rita are situated in the lower watershed. The Fabres site is a demonstrative site located outside of the RL/GB watershed limits.

All six sites consisted of either hydrologic soil group C or D which suggests these sites consist of a combination of sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, or clay (Table 2). These types of soil are indicative of slow to very slow infiltration rates that impede downward movement of water and is conducive to surface runoff. The Montelejos sites (1 and 2) and the Fabres site have relatively low K factors compared to the other sites with mean values of 0.02, 0.1, and 0.1 for the Montelejos 1, Montelejos 2, and Fabres sites respectively. The K factor is indicative of soil erodibility where slow infiltration rates and low structural stability would be conducive to a high K factor. The R-factor ranged from 551 to 737 across all sites. Steep slopes ranging from 70 to 90% dominated sites Montelejos 2 and Montelejos 1 while slopes where relatively low in María Bonita, Hacienda La Paz, Santa Rita and Fabres sites. Lastly, rainfall ranged from 35 to 84 inches across all sites, and was greatest in the high mountain regions of the watershed (e.g., Montelejos and Maria Bonita) and lesser in the Southwest portions of the watershed (e.g., Hacienda La Paz, Santa Rita, Fabres).

Table 2. Site characteristics for the 6 hydroseed sites. Soil type, hydrologic soil group, and K factor are from the NRCS Soil Survey of the San German Area (2008). Rainfall values were determined from a raster dataset that contains mean average annual rainfall from 1980-2010 in inches (NOAA). R-factor was provided by NOAA-CSC.

Site	Soil type	Hydrologic Group	K factor	R-Factor	Rainfall (inches)
Montelejos 2	Maricao Clay (MkF)	D	0.1	684	84
Montelejos 1	Humatas Clay (HmF)	D	0.02	737	76
María Bonita	Quebrada Clay Loam (QbF)	C	0.2	737	74
Hacienda La Paz	Descalabrado Clay (DsF)	D	0.24	578	53
	San Germán Duey Complex	D	0.28		
Santa Rita	La Luna Silty Clay Loam (LdA)	D	0.2	551	35
	El Papayo gravelly clay loam (EpF)	D	0.24		
	Fraternidad Clay (FrA)	D	0.24		
	Jácana Clay (JaC)	D	0.1		
Fabres	Urban Land (Ua)	D	0	621	48
	Guanabano Clay (GbF)	D	0.24		

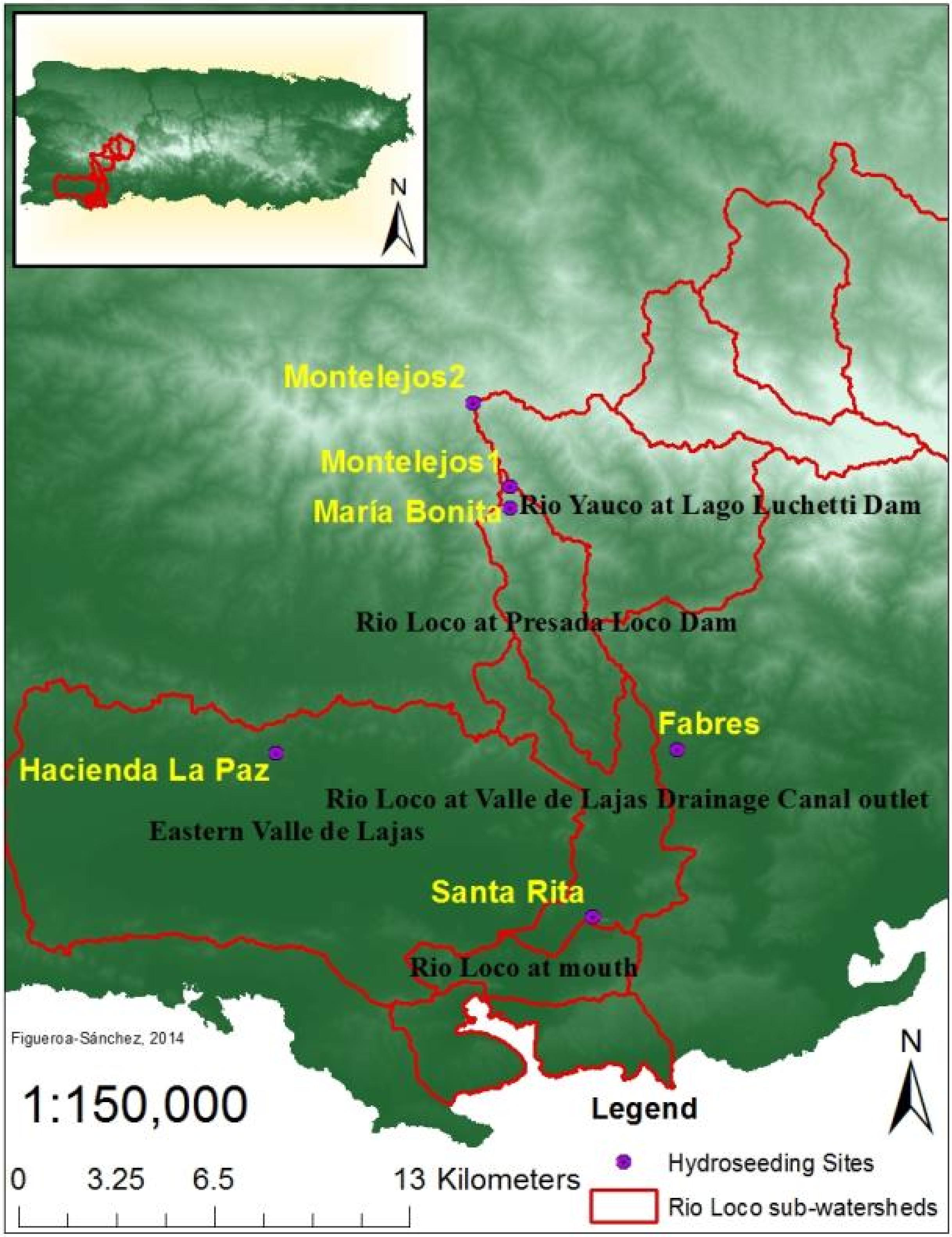

Figure 3. Map of the Río Loco/Guánica Bay sub-watersheds as identified by the USGS hydrological code system (HUC 12) with their respective names in black and the hydroseeding sites represented by the purple bullets with their respective names in yellow. The green surface corresponds to the Digital Elevation Model where the highest elevations are represented by the lightest colors (white) and the lowest elevations by the darker colors (green).

Baseline Runoff and Pollutant Loadings at the Practice

Runoff and pollutant loadings were estimated at each site under 'bareland' conditions to represent baselines for the study. These values were then standardized by area to allow for comparisons across sites. In general, runoff is greatest at the Montelejos and Maria Bonita sites and least at the Santa Rita and Fabres sites. This is consistent with trends in rainfall. However, sediment loads are greatest at the Maria Bonita and Santa Rita site and least at the Montelejos and Fabres sites. This is counter to our expectations for the Montelejos sites since these sites received the greatest amount of runoff and consisted of clayey soils and very steep slopes. Also, the K factor at the Montelejos sites is relatively low given the soil type. In addition the slopes of each site were calculated over a buffered region, which would have led to an averaging over the buffered area and likely reduced the LS value used in the model to calculate sediment loads.

Table 3. Baseline runoff and sediment loadings for each site standardized by area.

Site	Area (m2)	Annual rainfall (inches)	Runoff (L/area)	Sediment (Mg/area)
Montelejos 2	1,376	84	1,153.03	42.23
Montelejos 1	7,325	76	1,327.37	67.93
María Bonita	1,983	74	1,133.92	3,900.08
Hacienda La Paz	9,955	53	933.02	1,665.82
Santa Rita	21,732	35	441.34	3,982.94
Fabres	9,955	48	755.70	39.72

Runoff and Pollutant Loading Changes at the Practice

This section will present the results produced by OpenNSPECT for runoff and pollutant loading changes both at the practice and downstream of the practice. The results estimated for the changes at the practice will be presented by site, and every site will be described briefly. For the changes estimated downstream of the practice the results will be presented by sub-watershed.

Montelejos 2

Figure 4. Montelejos 2 pre (left picture) and post-hydroseeding (right picture). Note the steep slope on the site.

Table 4: Changes in runoff and pollutant loadings at Montelejos 2

Montelejos 2		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-48.1	-82.8
Runoff (Millions of L)	-0.8	-56.0
Nitrogen (kg)	-0.6	-43.5
Phosphorus (kg)	-0.1	-81.7

Montelejos 1

Figure 5. Montelejos 1 pre (left picture) and post-hydroseeding (right picture).

Table 5: Changes in runoff and pollutant loadings at Montelejos 1

Montelejos 1		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-390.6	-82.8
Runoff (Millions of L)	-5.0	-59.5
Nitrogen (kg)	-3.9	-47.5
Phosphorus (kg)	-0.9	-83.0

<u>María Bonita</u>

Figure 6. María Bonita pre (left picture) and post-hydroseeding (right picture).

Table 6: Changes in runoff and pollutant loadings at María Bonita

María Bonita		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-6,071	-82.8
Runoff (Millions of L)	-1.4	-72.0
Nitrogen (kg)	-1.2	-64.0
Phosphorus (kg)	-0.2	-88.3

Hacienda La Paz

Figure 7. Hacienda La Paz pre (left picture) and post- hydroseeding (right picture).

Table 7: Changes in runoff and pollutant loadings at Hacienda la Paz

Hacienda La Paz		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-13,726.7	-82.8
Runoff (Millions of L)	-6.3	-71.5
Nitrogen (kg)	-5.4	-63.0
Phosphorus (kg)	-0.9	-88.0

Santa Rita

Figure 8. Santa Rita sediment pond pre (left picture) and post-hydroseeding (right).

Table 8: Changes in runoff and pollutant loadings at Santa Rita

Santa Rita		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-68,795.7	-83.3
Runoff (Millions of L)	-7.5	-85.0
Nitrogen (kg)	-6.9	-80.8
Phosphorus (kg)	-1.0	-93.8

Fabres

Figure 9. Fabres pre (left picture) and post-hydroseeding (right picture).

Table 9: Changes in runoff and pollutant loadings at Fabres

Fabres		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-327.6	-82.8
Runoff (Millions of L)	-5.4	-74.5
Nitrogen (kg)	-4.7	-67.1
Phosphorus (kg)	-0.8	-89.3

Comparisons across sites

According to the results produced by OpenNSPECT, transforming an area of land from bareland to grassland results in runoff and pollutant loadings reductions ranging from 61% to 87% depending on the pollutant (Figure 10). All the parameters that were assessed: runoff, sediment, nitrogen and phosphorous, presented reductions when the pre and post-hydroseeding loadings were compared. Comparing between parameters, the results suggest that hydroseeding is most effective at reducing phosphorous and erosion from a percentage basis. Figure 10 presents a graph that compares the average percentage reductions by the different parameters. Furthermore, as Figure 10 presents all the parameters loadings were reduced by more than 60%.

Evaluations of the volume or pollutant mass load reductions indicate that hydroseeding is also an effective practice for reducing runoff and pollutant loads (Table 10). On average per meter squared hydroseeding, the model calculated a 582 liter reduction in runoff annually and 1,288 kg, 90 mg, and 485 mg reduction in pollutant loads annually for sediment, phosphorus, and nitrogen, respectively. Sediment load reductions for the Montelejos and Fabres sites are significantly lower than other locations and, given previous concerns, likely underestimate sediment load reductions achieved. Future applications of OpenNSPECT for mass loading analysis should evaluate the appropriateness of data input layers (e.g., K-factor).

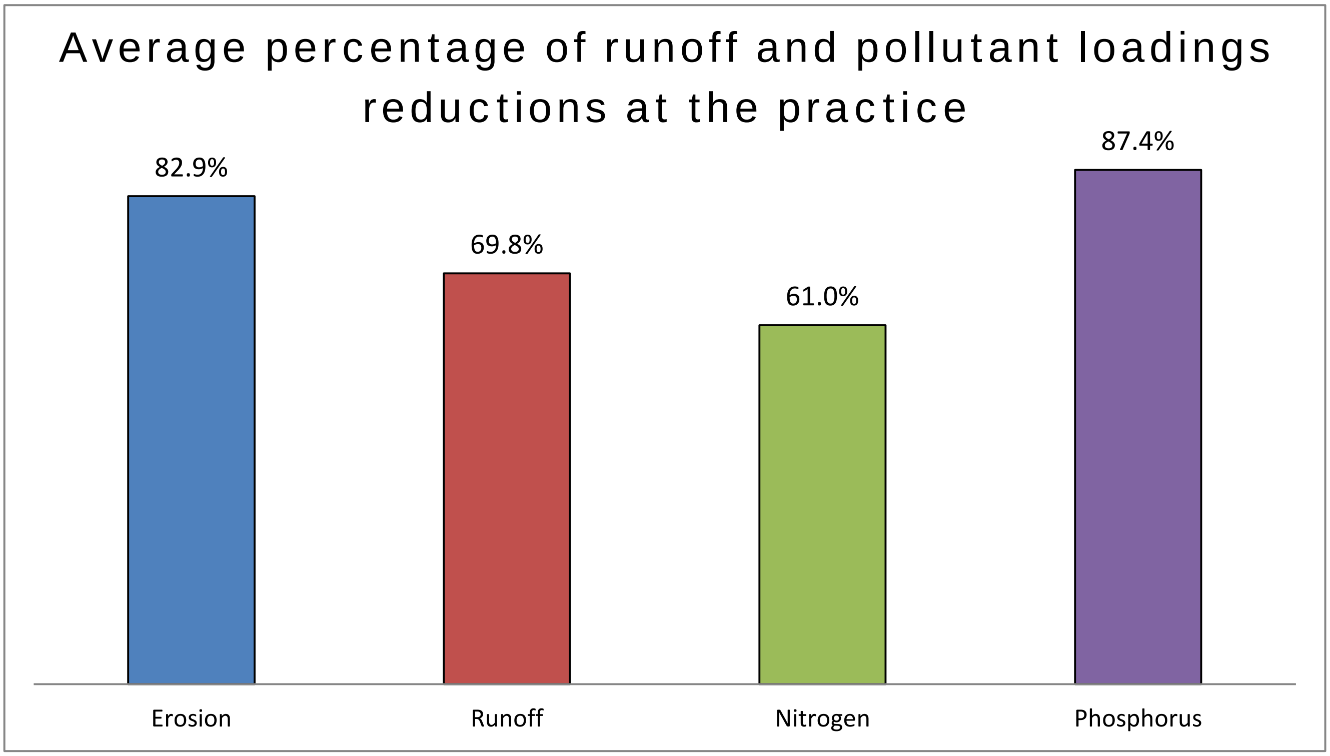

Figure 10. Comparison between the average percentage reduction of runoff and pollutant loadings suggests that hydroseeding is most effective at reducing phosphorous, and sediment loadings caused by erosion.

Table 10. Average load reductions for each site and each parameter (runoff, sediment, phosphorus, and nitrogen).

Site	Runoff Load Change (L/m2)	Sediment Load Change (kg/m2)	Phosphorus Load Change (mg/m2)	Nitrogen Load Change (mg/m2)
Montelejos 2	-595.5	-35.0	-104.0	-447.6
Montelejos 1	-688.5	-53.3	-115.5	-536.2
María Bonita	-692.8	-3061.8	-101.9	-596.8
Hacienda La Paz	-629.5	-1378.8	-93.1	-540.2
Santa Rita	-343.1	-3165.7	-45.4	-316.0
Fabres	-542.0	-32.9	-78.0	-473.7
AVERAGE	-581.9	-1287.9	-89.7	-485.1

Runoff and Pollutant Loading Changes Downstream of the Practice

This sub-section presents the results produced by OpenNSPECT for runoff and pollutant loadings changes downstream of the practice. The goal here was to determine what proportion of the reductions at the practice translated downstream. The values presented here correspond to the compare outputs accumulated effects grids. Unlike the last section in which the results were presented by site, results here are presented by sub-watershed. Table 11 presents a list of the subwatersheds of the RL/GB watershed with their respective contributing hydroseeding sites and the percent of hydroseeded area in each sub-watershed, while Figure 3 presents a map of the subwatersheds and the hydroseeding sites.

Table 11: Río Loco/Guánica Bay assessed sub-watersheds for downstream reductions

Sub-watershed	Contributing Hydroseeding Sites	Sub-watershed area (acres)	Hydroseeded Area (%)
Rio Yauco at Lago Luchetti Dam	Montelejos 2, Montelejos 1*	11,171	0.003
Rio Loco at Presada Loco Dam	Montelejos 1, María Bonita	5,415	0.042
Eastern Valle de Lajas	Hacienda La Paz	35,992	0.07
Rio Loco at the Valle de Lajas Drainage Canal Outlet	Santa Rita	7,199	0.075
Rio Loco at Mouth	N/A	3,254	N/A

*Montelejos 1 contributes to the reduction but not to hydroseeded area percentage.

Rio Yauco at Lago Luchetti Dam

Sites Montelejos 2 and Montelejos 1 contribute to the runoff and pollutant loading changes identified in the Rio Yauco at Luchetti Dam sub-watershed. In this sub-watershed the hydroseeded sites represent only 0.003% of the total sub-watershed area. Table 12 presents the results for this sub-watershed.

Table 12: Changes in runoff and pollutant loadings identified in the Rio Yauco at Luchetti Dam sub-watershed

Rio Yauco at Luchetti Dam		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-92.7	-0.01
Runoff (millions of L)	-1.4	-0.05
Nitrogen (kg)	-1.1	-0.02
Phosphorus (kg)	-0.2	-0.15

Rio Loco at Presada Loco Dam

Sites Montelejos 1 and María Bonita contribute to the reductions identified in the Rio Loco at Presada Loco Dam sub-watershed. These sites represent 0.042 % of the total area of the subwatershed. Table 13 presents the results obtained for this subwatershed.

Table 13: Changes in runoff and pollutant loadings identified in the Rio Yauco at Presada Loco Dam sub-watershed

Rio Loco at Presada Loco Dam		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-6,485.3	-3.80
Runoff (Millions of L)	-6.3	-0.43
Nitrogen (kg)	-4.9	-0.27
Phosphorus (kg)	-1.02	-1.3

Eastern Valle de Lajas

In the Eastern Valle de Lajas sub-watershed the only hydroseeding contributing site is Hacienda La Paz. Hacienda La Paz accounts for 0.007% of the total sub-watershed area. Table 14 presents the results for this watershed.

Table 14: Changes in runoff and pollutant loadings identified in the Eastern Valle de Lajas sub-watershed

Eastern Valle de Lajas		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-13,776.5	-0.05
Runoff (Millions of L)	-6.3	-0.04
Nitrogen (kg)	-5.4	-0.02
Phosphorus (kg)	-0.9	-0.03

Rio Loco at the Valle de Lajas Drainage Canal Outlet

The Santa Rita hydroseeding site is the only contributing site for the Rio Loco at the Valle de Lajas Drainage Canal Outlet. This site represents 0.075% of the area of the sub-watershed. Table 15 presents the results for this site.

Table 15: Changes in runoff and pollutant loadings identified in the Rio Loco at Valle de Lajas Drainage Canal Outlet sub-watershed

Rio Loco at Valle de Lajas Drainage Canal Outlet		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-92,790.5	-2.26
Runoff (millions of L)	-18.9	-0.44
Nitrogen (kg)	-16.2	-0.25
Phosphorus (kg)	-2.8	-0.58

Rio Loco at Mouth

The runoff and pollutant loading changes presented for this sub-watershed were identified at the mouth of the river. The goal here was to determine if the hydroseeding practice had an effect on the waters that flow to the Guánica Bay. All hydroseeding sites contribute to the values presented for this sub-watershed, together the sites represent 0.011% of the total area of the RL/GB watershed. Table 16 present the results for the changes identified at the mouth of the Rio Loco.

Table 16: Changes in runoff and pollutant loadings identified in the Rio Loco at Mouth sub-watershed

Rio Loco at Mouth		
Output	**Estimated Actual Change**	**Percent change (%)**
Sediment (Erosion) (Mg)	-94,797.3	-0.46
Runoff (millions of L)	-23.9	-0.15
Nitrogen (kg)	-20.2	-0.08
Phosphorus (kg)	-3.6	-0.13

The results produced by OpenNSPECT suggest that the reductions accomplished by the hydroseeding practice do translate downstream. It is interesting to note that with such a small percentage of hydroseeded areas the estimated reductions have an effect on the whole watershed. Table 17 presents the relative contribution of the hydroseeding sites reducing sediment loading for sub-watersheds that have hydroseeding sites; this was calculated following Equation (3). The sediment loading percent change reported for the sub-watershed was divided by the proportion of hydroseeded area in the sub-watershed.

Equation:

$$(3) \qquad \frac{Sediment\ Loading\ Percent\ Change\ (\%)}{Hydroseeding\ Area\ (\%)} = Relative\ Contribution\ Factor$$

Table 17: Relative contribution of hydroseeding sites reducing sediment loadings downstream of the practice

Subwatershed	Contributing Hydroseeding Sites	Relative Contribution Factor
Rio Yauco at Luchetti Dam	Montelejos 2, Montelejos 1	3
Rio Loco at Presada loco Dam	Montelejos 1, María Bonita	90
Eastern Valle de Lajas	Hacienda La Paz	0.7
Rio Loco at Valle de Lajas Drainage Canal outlet	Santa Rita	30
Average RFC (not including whole watershed RCF)		**31**
Whole watershed (all subwatersheds)	All sites	119

Discussion

This study demonstrates that hydroseeding is effective at reducing runoff and pollutant loadings both at the practice (Tables 4-10) and downstream of the practice (Tables 12-16). The estimated percent reductions and mass loading reductions are noteworthy, as Figure 10 presents, reductions at the practice for all the assessed pollutants (i.e. sediment, runoff, nitrogen, phosphorus) range between 61% and 87% depending on the pollutant. The results suggest hydroseeding is most effective reducing phosphorous and sediment loadings, which were reduced by 87% and 83% respectively (Figure 10).

Regarding sediment loadings, the average reduction at the practice was 1,287 Kg/m^2/year and the estimate of total sediment mass reduction over the entire area restored on a year was

89,360 Mg/year (Metric Tons/year). Furthermore, the average percentage reduction due to hydroseeding is 83% which means that after the practice is implemented the amount of sediment produced by the site is reduced by 83%. This percentage reduction is comparable with results produced by a study that assessed the use of polyacrylamide (PAM) (i.e. a bonding agent used in hydroseeding) as an erosion control strategy for highly erodible soils in Puerto Rico. Martinez-Rodríguez et al. (2007) concluded that PAM products reduced sediment runoff by more than 75%, this comparison suggesting that the percent change estimates produced by OpenNSPECT are within a similar order of magnitude of field estimates.

Reductions were also observed for runoff and pollutant loadings downstream of the practice. At the subwatershed level the average reduction in sediment loading was 41,588 Mg, while the average percentage reduction for sediment loading was 1.3%. According to the estimates produced by OpenNSPECT, due to the hydroseeding practices implemented in the watershed there are 94,797 less Mg of sediment reaching the mouth of the Rio Loco which corresponds to a reduction of 0.46% at the mouth of the river (Table 16). This estimate is significant considering that the hydroseeded areas represent a minimal portion of the entirety of the RL/GB watershed area, merely 0.011%, thus exalting the potential of hydroseeding.

The relative contribution of the hydroseeding sites reducing sediments downstream of the practice was determined using Equation 3, and is presented on Table 17 as the Relative Contribution Factor (RCF). The RCF represents the contribution of the hydroseeding sites reducing sediment downstream of the practice relative to the area they cover in their respective sub-watershed. The average RCF for the hydroseeding sites is 31, suggesting that the sites reduced an amount of sediment equivalent to 31 times their area. In other words, the contribution of the hydroseeding sites reducing sediment in the watershed equals hydroseeding an area 31 times bigger than the actual hydroseeded area. Such results indicate that the hydroseeded areas were significant contributors of sediment throughout the watershed. Assessing the hydroseeding sites individually, sites María Bonita, Montelejos 1 and Santa Rita present the biggest RCF's (Table 17), thus indicating that these sites were the most effective and contributed the most to the reduction of sediments downstream of the practice.

It appears that the effects of hydroseeding on a percentage basis are greater at the practice than downstream of the practice. This is simply because the reductions achieved through the implementation of hydroseeding are diluted by other sediment inputs that impact downstream of the practice, reducing the proportion of sediment reductions over the landscape. In addition, OpenNSPECT does not include factors like redeposition of sediment in the stream, thus making the estimates for reductions downstream of the practice less reliable than the estimates for the reductions at the practice.

Without a doubt, this analysis provides valuable information for the development of monitoring strategies as it gives an idea on what to monitor, where to monitor it, how many monitoring sites will be needed, among others. As an example, the U.S. Coral Reef Task Force (US-CRTF) is carrying out efforts to develop metrics to measure the effectiveness of Best Management Practices (BMP) (i.e. hydroseeding, wetland treatment plants, riparian buffer restoration, etc.) that target to reduce land-based pollutants. As changes in coral reef quality are slow and more difficult to track, the intention is to develop a monitoring strategy that determines multiple lines of evidence showing the success of BMPs. To this date decisions regarding the location of the monitoring efforts, the parameters to measure, and the quantity of monitoring sites, among others are still under discussion for the RL/GB watershed priority area.

Hence, this is a great opportunity to analyze the outcomes of this project and apply them to the process of developing strategies for monitoring. First, when it comes to in-situ monitoring, this analysis suggests that these efforts should target at the practice reductions as the efficiency of the BMP (e.g., hydroseeding) is best analyzed at the practice, where you can minimize the number of uncontrolled variables which will influence monitoring outcomes. Scale is an important factor in considering monitoring protocols across a landscape. This is particularly true in the RL/GB watershed where the upper watershed water resources are controlled by a combination of five reservoirs, several inter-basin water transfers, and two hydropower plants established by the Southwest Water Project in the 1950's (Ortiz-Zayas et. al.; 2001). If in-stream monitoring is preferred, despite the progressive 'muting' of BMP efficiencies as you move away from the practice, then monitoring should occur closest to the BMP of interest as possible. The outcomes of this project provide valuable baseline information that has the potential of informing the development of in-situ monitoring protocols for evaluating the performance of BMPs and LBSP reduction projects.

Although the project outcomes provide valuable information, there are several concerns regarding this project that should be taken into consideration while analyzing the results, and should be addressed to produce more reliable results. First, the analysis was executed using 30 meter resolution data since the Landcover data for Puerto Rico is still not available in higher resolution. With a higher resolution data it should not be necessary to buffer the hydroseeding sites (see Processing Issues and Limitations section), hence achieving more reliable results should be expected. Also, the Landcover classification is of year 2001 which represents an offset of more than 10 years.

As it has been mentioned, the principal focus and strength of OpenNSPECT is comparing landscapes and management scenarios, thus making the percentage change values more accurate than values presenting an absolute mass. In comparing sediment mass loadings at the practice across sites we found that sediment loading estimates from the Montelejos sites, which has high rainfall, clay soils, steep slopes, and would be expected to have some of the highest levels of erosion, actually had the lowest estimates of sediment loading. It is uncertain what is causing this discrepancy, but it is possible that the soils input dataset may underestimate the K factor for these sites. In addition, the required buffering likely muted the calculation of the slopes at the site, which would also be expected to reduce the calculation of erosion and sediment loadings. Future efforts should include coordination with NRCS soils scientists to determine if additional soils tests are needed to refine estimates of soil characteristics at these sites. Regardless, the sediment load reductions at the Montelejos and Fabres sites likely represent an underestimate of actual values.

On the other hand, sediment masses calculated downstream of the practice likely represent an overestimate, as the model does not account for pollutants settling out of solution as they move through the stream network. Also, it is important to consider that OpenNSPECT is more accurate estimating results for plain lands than for steep slopes. Finally, the OpenNSPECT default pollutant coefficients were used for this project as no pollutant coefficients have been derived for the RL/GB watershed, thus the certainty of the estimated pollutant loadings should be assessed.

Next Steps

Future uses of OpenNSPECT in the Guanica watershed should focus on defining the uncertainty associated with model calculations and refining model inputs and outputs where feasible. Specifically the soils data input should be evaluated by USDA soil scientists to determine whether there is a need and/or ability to update certain locations of the data set. In addition, an uncertainty analysis comparing USGS flow data (e.g., rainfall to runoff ratios) with OpenNSPECT estimates should be conducted, most probably at a small scale within a small sub-watershed. In-situ monitoring of sediment loadings from plots pre- and post-hydroseeding could also be useful to evaluate the accuracy of model outputs. If feasible, monitoring could also target the refinement of data inputs for the region including the development of pollutant coefficients for the RL/GB watershed. Lastly, 10 meter land cover classifications will be available through NOAA's by the end of 2015 if not sooner. Re-running the analysis using higher resolution data is strongly recommended. All in all, the information produced by this project provides an initial footing which can be used in the future to assess and compare the impact of management and restoration efforts.

Acknowledgements

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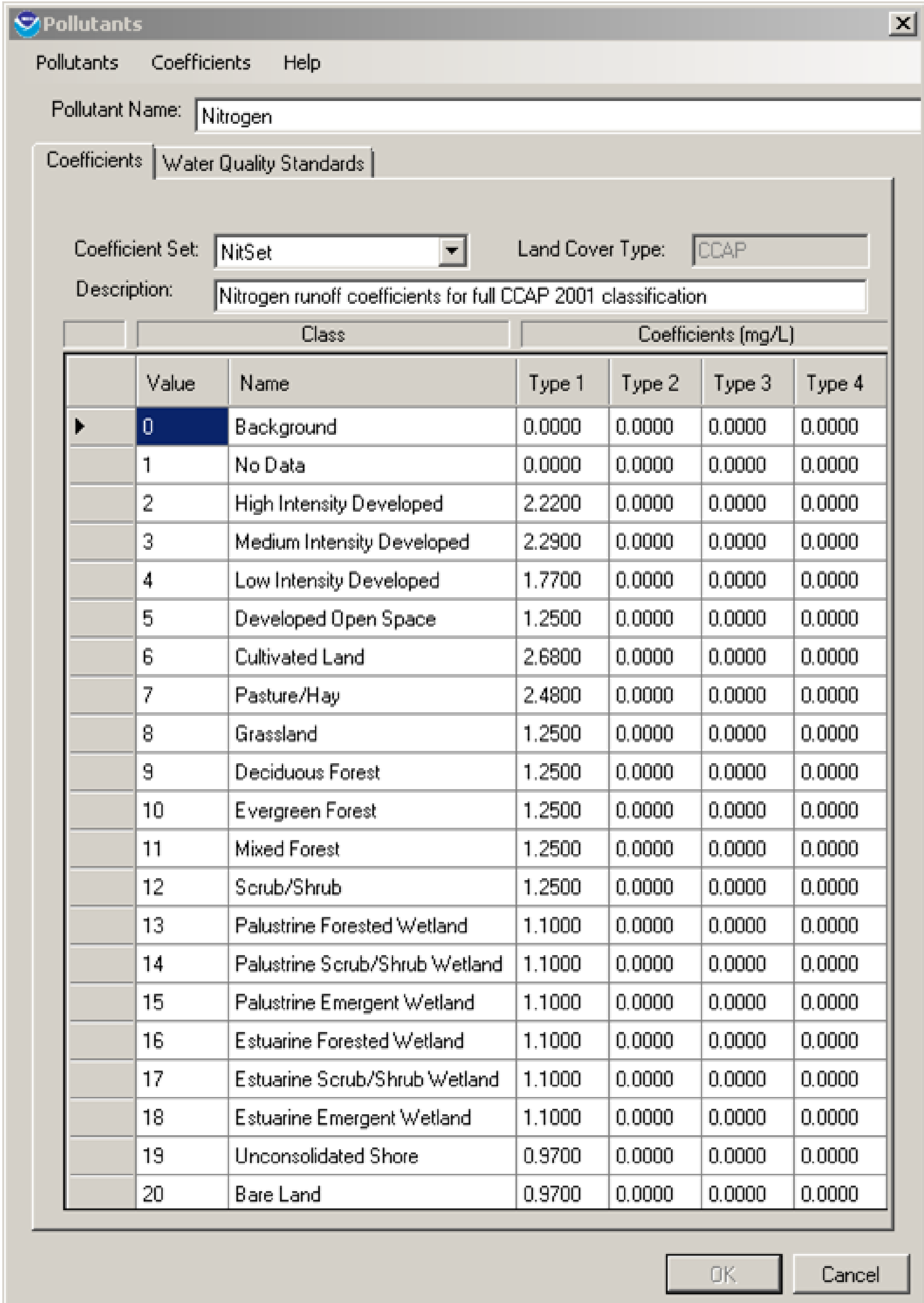
Appendix

Appendix A: Data inputs

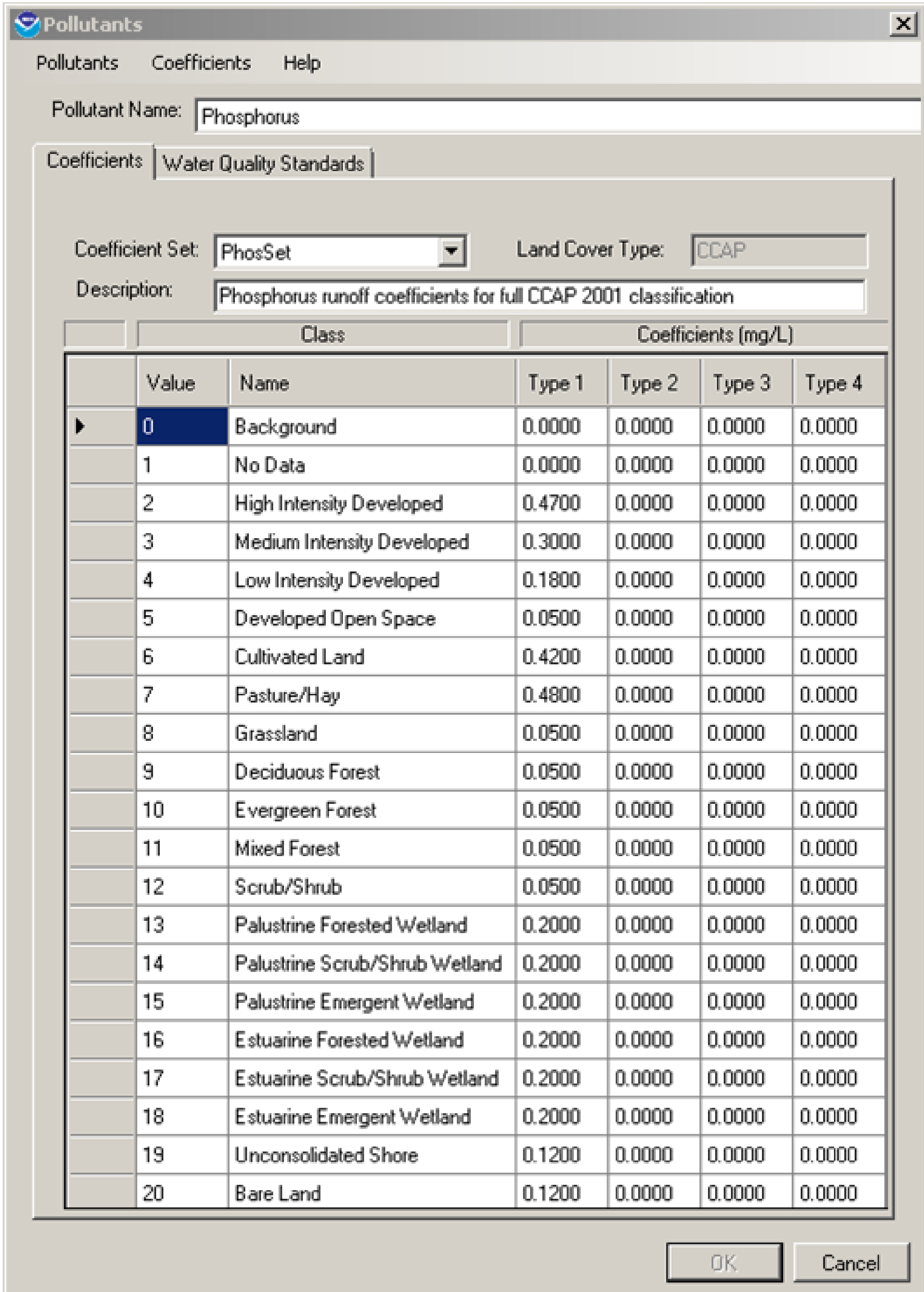
Dataset	Product	Source	Publication date	Description	Link
Digital Elevation Model (DEM)	Puerto Rico, PR 1 arc-second Mean High Water (MHW) Digital Elevation Model (DEM)	NOAA- National Geophysic Data Center	June 2007	30 meter resolution raster topo-bathymetric DEM	http://www.ngdc.noaa.gov/dem/squareCellGrid/download/1561
Land Cover	Coastal Change Analysis Program Land Cover	NOAA- Digital Coast	August 2009	30 meter resolution raster 2001-era classification land cover for the island of Puerto Rico	http://www.csc.noaa.gov/digitalcoast/data/ccapregional
Precipitation	Mean Annual Rainfall 1981-2010	NOAA National Weather Service Weather Forecast Office, San Juan, Puerto Rico	N/A	Map graphic depicting average annual rainfall	http://www.srh.noaa.gov/sju/?n=mean_annual_precipitation2
R-factor	Rainfall runoff erosivity factor	NOAA-Coastal Services Center	December, 2013	30 meter R-Factor raster. Derived and digitized from isoerodent maps published in the Runoff Estimates for Small Rural Watersheds and Development of a Sound Design method by Fletcher et al. in 1977	www.csc.noaa.gov/htdata/nspect/R-factor_PR.zip
Soils	Soil Survey Geographic Database (SSURGO)	USDA Natural Resources Conservation Service, Web Soil Survey	December 2004	1:12,000 scale vector soil parameter database	http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627
RL/GB Watershed Limits	Polygon shapefile of the RL/GB watershed limits	N/A	N/A	Polygon shapefile of the RL/GB watershed limits	N/A

Hydroseeding Sites	Polygon shapefile of the hydroseeding sites assessed in the hydroseeding analysis	Protectores de Cuenca and Yasiel Figueroa	June 2014	Sites were georeferenced in the field and then digitized using ArcMap and Google Earth	N/A

Appendix B: Pollutant coefficients for nitrogen and phosphorus as related to land cover type



Class		Coefficients (mg/L)			
Value	Name	Type 1	Type 2	Type 3	Type 4
0	Background	0.0000	0.0000	0.0000	0.0000
1	No Data	0.0000	0.0000	0.0000	0.0000
2	High Intensity Developed	2.2200	0.0000	0.0000	0.0000
3	Medium Intensity Developed	2.2900	0.0000	0.0000	0.0000
4	Low Intensity Developed	1.7700	0.0000	0.0000	0.0000
5	Developed Open Space	1.2500	0.0000	0.0000	0.0000
6	Cultivated Land	2.6800	0.0000	0.0000	0.0000
7	Pasture/Hay	2.4800	0.0000	0.0000	0.0000
8	Grassland	1.2500	0.0000	0.0000	0.0000
9	Deciduous Forest	1.2500	0.0000	0.0000	0.0000
10	Evergreen Forest	1.2500	0.0000	0.0000	0.0000
11	Mixed Forest	1.2500	0.0000	0.0000	0.0000
12	Scrub/Shrub	1.2500	0.0000	0.0000	0.0000
13	Palustrine Forested Wetland	1.1000	0.0000	0.0000	0.0000
14	Palustrine Scrub/Shrub Wetland	1.1000	0.0000	0.0000	0.0000
15	Palustrine Emergent Wetland	1.1000	0.0000	0.0000	0.0000
16	Estuarine Forested Wetland	1.1000	0.0000	0.0000	0.0000
17	Estuarine Scrub/Shrub Wetland	1.1000	0.0000	0.0000	0.0000
18	Estuarine Emergent Wetland	1.1000	0.0000	0.0000	0.0000
19	Unconsolidated Shore	0.9700	0.0000	0.0000	0.0000
20	Bare Land	0.9700	0.0000	0.0000	0.0000



Class		Coefficients (mg/L)			
Value	Name	Type 1	Type 2	Type 3	Type 4
0	Background	0.0000	0.0000	0.0000	0.0000
1	No Data	0.0000	0.0000	0.0000	0.0000
2	High Intensity Developed	0.4700	0.0000	0.0000	0.0000
3	Medium Intensity Developed	0.3000	0.0000	0.0000	0.0000
4	Low Intensity Developed	0.1800	0.0000	0.0000	0.0000
5	Developed Open Space	0.0500	0.0000	0.0000	0.0000
6	Cultivated Land	0.4200	0.0000	0.0000	0.0000
7	Pasture/Hay	0.4800	0.0000	0.0000	0.0000
8	Grassland	0.0500	0.0000	0.0000	0.0000
9	Deciduous Forest	0.0500	0.0000	0.0000	0.0000
10	Evergreen Forest	0.0500	0.0000	0.0000	0.0000
11	Mixed Forest	0.0500	0.0000	0.0000	0.0000
12	Scrub/Shrub	0.0500	0.0000	0.0000	0.0000
13	Palustrine Forested Wetland	0.2000	0.0000	0.0000	0.0000
14	Palustrine Scrub/Shrub Wetland	0.2000	0.0000	0.0000	0.0000
15	Palustrine Emergent Wetland	0.2000	0.0000	0.0000	0.0000
16	Estuarine Forested Wetland	0.2000	0.0000	0.0000	0.0000
17	Estuarine Scrub/Shrub Wetland	0.2000	0.0000	0.0000	0.0000
18	Estuarine Emergent Wetland	0.2000	0.0000	0.0000	0.0000
19	Unconsolidated Shore	0.1200	0.0000	0.0000	0.0000
20	Bare Land	0.1200	0.0000	0.0000	0.0000

<u>Appendix C: SCS Curve Numbers and RUSLE Cover-Factor as related to land cover type</u>

Land Cover Types

Options Edit Help

Land Cover: CCAP

Description: CCAP Landcover (2001 Classification Scheme)

Classification		SCS Curve Numbers				RUSLE	
Value	Name	CN-A	CN-B	CN-C	CN-D	Cover-Factor	Wet
0	Background	0.0000	0.0000	0.0000	0.0000	0.000	☐
1	No Data	0.0000	0.0000	0.0000	0.0000	0.000	☐
2	High Intensity Developed	0.8900	0.9200	0.9400	0.9500	0.000	☐
3	Medium Intensity Developed	0.7700	0.8500	0.9000	0.9200	0.010	☐
4	Low Intensity Developed	0.6100	0.7500	0.8300	0.8700	0.030	☐
5	Developed Open Space	0.4900	0.6900	0.7900	0.8400	0.005	☐
6	Cultivated Land	0.6700	0.7800	0.8500	0.8900	0.240	☐
7	Pasture/Hay	0.3900	0.6100	0.7400	0.8000	0.050	☐
8	Grassland	0.3000	0.5800	0.7100	0.7800	0.120	☐
9	Deciduous Forest	0.3000	0.5500	0.7000	0.7700	0.009	☐
10	Evergreen Forest	0.3000	0.5500	0.7000	0.7700	0.004	☐
11	Mixed Forest	0.3000	0.5500	0.7000	0.7700	0.007	☐
12	Scrub/Shrub	0.3000	0.4800	0.6500	0.7300	0.014	☐
13	Palustrine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	☑
14	Palustrine Scrub/Shrub W...	0.0000	0.0000	0.0000	0.0000	0.003	☑
15	Palustrine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	☑
16	Estuarine Forested Wetland	0.0000	0.0000	0.0000	0.0000	0.003	☑
17	Estuarine Scrub/Shrub We...	0.0000	0.0000	0.0000	0.0000	0.003	☑
18	Estuarine Emergent Wetland	0.0000	0.0000	0.0000	0.0000	0.003	☑
19	Unconsolidated Shore	0.0000	0.0000	0.0000	0.0000	0.500	☐
20	Bare Land	0.7700	0.8600	0.9100	0.9400	0.700	☐
21	Water	0.0000	0.0000	0.0000	0.0000	0.000	☑
22	Palustrine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.000	☑
23	Estuarine Aquatic Bed	0.0000	0.0000	0.0000	0.0000	0.000	☑
24	Tundra	0.3000	0.4800	0.6500	0.7300	0.014	☐
25	Snow/Ice	0.0000	0.0000	0.0000	0.0000	0.000	☐

Restore Defaults | OK | Cancel