PROPOSAL
Water Resources Research Institute and Center for Hemispherical Cooperation (CoHemis)
Comprehensive Integrated Management Plan for the Mayagüez Bay Watershed

PROPOSAL TITLE: NUTRIENT DISCHARGES FROM MAYAGUEZ BAY WATERSHED

PROPOSAL RESEARCH AREA: Water quality, Eutrophication, Phosphorus concentrations, Geographic information systems, point-source pollution, non-point source pollution

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DURATION OF PROJECT: 1 September 2001 – 30 August 2004

REQUESTED BUDGET: Year1 $40,000, Year2 $40,000, Year3 $40,000

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PROJECT SUMMARY

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REQUESTED FUNDS:

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PROJECT SUMMARY NARRATIVE:
Water resources in Puerto Rico are subject to tremendous pressure from urban, industrial, and agricultural activities. As a result, most surface waters exhibit some kind of impact from anthropogenic activities. High P concentrations in surface waters of Puerto Rico suggest this to be the single most important nutrient that must be controlled to reduce the accelerated eutrophication of fresh waters. Although local data is not available, agricultural non-point sources are believed to be the leading cause of nutrient (primarily N and P) and sediment contamination of surface waters. Still, diverse point- and non-point sources such as unsewered communities in urban, suburban, and rural areas, landfills, agricultural activities, and wastewater treatment facilities have been identified as major contributors of nutrient loads to surface waters in the island. A systematic approach to water quality and watershed restoration must first identify specific contaminant sources as well as characterize their pollution pattern (i.e., relative contribution, seasonal variability, etc).

We propose an intensive research study to identify and quantify nutrient discharges along the main channel and major tributaries of the Rio Grande de Añasco in the Mayagüez Bay Watershed (MBW). We will examine seasonal and spatial trends in sediment and nutrient (nitrogen and phosphorus) concentrations in areas of contrasting land use characteristics. Trends in total P concentrations in water will be related to land use, soil test P information, hydrologic discharge, and known point inputs to assess the relative contribution of different sources to the watershed. This information in combination with land use characterization will serve to better delineate the various nutrient contributing sources and establish a targeted nutrient management program for the watershed.
PROJECT DESCRIPTION

BACKGROUND AND JUSTIFICATION

Description of the problem: Eutrophication due to excessive nutrient loadings has been identified as the critical problem in surface waters having impaired water quality in the USA (Parry, 1998). In Puerto Rico, the observed eutrophication in surface waters is an issue of concern for all people preoccupied with the safety, health and quality of life. Although it is an obvious visual sign in many of our surface waters there is limited information available to ascertain the magnitude nor the contributing sources (Negrón, 1983; Vachier, 1994; Rámos-Gínés, 1997).

Rivers export large quantities of nitrogen (N) and phosphorus (P) to lakes and coastal waters where the adverse effects of nutrient enrichment are most clearly seen (Rámos-Gínes, 1997; Castillo et al., 2000). Eutrophication restricts freshwater use for fisheries, recreation, industry, and drinking due to the increased growth of undesirable algae and aquatic weeds and resulting oxygen shortages caused by their death and decomposition (Daniel et al., 1998; Sharpely et al., 2000). Coastal seas also suffer from eutrophication, where nutrient imbalances can cause blooms of noxious algal species, which negatively impact recreation, commercial fishing and shell-fish production (Burkhart and James, 1999).

Management activities for controlling eutrophication typically focus on P as the single most important nutrient that must be controlled to reduce the accelerated eutrophication of fresh waters. Once P reaches surface water, it is retained fairly efficiently by a combination of biological assimilation and the deposition of sediments and biota to the bottom sediments (Correl, 1998). This process makes slow flowing rivers, estuaries, and lakes very sensitive to pollution with excessive amounts of P. Although N may limit plant and algal growth during certain periods of the year P is most often the limiting nutrient in fresh water areas due in part to the difficulty in controlling naturally occurring N and C inputs to surface waters. The difficulty in removal of P from surface waters creates a challenging task for planners and scientists involved in water quality maintenance, and remediation costs are expected to be in the billions of dollars in the next decade. Thus, efforts directed towards reductions in nutrient loads from distinct sources at the watershed level rather than remediation present the best alternative.

Scientific evidence to date indicates that to control eutrophication total P should not exceed 0.05 mg L\(^{-1}\) in streams entering lakes/reservoir nor 0.025 mg L\(^{-1}\) within lakes/reservoirs. For the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes/reservoirs the concentration of total P should not exceed 0.1 mg L\(^{-1}\) (USEPA, 1986; Daniel et al., 1998). Although threshold limits are important, these should not be used as the sole determinant to guide decision making for P management because of the complex relationships that occur with regards to P transport, background inputs, chemical behavior in soil and water, relationship with other nutrients, among others.

High P concentrations in surface waters of Puerto Rico suggest that this may be the leading cause of observed eutrophication. Sotomayor-Ramírez et al. (2000) summarized total P concentrations and trends occurring in 21 surface water quality stations of eleven rivers in Puerto Rico from 1989-1997 (Fig. 1). Four rivers had median total P concentrations in excess of 0.1 mg P L\(^{-1}\) (a suggested threshold limit for eutrophication) and the remaining seven rivers had at least 25% of...
the sampling episodes exceeding 0.1 mg P L\(^{-1}\). Rio Grande de Añasco and Río Yagüez had mean total P values of 0.10 and 0.09 mg P L\(^{-1}\), respectively. Rámos-Giné (1997) reported on studies made at Lago Cidra, Puerto Rico that total P concentrations increased from 0.28 mg L\(^{-1}\) in 1981 to 1.7 mg L\(^{-1}\) in 1991. Other studies in temperate areas have also documented the long-term deterioration of surface waters as a result of nutrient enrichment (Muscott and Withers, 1996; Castillo et al., 2000; Withers et al., 2000).

Since the 1970’s efforts throughout the United States and the European Community have been directed towards reducing point source emissions contributing to nutrient (N and P) loadings with success. Nutrient emissions from agricultural activities have thus become the dominant source of nutrient loads to freshwater (Van der Molen et al., 1998). In Puerto Rico other water quality contaminants such as sedimentation and the presence of high fecal coliform and streptococcal bacteria have been identified as the main water quality problems (Vachier, 1994). Reductions in point source nutrient emissions have occurred somewhat with improvements in the waste-water treatment facilities and stringent controls on industrial point source emissions. Still, diverse point- and non-point sources such as un-sewered communities in urban, suburban, and rural areas, landfills, agricultural activities, and waste-waster treatment facilities are actively contributing substantial nutrient loads to surface waters especially in the Rio Grande de Manatí, and the Rio Grande de Añasco (Vachier, 1994).

The transport of P to surface waters can occur via surface runoff and erosion from urban, rural, and agricultural lands. Seepage from septic tanks, and direct discharges from waste-water treatment facilities also contribute to P loadings. The different processes governing P availability in soil and water (Frossard et al., 2000) make the identification of source areas difficult. Since the movement of surface water and associate pollutants is governed by watershed boundaries (Hession and Storm, 2000) water quality assessments and management activities should focus on the watershed as the management unit.

This study proposes an intensive research program to identify and quantify nutrient discharges including P concentrations along the main channel and major tributaries of the Rio Grande de Añasco in the Mayagüez Bay Watershed (MBW). This information in combination with the identification of land use in selected areas will serve to better delineate the various contributing P sources. The use and adequate interpretation of soil test P status of agricultural land areas in subcatchments within the watershed, and quantification of actual P exports from these areas will
help to delineate the relative importance of agricultural activities as potential contributors of P to surface water in this area.

**Approaches for water quality assessment:** Sampling designs utilized in these types of studies rely on two general types of design sites: integrator and indicator. Integrator sites represent water-quality conditions of streams with large basins that are often affected by complex combinations of land-use settings. Indicator sites, represent water-quality conditions of streams associated with specific individual environmental settings and land use conditions (Gilliom et al., 2000). We will use both indicator and integrator sites fixed-sites for the evaluation of water quality in the Rio Grande de Añasco.

Gilliom et al. (2000) summarized sampling strategies for this type of study. Integrator sites are on major streams within the drainage basins of the main hydrologic unit area (typically 10-100 percent). When possible, one of the integrator sites should be located at the outlet of the hydrologic unit. Other sites are located at key nodes in the drainage network so that the most significant contaminant sources in the unit are included in at least one of the sampling stations.

Indicator sites are located at the outlet of drainage basins with relatively homogeneous land-use and physiographic conditions (Castillo et al., 2000; Gilliom et al., 2000). Generally, the drainage basin of an indicator site has more than 50 percent of its area in the targeted environmental setting (land use, geology, and other contributing influences). Sites are selected in an attempt to include as much of the representative influencing basin as possible.

Water-column synoptic studies are short-term water quality investigations during selected seasonal periods or hydrologic conditions. Every water-column synoptic study should be custom designed to provide improved spatial resolution, for critical water-quality conditions during selected seasonal periods or hydrologic conditions. They also evaluate the distribution and trends of selected water-quality conditions in relation to causative factors, such as land uses and other contaminant sources. We will perform water-column synoptic studies from areas suspected to be actively contributing to P loads to surface water providing thus for more-detailed characterization of critical source areas.

**Guideline development for total maximum daily loads (TMDL):** The Clean Water Act requires states to set water quality standards to evaluate their condition. These standards are based on (i) the beneficial use of the water body, (ii) acceptable concentration limits for pollutants, and (iii) acceptable maximum contaminant loads or inputs for the maintenance of the water body (Parry, 1998). Where standards are not being met, point source permits are written considering best available technology for the water quality of the discharging effluents. States must develop TMDLs in order to set new permit limits among stakeholders. A TMDL is a pollution critical level that states must establish to maintain water quality based on maximum allowable loads among the sources of pollution (Parry, 1998). If states do not develop the TMDL, USEPA is required to develop the necessary guidelines. Recently, the USEPA has been sued by environmental groups in states where TMDLs have not been developed in water bodies that continue to be impaired.

Non-point agricultural sources are the leading cause of water quality impairments in rivers and lakes in the USA (USEPA, 1988). A major proportion of nutrient loads originate from soils with high soil test P levels (high soil P content) or those amended with organic wastes such as dairy
sludge and poultry manure in excess of crop nutrient requirements. Point sources may increase pressure on state water quality agencies to control non-point sources where it would be more cost effective than tighter point source permits. TMDL related studies must therefore focus in assessing the relative magnitude of background and agricultural nonpoint source pollution to surface waters. This must be done to insure that required water quality improvements are obtained with minimum hardship to the agricultural community. Unfortunately, the TMDL planning program may possibly result in nationwide regulatory programs for agricultural nonpoint source pollution control before many of these studies are completed. Ultimately these guidelines may be based more on speculation and public concerns than on scientific facts (CSA News, 2000). The Rio Grande de Añasco and its tributaries are projected to be included for determination of TMDLs (USDA-NRCS, 1998).

Water quality monitoring (including biological, physical and chemical) and mathematical modeling are used to help understand watershed processes governing pollutant movement in surface water. These tools are used to help understand and investigate watershed-level processes, fill in gaps in monitoring data, identify sources of pollution, and predict system resilience. At present, hydrologic models have a high degree of uncertainty and there are gaps in the data regarding what is natural background pollution versus what is caused by human activity (Hession and Storm, 2000). In Puerto Rico, there is a need to develop the data to evaluate actual P inputs to surface water and for future model validation. Because of this research team’s expertise in agriculture, P behavior in soil and water, and water quality and quantity, we believe that we are in a unique position to evaluate existing watershed and TMDL tools to insure that they are based on sound science. This proposal will focus on the collection and assemblage of data necessary for future model development and evaluation.

**Study Area:** The Mayagüez Bay Watershed (MBW) (also called Rio Grande de Añasco) watershed is one of the largest in Puerto Rico and lies within the municipalities of Adjuntas, Lares, San Sebastian, Maricao, Las Marias, Mayagüez and Añasco (USGS, 1998) (Fig. 2). Its east-west axis is aligned with the predominant weather patterns occurring in the Caribbean. The northern limit of the watershed is delineated by the Atalaya Mountains, where near the town of Añasco they merge with the dissected plateau remnants at slightly lower elevations. The Cordillera Central delineates eastward and southeastern portions of the watershed rising south of Maricao and extending eastward near Adjuntas. Although elevations throughout the Cordillera Central range from 900 to 1200 m above mean sea level most of the peaks of the dissected highland between the mountain ranges have elevations of between 300 to 340 m above mean sea level. The Atalaya Mountains have a maximum elevation of around 305m above mean sea level (USDA-SCS, 1973).

All of the mountain masses have heavy precipitation on their north slopes as the trade winds from the northeast are forced to rise over them. All of the uplands exhibit rugged steep topography with frequent slopes ranging from 70 to 100 percent. On the south side of the watershed there are foothills with elevations ranging from 43 to 62 m above mean sea level which become progressively greater eastward with slopes varying from 25 to 45 percent.
The climate is characterized by warm, wet summers and warm but dry winters with progressively cooler temperatures occurring in the mountainous regions. The long term average annual rainfall at Mayagüez is approximately 220 cm that is similar to the weighted average annual rainfall for the watershed of 236 cm (USDA-SCS, 1973). A wet season usually occurs from April through November and a drier season from December through March.

The Añasco River is born at elevation 1,204 m (3,950 ft) near Monte Guilarte and flows westward for 74 km to discharge into the Añasco/Mayagüez Bay. The major tributaries of this river are: Rio Daguey, Rio Humatas, Rio Canas, Rio Casei, Rio Arenas, Rio Mayagüecillo, Rio Guaba, Rio Prieto, and Rio Blanco. Streams in the uplands carry a base flow at all times except during extreme drought. Some of the small streams in the Atalaya Mountains are classified as intermittent while those in the lowland are classified as perennial. Streams in the lowland are almost all modified channels (for agricultural purposes) or man-made ditches.

Of the total catchment area (52,278 ha), 48,130 ha are classified as mountainous' and 4,148 ha are lowland (USDA-SCS, 1973). In 1973, more than 97% of the land area was either idle or planted to cropland that includes minor crops, coffee, and sugarcane (Table 1). Land use, specifically conversion from agricultural to urban land has changed significantly since then. As of 1973, approximately 50,000 people resided within the watershed (USDA-SCS, 1973). It is estimated that Rio Grande de Añasco serves more than 150,00 people with drinking water (USDA-NRCS, 1998).

Table 1. Land use in the Rio Grande de Añasco basin as of 1973. (Source: USDA-SCS, 1973)

<table>
<thead>
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<th>Land use</th>
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<tr>
<td>Cropland</td>
<td></td>
</tr>
<tr>
<td>Minor crops</td>
<td>3498</td>
</tr>
<tr>
<td>Coffee</td>
<td>20841</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>3411</td>
</tr>
<tr>
<td>Pasture</td>
<td>11438</td>
</tr>
<tr>
<td>Forest</td>
<td>8506</td>
</tr>
<tr>
<td>Idle</td>
<td>3265</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1297</td>
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</table>

Soils in the uplands are mostly sub-lateritic, red, acid soils with a silty clay profiles. Soils in the bottomlands have developed from sediments of the upland soils. The bottomland soils have varying textures, but are mostly fine to moderately fine and vary in drainage properties from well to poorly drained (USDA-SCS, 1975).

Three main types of geologic groups predominate in the Rio Grande de Añasco basin. Quarternary alluvium deposits predominate in the lower flood-plains and the river valleys. The northern part of the watershed including Atalaya mountains consist of Tertiary and Late Cretaceous volcanic and sedimentary rocks. In the eastern, central and southern parts of the watershed Cretaceous sedimentary and volcanic rocks predominate (USDA-SCS, 1975).
Water quality in Rio Grande de Añasco: Water resources in Puerto Rico are subject to tremendous pressure from urban, industrial, and agricultural activities. As a result, most surface water streams in the island exhibit some kind of impact from anthropogenic activities. Although local data is not available to quantify their contribution, agricultural non-point sources are believed to be the leading cause of nutrient (primarily N and P) and sediment contamination of surface waters as occurs in the mainland USA. However, other activities can also serve as contaminant sources of surface waters. In Puerto Rico, the large degree of sedimentation and the presence of high fecal coliform and streptococcal bacteria levels are the main surface-water quality problems. For example in the Rio Grande de Añasco total P concentrations were significantly correlated to fecal coliform and streptococcal bacteria, NO$_3^-$, TKN, with Pearson correlation coefficients of 0.47, 0.60, 0.44 and 0.74, respectively (Sotomayor et al., 2000). This suggests that runoff from unsewered urban communities could be a major source of nutrients on this watershed. Total P concentrations in surface water at selected stations of the Rio Grande de Añasco were near or above the suspected threshold for eutrophication of 0.1 mg P L$^{-1}$ (Fig. 3). Total P concentrations at USGS gaging station 50144000 (midstream) were similar to 5014600 (downstream) but significantly higher than those at 50143000 (upstream).

The MBW including the Rio Grande de Añasco in one of eighteen watersheds which have been included in category I restoration priority by local authorities. Category I watersheds are those for which the available information shows that the water quality standards are exceeded in terms of magnitude and frequency and are in the highest restoration priority (USDA-NRCS, 1998). It has 51 registered livestock enterprises and croplands (non-point sources) (ninth lowest for this classification among the eighteen category I watersheds in need of restoration). It has ten point-sources with permits and one registered landfill (USDA-NRCS, 1998). An interagency group has determined that it has a prioritization rating of six among the eighteen watersheds in need of restoration.

Fertilizer use in Puerto Rico has been reduced by 40% in the last ten years (Commonwealth of Puerto Rico, 1999) and we have unpublished information that reveals that this land area is not a major receptor of organic waste material such as poultry litter, and dairy waste sludge. Soils receiving applications of these organic materials can serve as potential sources of P to freshwater (Martínez et al., 1999; Kuykendall et al., 1999; Beegle et al., 2000). Nevertheless positive relationships between total P concentrations and hydrologic discharge suggest that part of the P loads to the Rio Grande de Añasco are related to surface runoff from drainage areas.

This work will be undertaken then, with the hypotheses that (i) P concentrations found in the Rio Grande de Añasco are associated with a combination of transported sediment and overland flow from land surfaces and from point sources within the watershed, and (ii) important contributing areas contain high soil test P levels regardless of whether these have recently received organic or inorganic P additions.
The purpose of the proposed study will be to examine seasonal and spatial trends in nutrient (phosphorus) concentrations in a predominantly tropical agricultural watershed, which is impacted by urban and suburban influences. This investigation will establish indicator sites in addition to integrator sites (already established) in order to link the status and trends in P concentrations and other nutrients with an understanding of the natural and human factors that affect the quality of the water. To identify probable factors influencing nutrient concentrations and to determine the relative magnitude of point and non-point sources, trends in total P concentrations in water will be related to land use, soil test P information, hydrologic discharge, and known point inputs. Phosphorus exports from two benchmark fields will be performed to evaluate the factors affecting P export via overland flow. This information will be used to provide guidelines for the draft development of total maximum daily loads (TMDL) for major nutrients by major stakeholders within the RGA basin.

OBJECTIVES:
The specific objectives of the research study are:
1. To quantify seasonal and spatial trends in nutrient loads including P fractions (total P, sediment-P and total dissolved P) in principal tributaries and along the main channel of the RGA basin.
2. Relate observed trends to land use, soil test P, orographic characteristics of the tributary, soil type and known point sources in the RGA basin.
3. Evaluate P exports and factors influencing P losses from two agricultural fields within the RGA watershed.
4. Provide guidelines for the development of draft total maximum daily loads (TMDLs) for major nutrients by major stakeholders within the RGA basin.

RESEARCH PLAN

To meet the above stated objectives the following tasks will be performed:
- Land use evaluation within the RGA watershed and subcatchments.
- Topographic delineation of subcatchments.
- Establishment of monitoring stations, using USGS stations and land use information within subcatchments as criteria.
- Generate hydrographs and rating curves for sampling locations.
- Data collection at low-frequency intervals to identify major contributing areas.
- Data collection high-frequency intervals in selected stations.
- Use two benchmark farms to quantify P exports and factors affecting P exports from agricultural areas.

Objective 1: Quantification of seasonal and spatial trends in nutrient loads including P fractions (total P, total dissolved P, and dissolved P) in principal tributaries and along the main channel of the RGA basin.

Topographic delineation and Land Use Evaluation:
Using the same sub-catchment approach of the hydrologic analysis (HEC-1), the RGA basin will be divided and its landuse characterized using a variety of techniques including remote sensing images and the most recent air photography of the region available at the PR Highway and
Transportation Authority (PRHTA). Satellite image will be classified using supervised classification techniques in the ERDAS computer package. It is expected that the entire RGA watershed will be classified using ERDAS, but ground truthing will be done at the selected subcatchment were water quality monitoring is carried out. We intent to characterize the environmental settings of the Rio Grande de Añasco basin by dividing it into several major subareas that have relatively homogeneous combinations of natural features and land-use conditions. This information will be used to establish the locations of the sampling stations.

**Establishment of sampling stations:** At present, there are three sampling stations within the main channel of the Rio Grande de Añasco established by the USGS (USGS, 1998). The sampling strategy in these are characteristic of integrator basic fixed sites (Gilliom et al., 2000) and integrate the multiple influences throughout the entire basin including urban and agricultural sources and discharge from waste-water treatment plants. Two additional integrator basic fixed sites will be established within the river.

Additional sampling stations will be established that will evaluate the relationship between water-quality conditions and specific environmental settings within subcatchments (indicator basic fixed sites). The criteria for site selection within the tributaries will be based on the homogeneity of land use within subcatchments, proximity to USGS sampling stations and relative importance of the tributary to watershed hydrology. Based on a preliminary assessment of land use within the area, in that many land areas exhibit land-use homogeneity, we expect that not all of the tributaries will be sampled and that some will have multiple sampling stations (for example in upper, middle and lowlands). The spatial location of the sampling station in relation to point sources of contamination such as wastewater treatment plants and other nonpoint sources such as animal feeding operations, and proportion of catchment as urban, agriculture, rangeland, and forest will be used to evaluate the relative magnitude of each source’s role as contributor of P to surface waters.

**Hydrographs and rating curves:**
The hydrology of each subcatchment will be developed using the methodology of Flood hydrograph package (HEC-1) of the Army Corps of Engineers (USCOE, 1984). Hydrographs at USGS stations will be compared with comparable rainfall events registered at those specific locations to provide calibration of the HEC model. Preliminary rating curves for the location will be developed using the cross section of the main channel at the sampling location. Automatic samplers will be adjusted to allow sampling of events that reach specific surface water elevations and equivalent flow. It is expected that three or four sampling stations will be set up in addition to the ones operated by the USGS in this watershed.

**Sampling design and sample collection:** Water sampling will be conducted based on a fixed-interval sampling schedule. This arrangement is the collection of discrete samples at regular time intervals for laboratory analysis of chemical and physical properties and for associated field measurements (Gilliom et al., 2000). We expect to collect water samples at monthly intervals during the 2-year period of sample collection which is the most common sampling frequency in this type of operation.
Sampling at selected basic fixed sites will also include sampling at extreme flow conditions (we expect about four to five additional samples per year per station) to supplement interval sampling. This will be done only at selected sampling stations where known homogeneous land use occurs, and during particular extreme flow events such as during the onset of the rainy season. Although fixed-interval sampling provides data for the most common flows and concentrations, high and low flows and concentrations that occur less often during the study period have a small chance of being sampled even though they are particularly important. Occurrence of high and low flows and associated constituent transport and concentrations are of high significance for water quality far beyond the proportion of time during which they occur because they can transport large concentrations in relatively small time-intervals.

Acid-rinsed containers will be used to manually collect two grab water samples from mid-channel or as close to mid-channel as possible at each site (Castillo et al., 2000).

Two sampling stations will be used for water-column synoptic studies because intense sampling is usually feasible for only a few sites. The process of choosing the location of stations and the design structure will be based on land-use information and observed trends in nutrient concentrations in the basic fixed sites. We hypothesize that P concentrations in particular areas will be most relevant during runoff events or unsteady flow conditions which will require frequent sampling at study sites during storm events for a limited period of time. Nutrient and sediment transport are closely related to rainfall events and runoff, and the sampling time and location is crucial in the determination of contributing areas. To document this effect of runoff and timing, automated sampling systems will be used to sample water during the increase in stage-discharge at the specific location. The automatic sampling equipment will be set up to draw samples during the rising limb of the runoff hydrograph in each of the sampling locations. The automatic samplers will be equipped with pressure transducers able to recognize the stage of surface water and therefore discharge.

*Streamwater discharge determination:* Stream discharge will be determined with the Flood Hydrograph package (HEC-1) as described before in this manuscript. Discharges will be calculated at the same sampling locations. Rating curves will be developed for each of these location using the cross section of the channel.

*Water chemistry data:* Acid rinsed containers will be used to store and transport the water samples. Samples will be transported in a cooler to the laboratory because the expected travel time from field sites to the laboratory is < 2 hours. Samples will remain frozen until analysis (Haygarth and Edwards, 2000).

Water samples will be analyzed for total phosphorus, soluble phosphorus, total kjeldahl nitrogen (TKN), NO$_3^-$-N + NO$_2^-$-N, NH$_4^+$-N, and suspended sediments (Pote and Daniel, 2000). Water aliquots will be oven-dried (105°C) for determination of sediment content. Unfiltered aliquots will be digested using Kjeldahl digestion analyzed for total phosphorus. Additional aliquots will be vacuum filtered through a Whatman 0.45 µm filter and the filtrate analyzed for soluble P. Sediment P will be determined by subtracting soluble P from total P. Phosphorus in extracts will be analyzed colorimetrically (Murphy-Riley, 1962) using a UV-VIS spectrophotometer. NO$_3^-$-N + NO$_2^-$-N will be analyzed by the cadmium reduction method (Keeney and Nelson, 1982). Chlorophyll content in water will be quantified as an index of algal biomass.
**Objective 2: Relate observed trends to land use, soil test P, orographic characteristics of the tributary, soil type and known point sources in the RGA basin.**

Spatial and seasonal patterns in P concentrations will be examined using simple and multiple regression analyses and a number of independent variables such as: time, season, location in the watershed, land use and cover, nutrient discharges from wastewater treatment plants, distance from the mouth. Land use and cover categories for areas upstream from each sampling site will include proportion of catchment as urban, agriculture, rangeland, wetland, forest and urban. Land use ratios will be included in the analyses because these have been found to correlate favorably to nutrient concentrations in other studies (Castillo et al., 2000). To examine which areas represent the greatest water quality problems, data will be summarized using frequency distributions. To select the best multiple predictors of P concentrations multiple regression analysis between P concentrations and biological and chemical parameters will be performed.

We expect and anticipate the cooperation of the Compañía de Aguas in providing information related to discharge volume and phosphorus and nitrogen concentrations from waste-water treatment plants. This information can be used to estimate P loads to surface waters and further ascertain the relative contribution of different sources as P contributors to surface waters.

**Objective 3: Evaluate P exports and factors influencing P losses from two agricultural fields within the RGA watershed**

Two agricultural fields will be selected to quantify P exports and factors affecting transport from soils. This will be done in year 3 of the study. Fields will be selected based on information provided by land use maps and topographic information, University of Puerto Rico Agricultural Extension Agronomists, USDA Census of Agriculture information, and personal visits by the researchers. The fields selected must: be in active agricultural commercial production, contain a well defined drainage and catchment area, be away from high traffic areas or from other environmental external factors which could confound the results. The farmers will be interviewed to ascertain input and output variables in the fields. These include information on crops grown, rotation practices, yields, fertilizer rates, fertilizer timing, manure utilization and application, irrigation practices, proximity to surface water, and other crop and soil management practices.

Within each field, soil samples will be collected at depths of 0-5 and 5-15 cm from the surface and will be analyzed for: pH, electrical conductivity, total nitrogen, total P, soil test P, cation exchange capacity (CEC), exchangeable bases and aluminum, and organic matter content using established procedures (Page A. L., et al., 1982).

The drainage area at the site will be identified. A monitoring location will be established at the lowest topographic location of the field where runoff from the field drains. Runoff entering the location will be diverted to a monitoring point by a diversion wall (Nash et al., 2000). The sites will be instrumented with a diversion wall flume-weir combination, and a CISCO storm monitoring system comprising a Model 3700 automatic sampler, a bubbler flowmeter, and a rain gauge. Water sampling will be flow-integrated (approx. every 8,000 L) to maximize sampling
frequency at higher flow rates, when greater P loads are expected. (Kuykendal et al., 1999; Nash et al., 2000)

Water samples will be returned to the laboratory and analyzed. Total solids will be determined by evaporation of water aliquots at 105°C followed by gravimetric determination of remaining solids. Total dissolved solids will be determined in a similar manner for water aliquots filtered through a 0.45 µm filter. Electrical conductivity of the unfiltered sample will be determined using a conductivity bridge. Unfiltered aliquots will be digested using Kjeldahl digestion analyzed for total phosphorus. Additional aliquots will be vacuum filtered through a Whatman 0.45 µm filter and the filtrate analyzed for soluble P. Sediment P will be determined by subtracting soluble P from total P. Phosphorus in extracts will be analyzed colorimetrically (Murphy-Riley, 1962) using a UV-VIS spectrophotometer.

Phosphorus concentrations in runoff water and runoff volume will be used to determine flow-weighted mean concentrations, runoff, and P exports from the sites. Relationships between P concentrations (including P fractions) and days since fertilizer application, total flow, soil test P, will be established to evaluate the factors affecting P export from the sites and the relative importance of agricultural systems as sources of P to water (Kuykendall et al., 1999).

A Global Positioning System (GPS) will be utilized to locate the benchmark farms and fields within the study zone. The locations will be stored, (together with chemical analyses results) in a GIS file format for later analysis and manipulation of data. Topographic information on the area will be gathered from the Digital Elevation Model (DEM) (1:20,000 scale) equivalent to quad sheets of the U.S. Geological Survey. Soil maps in the area will be obtained from the Puerto Rico Planning Board (Junta de Planificación de Puerto Rico), additional data quality control will be performed to soils data sets. Remote sensing analyses of Landstat TM images and air photo interpretation will be used to classify land cover. All this will allow the research team to generate information on land cover, slope and slope length, and erodibility factors for benchmark farms and other zones within the area. A linkage between these data sets, the soil P content, and RUSLE parameters will be developed with the geographic information system package PC ARC/INFO and Small Macro Language (SML). A series of maps will be generated using tools in the GIS software illustrating critical or sensitive areas within the watershed, as well as the benefits of implementing different conservation practices at these sites.

A Nutrient Management Plan and a Soil Erosion Control Plan, will be developed for the benchmark farms located in the subcatchments where major water quality impairment is observed. This will be implemented in cooperation with the environmental quality board and USD-NRCS.

Objective 4: Provide guidelines for the development of draft total maximum daily loads (TMDL) for major nutrients by major stakeholders within the RGA basin.

A total maximum daily load is the acceptable level of nutrient discharge from a stakeholder that allows the achievement of set goals at the watershed level. This study will document the contribution of major stakeholders in the RGA by quantifying the impact of land use and land management to the nutrient loading into the RGA. At the end of the study, the team of researchers will be able to deliver a draft of what could become the TMDL’s for the Río Grande...
de Añasco that will be used as a working draft document by local agencies to raise awareness and reach compromise with stakeholders and the community in general. To do this, the team will study other TMDLs developed for other watersheds in several other states in the USA.

EXPECTED RESULTS AND BENEFITS:
The results to be generated in this study will serve to: (i) quantify the temporal variation of nutrient concentrations and discharges along the RGA; (ii) identify and provide an assessment of the relative magnitude from contributing sources (point versus non-point); iii) provide sound data and understanding to guide the process of developing guidelines (Barnes et al., 2000) to address the 1996 amendments of the Clean Water Act regarding establishment of Total Maximum Daily Loads (TMDL) for the RGA watershed by the Commonwealth of Puerto Rico. The outcomes of the proposed research are of utmost importance to be included in the proposed comprehensive integrated management plan for the Mayagüez Bay Watershed.

PROJECT TIMETABLE:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use evaluation within the RGA watershed and subcatchments.</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topographic delineation of the RGA watershed and subcatchments</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validation of analytical methods for nutrient determination.</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Establishment of monitoring stations</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Generate hydrographs and rating curves for sampling locations</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Data collection at integrator and indicator basic fixed sites</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Data collection at synoptic water quality study sites</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Quantification of P exports and factors influencing P losses from two agricultural fields</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Provide guidelines for the development of draft total maximum daily loads</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Preparation of manuscripts</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

EQUIPMENT AND FACILITIES:
The project will utilize the laboratory facilities of the soil chemistry and soil fertility laboratories of the Department of Agronomy and Soils in Mayagüez and at the Agricultural Experiment Station Rio Piedras. The laboratories have the necessary facilities and technical personnel to perform sample preparations and water analyses for the research. Graduate and undergraduate students will provide support for these activities and have been budgeted appropriately.

Assistance for the data collection of streamwaters and for the field runoff experiments will be provided by scientific support personnel of the Research and Development Centers (RDC) of the
Agricultural Experiment Stations of the University of Puerto Rico. Graduate and undergraduate students will also provide support for these activities and have been budgeted appropriately.

The Agricultural & Bio-systems Engineering Department through its director and Co-Pi in this proposal (Dr. Pérez-Alegría) has the computing resources and personnel to manage the data needed and generated by the proposal. The department has the necessary resources (hardware, software and technical expertise) to meet the needs of the proposal in the area of remote sensing and GIS. Further assistance can be obtained via the Laboratory of Remote Sensing and GIS of the Department of Agronomy and its collaborator, Mr. Luis Olivieri.

COORDINATION WITH OTHER AGENCIES AND ORGANIZATIONS:
At present, our research group has a joint collaborative agreement with the Natural Resource Department of Puerto Rico and the Environmental Quality Board (See Current and Pending Research). Besides providing economic support for the project both agencies provide assistance and support by means of sharing specific data and information on the Río Grande de Arecibo watershed. We expect the same relationship to develop on the Río de Añasco watershed once this project is granted. In addition, being from the College of Agriculture our research team has privilege access to the resources available on its three components, namely the Agriculture Experiment station, The Agriculture Extension Service and the Faculty.

CONTRIBUTION OF OTHER RESEARCH PROJECTS TO THE PROPOSED PROJECT:
The research team is actively pursuing research in two projects related to the proposal. In the first project, the research team is in year 1 of a USDA-TSTAR-CBAG funded grant that will identify critical environmental soil test P levels. The information generated will serve to identify land areas that can serve as sources of P to surface water if surface runoff occurs in proximity to a water body. The project is also creating a GIS compatible database of potential runoff-P (P index) for Puerto Rican soils, using thousands of historical agronomic soil P tests from farms throughout the island in combination with NRCS-generated runoff estimates. Maps will be constructed showing agricultural land areas in Puerto Rico susceptible to P runoff losses based on both P index and soil test P criteria.

In the second project, the research team is in year 1 of a Commonwealth of Puerto Rico Department of Natural Resources Special Project Grant that will assess the impact of agricultural activities on water quality impairment in the Río Grande de Arecibo Watershed. It will also identify critical source areas within the watershed.

Both of the abovementioned projects will contribute effectively towards the timely and effective completion of this proposed research project.
LITERATURE CITED:


Correl, D.L. The role of phosphorus in the eutrophication of receiving waters: A review. J. Environ. Qual. 27:261-266.


### RESEARCH BUDGET

<table>
<thead>
<tr>
<th>Item</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost ($)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Salaries and Wages</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Summer compensation</td>
<td>11,000</td>
<td>11,000</td>
<td>11,000</td>
<td>33,000</td>
</tr>
<tr>
<td>- 1 month of each (3) PI’s salary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Graduate student assistantships @ $7,000/yr/student</td>
<td>7,000</td>
<td>14,000</td>
<td>14,000</td>
<td>35,000</td>
</tr>
<tr>
<td>c. Undergraduate students @ $6.00/hr &amp; 480 hrs/yr</td>
<td>2,880</td>
<td>2,880</td>
<td>2,880</td>
<td>5,760</td>
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<tr>
<td>2. Materials (laboratory reagents and supplies)</td>
<td>4,000</td>
<td>2,120</td>
<td>2,120</td>
<td>8,240</td>
</tr>
<tr>
<td>3. Equipment</td>
<td>16,000</td>
<td>6,000</td>
<td>6,000</td>
<td>28,000</td>
</tr>
<tr>
<td>4. Travel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Local to and from field sites</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>6,000</td>
</tr>
<tr>
<td>b. National and international</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Total</td>
<td>40,000</td>
<td>40,000</td>
<td>40,000</td>
<td>120,000</td>
</tr>
</tbody>
</table>

**Budget Narrative:** Each of the principal investigators will receive one month salary as summer compensation during the duration of the investigation. Two of the principal investigators (Sotomayor and Pérez-Alegría) are full time faculty members with the University of Puerto Rico and are on nine-month appointments. Dr. Martínez will devote time to the project outside regular working hours. The researchers have an excellent working relationship and will be laboring closely in all aspects of the project, although, Dr. Sotomayor will oversee the project. In the initial phases (year 1 and part of year 2) of the project, Dr. Pérez Alegría will be leading the completion of tasks a, b, c, and d. Drs. Sotomayor and Martínez will be providing support to Dr. Pérez-Alegría and will be planning the establishment and installation of the sampling stations. Once the sampling protocols are validated and sampling gets underway (year 2), Drs. Martínez and Sotomayor will be leading and coordinating the analysis of water and sediment samples. Dr. Pérez-Alegría will be providing support in this area. In year 3, water sampling and analyses will continue and all three researchers will be working to meet the final two objectives (Objectives 3 and 4). Drs. Martínez and Sotomayor have experience working in the areas of soil chemistry and soil fertility, respectively and will be relating actual runoff losses from benchmark farms to mechanisms of P behavior in soil and soil test P levels.

A total of two graduate students will be working directly on the research project and will receive graduate research assistantships. In the first year of the project an M.Sc. student will be working with Dr. Pérez-Alegría in the completion of tasks a, b, c, and d. which will be used to eventually meet Objectives 1 and 2 of years two and three of the project. The information generated will be used by a second graduate student who will begin on year 2 working on tasks e, f, and g under
the supervision of Drs. Sotomayor and Martínez. The latter student will participate in the completion of Objectives 2 and 3.

Undergraduate students from the Department of Agronomy and Soils and from the Agricultural & Bio-systems Engineering Department will be hired to provide support to the principal investigators and to the graduate students during years 2 and 3 of the project. Additional cooperation is available with undergraduate students working with Mr. Olivieri whom are under the auspices of PasCoR program. The students have access to state of the art computing facilities and have the basic training in GIS to provide support in the preparation of maps, and in the storing and manipulation of spatial data.

A large proportion of the materials needed will be purchased during year 1 of the project. The money will be used for the purchase of laboratory reagents, sampling bottles, and other equipment needed to instrument the field sites.

Funds allocated for equipment purposes will be used to purchase two ISCO water sampling units ($6,000/each) during year 1 which will be installed in one of the sampling stations. A second water sampling unit will be purchased at year 2 of the project for installation at a second sampling station. The third water sampling unit will be used for water sampling from runoff plots.

Travel to and from field sites will be intense during all years of the project. The money will be used for per diem of the researchers. Travel to present the information at scientific meetings will be performed at years 2 and 3 of the research project.
## CURRENT AND PENDING RESEARCH

<table>
<thead>
<tr>
<th>Researcher†</th>
<th>Project Title‡</th>
<th>Funding Agency</th>
<th>Amount</th>
<th>Starting Date</th>
<th>Ending Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sotomayor-Ramírez¹</td>
<td>Nutrient discharges from Mayaguez Bay Watershed⁵</td>
<td>UPR-RUM-WRRI</td>
<td>$40,000/yr</td>
<td>Sept. 2001</td>
<td>Aug. 2004</td>
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<tr>
<td>Pérez-Alegría¹</td>
<td>Nutrient discharges from Mayaguez Bay Watershed⁵</td>
<td>UPR-RUM-WRRI</td>
<td>$40,000/yr</td>
<td>Oct. 2001</td>
<td>Aug. 2004</td>
</tr>
<tr>
<td>Pérez-Alegría¹</td>
<td>Atmospheric carbon sequestration in tropical watersheds⁵</td>
<td>NASA</td>
<td>$85,000/yr</td>
<td>Oct. 2001</td>
<td>Sept. 2005</td>
</tr>
<tr>
<td>Martínez¹</td>
<td>Characterization and management of non-point pollution sources and wetland areas in the Rio Grande de Arecibo Watershed⁴</td>
<td>Comm. of P.R. Dept. of Natural Resources</td>
<td>$35,000/yr</td>
<td>Oct. 2000</td>
<td>Aug. 2001</td>
</tr>
</tbody>
</table>

† Role of researcher is: 1. Principal investigator, 2. Co-Principal Investigator, 3. Collaborator
‡ Status of project is: 4. Active, 5. Pending Approval, 6. Granted
CURRICULUM VITAE (Principal Investigators):

David Sotomayor-Ramírez

Current Position:
Associate Professor, University of Puerto Rico, Agronomy and Soils Department, Box 9030 Mayagüez, P.R. 00680-9030; Tel./Fax: 787-832-4040 x3734; E-Mail: d_sotomayor@rumac.upr.clu.edu

Education:
Ph.D., Agronomy (Soil Microbiology), Kansas State University - Manhattan, May 1996.

Professional Experience:
Associate Professor, Soil Fertility and Nutrient Management, University of Puerto Rico, Agronomy and Soils Department. Aug. 2000 – Present
Assistant Professor, Soil Fertility and Nutrient Management, University of Puerto Rico, Agronomy and Soils Department. Aug. 1997 – July 2000
Graduate Teaching Assistant - Kansas State University, Dept. of Agronomy, Manhattan, KS. Aug. - Dec. 1994, 1995

Honors and Awards
Dean F. Weber Graduate Scholarship - Kansas State University, 1994 - 1995.

Teaching Experience at Univ. of Puerto Rico:
Agro 4037 - Soil Fertility and Fertilizers; Agro 6604 - Soil Plant Relations; Agro 6607 – Soil Chemistry; Agro 4018 – Soil Physical and Chemical Properties; Agro 4032 – Summer Practice ; Agro 5016 – Advanced Soil Fertility; Agro 3005 – Introduction to Soils

Refereed Publications and Theses:


**Published Abstracts and Formal Presentations:** (26 total; only the five most recent are included)


PROFESSIONAL INTERESTS
- Land application of non-hazardous wastes.
- Spectroscopic characterization of surface controlled processes in natural environments.
- Characterization of organic matter interactions in highly weathered soils.
- Speciation of trace elements in soils.
- Chemical remediation of trace element contaminated sites.

EDUCATION
June, 1995 - The Ohio State University - Ph.D.
June, 1988 - Cornell University - M.S.
May, 1985 - U.P.R. - Mayagüez College of Agriculture - B.S.

WORK EXPERIENCE
2000 - Present  Assistant Deputy Director for Research Office, Agricultural Experiment Station, U.P.R., P.O. Box 21360, Rio Piedras, P.R. 00928.
1997 - 2000:  Associate Soil Chemist, Agronomy and Soils Dept., Agricultural Experiment Station, U.P.R., P.O. Box 21360, Rio Piedras, P.R. 00928.
1995 - 1997:  Assistant Soil Chemist, Agronomy and Soils Dept., Agricultural Experiment Station, U.P.R., P.O. Box 21360, Rio Piedras, P.R. 00928.
1993 - 1995:  Graduate Teaching Assistant. Agronomy Dept. The Ohio State University.
1988 - 1995:  Assistant Researcher, Agricultural Experiment Station, U.P.R., HC-02, Box 10322, Corozal P.R., 00643.

AWARDS
1994:  Graduate Student Research Award - The Ohio State University
1991:  Minority Fellowship - Graduate School - The Ohio State University
1990:  Best Scientific Presentation - Annual meetings Puerto Rican Society of Agricultural Sciences (SOPCA)
1985:  Best Student Award, Agronomy Faculty, U.P.R.
1985:  Best Student Award, Agronomy and Soils Dept., U.P.R.
1985:  Best Student Award - Agronomy Dept.: GAMMA PHI DELTA
1985:  Best Student Award- University Level: ETA GAMMA SIGMA, Juana Díaz, P.R. 1985.
1981-85:  Best Student Award: ALPHA ZETA Honor Society
Gustavo A. Martínez - 2
PUBLICATIONS (most recent)

   Nutrient uptake and Yield Performance of Cassava in two Compost Amended Soils. J. Agric.
   Univ. of P.R. (on review).

   Effects of a Sewage Sludge Compost on the Chemical and Physical Properties of two Soils of
   the Tropics. J. Agric. Univ. of P.R. (on press).


   Nutritional Status of Soils from the Poultry Zone in Puerto Rico. J. Agric. Univ. of P.R. 83

   sewage sludge compost. Caribbean Food Crop Society, 34th Annual Meeting Proceedings,
   Montego Bay, Jamaica.

   Binding Reactions in a Sewage Sludge Humic Acid. J. Agric. Univ. of P.R. 82 (no. 3-4) p.
   121 - 140.

   in Multiligand Systems with Lanthanide Luminescence. J. of Colloid and Interface Sci. 204,
   33-44.

   Reactions in Polyelectrolytes: Discrete vs. Continuous Distribution of Sites. J. of Colloid and
   Interface Sci. 199, 53 - 62.

9) Martínez, G. A., and V. Snyder. 1997. Phosphorus Status of Soils from the Poultry Zone of

    Contaminant Potential of Soils From the Poultry Zone in Puerto Rico. Caribbean Food Crop

    Organic Wastes Stabilized with Fluidized Bed Combustion Solid Residues. Caribbean Food

    Sludge Compost on the Chemical and Physical Properties of two Soils of the tropics.
    33. p. 311.

    Addition of Ca and Mg to an Ultisol: II-CaSO4 additions. J. Agric. Univ. P.R.. 80 (1-2) pp. 1
    - 12.
LUIS R. PEREZ-ALEGRIA

Telephone: (787) 834-2575
FAX: (787) 265-3853
e-mail: lu_perez@rumac.uprm.edu

Education and Experience:

2000: Faculty Summer Internship at NASA Goddard Institute for Space Studies, New York, NY
1999: Faculty Summer Internship at NASA Goddard Institute for Space Studies, New York, NY
1998: Professor - University of Puerto Rico-Mayagüez (UPR-Mayagüez)
1994 - 1995: Agricultural Engineering Department Director - UPR-Mayagüez
1992 - 1997: Associate Professor - University of Puerto Rico-Mayagüez

Awards and Honors:

1988: Alpha Epsilon Honor Society of Agricultural Engineering

Collaborators:

Dr. David Brune (U.Clemson, SC) Dr. Cinthya Rosenzweig (NASA-GSFC)
Dr. Art Cohen (Los Alamos, NM) Dr. Gustavo Martínez (UPRM)
Dr. David Sotomayor (UPRM) Dr. Rafael Dávila (UPRM)

Publications: (most important):


External Funding:

- USDA-Higher Education Program. Watershed management strategies for soil and water conservation and atmospheric carbon sequestration. Undergraduate and High School Learning
- Evaluation of best management practices for sludge from the Barceloneta Wastewater Treatment plant in Barceloneta, Puerto Rico. INDUNIV. Jun 97-Jul 98. $100,000.
- Field Evaluation of Tropical Aquatic Vegetation for Constructed Wetlands for Waste Water Treatment. Research Grant Award, USEPA-PREQB. May 1994-June 1995. $60,000.

Graduate Students Advised (M.Sc.):
Zaide Morales, AGRO (2000)

Professional Associations:
- American Association for the Advancement of Science, AAAS.
- American Society of Agricultural Engineers. ASAE.
- The Scientific Research Society.
- Puerto Rico Water Resources Association, PRWRA.
- Colegio de Ingenieros y Agrimensores de Puerto Rico. Registered Professional Engineer, L. Number 13458.