

**Puerto Rico Water Resources Research Institute
Annual Technical Report
FY 2008**

Introduction

This report covers the period from March 1, 2008 to February 28, 2009. All activities relate to the base grant, National Competitive Grant Program awards for which the Institute was the lead institute, NIWR-USGS Internships, and supplemental awards funded by either the USGS or by pass-through funds from another Federal agency are summarized herein. The Puerto Rico Water Resources and Environmental Research Institute is located at the Mayagüez Campus of the University of Puerto Rico.

The Puerto Rico Water Resources and Environmental Research Institute (PRWRERI) is one of 54 water research centers established throughout the United States and its territories by Act of Congress in 1964 and presently operating under Section 104 of the Water Research and Development Act of 1984 (P.L.98-242). The general objectives of the Puerto Rico Water Resources and Environmental Research Institute are...

- (1) to conduct research aimed at resolving local and national water resources problems,
- (2) to train scientists and engineers through hands-on participation in research, and
- (3) to facilitate the incorporation of research results in the knowledge base of water resources professionals in Puerto Rico and the U.S. as a whole.

To accomplish these objectives, the Institute identifies Puerto Rico's most important water resources research needs, funds the most relevant and meritorious research projects proposed by faculty from island universities, encourages and supports the participation of students in funded projects, and disseminates research results to scientists, engineers, and the general public. Since its creation, the Puerto Rico Water Resources and Environmental Research Institute has sponsored a substantial number of research projects, supported jointly by federal, state, private, and University of Puerto Rico's funds. Through its website, the Institute's work is more widely known to the Puerto Rican and world communities and, at the same time, provides means of information transfer with regard to the reports produced through the institute's research activities.

Research Program Introduction

Under the direct supervision of the Chancellor Office, the PRWRERI is a component of the Research and Development Center of the University of Puerto Rico at Mayaguez. As such, it acts as official liaison of the University of Puerto Rico with industry and government for all water resources research activities. The Institute also functions as a highly recognized advisor to these two sectors on water resources and environmental issues. This role translates into multidisciplinary functions and activities that add relevance and impact to the research program the Institute supports. By virtue of the local relevance of its research and the prestige and leadership of the investigators it has supported, the Institute has become the focal point for water-related research in Puerto Rico.

Meetings, seminars, technical reports, quarterly newsletter and a web site are used by the Institute to keep the water resources community and general public informed about advances in research. Approximately once every three years, the Institute organizes a major conference on water-related research in Puerto Rico and the Caribbean Islands, in collaboration with other technical organizations in the region. All these activities facilitate the translation of the research sponsored by the Institute into practical applications of direct benefit to industry, government, and the general public.

In FY 2008, the PRWRRI submitted 7 research and technical project proposals to federal and state government agencies, municipalities, and private sector. Three were approved for total funds of \$96,607. One was rejected and three are still pending. The proposals are as follows.

1. Perform an Evaluation for Heavy Metal Removal from the Miradero Water Treatment Facility – Extension to other metals, CDM, \$14,997, (Approved).
2. The Northeast State & Caribbean Islands Regional Water Program, USDA, \$70,332, (Approved).
3. A Hydrogeology Study to determine the groundwater hydraulic gradient at Añasco's Sanitary Lanfill, Municipality of Añasco, \$11,278, (Approved).
4. Hydrodynamic and Salinity Study for Boqueron Wildlife Refuge – Resubmission to PRDNER, \$210,000, (Pending).
5. Development of a Comprehensive Integrated Management Plan for the Río Grande de Manatí, PRDNER, \$75,891, (Pending).
6. Development of a stormwater management plan for the Municipality of Mayagüez, \$92,000, Municipality of Mayagüez, (pending).
7. BMP Training and Demonstration Farm for the Reduction of NPS of Pollution, EPA, \$179,765 (Rejected).

During FY 2008 the PRWRRI administered two projects funded under Section 104B (one new project and one extended from FY2005), in addition to other projects funded by other agencies, as per approved proposals. Previous fiscal year continuing projects include...

1. Regional Water Quality Coordination project in USEPA Region III, in collaboration with Rutgers University and Cornell University.
2. Comprehensive Integrated Management Plan for the Mayaguez Bay Watershed.

3. Establishment of the Center of Excellence for Water Quality.
4. Evaluation of bridges subjected to military loadings.
5. Perform an Evaluation for Heavy Metal Removal from the Miradero Water Treatment Facility,
6. Selection of Sediment Transport Functions for the St. Thomas Island Guts.
7. Hydrologic and Hydraulic studies appraisal for the Department of Natural and Environmental Resources of PR.

A Call for Proposals to the research community of Puerto Rico was issued in October, 2008. Only five submissions were received. These are...

1. Water Quality Problems Associated with Carbonatic Soils from Rio Grande de Manati Watershed: Pesticide Interactions in Soils. (rejected)
2. Rapid Erosion Susceptibility of Coffee Vegetated River Basin Hillslopes due to Rainfall-induced Shallow landslides. (rejected)
3. A Novel Environmental Remediation Technology: Enhanced Elemental Iron/Molecular Oxygen System by Bimetallic Nanoscale Zero-Valent Iron (nZVI). (rejected)
4. Atmospheric Deposition of Persistent Organic Pollutants (POPs) to Jobos Bay National Research Reserve Watershed. (rejected)
5. Open Pit Quarry Restoration to Bio-Viable Land (continuing project). (approved)

Dr. Jorge Rivera-Santos continued to monitor the progress of the research projects and continued to be a liaison between the University of Puerto Rico and other agencies including the Caribbean Office of the US Geological Survey. The director targeted other local government agencies to become directly involved with through the arrangement of Memorandums of Understanding (MOUs).

Monitoring Nutrients Content in the San Juan Bay Estuary using Hyperspectral Remote Sensing

Basic Information

Title:	Monitoring Nutrients Content in the San Juan Bay Estuary using Hyperspectral Remote Sensing
Project Number:	2005PR20B
Start Date:	3/1/2004
End Date:	12/31/2008
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Nutrients, Nitrate Contamination, Non Point Pollution
Descriptors:	
Principal Investigators:	Fernando Gilbes

Publication

FINAL REPORT

Project Number: 2005PR20B (extended to FY2008)

Start: 03/01/2004

End: 12/31/2008

Title: Monitoring Nutrients Content in the San Juan Bay Estuary using Hyperspectral Remote Sensing

Investigators: Gilbes-Santaella, Fernando

Focus Categories: Hyperspectral Remote Sensing, Total Phosphorus Contamination, Non-Point Source Pollution

Congressional District: N/A

Descriptors: N/A

PROBLEM AND RESEARCH OBJECTIVES:

Several point and non-point sources pollution have been identified in the San Juan Bay National Estuary (SJBNE) and represent a potential threat to the site in maintaining its environmental balance and protection of the local surviving species. During 1994 and 1995, the United States Geological Survey (USGS), in cooperation with the United States Environmental Protection Agency (EPA), and the Puerto Rico Environmental Quality Board (EQB), conducted water and sediments sampling survey on the SJBNE. While on certain sections of the SJBNE the conditions have improved, there are still degraded conditions at the Caño Martin Peña and at the San Jose Lagoon (SJL), the results of the survey reflected presence of toxic sediments deposited in the above surface water systems. Furthermore, anoxic and abiotic conditions persisted at both systems caused by stagnant water conditions with virtually no mixing during daily ocean tides events. During 1995 the United States Army Corp of Engineers (USCOE) used the CH3D-WES and CE-QUAL-ICM hydrodynamic and water quality models, respectively, in developing water quality management scenarios for the SJL.

Monitoring of water pollution with satellite imaging could provide important information related to the total phosphorus (TP) loadings along the SJL. Remote sensing techniques are appropriate due to the complexity of the SJL's ecosystem particularly because of the larger mangrove population. This study suggests the use of hyperspectral imaging as a TP pollution monitoring tool in tropical estuaries. The Hyperion hyperspectral sensor has the capability to define spectral profiles in the visible and near infrared bands where TP is suspected to reflect. Field reflectance validation was performed to correlate the satellite measurements with true TP reflected water quality characteristics at the deeper SJL sections, based on field sampling results. Finally, a mathematical algorithm was developed from a separate research to extract TP information from the satellite image based on reflectance characteristics. These data were used to determine TP concentration in the lagoon waters. A water quality model was used to verify the spectral results with predicted TP concentrations inside the SJL.

METHODOLOGY:

A. Satellite Sensor

The Hyperion Hyperspectral Instrument (HIS), which was developed by the National Aeronautics and Space Administration (NASA) and installed at NASA's EO-1 satellite, provides a high spatial resolution of 30 meters ranging from the ultraviolet to the infrared spectral bands (operating within the 0.4 to 2.5 μm bands). The HIS also has a high spectral resolution as it provides high radiometric accuracy in 224 spectral bands. Such variety in spectral bands is necessary to identify different vegetation species present inside a small area such as the SJL, particularly swamp lands (NASA, 2002), distinguish between the bay's bottom bed and brushes, and identify planted areas. Other sensor alternatives, such as Thematic Mapper (installed in the Landsat 7 satellite), have been considered. However, most of the available sensors have much lower spatial and spectral resolutions not useful for the SJL study due to the site's small area.

B. Image Processing

The ENVI 4.2 version software, developed by Research Systems, was used to process and classify the SJL images used in this study. ENVI provides needed geometric correction, terrain analysis, radar analysis, raster, and vector Geographic Information System (GIS) capabilities. The ENVI 4.2 was purchased by the Geology Department at the University of Puerto Rico's Mayagüez Campus (RUM) where a significant amount of the study activities were completed. Several HIS images were purchased to the USGS, with passes taken without presence of clouds.

Three (3) individual images (See Figures 1, 2 and 3) were produced from the San Jose Lagoon by the HIS on different occasions: February 24, May 12 and August 14, 2006. Raw images were radiometrically calibrated and geometrically corrected using different United States Geological Survey's (USGS) Level 1R algorithms.



FIGURE 1
FEBRUARY 24, 2006



FIGURE 2
MAY 12, 2006



FIGURE 3
AUGUST 14, 2006

The first step was performed by the USGS to convert the images from Level 0 (atmospheric spectral raw data) to digital radiance numbers (radiance spectral data). After geometric correction, visible near infrared bands were aligned with the short wave infrared bands. As a result corrections were made to assign a digital number (zero) to 46 spectral bands for which Hyperion receives no spectral signal.

Atmospheric corrections were performed to the above radiance images with the ENVI-Fast Line-of-Sight Atmospheric Analysis of Hyperspectral cubes (FLAASH) atmospheric correction module. The FLAASH software was used to remove the spectral atmospheric transmission and scattered path radiance using the MODTRAN4 radiative transfer algorithm estimating the radiance received by the sensor. The atmospheric corrections were completed following the FLAASH Atmospheric Correction Guide (Morillo, 2005). Figures 4, 5 and 6 show the reflectance images after atmospherically corrected.



FIGURE 4
FEBRUARY 24, 2006



FIGURE 5
MAY 12, 2006

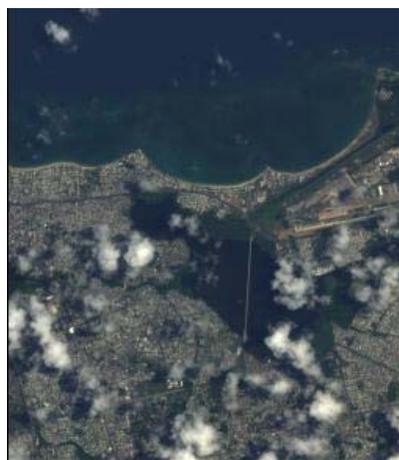


FIGURE 6
AUGUST 14, 2006

All images were georeferenced to UTM (Universal Traverse Mercator) units using a field geographic positioning system receptor. The image georeferencing was completed using the ENVI 4.2 map registration module with ground control points selected at convenient locations within the adjacent SJL area.

1. Field Data Processing

All terrain and water resources data have been obtained from available sources, such as the United States Environmental Protection Agency (USEPA), the United States Geological Survey (USGS), the United States Department of Agriculture's Natural Resource Conservation Service (NRCS), the National Oceanic and Atmospheric Administration (NOAA), the Puerto Rico Department of Environmental and Natural Resources (PRDENR), the Puerto Rico Environmental Quality Board (PREQB), and others. All satellite imaging has been obtained from NASA.

An *in-situ* sampling survey was conducted at approximately 40 (forty) sampling stations defined by a location map (Figure 7) during the months of February, May, and August, 2006 for the presence of nitrates and total phosphorus for each sampling station. Analyses and results of samples collected in the field were conducted by a private environmental laboratory in accordance with 40 CFR Part 136 (Methods for Chemical Analysis for Water and Wastes, EPA, 1974).



FIGURE 7
FIELD SAMPLING STATIONS

Nitrate as nitrogen samples were analyzed following EPA Method 353.2 (Nitrate-Nitrite Nitrogen by Colorimetry). Total Phosphorus samples were analyzed following EPA Method 365.3 (Ascorbic Acid). Quality Control/Quality Assurance documentation (chain-of-custody) for all samples was also provided by EQLab.

Field sample results and chain-of-custody records were obtained from EQLab. While the total phosphorus results were measured at different levels within the lagoon the total nitrates resulted in most of the station in below the method’s detection limit. Thus, total nitrates concentrations were not pursued as part of this study.

Radiance values were obtained with the use of a GER 1500 spectroradiometer (Figure 8) at each sampling stations per sampling survey. Field remote sensing reflectance was calculated from average radiance values at each sampling station per sampling survey.



FIGURE 8
GER 1500 SPECTRORADIOMETER

C. Water quality samples (QA/QC protocols)

Field nitrates and total phosphorus water quality samples were obtained from the SJL to validate the results from the Hyperion reflectance data. Grab samples for both parameters were collected from the field sampling locations previously defined in accordance with depth restrictions. Due to the high water turbidity the samples were obtained from the surface. Strict Quality Assurance/Quality Control (QA/QC) procedures were followed in accordance with the U.S. Environmental Protection Agency (EPA) established protocols. Samples handling was evidenced with the use of chain-of-custody documentation, which details: sample number, date, time, type, container information, site name, arrival temperature, and delivery receipt signatures. Five-hundred (500) milliliter polyethylene, uncolored bottles were used with sulfuric acid (H₂SO₄) as the preservative with a pH less than 2. Samples were analyzed using methods EPA 353.2 for Nitrate as Nitrogen, and EPA 365.3 for total phosphorus by EQ Lab, a private environmental quality laboratory, in charge of conducting the analyses. All samples were preserved at a temperature not exceeding 4°C inside coolers provided by EQ Lab until delivered to the laboratory facilities.

D. Algorithm Development

The images evaluation activities were concurrently undertaken with *in-situ* sampling of the bay's waters for nitrates or total phosphorus, with locations identified by the mentioned field grid. Such locations were sited at the San José lagoon. Several regression analyses between remote sensing reflectance vs. TP *in-situ* concentrations were completed for single band, bands ratio, and log bands ratio combinations. Statistical errors and uncertainty analyses were completed for the highest obtained regressions. Based on the above data, an algorithm for nutrients concentration was defined using total phosphorus as the leading indicator. The field sampling was accomplished to test and validate the developed algorithm. Since the lagoon is excessively polluted with phosphorus, the algorithm was developed to provide total phosphorus concentrations uniformly distributed throughout the lagoon. However, there are certain limitations in the use of total phosphorus as an indicator. Organic phosphorus is one of the leading components in the sediments of an eutrophic surface water body. While the intent of the algorithm is to develop a nutrients pollution control management tool, it may provide misleading results as excessive organic phosphorus may influence the spectral map final results without necessarily identifying point and non-point pollution sources. A water quality model was used to verify the total phosphorus concentrations throughout the lagoon with corrections accounting for the organic phosphorus content within the sediments. Another disadvantage may be the inability of the sensor to adequately obtain reflectance measurements from the water column, particularly if turbidity conditions prevail during most part of the year. Thus, surface concentrations are only used for purposes of this research. However, and since the algorithm is intended to provide TP concentrations from suspected or unknown pollution sources, spectral characteristics of the water column may not be affecting such purposes.

E. Water Quality Model Verification

The United States Army Corp of Engineers (COE) CH3D-WES hydrodynamic and CE-QUAL-ICM (ICM) water quality models results were used as a comparison to verify the total phosphorus concentrations obtained from the Hyperion image after application of the empirical algorithm. All hydrodynamic data used by the ICM model was provided by the CH3D-WES, as obtained from the 1995 study conducted by the COE. The inputs to the CH3D-WES model consisted on field data obtained during a previous study conducted by the COE from June to August, 1995. Recently, the COE conducted an additional run to the model and provided a TP distribution color map which shows the changing TP concentrations during the 90-day sampling period. The COE water quality distribution is in the process of verification with the TP distribution color map developed as part of this study.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Both field sampling and imaging data were collected in several stations within the SJL sampling locations. Total phosphorus concentration was measured for August 8 and November 7, 2005, and for February 24, May 12, and August 14, 2006. The results are shown in Figure 9.

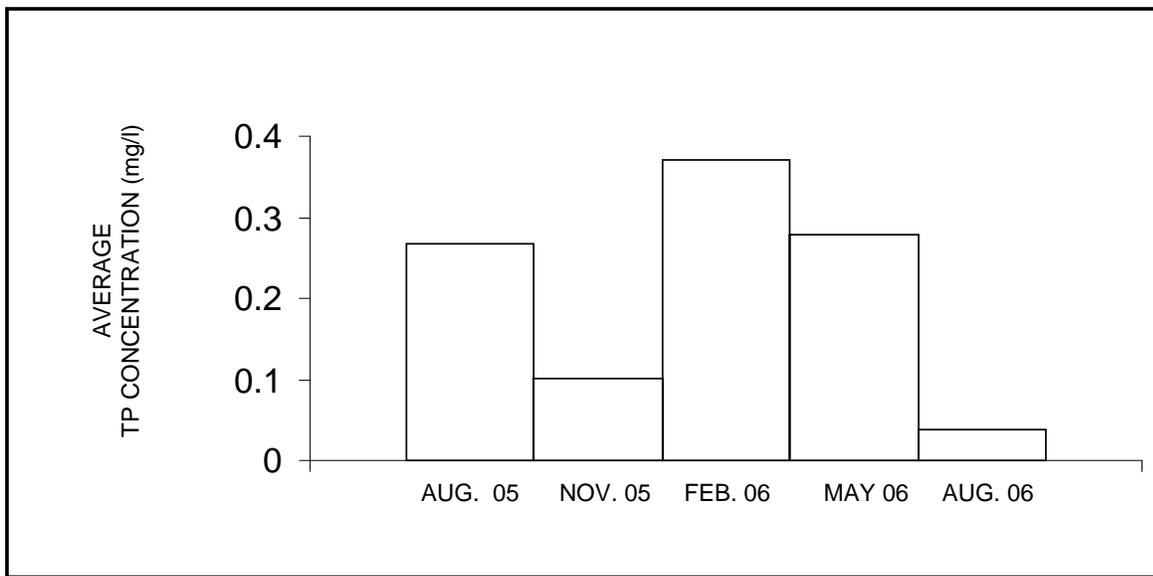


FIGURE 9: MEAN CONCENTRATION OF TOTAL PHOSPHORUS.

Total phosphorus concentrations at all sampled stations were correlated with the reflectance results obtained from the 2006 geo-referenced Hyperion images. No 2005 images were obtained. Individual bands, bands ratio and logarithmic bands ratio were correlated with total phosphorus concentrations for several surveyed stations. The regression analyses were conducted using the statistical least square method by best fitting the data obtained from both the images and the field sampling results. Each one of the regressions developed from the single, band ratios, and log band ratios analyses produced separate empirical algorithms, for the determination of TP, based on the images reflectance characteristics. An algorithm selection criterion was developed based on the combination of higher co-relation coefficients, statistical errors, and uncertainty determination obtained from the different band combinations, and scatter

plots results. The TP results obtained from the images, after the selected algorithm application, were validated against TP *in-situ* samples results. Scatter plots were developed for each band combination where TP concentrations from the images were compared with the TP results obtained from the *in-situ* sampling to verify the adequacy of the algorithm. Regression, validation, and scatter plots results are shown in Figures 10 to 28.

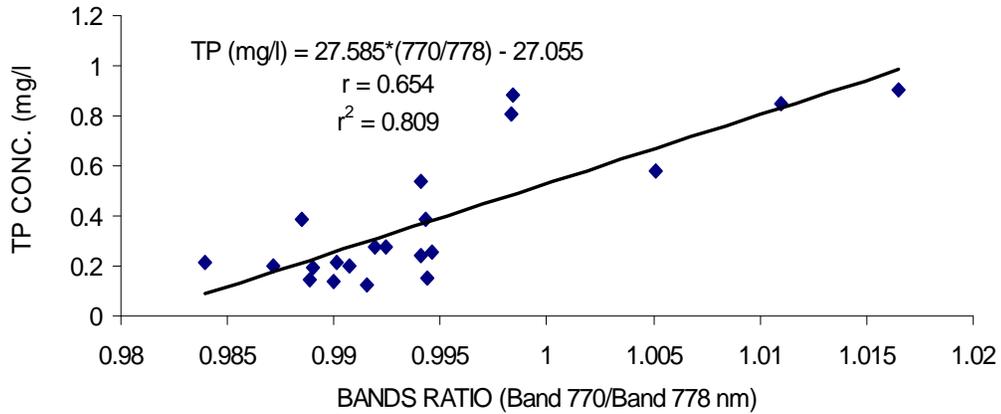


FIGURE 10: GER -1500 SPECTRORADIOMETER VS. TP (LINEAR)

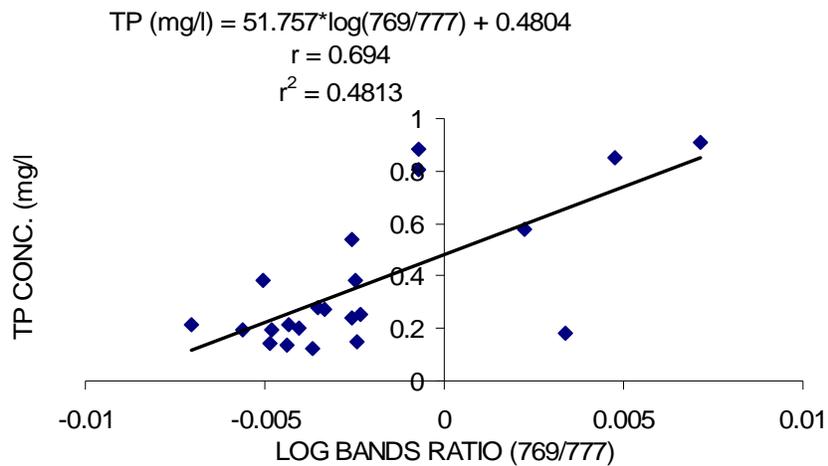


FIGURE 11: GER 1500 SPECTRORADIOMETER VS. TP (FEBRUARY 24, 2006) (LINEAR)

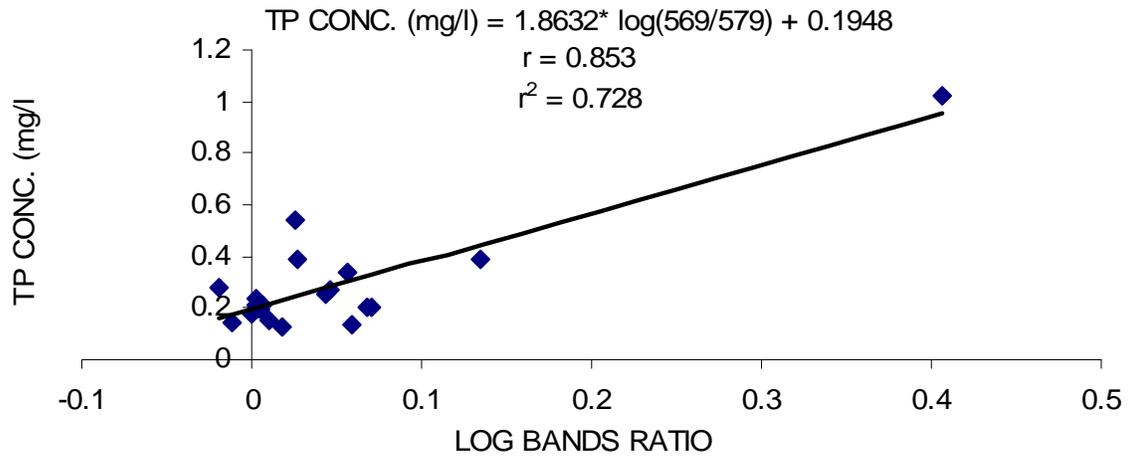
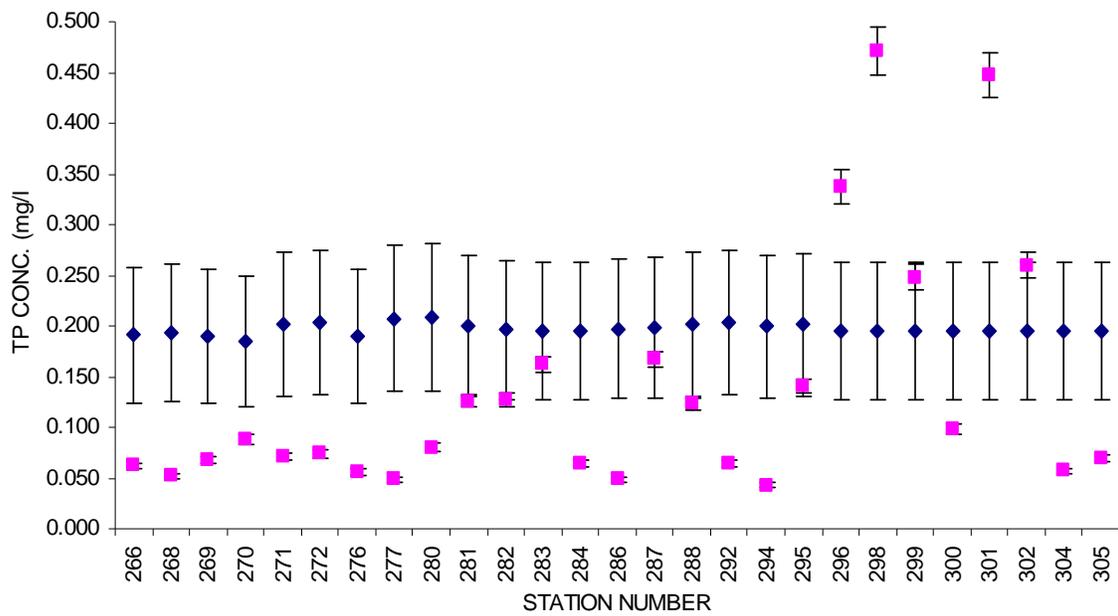


FIGURE 12: HYPERION RELECTANCE VS. TP (FEBRUARY 24, 2006) (LINEAR)



**FIGURE 13: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006) (LINEAR)
 ALGORITHM VALIDATION WITH 5 -12 2006 *IN-SITU* SAMPLES**

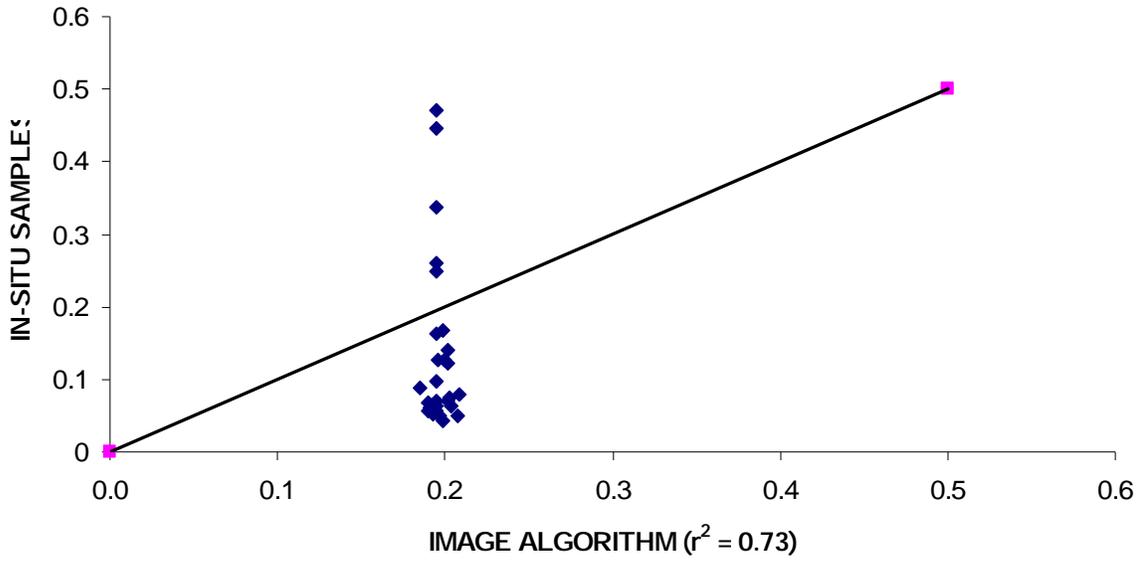


FIGURE 14: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006) (LINEAR) VS. IN SITU SAMPLES (5-12-2006) (log Band 569/log Band 579)

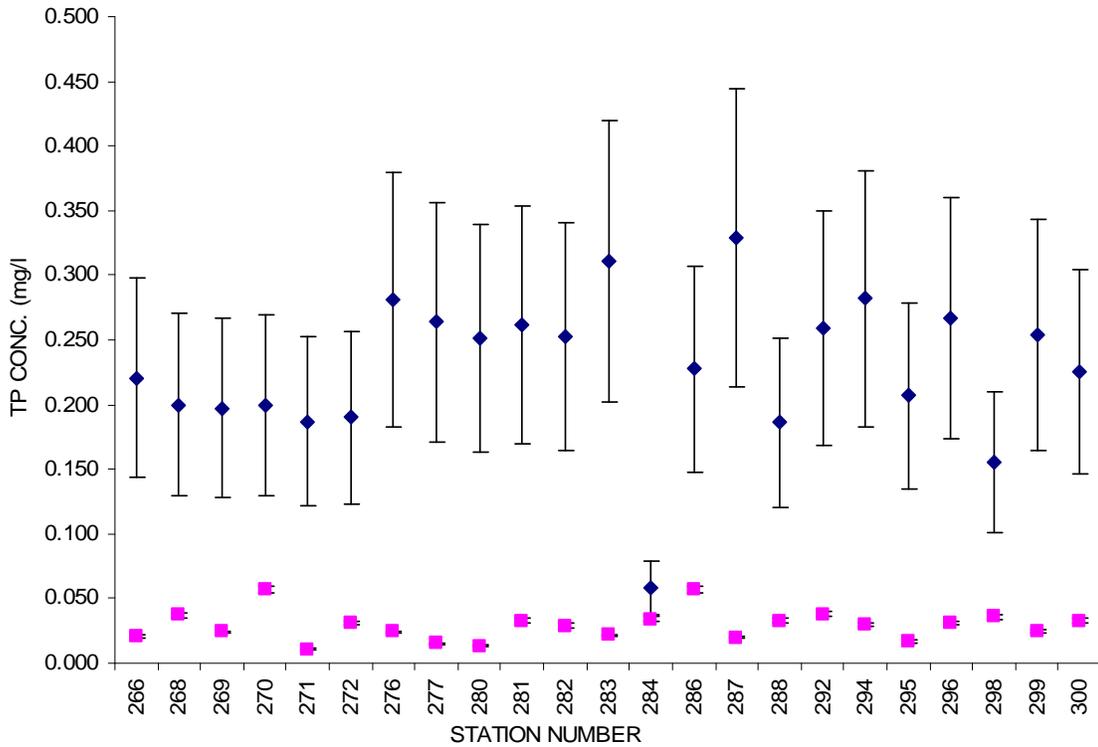


FIGURE 15: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006) (LINEAR) ALGORITHM VALIDATION WITH 8-14-2006 IN-SITU SAMPLES

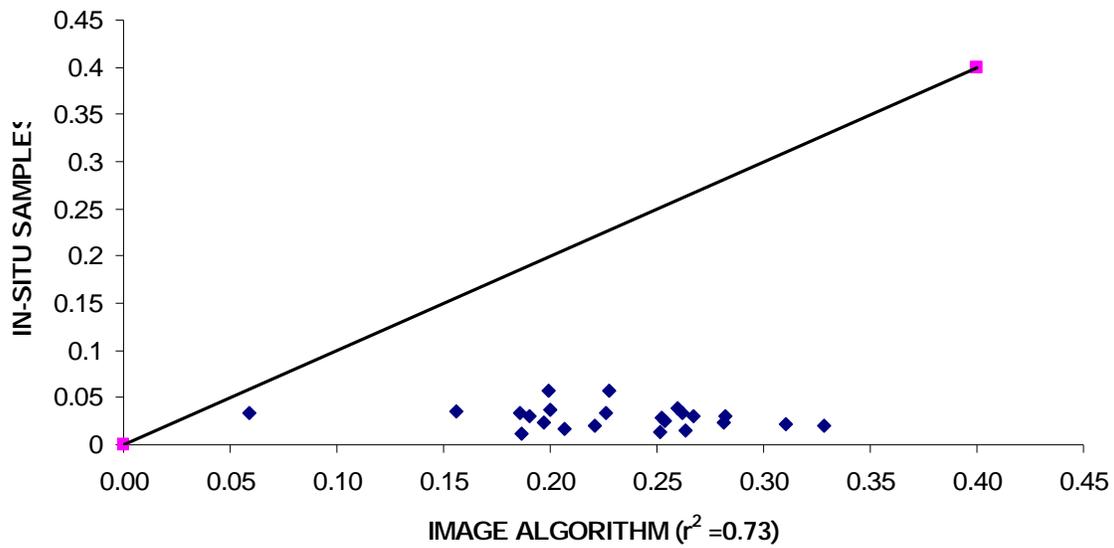


FIGURE 16: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006) (LINEAR) VS. IN SITU SAMPLES (8-14-2006) (log Band 569/log Band 579)

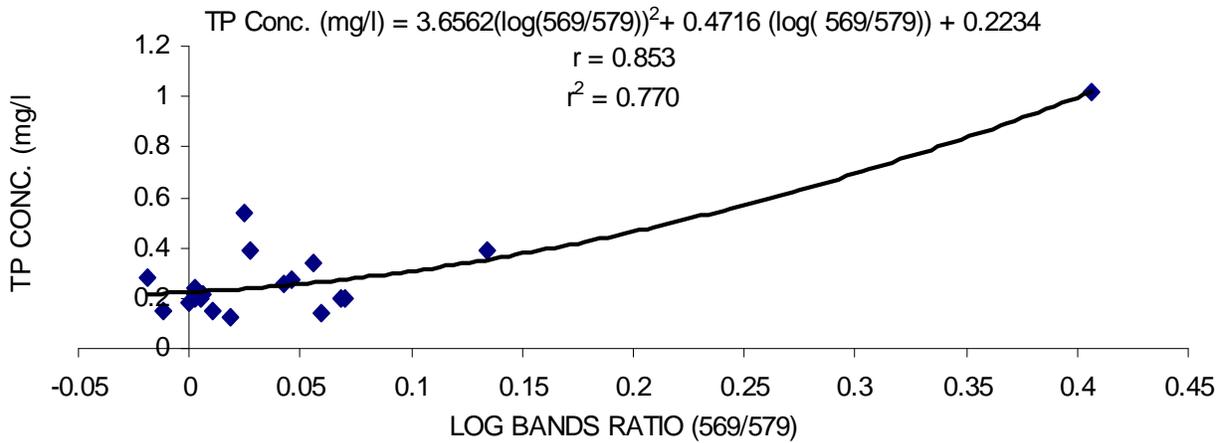


FIGURE 17: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006) (POLYNOMIAL)

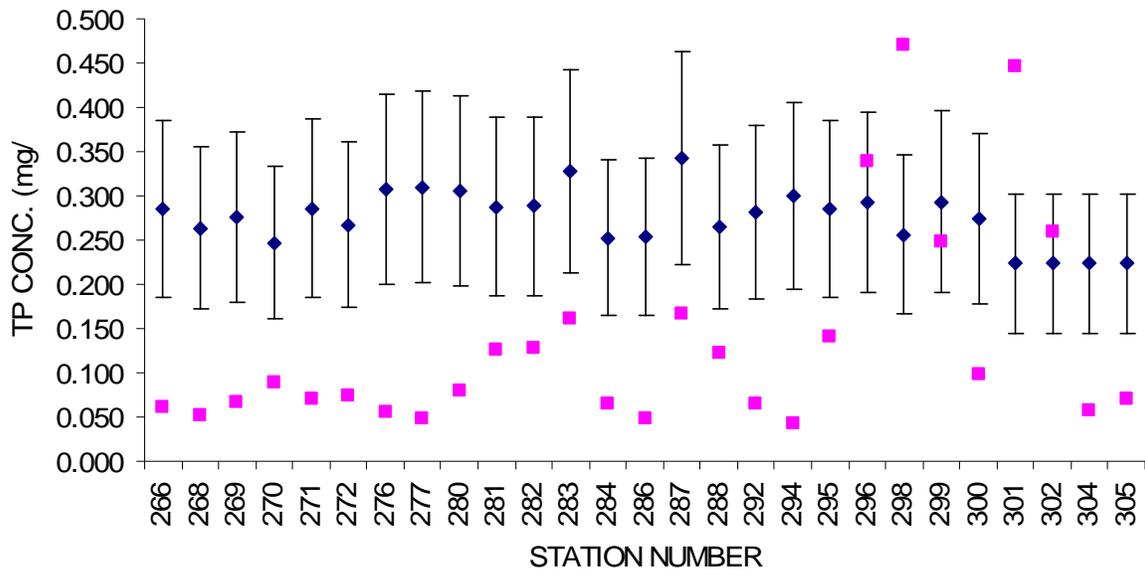


FIGURE 18: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006) (POLYNOMIAL) ALGORITHM VALIDATION WITH 5-12-2006 *IN-SITU* SAMPLES

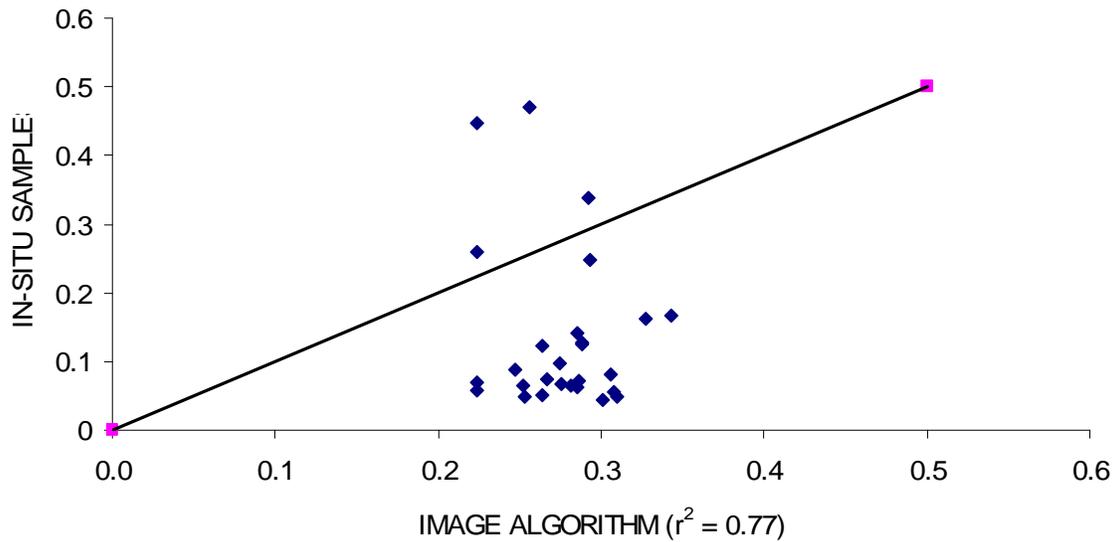


FIGURE 19: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006) (POLYNOMIAL) VS. IN SITU SAMPLES (5-12-2006) (log Band 569/log Band 579)

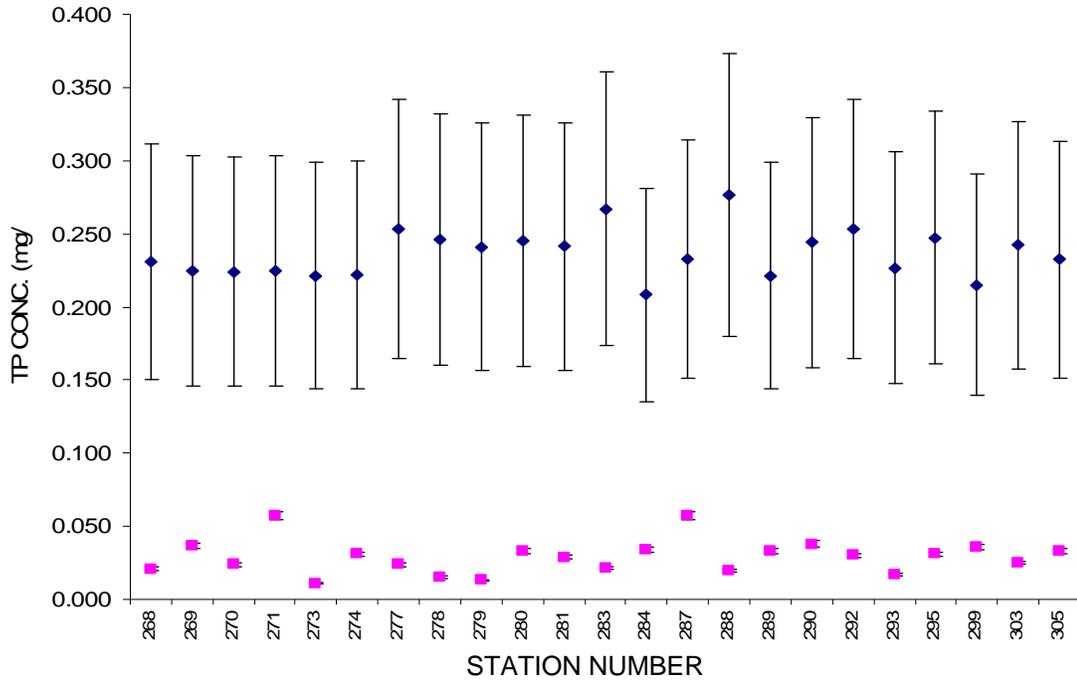


FIGURE 20: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006) (POLYNOMIAL) ALGORITHM VALIDATION WITH 8-14-2006 *IN-SITU* SAMPLES

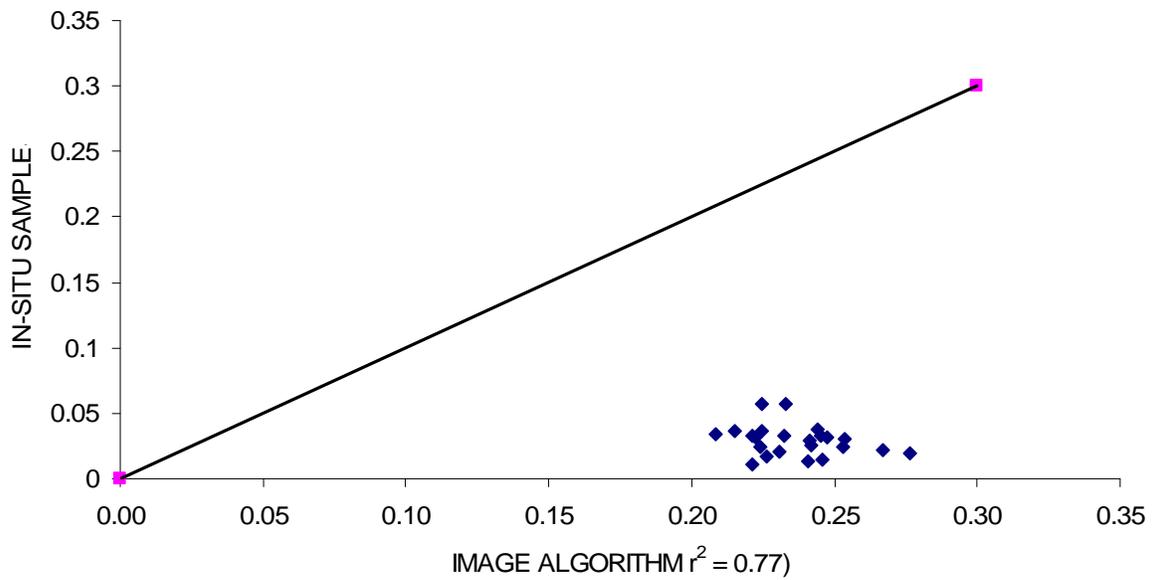


FIGURE 21: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006) (POLYNOMIAL) VS. IN SITU SAMPLES (8-14-2006) (log Band 569/log Band 579)

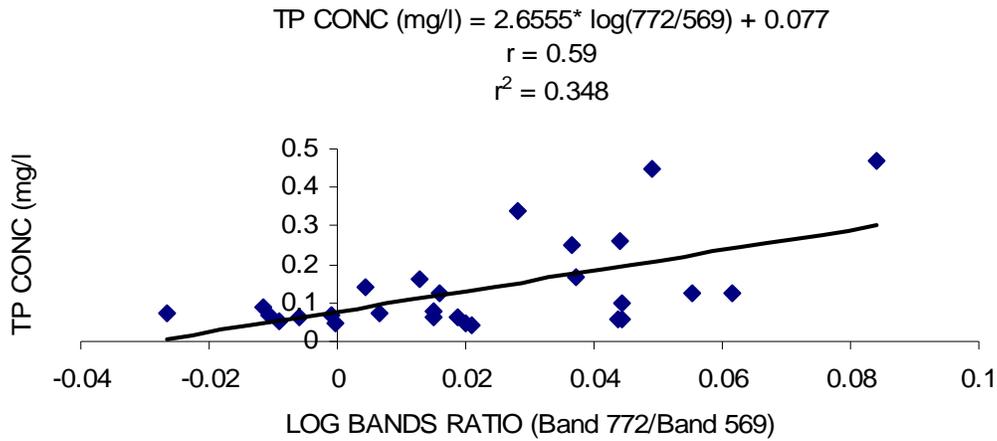


FIGURE 22: HYPERION REFLECTANCE VS. TP (MAY 12, 2006)

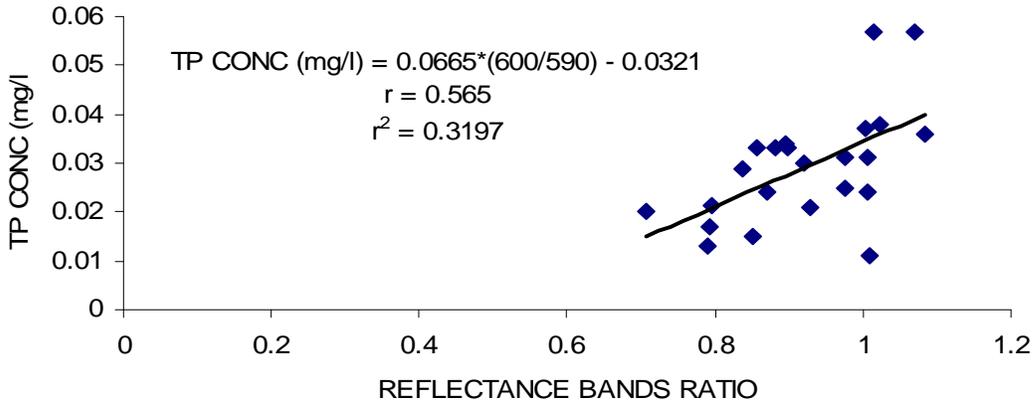


FIGURE 23: HYPERION REFLECTANCE VS. TP (AUGUST 14, 2006)

No validation was completed for the May 12, 2006 and August 14, 2006 individual bands due to their low co-relation coefficient as compared to other bands and band combination regression analyses.

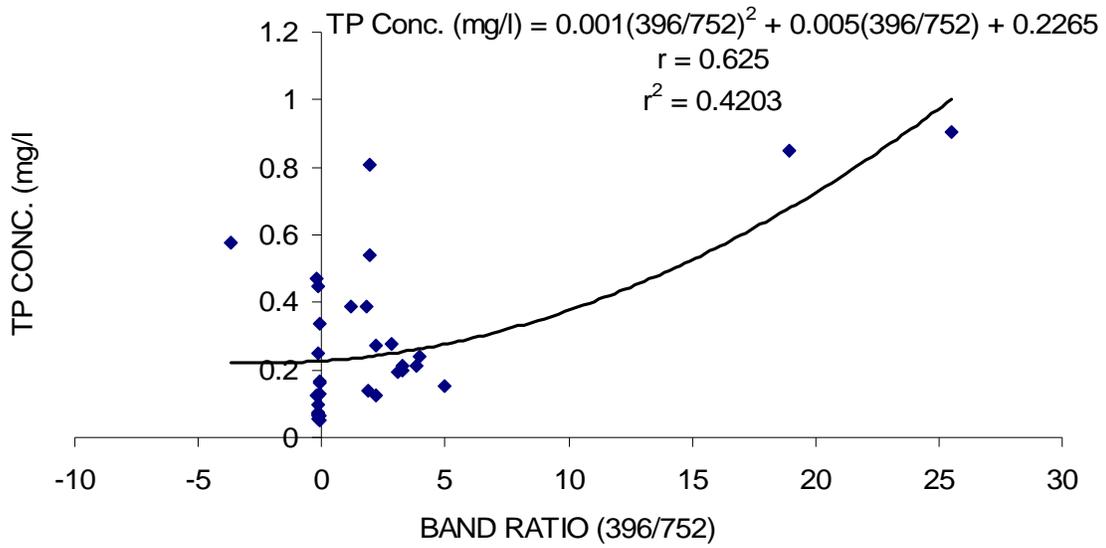


FIGURE 24: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND MAY 12, 2006)

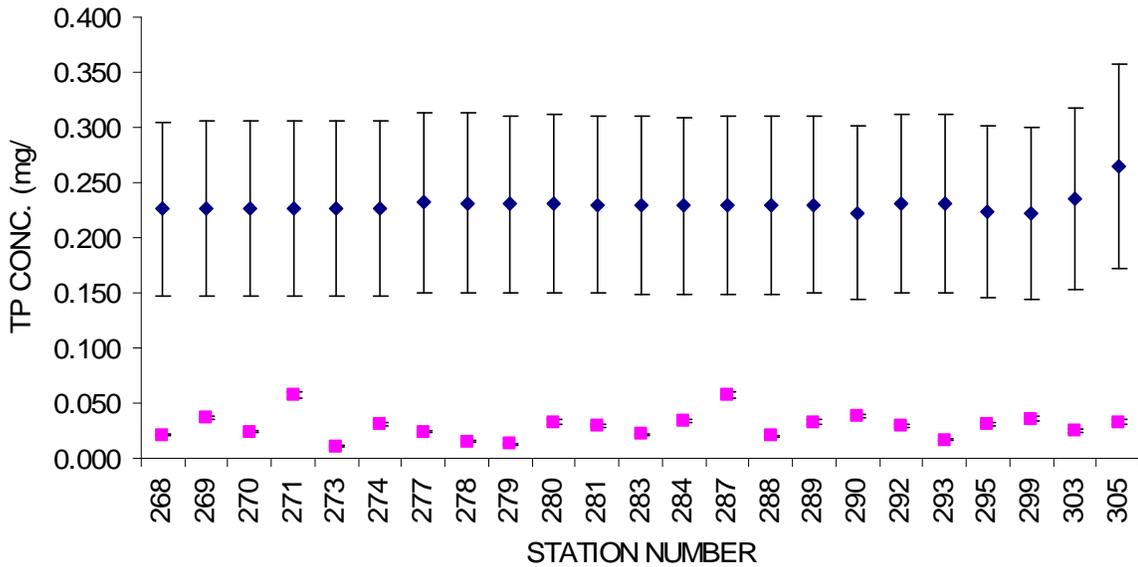


FIGURE 25: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND MAY 12, 2006) ALGORITHM VALIDATION WITH 8-14-2006 *IN-SITU* SAMPLES

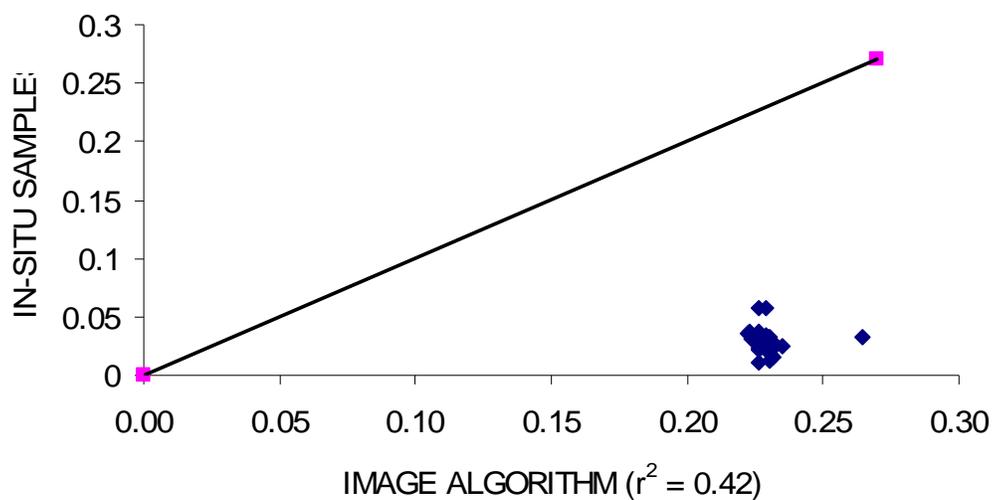


FIGURE 26: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006 and 5-12-2006) VS. IN SITU SAMPLES (8-14-2006) (Band 396/Band 752)

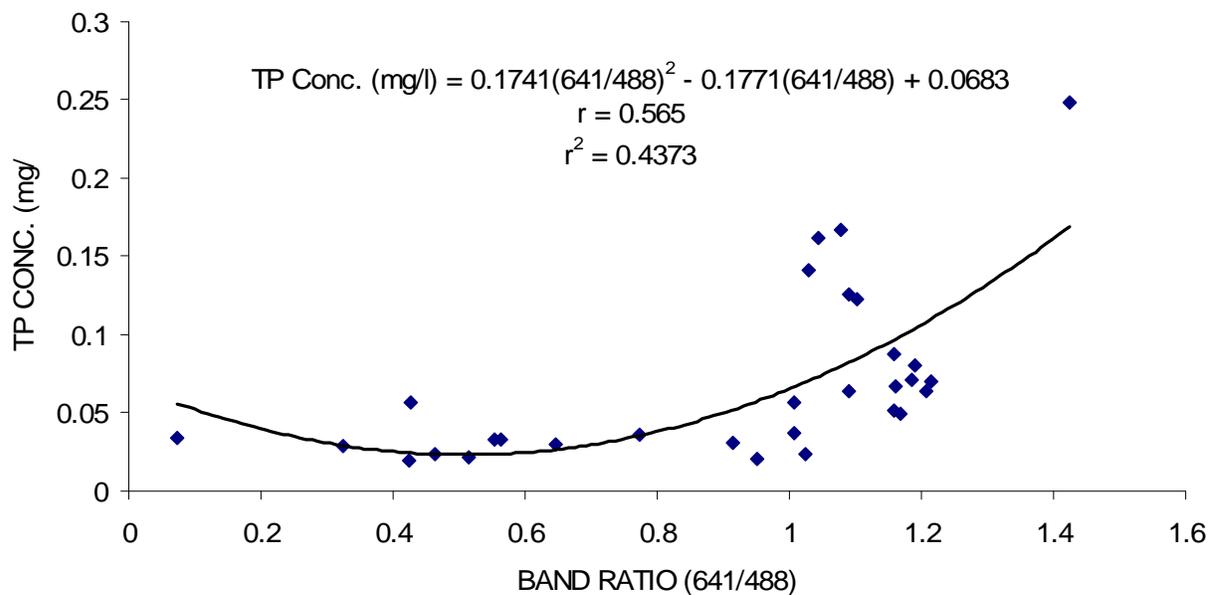


FIGURE 27: HYPERION REFLECTANCE VS. TP (MAY 12, 2006 AND AUGUST 14, 2006)

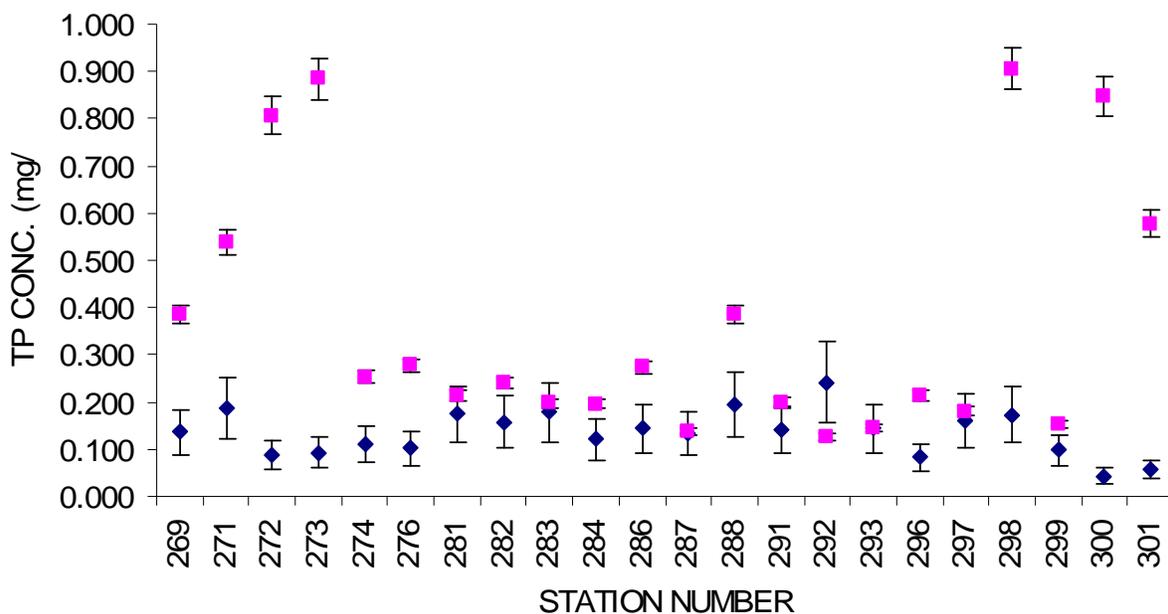


FIGURE 28: HYPERION REFLECTANCE VS. TP (MAY 12, 2006 AND AUGUST 14, 2006) ALGORITHM VALIDATION WITH 2-24-2006 *IN-SITU* SAMPLES

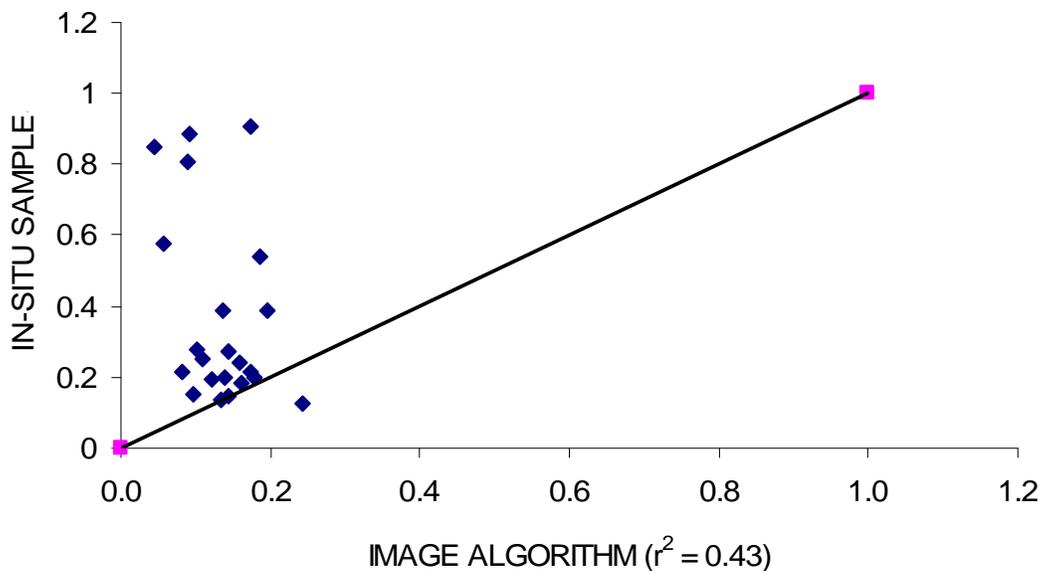


FIGURE 29: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (5-12-2006 and 8-24-2006) VS. IN SITU SAMPLES (2-24-2006) (Band 641/Band 488)

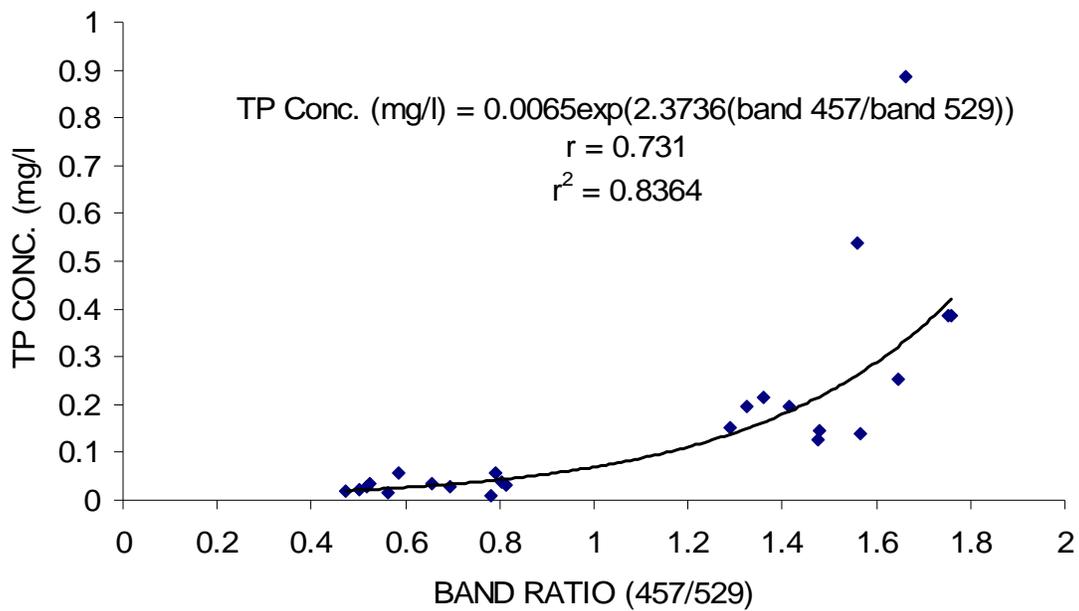


FIGURE 30: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) (Band 457/Band529)

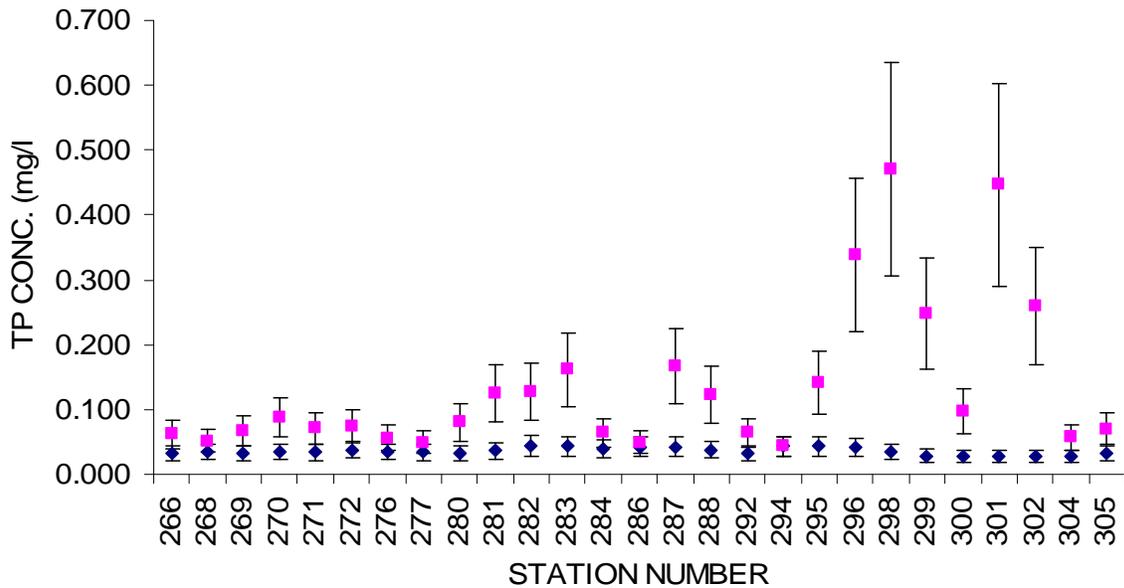


FIGURE 31: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) ALGORITHM VALIDATION WITH 5-12- 2006 *IN-SITU* SAMPLES (Band 457/Band 529)

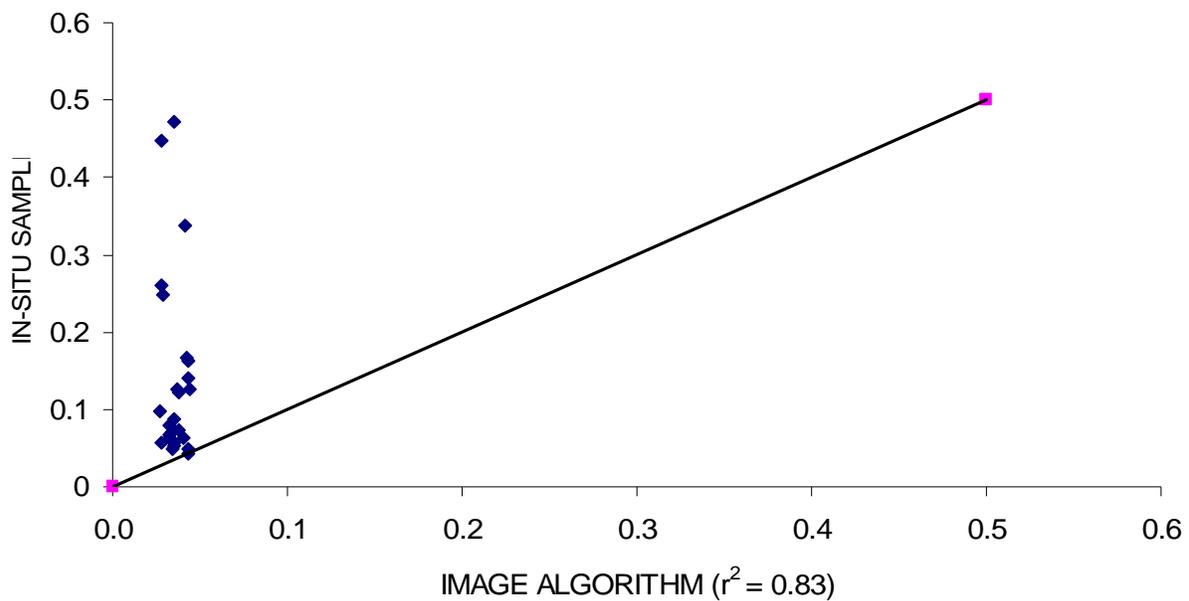


FIGURE 32: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006 and 8-24-2006) VS. IN SITU SAMPLES (5-12-2006) (Band 457/Band 529)

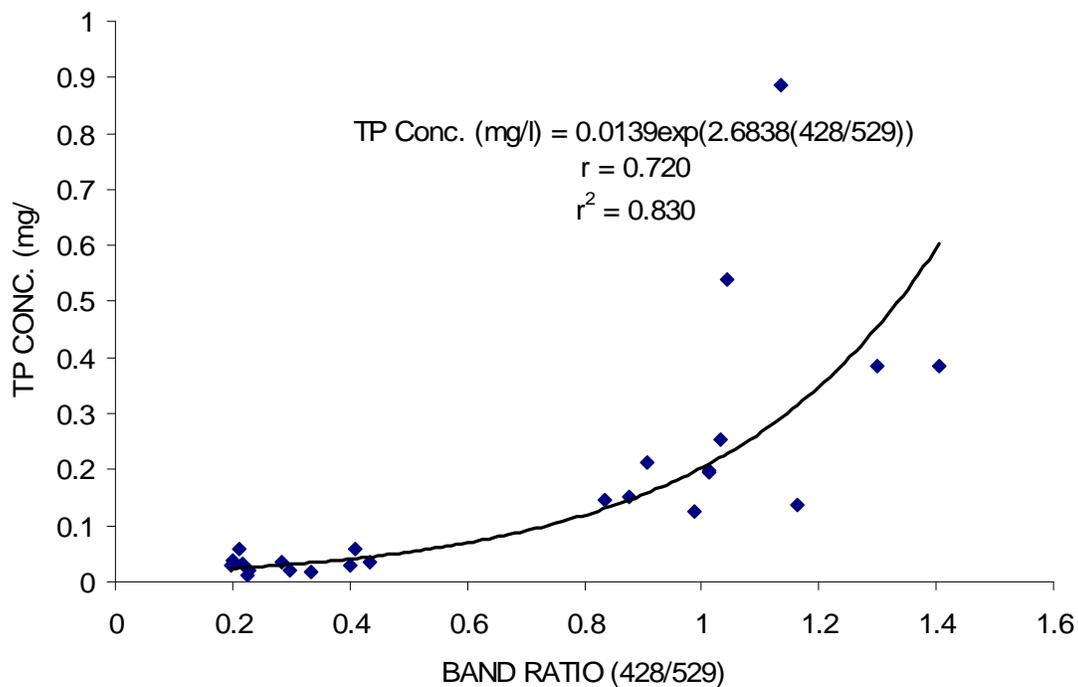


FIGURE 33: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) (Band 428/Band529)

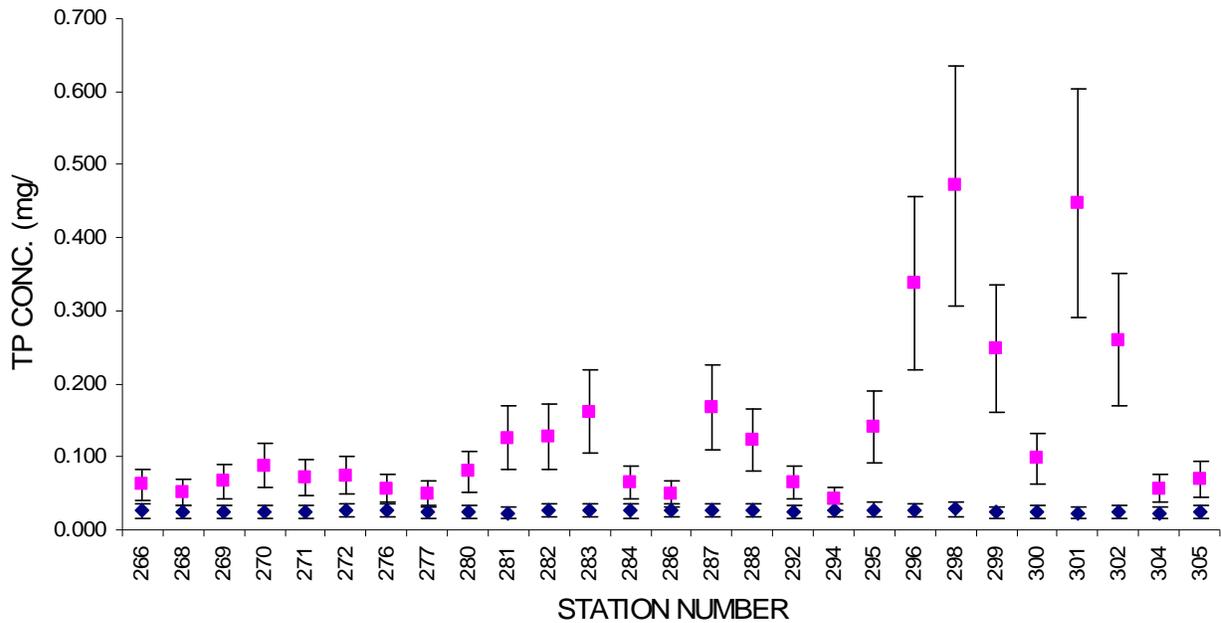


FIGURE 34: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) ALGORITHM VALIDATION WITH 5-12- 2006 *IN-SITU* SAMPLES (Band 428/Band 529)

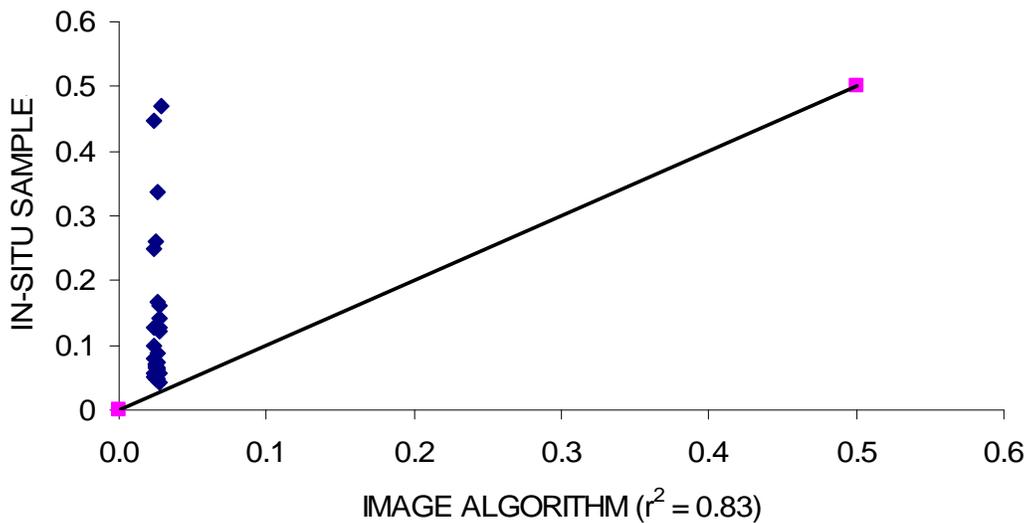


FIGURE 35: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006 and 8-24-2006) VS. IN SITU SAMPLES (5-12-2006) (Band 428/Band 529)

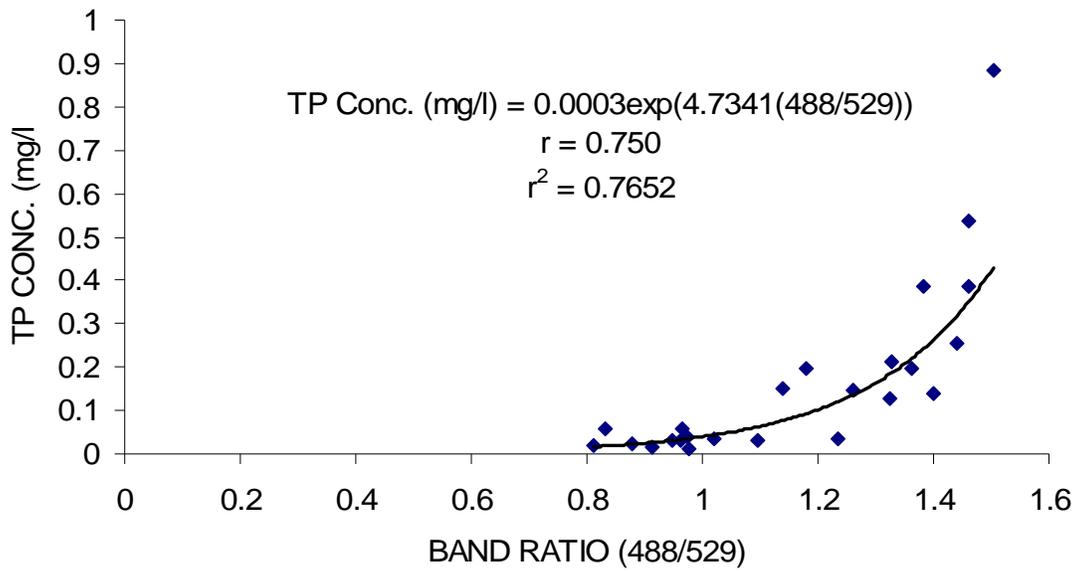


FIGURE 36: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) (Band 488/Band 529)

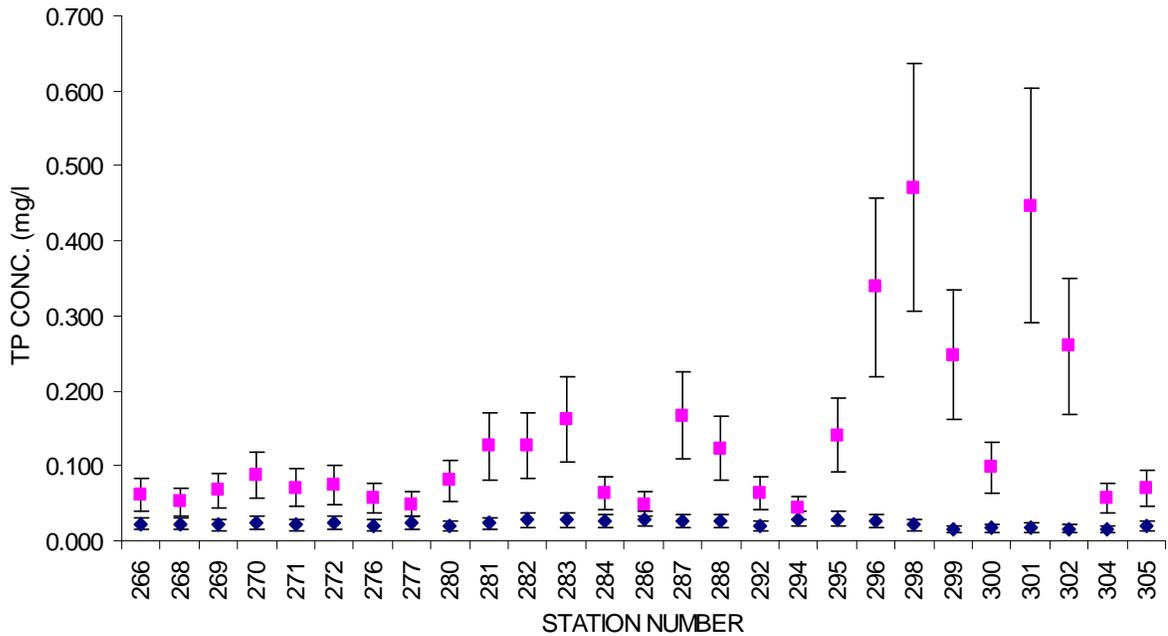


FIGURE 37: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) ALGORITHM VALIDATION WITH 5-12- 2006 *IN-SITU* SAMPLES (Band 488/529)

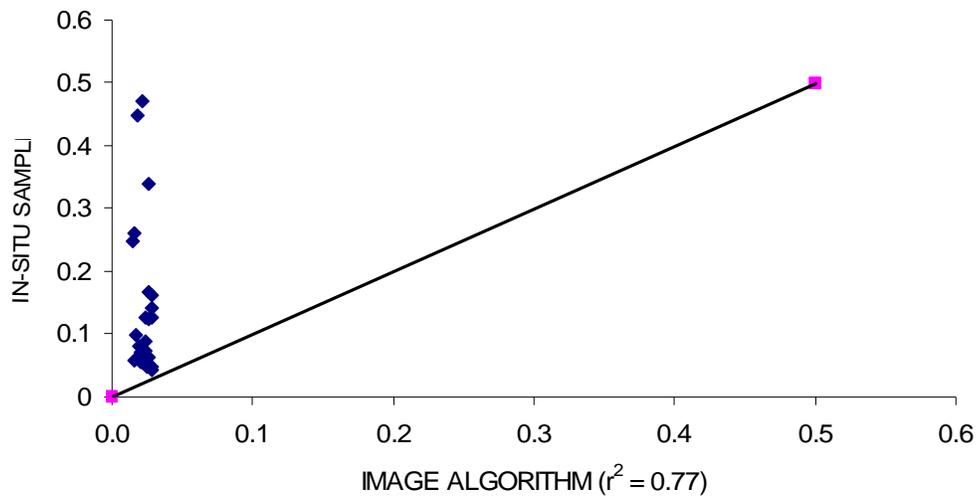


FIGURE 38: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM (2-24-2006 and 8-24-2006) VS. IN SITU SAMPLES (5-12-2006) (Band 488/Band 529)

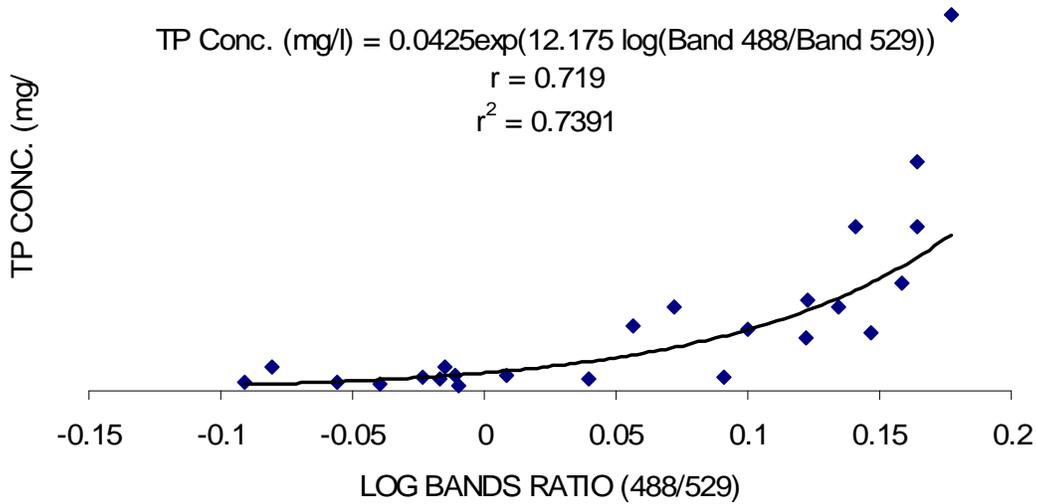


FIGURE 39: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) (log Band 488/log Band 529)

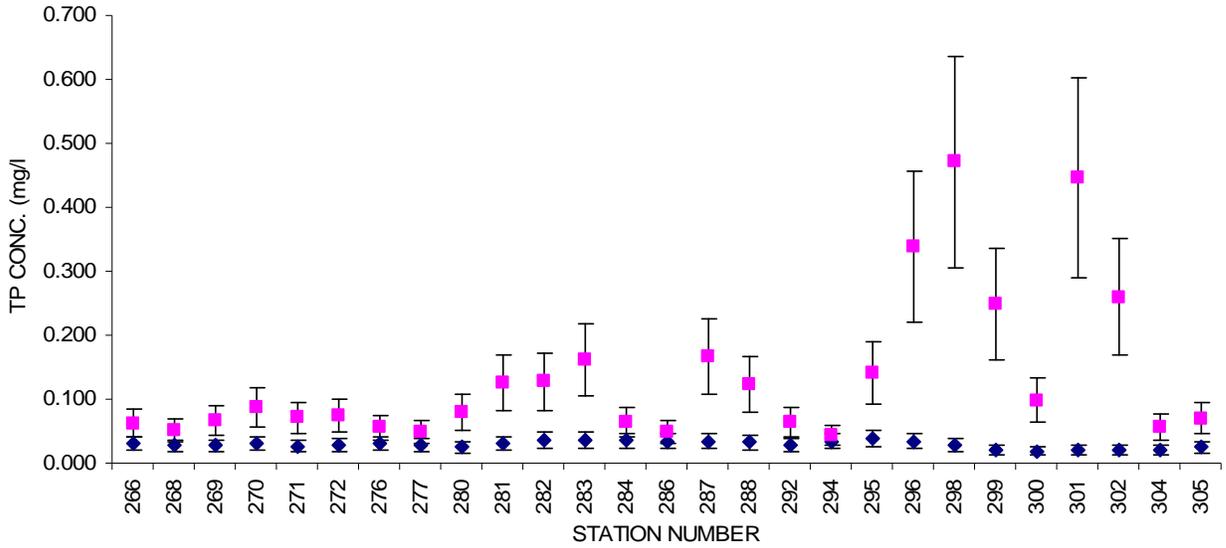


FIGURE 40: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) ALGORITHM VALIDATION WITH 5-12- 2006 *IN-SITU* SAMPLES (log Band 488/log Band 529)

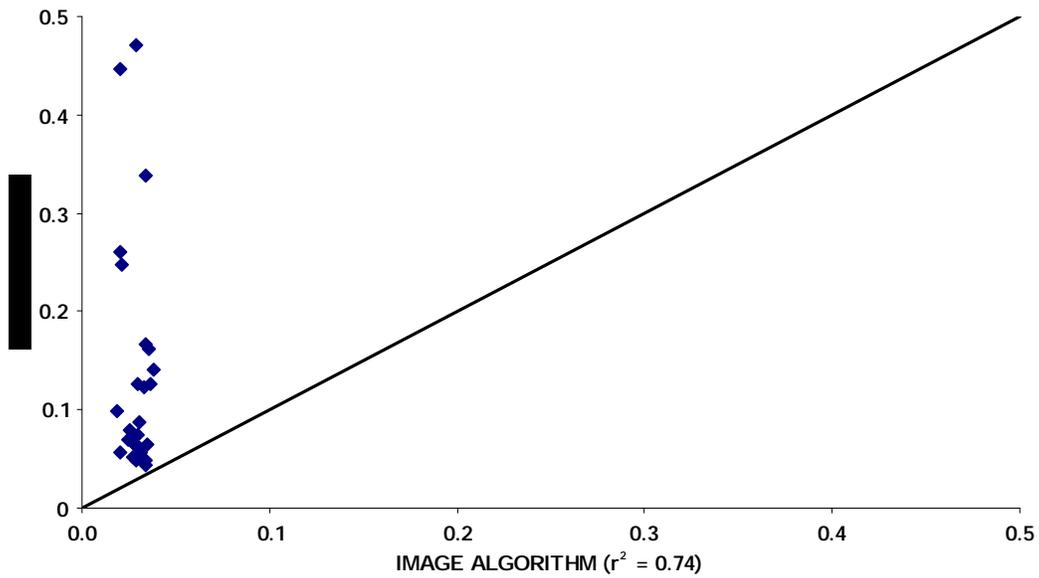


FIGURE 41: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM VS. IN SITU SAMPLES (log Band 488/log Band 529)

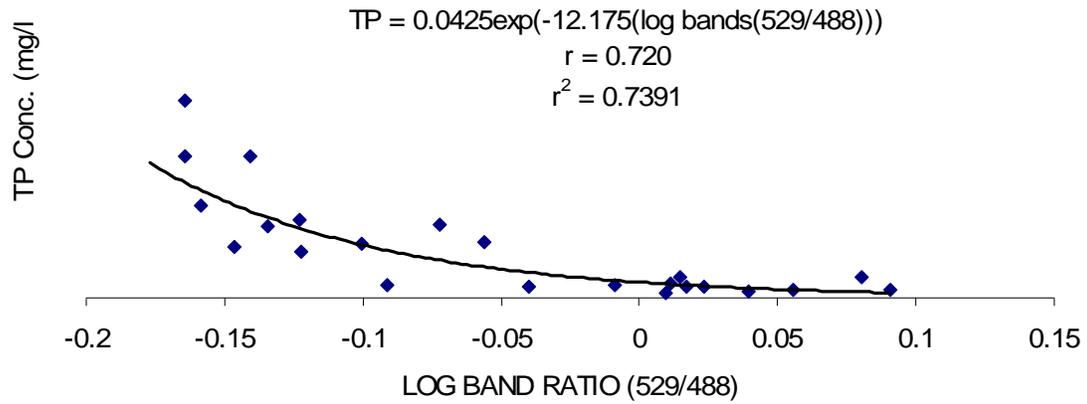


FIGURE 42: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) (log Band 529/log Band 488)

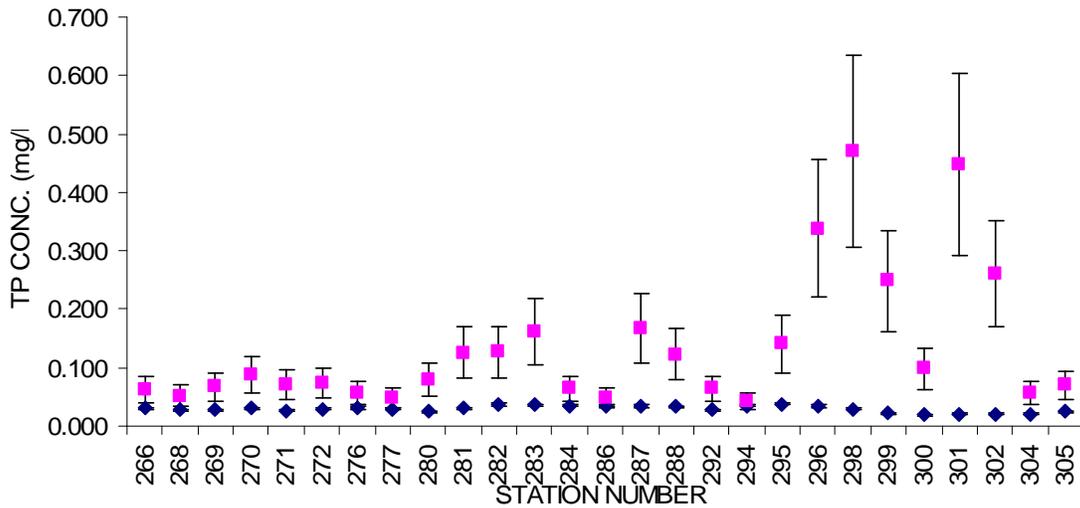


FIGURE 43: HYPERION REFLECTANCE VS. TP (FEBRUARY 24, 2006 AND AUGUST 14, 2006) ALGORITHM VALIDATION WITH 5-12- 2006 *IN-SITU* SAMPLES (log Band 529/log Band 488)

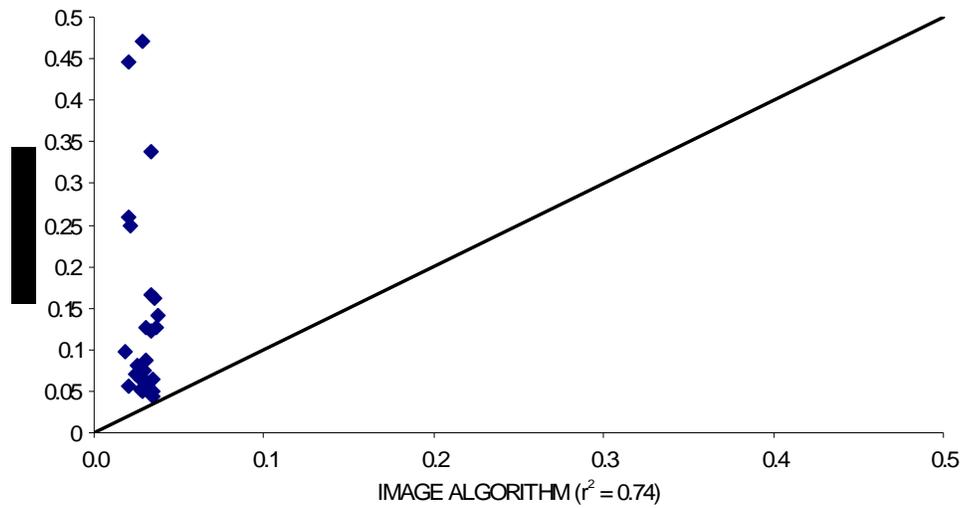


FIGURE 44: SCATTER PLOT FOR TP CONCENTRATION IMAGE ALGORITHM VS. IN SITU SAMPLES (log Band 529/log Band 488)

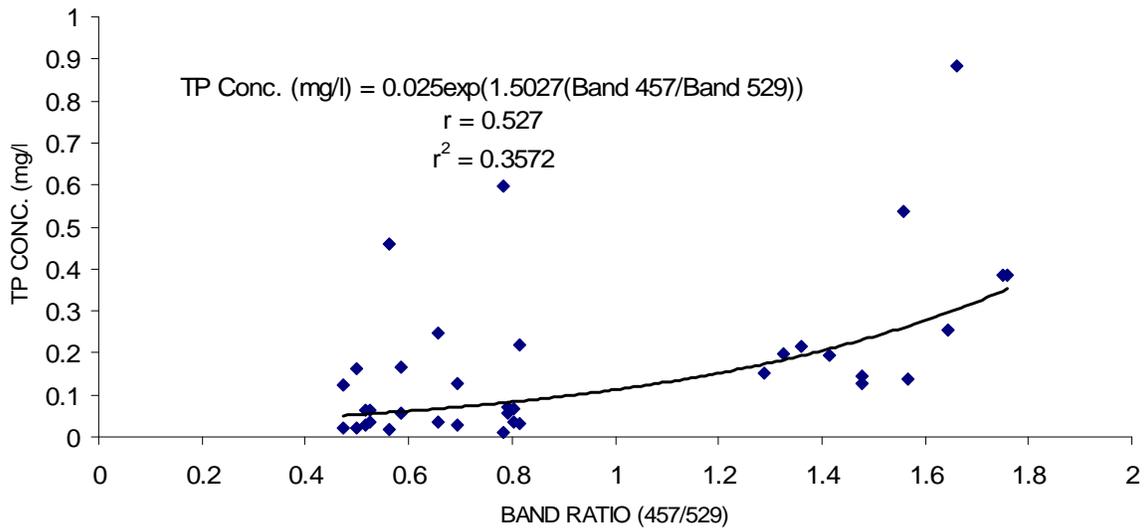


FIGURE 45: HYPERION REFLECTANCE VS. TP CONCENTRATIONS (FEBRUARY 24, MAY 12, AND AUGUST 14, 2006) (Band 457/Band 529)

Table 1 shows the estimated statistical errors for individual bands and combinations producing the higher co-relations.

TABLE 1- STATISTICAL ERRORS

REGRESSION ANALYSES	BAND COMB.	ME	RE (%)	AME	RMS	VARIANCE
2/24/2006- Algorithm with 5/12/2006 (Linear)	770/778	-0.913	4.06	0.913	0.949	0.246
2/24/2006- Algorithm with 5/12/2006 (Linear)	LOG (569/579)	-0.062	1.68	0.017	0.132	0.008
2/24/2006- Algorithm with 5/12/2006 (Polynomial)	LOG (569/579)	-0.170	25.40	0.170	0.209	0.012
2/24/2006 and 5/12/2006- Algorithm with 8/14/2006 (Polynomial)	396/752	-0.171	25.52	0.171	0.186	0.01
5/12/2006 and 8/14/2006- Algorithm with 2/24/2006 (Polynomial)	641/488	0.192	2.46	0.201	0.366	0.05
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	428/529	0.110	2.47	0.110	0.160	0.01
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	457/529	0.110	2.73	0.110	0.154	0.009
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	488/529	0.113	3.08	0.113	0.162	0.01
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	LOG (488/529)	0.106	1.03	0.106	0.158	0.01
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	LOG (529/488)	0.106	2.91	0.106	0.158	0.01

where:

ME = Mean error

AME = Absolute Mean Error

RMS = Root Mean Square Error

RE = Relative Error

Table 2 shows the uncertainty analyses, estimated by the safety margin method, also completed for individual bands and combinations.

TABLE 2- UNCERTAINTY ANALYSIS

REGRESSION ANALYSES	BAND COMB.	μ_{SM}	COV	σ_{SM}^2	σ_{SM}	α	CERT. PROB.
2/24/2006- Algorithm with 5/12/2006 (Linear)	LOG (569/579)	0.054	0.00002	0.014	0.118	0.462	0.6771
2/24/2006 and 5/12/2006- Algorithm with 8/14/2006 (Polynomial)	396/752	-0198	-0.00467	0.023	0.152	-1.30	0.097
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	428/529	0.054	0.00002	0.014	0.118	0.462	0.6771
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	457/529	0.045	-0.00009	0.014	0.119	0.38	0.6509
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	488/529	0.057	-0.000095	0.014	0.119	0.48	0.6843
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	LOG (488/529)	0.051	-0.000109	0.014	0.119	0.42	0.6626
2/24/2006 and 8/14/2006- Algorithm with 5/12/2006 (Exponential)	LOG (529/488)	0.051	-0.000109	0.014	0.119	0.42	0.6626

where:

CERT. PROB. = certainty probability

μ = mean value of x_i and y_i

μ_{sm} = mean value safety and margin

σ_{SM} = standard deviation safety and margin

σ_{SM}^2 = variance of x_i and y_i safety and margin

Cov = covariance of random variables

Based on the above evaluations, the selected algorithm corresponded to the log bands ratio vs. total phosphorus concentration for the February 24, 2006 and August 14, 2006 combined reflectance data and validated with the May 12, 2006 TP *in-situ* samples results. That data showed a correlation coefficient of 0.74. The exponential model is defined by the following empirical algorithm:

$$\text{TP Concentration (mg/l)} = 0.0425 * \exp(12.175 * \log(\text{Band 488} / \text{Band 529}))$$

The reflectance values of the Hyperion image collected during February 24, May 12, and August 14, 2006 were changed to total phosphorus concentration by applying the above algorithm, which resulted in three new images. The resulting images are shown as Figures 29, 30, and 31.

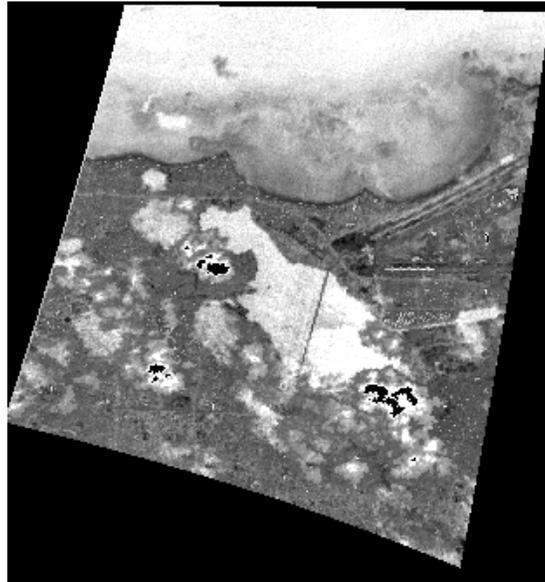


Figure 29
February 24, 2006

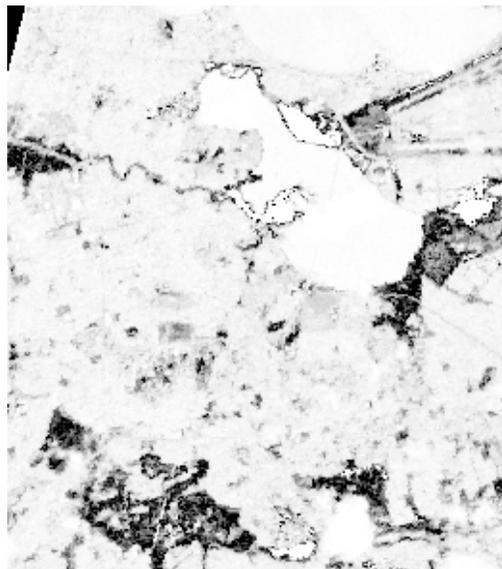


Figure 30
May 12, 2006



Figure 30
August 14, 2006

The results of this study show that hyperspectral remote sensing technology is of significant potential use for the water quality management of such impaired surface waters. The following conclusions are emphasized.

- Based on the image results the SJL is heavily polluted with TP where the water quality standard is exceeded in at least five times its maximum value of 0.1 parts per million.
- Hyperspectral remote sensing is an economically feasible tool for the monitoring of total phosphorus in a eutrophic tropical lagoon.
- The FLAASH atmospheric correction algorithm better adapts to the Hyperion image processing than ACORN when evaluating eutrophic water systems.
- The 1995 COE's calibrated hydrodynamic model shows TP results consistent with the February 24, 2006 Hyperion image, after transformed with the empirical algorithm. This is evidenced by the similar results shown by the model and Hyperion where significantly higher TP concentrations (over 0.5 parts per million) are produced within the dredged pits locations and at the Martín Peña inlet to the lagoon. Based on these results it can be inferred that:
 - No significant changes have occurred to Caño Martín Pena or Suárez Channel in the intervening years. This means that the flows in/out of the San José Lagoon are essentially the same in 2006 as 1995.
 - No significant changes in watershed directly contributing to the SJL. It was a fully developed watershed in 1995. The infrastructure is essentially unchanged in the watershed so the volume of and loads in the runoff are comparable.
 - Hydrodynamic and water quality information had been already been observed for 1995. It is unlikely to find as extensive a water quality data set in other years as compared to 1995. Any uncertainty induced using an incomplete data set for another year is as large, or larger than the uncertainty induced comparing 2006 and 1995.
 - No significant changes to the bathymetry of the lagoon, (i.e., no significant dredging or filling). This means that the hydraulic

residence time is "unchanged" and the sediment/water column processes associated with the existing dredge holes are unchanged.

- The correlation analysis completed between the spectral characteristics obtained and the TP suggests the possibility of accurately mapping the TP concentration in a surface water system.
- Log band ratios provide stronger co-relations between Hyperion reflectance values and TP concentrations (within the 428-529 nm range of the visible region of the spectrum) in eutrophic water systems.
- Band ratios provide better co-relations between field spectrometer reflectance results and TP concentrations (within the 770-780 nm range within the near infra-red region of the spectrum) in eutrophic water systems.

The following recommendation should be considered for further studies and research:

- The use of hyperspectral remote sensing technology may be a useful to establish and implement TP as point and non-point source pollution control strategies (i.e., Total Maximum Daily Loads, Waste Load Allocations, Assimilative Capacity Studies) in eutrophic surface waters and watersheds. Its use in larger surface water systems may be centered on the calibration and validation of water quality models based on the TP spectral characteristics.

Some of the limitations of the hyperspectral remote sensing technology applicability in the SJL may be summarized as follows:

- While the Hyperion high spectral resolution is responsible for the definition of the TP reflectance characteristics its applicability to smaller surface water systems may not result to be the best alternative due to its lower spatial accuracy.
- The use of remote sensing in shallow turbid waters requires additional spectral corrections, through modeling, due to the reflectance misleading effect caused by the bottom.
- The Hyperion's low signal-to-noise ratio in several spectral bands provides for its low reflectance responsiveness producing negative reflectance values in the blue (400-500 nm) and infrared (800-1200 nm) regions.

OPEN PIT QUARRY RESTORATION TO BIO-VIABLE LAND

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2. Hwang S., Z. Escobar, V. Hernandez, I. Latorre, I. Hernandez, A. Fonseca, A. Del Moral, 2008. "Environmental Engineering Applications of Coal Combustion Byproducts Aggregates", presentation at 2008 International Conference on Environmental Science and Technology (ICEST), Houston, TX, Jul 28-31, 2008.
3. Hwang, Sangchul. 2008, Open Pit Quarry Restoration to Bio-Viable Land, Puerto Rico Water Resources and Environmental Institute, University of Puerto Rico, Mayaguez, PR, 2nd Progress Report, 20 Pages.
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5. Hwang, Sangchul. 2009, Open Pit Quarry Restoration to Bio-Viable Land, Puerto Rico Water Resources and Environmental Institute, University of Puerto Rico, Mayaguez, PR, 4th Progress Report, 39 Pages.
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Final Report

Open Pit Quarry Restoration to Bio-Viable Land

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Problem Statement

As the magnitude of civil, transportation and construction infrastructure has expanded since the industrial revolution, demands for construction-grade sand and gravel has subsequently increased. These raw materials are heavily being exploited in PR today and used for concrete, general fill, and road subgrade material, bridges, airports, road surfacing, and aqueduct and sewer systems. Resulting open pit, in turn, may adversely affect health and safety of human beings if not appropriately managed or restored (MDNR, 1992).

As shown in Figure 1, the site of interest is located in Santa Isabel, PR. Gravel mining has been operated by a private mining company since 1985. Its maximum extraction of the aggregates reached at 2,000 m³/day. However, its operation ceased in October 2006 resulting in approximately 420 cuerdas (~420 Acre) of the open pits at the site. Old sites have been restored to the agricultural areas with Mango trees. Organic sediment materials for the backfilling have been transported from the Coamo Lake nearby the site. Most land areas surrounding the site are being used for the agricultural purposes.

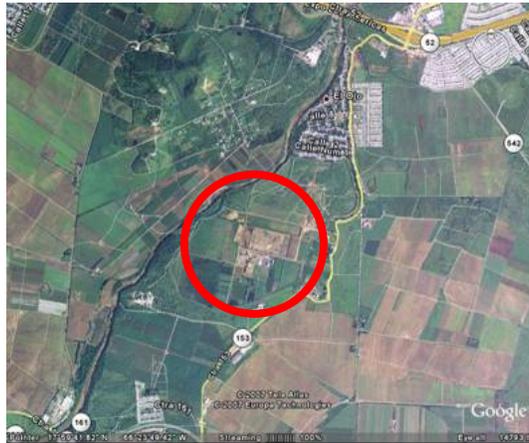


Figure 1. The location of the gravel mining site in Santa Isabel, PR.

Research Objectives

The main goal of this study is to investigate the feasibility of coal combustion ash aggregates (CAA)-based refill for the open pits in Santa Isabel. The site is planned to be used as an agricultural land after restoration. Therefore, this study aims to assess the potential risks in relation to contamination of soil and groundwater associated with the use of industrial byproducts CAAs. Another objective is to evaluate bio-viability on the land after restoration. To meet this end, laboratory feasibility tests and computational modeling were initially proposed to perform for the period of 2 years.

Methodology

Materials

The open pit site was filled with the dredged sandy sediments from the Guayama bay on the bottom at a depth of 0.3 m. As the site will be eventually used as an agricultural area, an organic-rich

soil from the Coamo Lake will be used as a top soil at a depth of 1 m. In these regards, two soils were sampled on site as shown in **Photo 1**. After being transported, the soil samples passed a sieve size 3/8" were collected for the experiment.



Photo 1. Soil Sampling on site.

Coal ash aggregates were obtained from a local coal burning power plant in Guayama, PR. It is a solidified mixture of fly and bottom ashes with water. Main chemical components, by weight, are: 51% of ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$), 30% Lime (CaO), and 15% SO_3 (Pando and Hwang, 2006). The CAAs were first oven dried at 105°C overnight, crushed with a mechanical mixer, and sieved to collect the CAA sizes of 2.36 ~ 9.53 mm (**Photo 2**).



Photo 2. Coal ash aggregates before (left) and after (right) preparation for the experiment,

Experimental Methods

Water Quality Assessment

3-Factor, 2-Level Statistical Design and Analysis

As shown in **Figure 2**, initial focus was given to the volume of CAAs that can be utilized as a substitute subsoil material. For this, as shown in **Photo 3**, PVC column reactors (3-in dia. and 30-in long) were designed, performed, and analyzed by a statistical design with three factors containing two levels each for the assessment of the unsaturated-zone fate and transport phenomena (**Table 1**).

The volumetric ratio of the CAAs to the organic top soil is a treatment factor with two levels of 8:4 and 4:8, which was the ratio of the depth of the top soil to the CAAs. Simulated precipitation was made three times a week by spraying tap water on the top of the reactors. Precipitation rates are another treatment factor with two different levels: high rainfall 60 mL each application, low rainfall 30 mL each application. Two rainfall amounts were calculated according to the actual maximum and minimum average precipitation in Santa Isabel. Half of the reactors were assigned to the smaller particle sizes (2.36 ~ 4.75 mm) of CAAs and the remainder to the greater particle sizes (4.75 ~ 9.53 mm). Thus, the particle size of the CAAs is another treatment factor containing two levels.

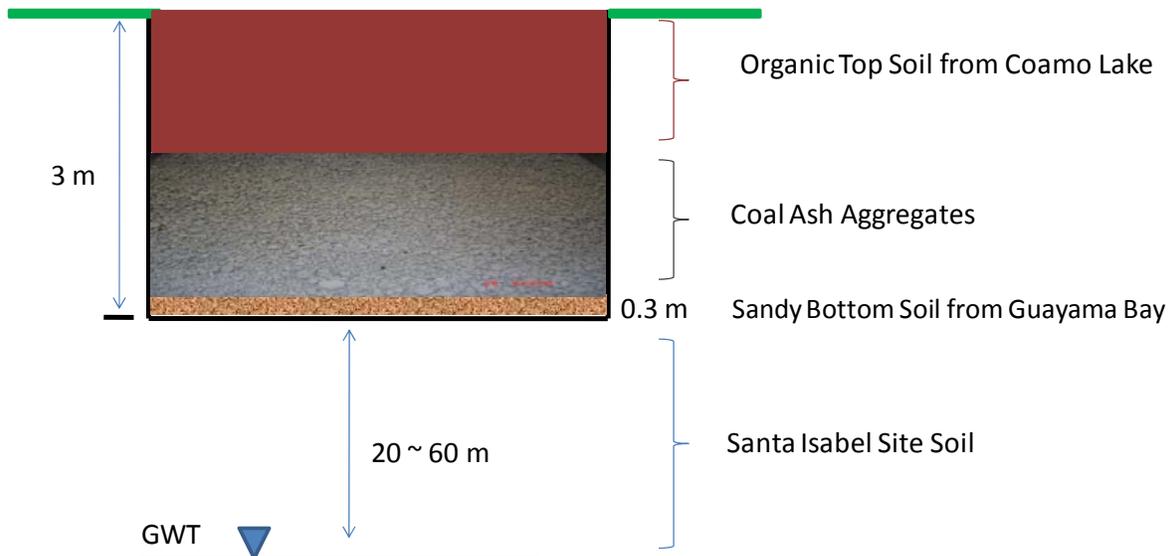


Figure 2. Schematic of backfilling of the site.



Photo 3. Column Reactors setup for water quality assessment in a statistical design and analysis.

Table 1. 3-factor, 2-level statistical design matrix.

Reactors	Top Soil (in)	CCPs (in)	Bottom Soil (in)	Site Soil (in)	CCPs Size	Rain Intensity
R ₁	8	4	4	10	A	High
R ₂	8	4	4	10	A	High
R ₃	8	4	4	10	A	Low
R ₄	8	4	4	10	A	Low
R ₅	8	4	4	10	B	High
R ₆	8	4	4	10	B	High
R ₇	8	4	4	10	B	Low
R ₈	8	4	4	10	B	Low
R ₉	4	8	4	10	A	High
R ₁₀	4	8	4	10	A	High
R ₁₁	4	8	4	10	A	Low
R ₁₂	4	8	4	10	A	Low
R ₁₃	4	8	4	10	B	High
R ₁₄	4	8	4	10	B	High
R ₁₅	4	8	4	10	B	Low
R ₁₆	4	8	4	10	B	Low

Preliminary Leaching Test for Each Solid Components

Total 8 plastic reactors (2.5-in D x 6-in L) were constructed to test leaching characteristics of each solid material being used in the project as shown in Photo 4. Each component was packed at a depth of 5 inches. Table 2 shows the design matrix of leaching test. Tap water was sprayed on the top of the reactors on every Mondays, Wednesdays, and Fridays. During the first 2 watering events, 40 mL was sprayed, but the amount of water added was increased to 100 mL to collect enough amount of infiltrated water with which water quality parameters were analyzed. This experiment was done over 4 weeks.



Photo 4. Views of leaching tests of each solid material used in the project.

Table 2. Design matrix of preliminary leaching test for each solid material.

Reactor #	1	2	3	4	5	6	7	8
Component	Top soil	Bottom soil	Site soil	Sand	CAA (smaller size)	CAA (bigger size)	Gravel	Top soil (duplicate)
Bulk density (g/cm ³)	1.34	1.49	1.49	1.65	0.78	0.88	1.61	1.35

Long-Term Water Quality Monitoring 1: Temperature Effect

Two identical column systems were constructed in parallel with a combination of soil and CAA distribution which had produced the worst water quality in the previous statistical experiment. The worst water quality was found when less top soil but more CAA with bigger particle sizes (4.75 ~ 9.53 mm) were used under lower rainfall intensity.

Rainfall was applied in this experiment by pumping 10 mL/min of water each weekday for 4 hours. Sampling was done weekly but analysis was done in an alternate manner. Water quality parameters of pH, turbidity, conductivity, and heavy metals (Pb and Cd) were measured from one week samples, whereas those of alkalinity, hardness and total heterotrophic bacteria (THB) counts were done from the other week samples.

One (System 1) was operated at 10 °C and the other (System 2) was at room temperature. A lower temperature set-up was to test water quality parameters in a condition similar to a field soil and groundwater environment with respect to temperature. Distribution of soils and aggregate was shown in Table 3 and schematics of column set-up are shown in Figure 3.

Table 3. Soils and CAA distribution of two identical columns used for Long-Term Water Quality Monitoring 1: Temperature effect.

	Top Soil	CAA	Bottom Soil	Site Soil
Numbers of columns	1	1	1	4
Lengths of columns (inches)	6.5	13	2.5	30 each
Bulk density (g/cm ³)	1.35	0.51	1.08	1.30 -1.49

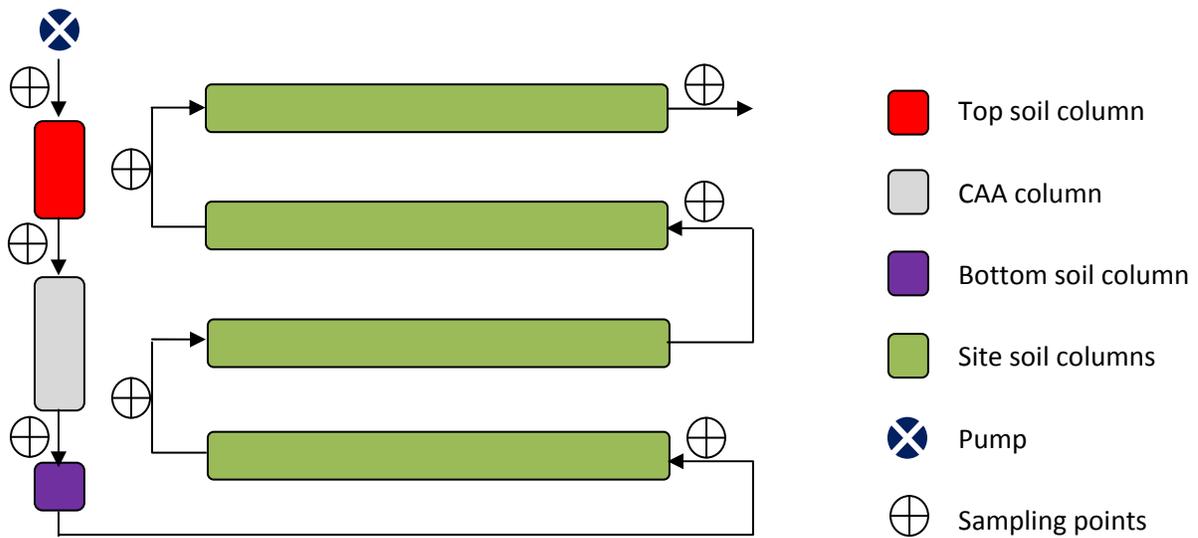


Figure 3. Schematics of column set-up for Long-Term Water Quality Monitoring.

The System 1 was constructed in the same way as the System 2, except for the operating temperature. It was coiled with a vinyl tube and cold water (10°C) was recirculated through it by a temperature controlled bath. The columns and coiled tubes were wrapped with an insulation sheet. Tap water was pumped to the Systems 1 and 2 at a rate of 10 mL/min from a reservoir by a peristaltic pump. Pumping was scheduled for 3 hours per week day at the consistent time frame using a timer. Samples were collected from the sampling ports once every two weeks and analyzed for water quality parameters.

Long-Term Water Quality Monitoring 2: Amendment Effect

Another column system was constructed with a combination of soil and CAA distribution which had produced the best water quality from the previous statistical experiment. The best water quality was measured when more top soil but less CAA with smaller particle sizes (2.36 ~ 4.75 mm) were tested under greater rainfall intensity (20 mL/min). The same rainfall frequency that was used for the Long-Term Water Quality Monitoring 1 was used for this experiment. Sampling and analysis schemes were the same as the previous experiment. Distribution of soils and aggregate was shown in [Table 4](#).

Table 4. Soils and CAA distribution of the column reactor used for Long-Term Water Quality Monitoring 2: Amendment effect.

	Top Soil	CAA	Bottom Soil	Site Soil
Numbers of columns	1	1	1	4
Lengths of columns (inches)	13	6.5	2.5	30 each
Bulk density (g/cm ³)	1.32	0.53	1.08	1.32

Bio-viability Assessment

Germination with CAA Water

Germination of bean and pumpkin seeds was assessed in a worst case scenario that the plants might get experienced due to the presence of the CAAs. A hypothesis was that no toxic chemicals from the CAAs, if any, would be taken up by the plants so that seeds would germinate and grow. For this, water infiltrated from the CAAs was collected from a separate column system. In the flat-bottom, porcelain funnel (6-in dia. and 8-in long), 1,080 g of CAAs were layered on the top of 835 g of gravels. 1,500 g of sand covered the CAAs layer. Both clean gravels and sands were used as supporting layers to facilitate the hydraulics of water. Total 3 L of tap water was poured to the column and infiltrated water was collected and used for spraying to the reactors prepared as shown in [Table 5](#).

Table 5. Initial germination experiment matrix where water infiltrated from the CAAs column was sprayed to the reactors.

Reactors	Gravel (grams) Nominal depth: 2.5 inches	Top Soil (grams) Nominal depth: 6.5 inches	Seeds
1	201	1262	Beans
2	202	1264	Beans
3	200	1270	Pumpkin
4	196	1262	Pumpkin

Four reactors (4-in dia. and 11-in length) were put in an environmental chamber which controlled temperature at 30 °C with a refrigerated and heating bath circulator (Thermo NESLAB RTE-10 Digital One). The chamber was also equipped with a 20 W lighting system (GRO-LUX, Sylvania) which was scheduled to turn on from 1 pm to 10 pm with a timer. The infiltrated water collected from the CAA column was sprayed on every other day at an amount of 105 mL which was calculated according to the actual maximum average precipitation in Santa Isabel. This germination experiment was performed for 2 weeks.

Multifactor Assessment on Germination and Growth

Another germination experiment was conducted after the first germination experiment aforementioned. This time, multiple factors were assessed on their effects on the germination rate and

growth. The parameter monitored is the product of the germination rate and shoot growth. First factor evaluated was a backfilling mode with a mixed or a layered application of the top soils and CAAs. Second factor was the type of seeds, bean or pumpkin. Third factor assessed was the ratio of the top soil to the CAAs. Lastly, the type of water sprayed to the systems was tested with natural rain water collected and tap water.

Sixteen treatments and 4 control reactors were constructed as shown in Table 6. Plastic reactors were dimensioned with 2.5-in dia. and 6-in long. Five seeds were placed to each reactor at a depth of 1.5 inches below surface. Like the previous germination experiments, the reactors were put in the environmental chamber. Corresponding to the actual maximum average precipitation in Santa Isabel, 40 mL of water (rain water or tap water) was sprayed on every other day for 2 weeks.

Table 6. Design matrix to assess the effects of multiple factors on the germination rate and growth.

Reactors	Mixed/Layered	Type of seed	Distribution	Type of water	Top Soil (g)	Aggregate (g)
R1	Layered	beans	4" top soil+2" aggregate	RW	440.1	134.3
R2	Layered	beans	2" top soil+4" aggregate	TW	225.1	254.3
R3	Mixed	beans	66.7% top soil+ 33.3% aggregate	RW	445.2	127.7
R4	Mixed	beans	33.3% top soil+ 66.7% aggregate	TW	222.7	258.6
R5	Layered	beans	4" top soil+2" aggregate	TW	439.6	134.5
R6	Layered	beans	2" top soil+4" aggregate	RW	227.5	254.5
R7	Mixed	beans	66.7% top soil+ 33.3% aggregate	TW	444.5	129.5
R8	Mixed	beans	33.3% top soil+ 66.7% aggregate	RW	222.5	259.5
R9	Layered	pumpkin	4" top soil+2" aggregate	RW	439.4	134.5
R10	Layered	pumpkin	2" top soil+4" aggregate	TW	227.5	254.5
R11	Mixed	pumpkin	66.7% top soil+ 33.3% aggregate	RW	444.4	129.5
R12	Mixed	pumpkin	33.3% top soil+ 66.7% aggregate	TW	222.3	256.5
R13	Layered	pumpkin	4" top soil+2" aggregate	TW	439.6	134.5
R14	Layered	pumpkin	2" top soil+4" aggregate	RW	227.5	254.5
R15	Mixed	pumpkin	66.7% top soil+ 33.3% aggregate	TW	447.2	129.5
R16	Mixed	pumpkin	33.3% top soil+ 66.7% aggregate	RW	222.9	262.5

Reactors	Mixed/Layered	Type of seed	Distribution	Type of water	Top Soil (g)	Aggregate (g)
CR1	N/A	beans	6" top soil	RW	664.9	/
CR2	N/A	beans	6" top soil	TW	674	/
CR3	N/A	pumpkin	6" top soil	RW	657.6	/
CR4	N/A	pumpkin	6" top soil	TW	677.3	/

Potential Effect of Physical Hindrance by CAA Layer

An experiment was conducted to assess potential physical hindrance of the CAAs against seeds germination and growth. In order to accommodate more numbers of the seeds (bean), 4 rectangular

reactors were constructed of acrylic plates with effective volume of 800 in³ (13 W x 8 L x 8 D). All 4 reactors had a supporting gravel layer of 2 in on the bottom. The reactors were packed as shown in the following Table 7 and Figure 4.

Table 7. Specifications of the reactors run for testing physical hindrance of the CAA against germination and growth.

Layers		Reactor 1	Reactor 2	Reactor 3	Reactor 4
Top soil layer	Depth (in)	8	6	5	4
	Bulk density (g/cm ³)	1.51	1.56	1.23	1.56
Hindrancelayer	CAA, depth (in)	-	2	1	-
	Bulk density (g/cm ³)	-	0.80	0.91	-
	Gravel, depth (in)	-	-	2	6
	Bulk density (g/cm ³)			1.77	1.40

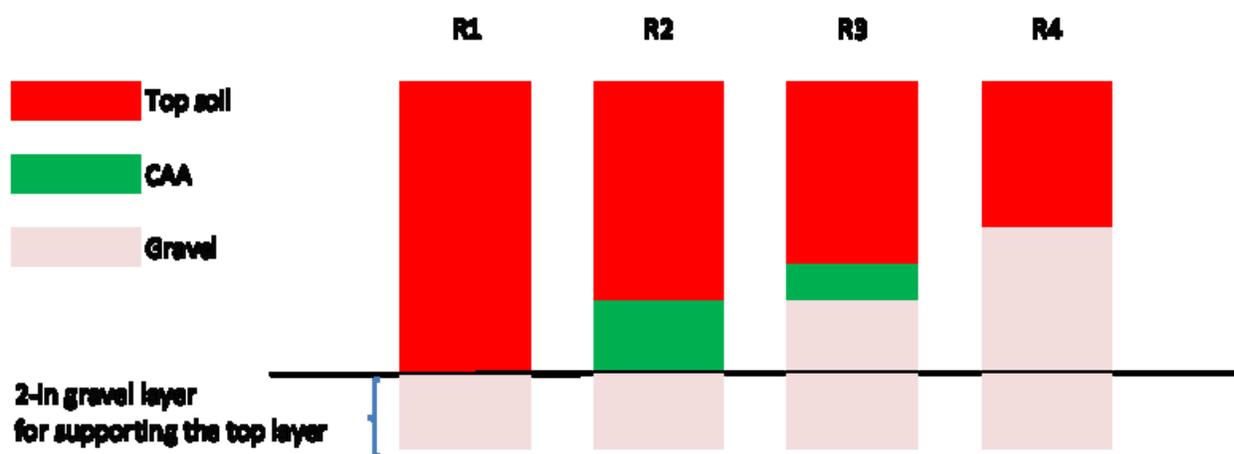


Figure 4. Schematics of the reactors run for testing physical hindrance of the CAA against germination and growth.

Six bean seeds were planted in each reactor at a depth of 1.5 inches. Corresponding to the actual maximum average precipitation in Santa Isabel, 840 mL of tap water was evenly sprayed on the top of the reactors every other day for over 5 weeks. Germination and growth monitoring was done every Mondays and Fridays.

Effect of Hardness in Water

An experiment was conducted to elucidate potential contribution of hardness to germination and growth. This experiment was initiated based on the results from the multiple factor germination experiments where the tap water (64.4 mg/L Hardness as CaCO₃) spraying showed better germination and growth compared to the rain water (6.3 mg/L Hardness as CaCO₃) spraying. Plastic reactors used for the multiple factor experiments (2.5-in dia. and 6-in long.) were filled with the organic top soil at a depth of 5 inches. Two seeds were placed to each reactor at a depth of 1.5 inches below surface. Each system was run in duplicate. Corresponding to the actual maximum average precipitation in Santa Isabel, 40 mL

of hardness water (0 to 80 mg/L Hardness as CaCO₃) was sprayed on every other day for a month. Table 8 shows the design of the experiment.

Table 8. Design of the experiment to assess the effect of hardness on germination and growth.

Reactor	A	B	C	D	E
Hardness in the water sprayed (mg/L as CaCO ₃)	0	4	20	40	80

Expansion of Assessment of Physical Hindrance with Various Plants

After completing Physical Hindrance experiment, all beans were removed from the reactors and the configurations of the reactors were slightly modified as shown Figure 5. This experiment was to assess potential contribution of the CAAs as nutrient source for the plants. Four different plants were tested: botellas, beans, papayas, and pumpkins. Baby botellas and papayas were obtained from a nursery farm at the site and planted in the reactors #1 and #2, and #3 and #4, respectively. Beans were seeded directly to the reactors #3 and #4. Pumpkins were later seeded to the reactors #3 and #4 after the beans were completed with the experiment and removed from the reactors. Due to deeper and bigger roots, the reactors #1 and #2 had deeper top soils by 40% than the reactor #3 and #4. Like the Physical Hindrance experiment, 840 mL of tap water was evenly sprayed on the top of the reactors every other day during the experiment. Germination and growth monitoring was done every Mondays and Fridays.

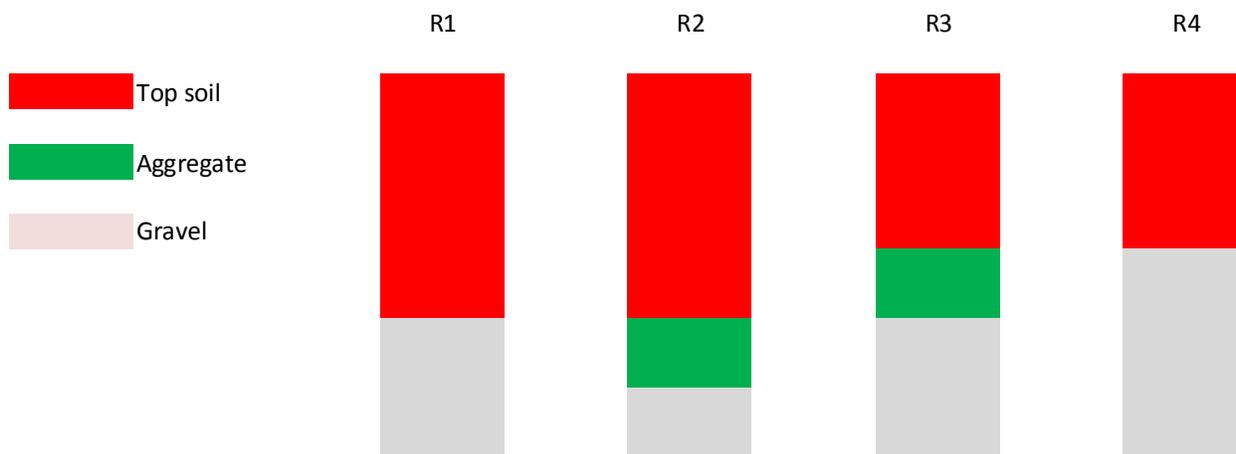


Figure 5. Assessment of CAAs as a nutrient source for the various plants: botellas, papayas, beans and pumpkins.

Analysis

Heavy metals, lead (Pb) and cadmium (Cd), were monitored with the Leadtrak (HACH) and an ion specific electrode (Orion), respectively. The value of pH was measured with an Orion pH meter. Specific conductivity was analyzed with Orion Specific Conductivity Meter Model 162. Turbidity was measured with LaMotte 2020 Turbidimeter. Hardness was analyzed with an ion specific electrode

(Orion). THB was done by the standard plate count using tryptic soy broth as the growth media and then counted after incubation at 30°C for 72 hrs.

For bio-viability assessment, beans and pumpkins were initially selected as the target plants. Their germination rates and shoot growth were monitored. The former is defined as the ratio of the germination to the numbers of the seeds planted. The latter is defined as the physical height of the shoots above the ground. Two target heavy metals, Pb and Cd, in the plants were also analyzed after the Digesdahl digestion (HACH).

Principal Findings and Significance

Water Quality Assessment

The water volume infiltrated in each reactor weekly is shown in Figure 6. Apparently, it seems the rainfall intensity influenced greatly on the infiltrated water volume.

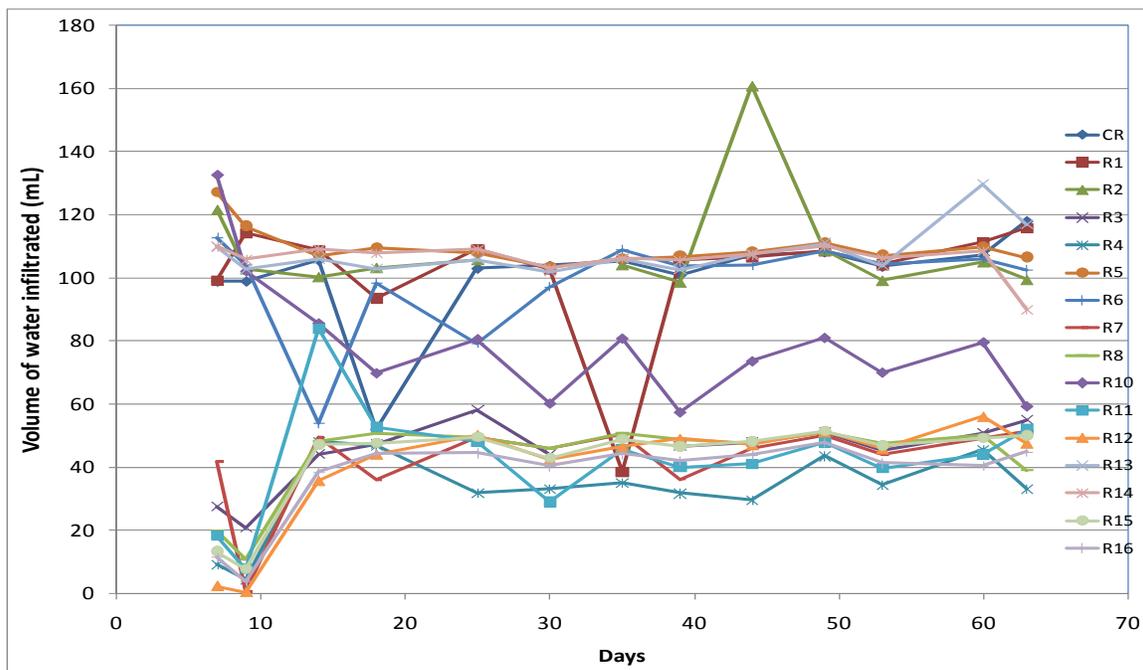


Figure 6. Volume of water infiltrated weekly in each reactor.

The infiltrated water from each reactor containing the CAAs had a slightly basic pH (~8.5) throughout the experiment, as shown in Figure 7. A higher pH of the control reactors was attributed to the characteristics of the sand used for the system.

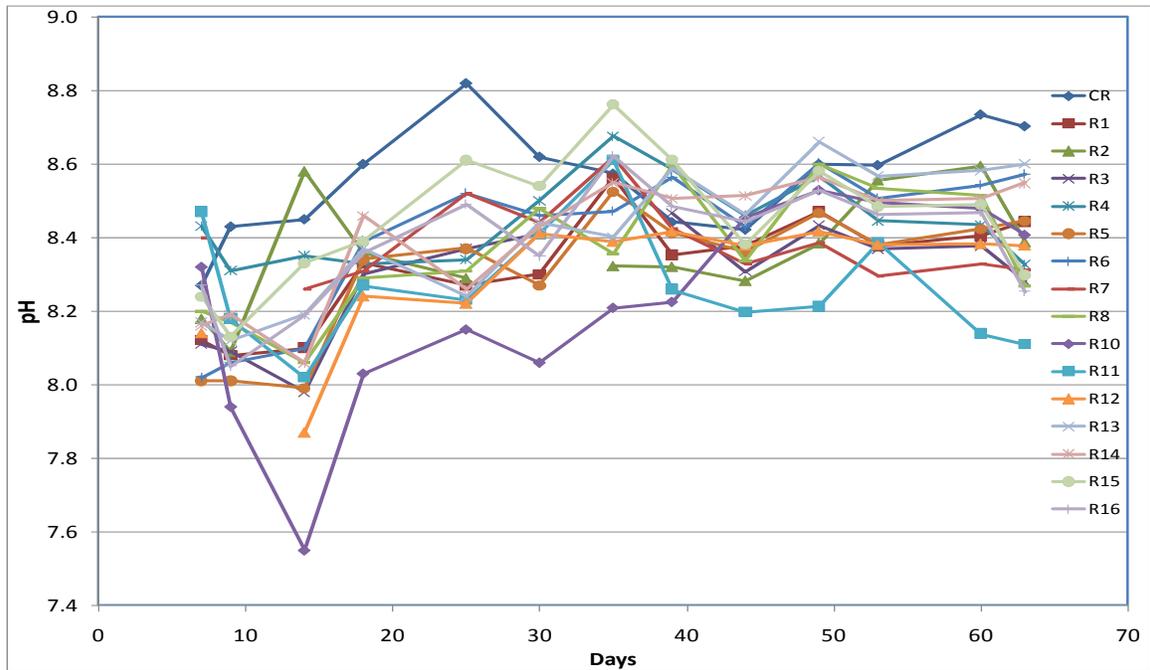


Figure 7. Value of pH in the water infiltrated weekly in each reactor.

Turbidity was monitored in the range between 0.5 and 1 NTU, except for a couple of outliers, in the beginning of the experiment. However, it reduced to a value less than 0.5 NTU as shown in Figure 8.

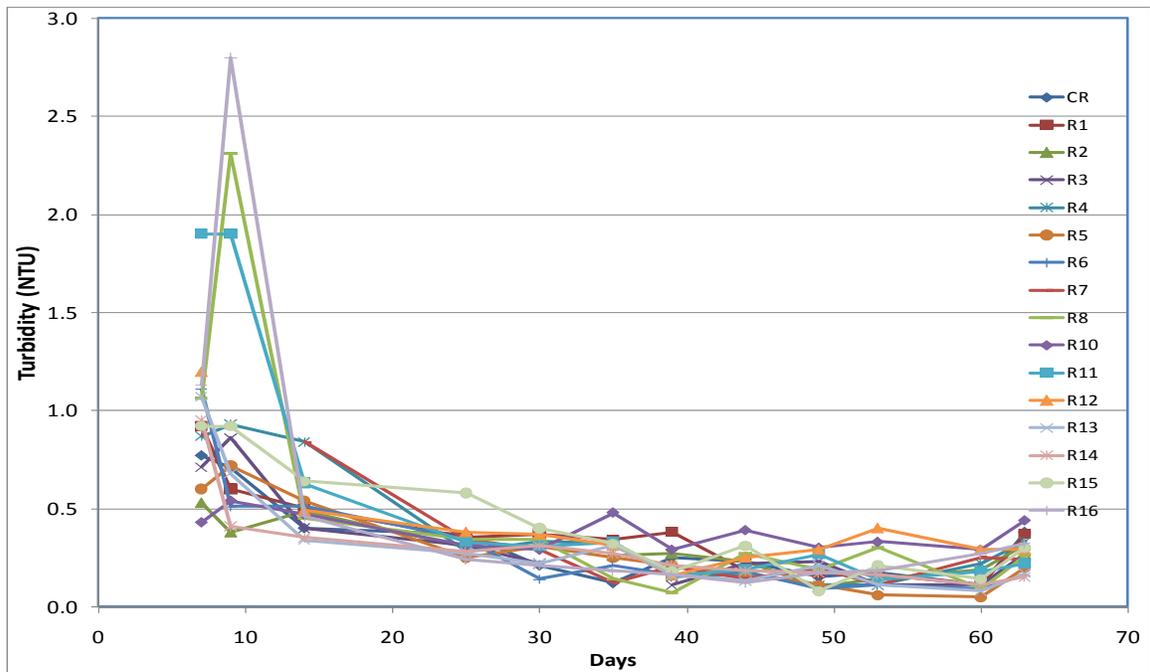


Figure 8. Turbidity in the water infiltrated weekly from each reactor.

Specific conductivity showed higher strengths in all treatment columns compared to that in the control reactor as shown **Figure 9**. A similar trend was observed for the hardness concentrations.

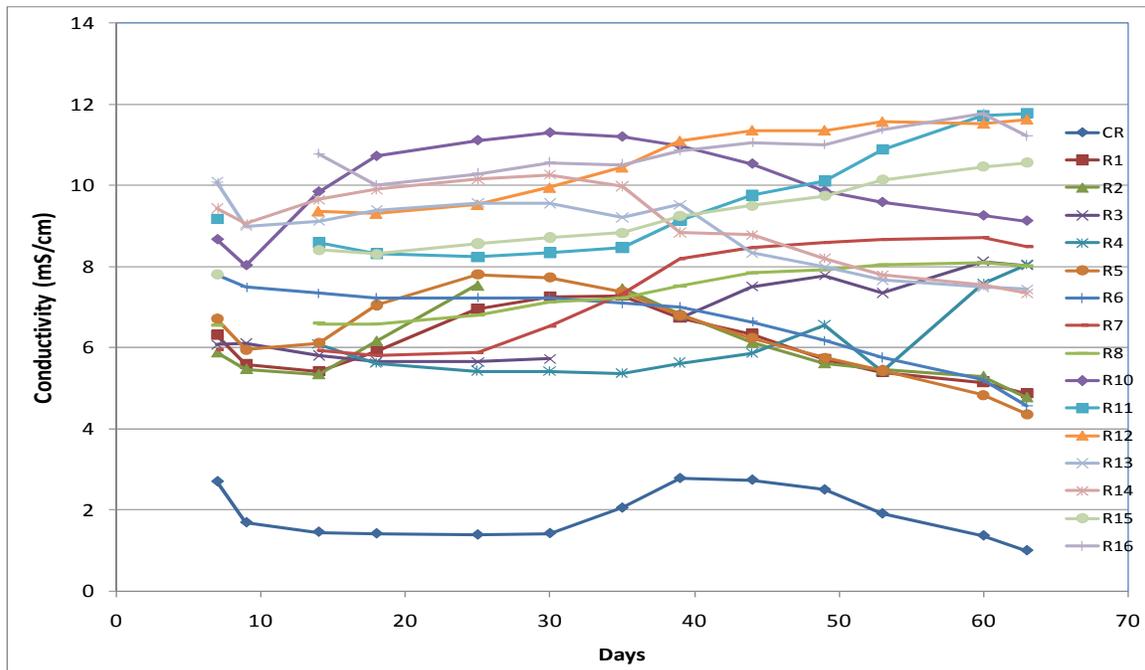


Figure 9. Specific conductivity in the water infiltrated weekly from each reactor.

Heavy metal analysis showed no concentrations of Pb and Cd. For Pb, the HACH LeadTrak testing methods can detect Pb as low as 5 µg/L as Pb. For ensuring quality of the measurement, a Cole-Parmer Pb ion selective electrode was also used for Pb analysis. Its lower limit was 0.2 mg/L. For Cd, both an AA spectrometer and a Cole-Parmer Cd ion selective electrode with a lower limit of 0.2 mg/L were used for the analysis.

3-Factor, 2-Level Statistical Analysis

To evaluate the causes and effects produced by the factors aforementioned in the Method section, 3-factor, 2-level statistical analysis was conducted based on the corresponding the statistical design. For this purpose, the latest version of the Minitab software was used. Example plots are shown in **Figure 10**.

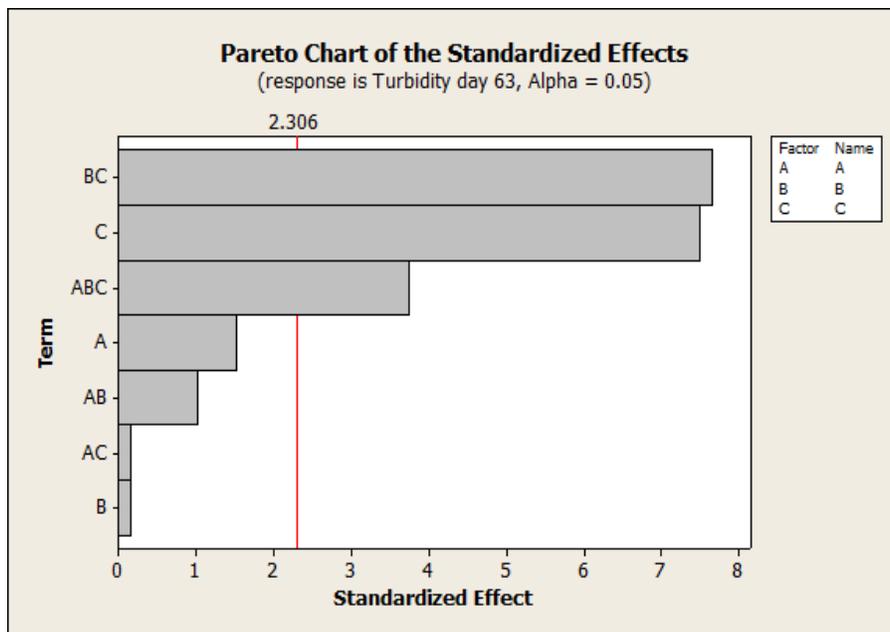
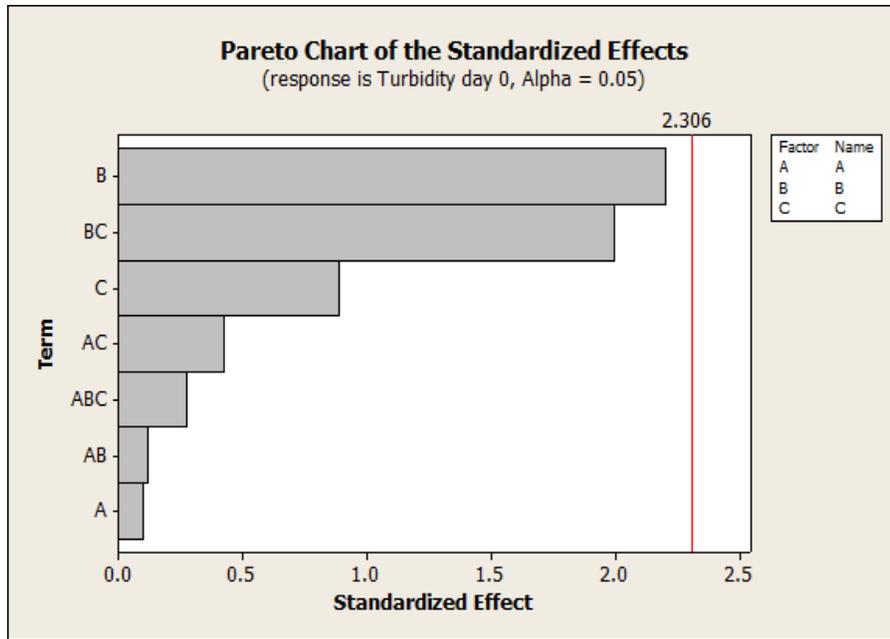


Figure 10. Examples of the statistical analysis using the Minitab software.

As shown in Figure 9 previously, the factors produced different effects on the monitored parameters throughout the experiment (i.e., temporal effects). In this regard, those factors which produced statistically significant difference in the monitored parameters were selected and plotted in order to compare temporal effects of the factors. Figures 11 and 12 show temporally significant factors which produced a statistical difference in pH values (top) and turbidity (bottom,) and hardness, respectively.

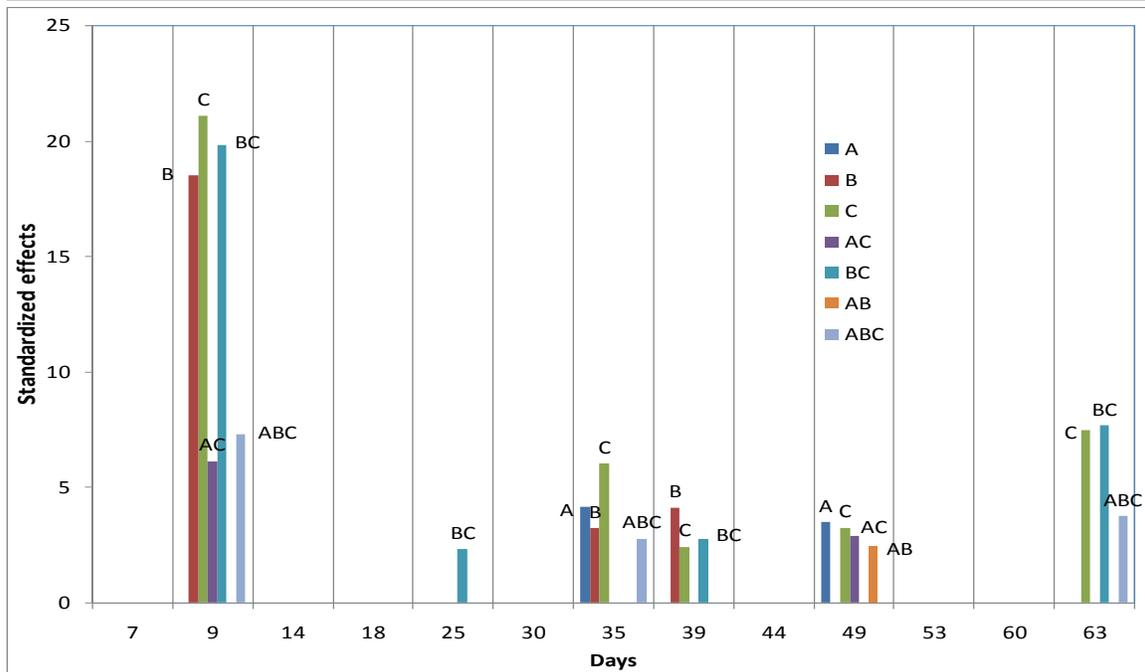
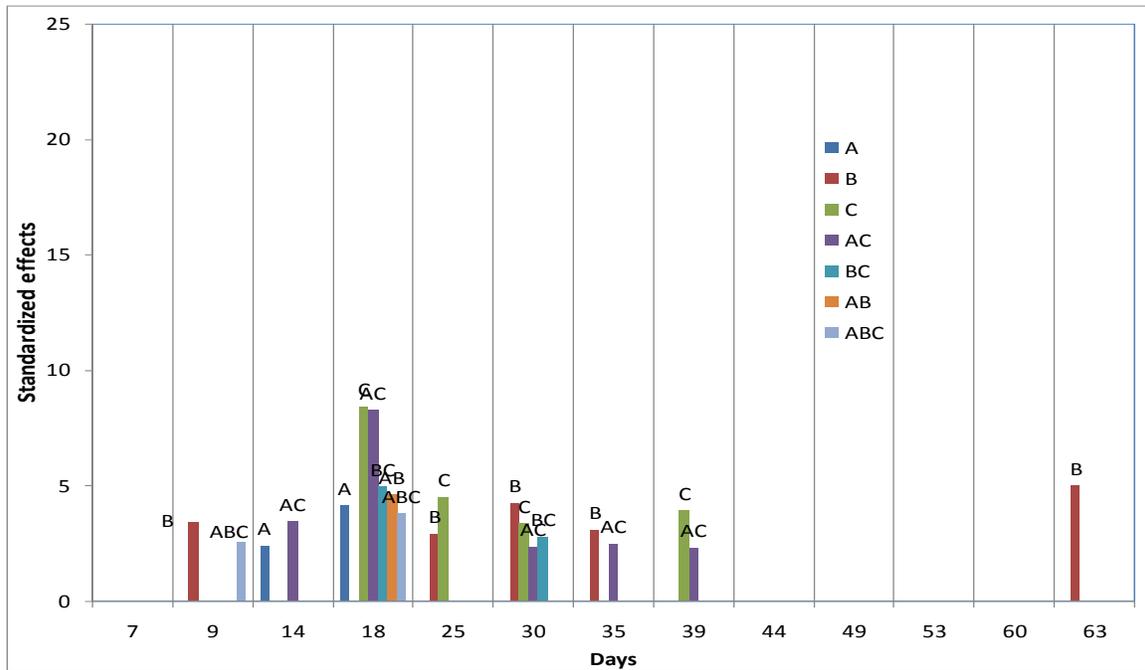


Figure 11. Factors and their extent to have produced a statistically significant difference in pH values (top) and turbidity (bottom).

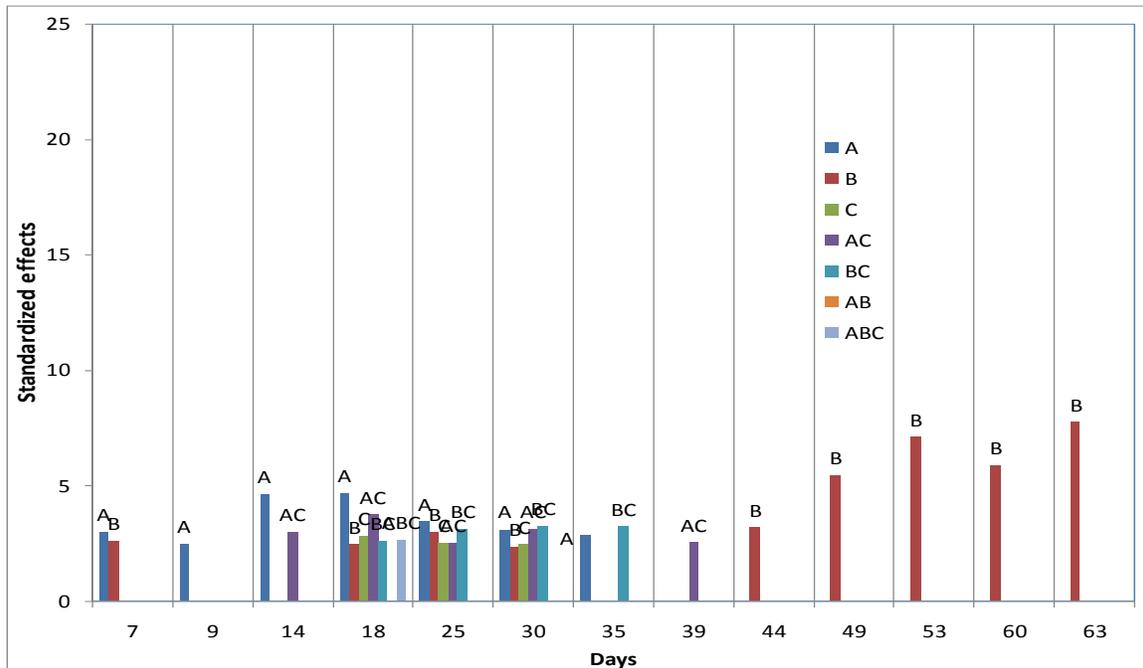


Figure 12. Factors and their extent to have produced a statistically significant difference in hardness.

For better understanding of statistically significant effects that were produced by the main factors, plots containing only the main effects and causes were constructed as shown in Figures 12 and 13. The rainfall intensity undoubtedly significantly influenced on the amount of the infiltrated water as shown in Figure 13. The difference in the amount of the infiltrated water was all statistically different, with the greater rainfall intensity being produced more amount of the infiltrated water. For the values of pH, significantly higher pH values were observed for the reactors with low-level rainfall intensities and small-sized CAAs.

As shown in Figure 1, turbidity was statistically higher for the reactors with low-level rainfall intensities, more CAAs ratio, and smaller size CAAs. However, in the later part of the experiment, the infiltrated water from the bigger size CAAs produced significantly higher turbidity. Statistically higher hardness concentrations were monitored for the reactors with more CAAs ratio up to the middle of the experiment. However, low-level rainfall intensity dominantly produced significantly higher concentrations of hardness in the later experiment.

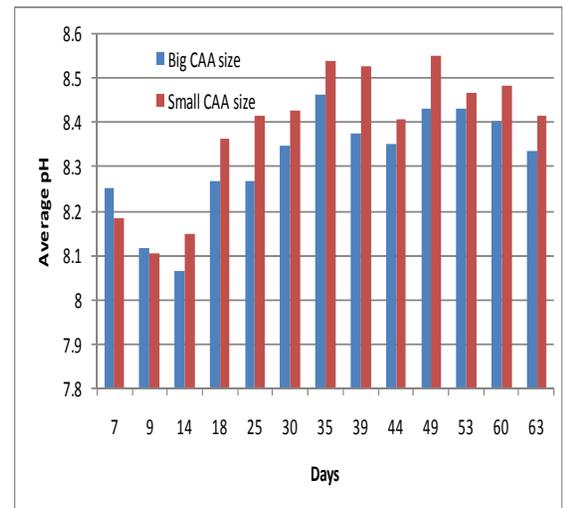
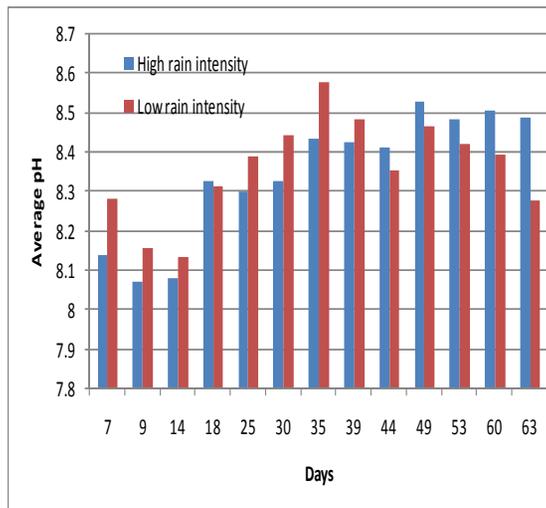
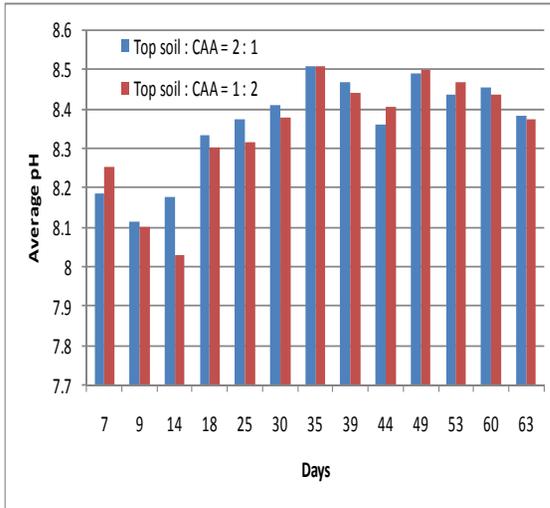
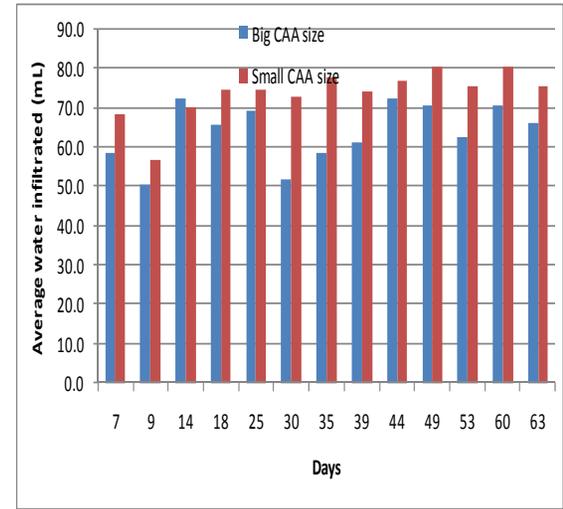
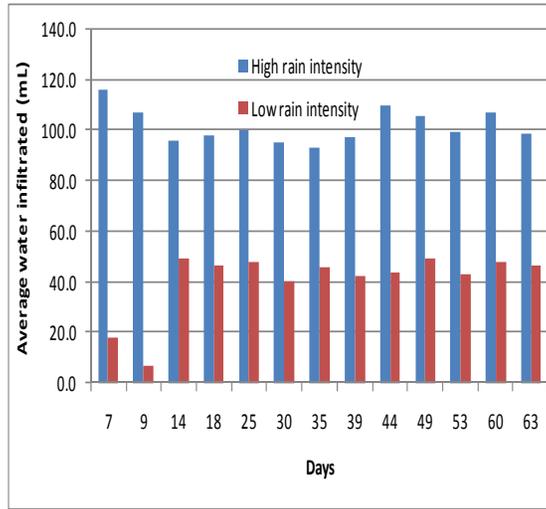
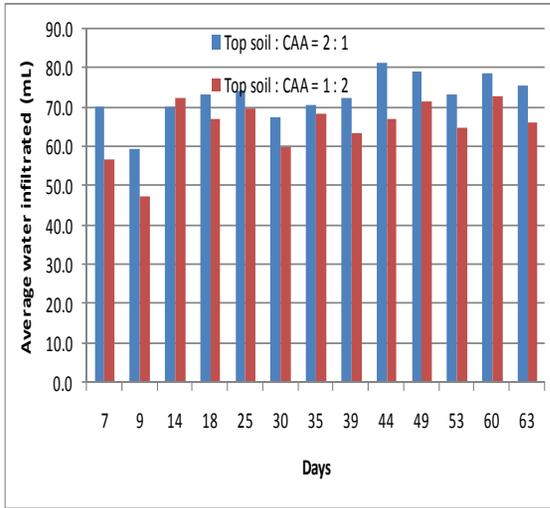


Figure 13. Plots of the main effects on the amount of infiltrated water (top row) and pH values (bottom row).

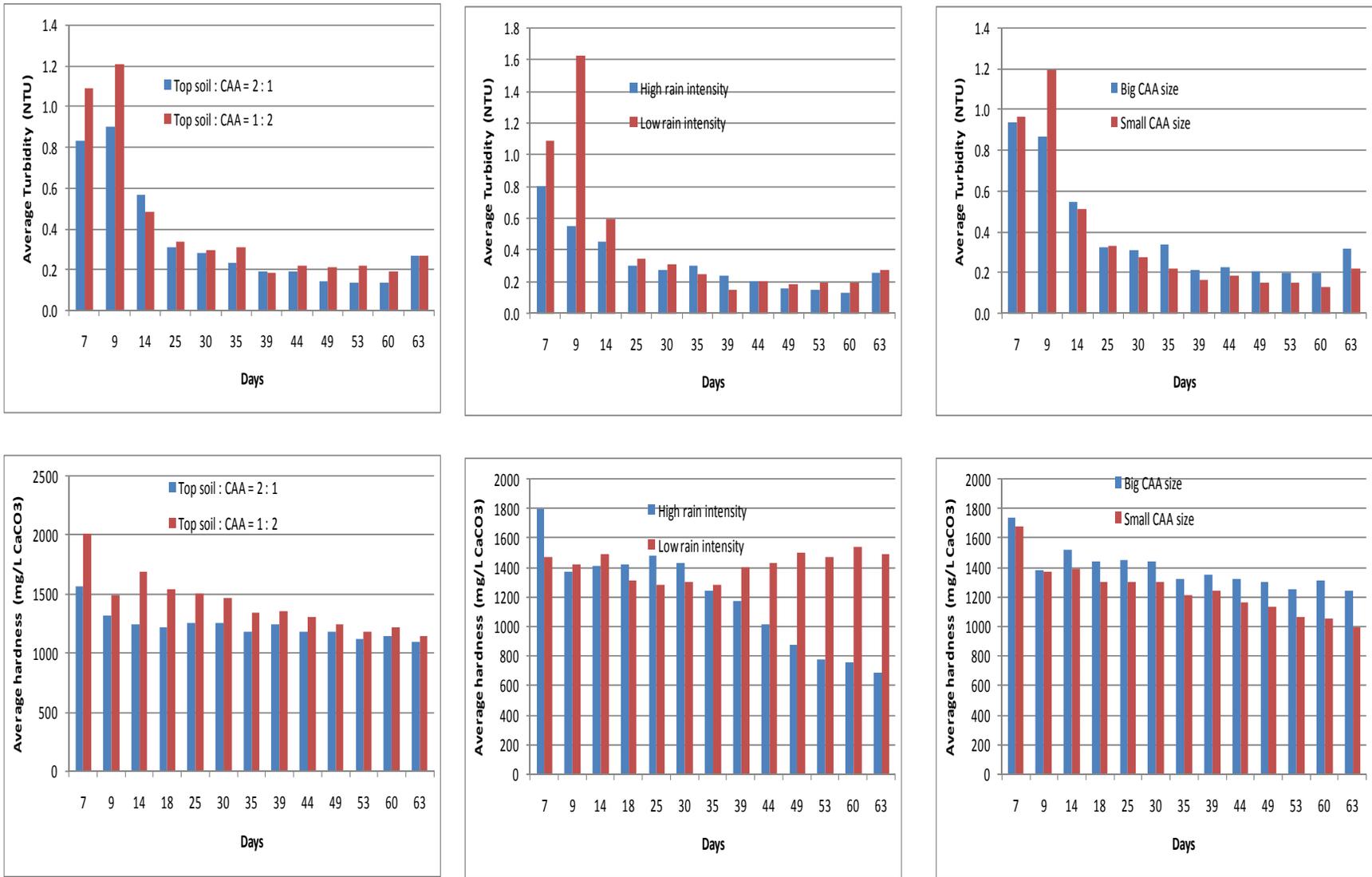


Figure 14. Plots of the main effects on the amount of turbidity (top row) and hardness (bottom row).

Preliminary Leaching Test for Individual Solid Components

Figure 15 shows the trends of water infiltration for each column packed with the different solid materials (i.e., top soil, bottom soil, site soil, sand, small CAA, big CAA, and gravel). A steady-state water infiltration was calculated by using infiltration volume data after total 120 mL was added to each column. After that event, the infiltration trend reached a pseudo plateau producing a constant amount of water. Results are shown in Table 9. With those infiltration ratio data, water retention capacity at a steady-state was calculated per grams of solid materials tested.

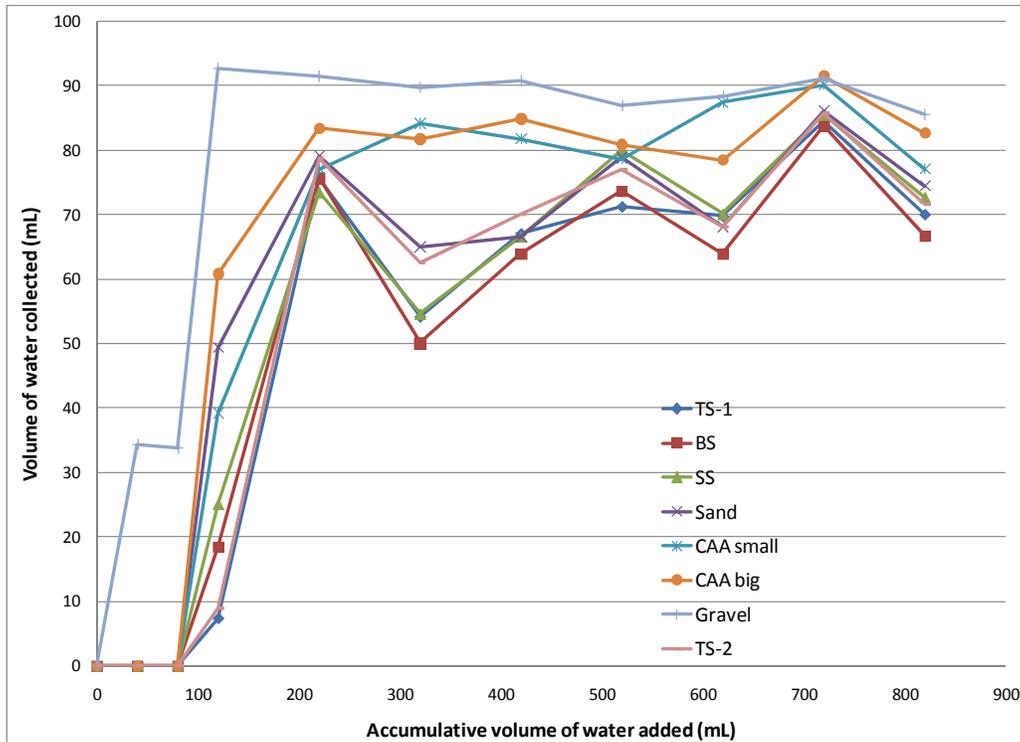


Figure 15. Volume of water collected from each reactor.

Table 9. Water infiltration ratio and water retention capacity of each column packed with different solid materials.

Solid Type	Top soil 1	Bottom soil	Site soil	Sand	CAA small	CAA big	Gravel	Top soil 2
Steady-state Water Infiltration Ratio (%)	70.6	68.4	72.9	73.7	83.5	83.2	88.9	73.3
Water Retention (mL H ₂ O/g solid)	0.131	0.114	0.121	0.111	0.267	0.236	0.137	0.135

In addition, several water quality parameters were monitored. The values of pH were ranged between 7.5 and 8.5 as shown in Figure 16 (top). Turbidity was also monitored. Interestingly, the bottom and site soils were the most influencing solids which exerted abnormally high turbidity during

the infiltration test as shown in **Figure 16 (bottom)**. Further sophisticated experiment is warranted to assess the contribution extent of each solid material to overall water quality parameters.

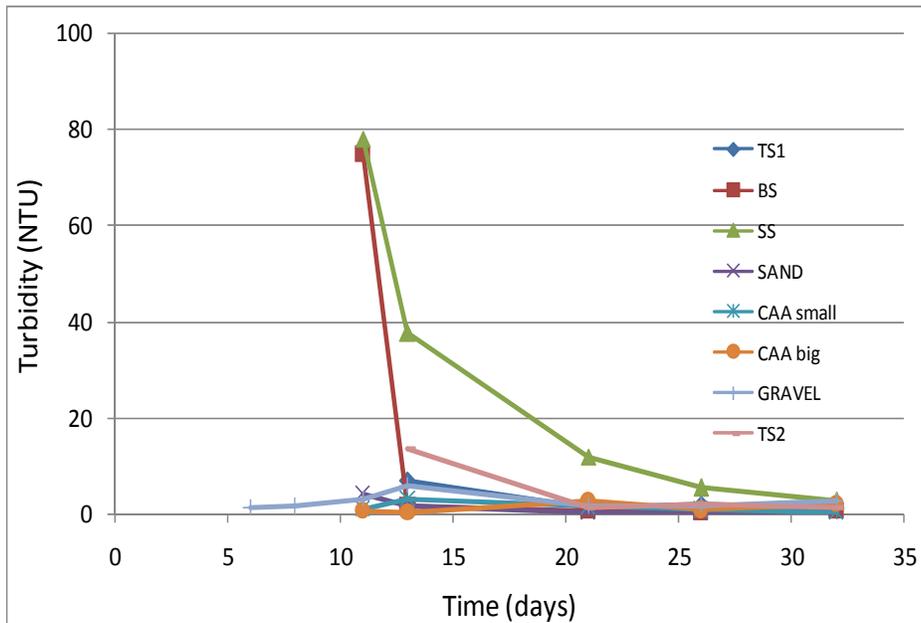
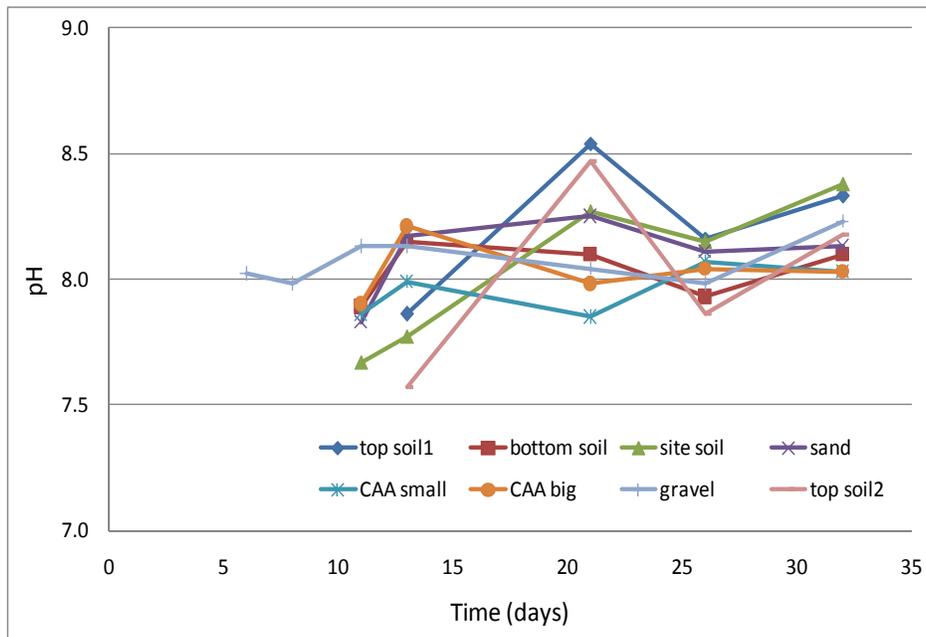


Figure 16. Trends of pH (top) and turbidity (bottom) in the infiltrated water collected.

Long-Term Water Quality Monitoring 1: Temperature Effect

Column reactors have been constructed as shown **Photo 5**. Sampling and water quality assessment have been actively conducted. Concrete results will be delivered in the next progress report.



Photo 5. Column set up for the experiment of water quality assessment with the worst-case combinational refilling and temperature effect.

Long-Term Water Quality Monitoring 2: Effect of Compositions

Another set of column reactors were constructed to assess water quality parameters for the case when backfilling is done with the deeper top soil layer, shallower CAA layer with smaller particle sizes and greater rainfall intensity. Together with the Water Quality Monitoring 1, this experiment is the main components of the proposed work during the second project year. Data will be presented as they come out in the progress reports.



Photo 6. Column set up for the experiment of water quality assessment with the best-case combinational refilling.

Bio-viability Assessment

Germination in a Worst Case Scenario

It was hypothesized that neither toxic chemicals would be leached out of the CAAs nor the plants would take up them, if any, so that the seeds would germinate and the plants would grow. To test this hypothesis, water collected from a column filled with the CAAs was sprayed to the seeds as a worst case scenario and their germination was monitored. As shown in **Photo 7**, both beans and pumpkins germinated and grew in a good shape. After 2 weeks, roots, leaves and stems of both plants were analyzed with respect to the target heavy metals, Pb and Cd. Both heavy metals were not detected.

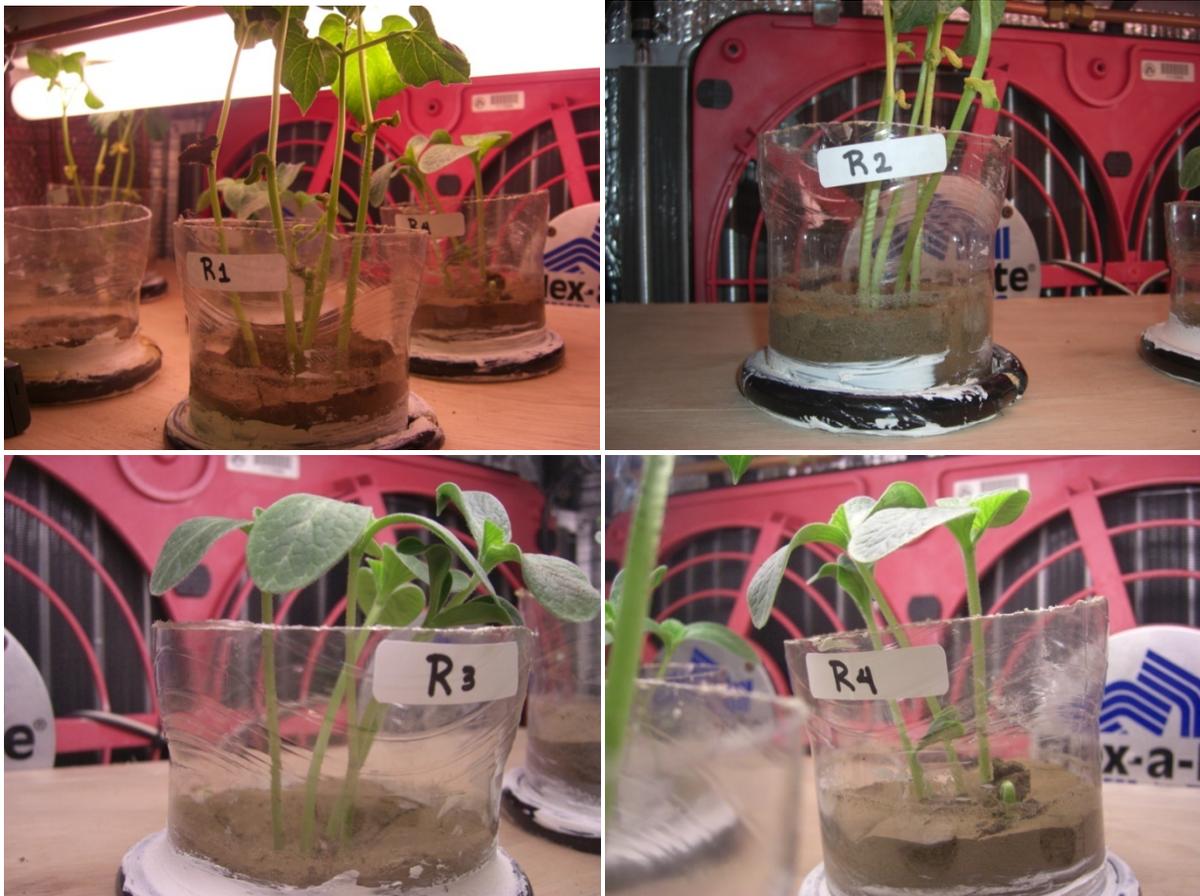


Photo 7. Germination results of bean (top row) and pumpkin (bottom row) seeds.

Germination and Growth Assessment with Multiple Factors

Generally, beans germinated and grew much better than pumpkins during the period of the experiment (2 weeks) as shown in **Photo 8** and **Figure 17**. Between two backfilling modes, a layered mode showed better results than a mixed mode. Regardless of the seed type, better results were observed with a greater depth of the top soil for a layered backfilling mode and a higher ratio of the top soil to the CAAs for a mixed mode. Both plants also showed better results when their seeds were planted into the system that had more top soils than the CAAs.

It was suspected that a physical hindrance due to the presence of the CAAs occurred, thereby poorer germination and growth patterns for the mixed backfilling mode and the more CAA ratio in the layered mode. Additional experiment was conducted to disclose this suspicion.



Photo 8. Beans and pumpkins growing in various reactors which were designed to assess the effects of multiple factors on the germination rate and shoot growth.

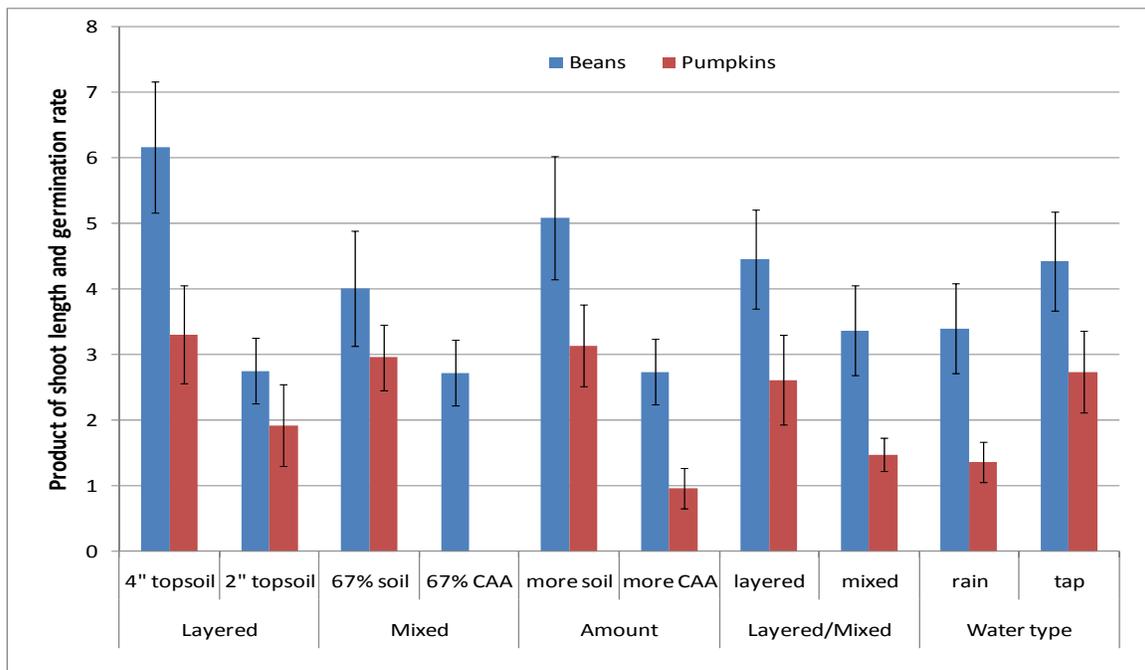


Figure 17. Results of the effects of multiple factors on the product of germination rate and shoot length.

When sprayed with the tap water, better germination and growth were observed in comparison to the rain water application. Water quality analysis was done with respect to specific conductivity, pH, and hardness of both waters (Table 10).

Table 10. Results of analysis on pH, specific conductivity and hardness of rain and tap waters (two samples each).

	pH	Specific Conductivity ($\mu\text{S}/\text{cm}$)	Hardness (mg/L as CaCO_3)
Tap water	7.9 ± 0.1	42.6 ± 0.2	64.4 ± 4.0
Rain water	7.5 ± 0.1	37.5 ± 28.1	6.3 ± 0.6

As shown, a major difference between two waters was found in the concentration of hardness, with the tap water being greater 10 times. Additional experiment was performing to elucidate potential contribution of hardness in the tap water which showed better germination and growth compared to the rain water.

Physical Hindrance

As shown in Photo 9 and Figure 18, all of 6 bean seeds germinated from each reactor. However, after about a month of growth, 3 shoots died from the Reactors 1 and 4 (i.e., 50% survivability), and 1 shoot died from the Reactor 2 (i.e., 83% survivability). No shoot death was observed from the Reactor 3, resulting in 100% survivability).

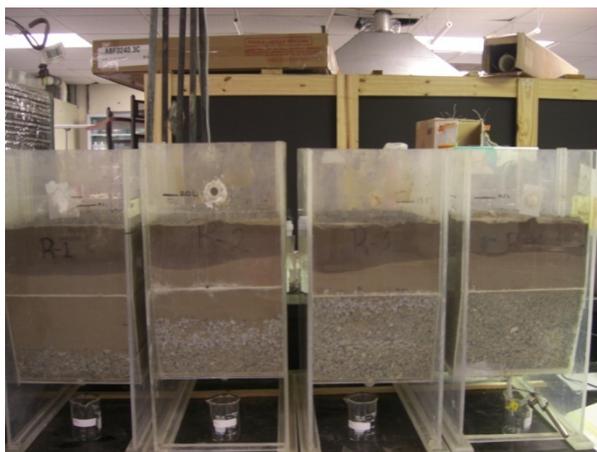


Photo 9. Scene of the 1st day (left) and the 20th day (right) of the reactors to assess physical hindrance of the CAAs.

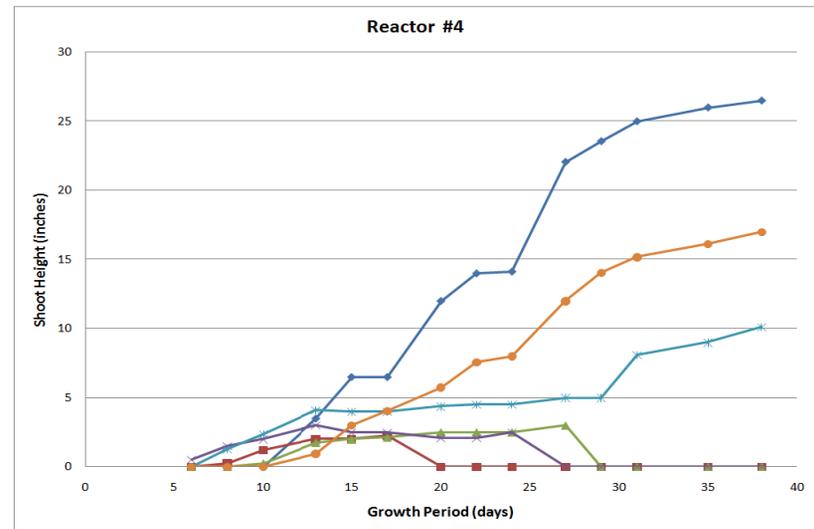
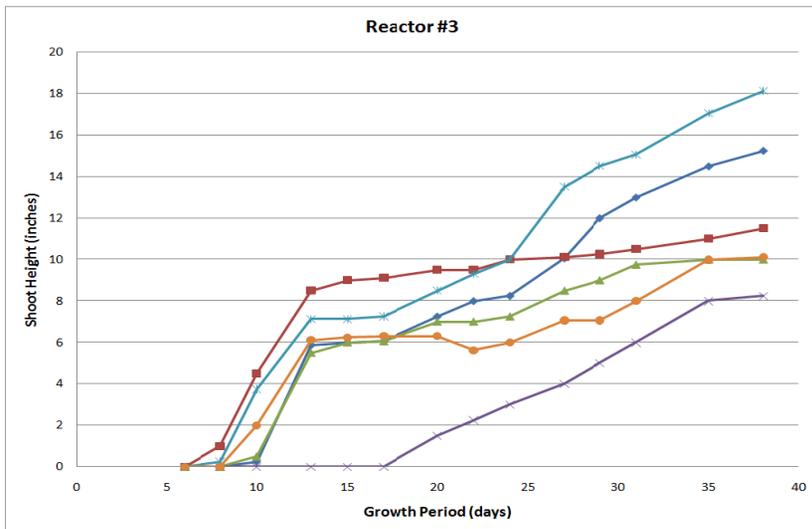
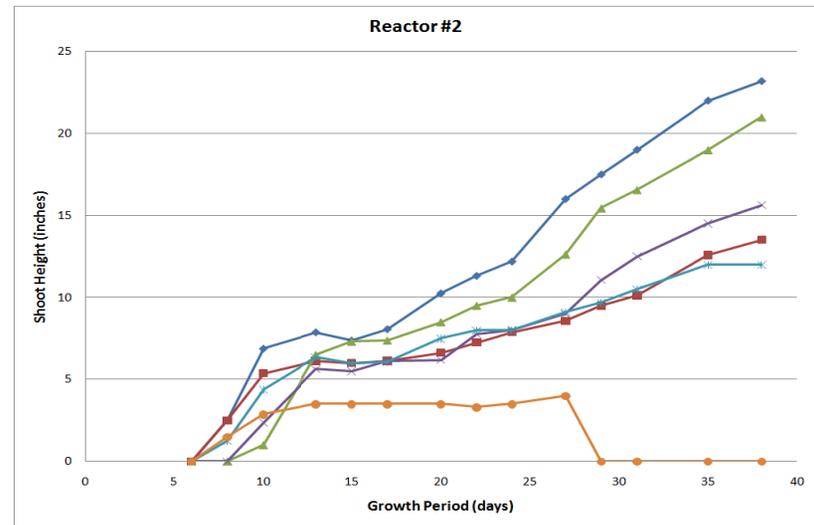
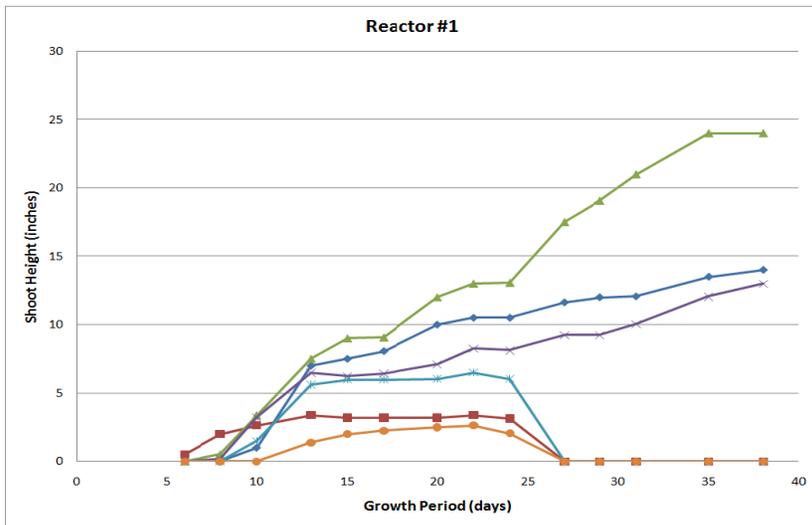


Figure 18. Height of 6 shoots germinated from each pot. 3 shoots, 1 shoot and 3 shoots did not survive after about a month of growth in the Reactor 1, 2 and 4, respectively.

Generally, the Reactor 2 had the best shoot growth as shown **Figure 19**, followed by the Reactor 3. Both Reactors had the CAA layers: 2-inch CAA layer below 6-inch top soil for the Reactor 2, whereas 1-inch CAA layer below 5-inch top soil for the Reactor 3. The shoots in the Reactor 1 which had only 8-in top soil grew a similar manner that those in the Reactors 2 and 3 which had the CAA layers up to 3 weeks of growth. However, its growth was limited.

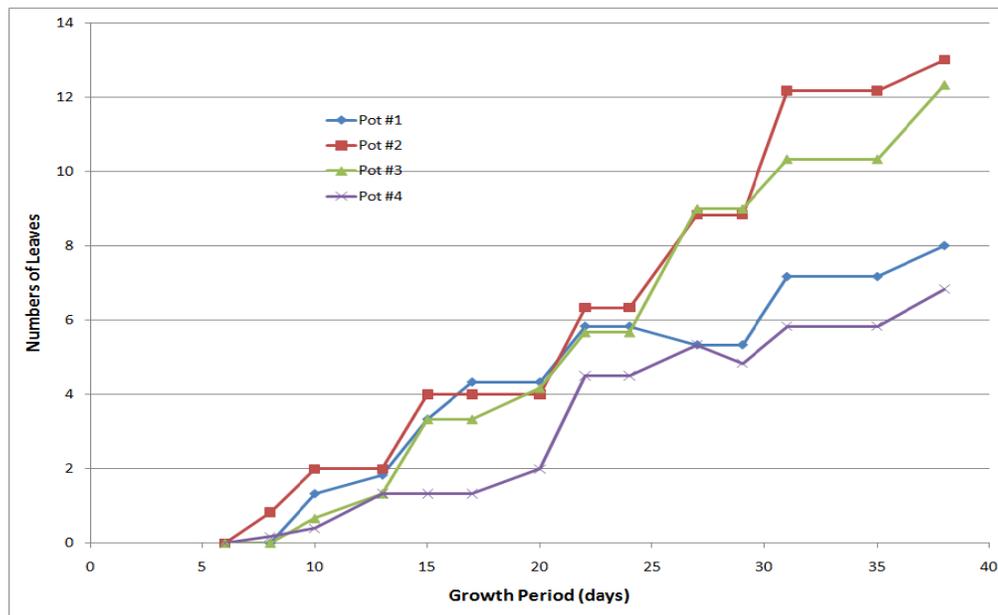
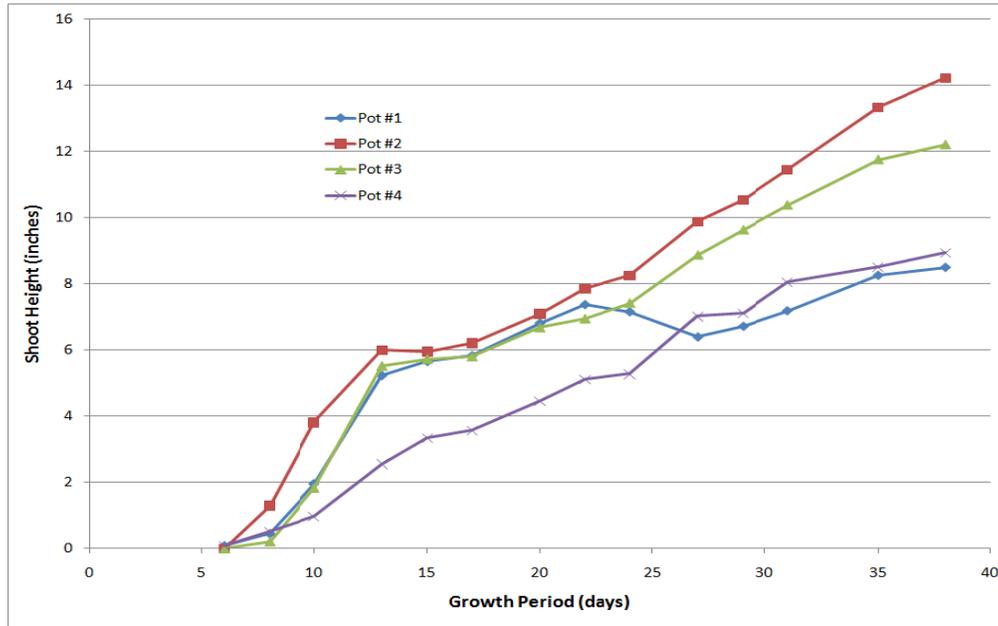


Figure 19. Results of the study which aimed to assess effect of physical hindrance on germination and growth.

Effect of Hardness

Reactors in duplicate were sprayed with water having different hardness concentrations (0 ~ 80 mg/L as CaCO_3). The Reactors having received the highest hardness water made 100% germination (i.e., 4 germinations out of 4 seeds planted). Other Reactors made 75% (i.e., 3 out of 4) germination. As shown in **Photo 10** and **Figure 20**, the highest growth of the beans was achieved in Reactor D which has been sprayed with water at a hardness concentration of 80 mg/L as CaCO_3 . In general, the numbers of leaves were not significantly different among the reactors (**Figure 21**).



Photo 10. Resulting view of the experiment to assess the effect of hardness on germination and growth.

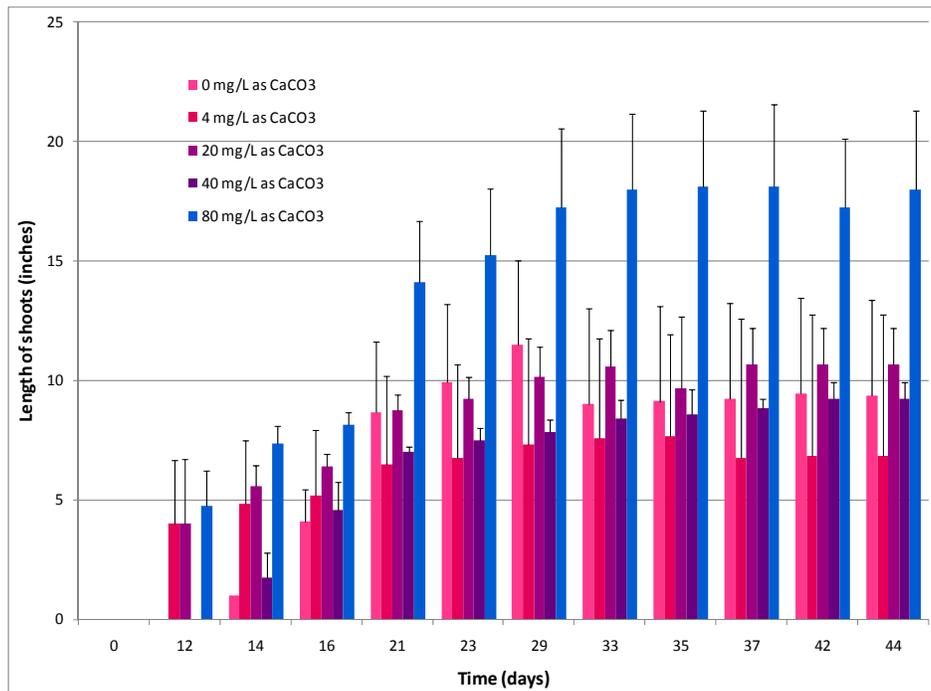


Figure 20. Length of bean shoots when receiving water at different hardness concentrations. Bars indicate standard deviations: $n=3$ for the reactors receiving 0, 4, 20, and 40 mg/L hardness as CaCO_3 , whereas $n=4$ for 80 mg/L case.

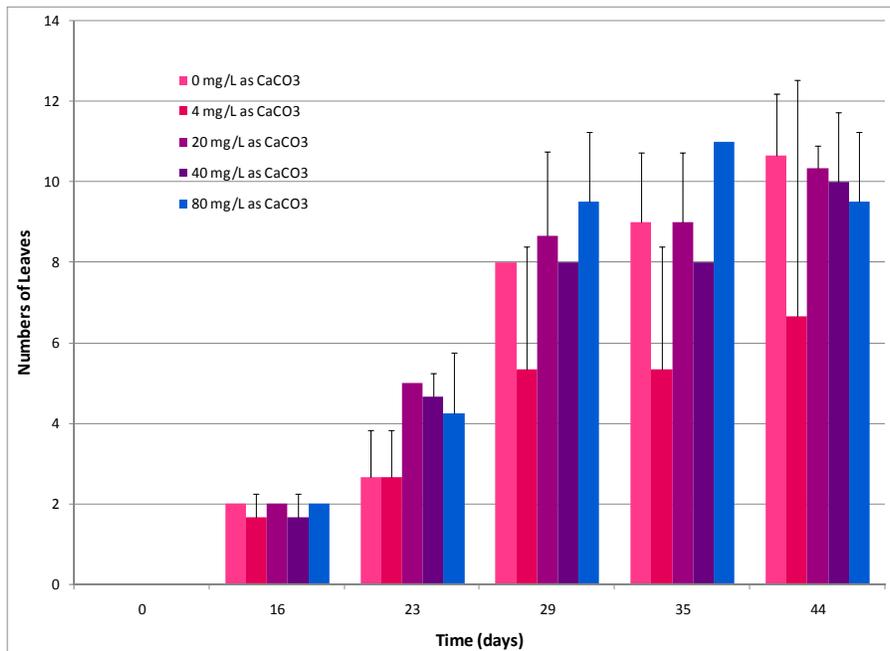


Figure 21. The numbers of bean leaves when receiving water at different hardness concentrations. Bars indicate standard deviations: n=3 for the reactors receiving 0, 4, 20, and 40 mg/L hardness as CaCO₃, whereas n=4 for 80 mg/L case.

Expansion of Physical Hindrance Experiment with Various Plants

As shown in Photo 11, botellas, papayas, beans and later pumpkins were tested with respect to physical hindrance that the CAA layer might exert for their roots and consequently their growth. Baby botellas (~8 inches) and papayas (~5 inches) were planted directly to the Reactors, whereas beans and pumpkins were seeded to the Reactors.



Photo 11. Various plants (botellas, beans, papayas, and pumpkins) tested for potential physical hindrance.

Botellas: Two identical baby botellas were planted in the Reactor 1 and 2 (Photo 12). Due to the physical characteristics of their leaves, no specific measurements have done with them. However, regardless of the amendments (CAAs vs. gravel) below 7-in top soil, both botellas have grown well so far up to more than 4 months.

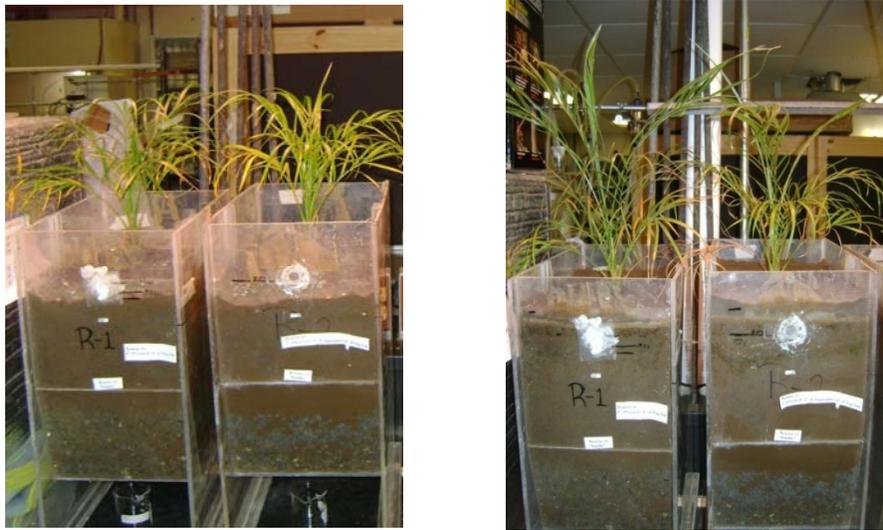


Photo 12. Comparison of the growth of botellas between the initial day (left) and 160th day later (right).

Papayas: Initially, one papaya was planted to each Reactor (Reactors 3 and 4). However, those two baby papayas died after one month due to parasites developed on the leaves. Four new baby papayas were obtained from a nursery farm and two were planted again to one reactor. This time, a commercial pesticide (VEL 4283) was diluted 130 times as instructed and the leaves were gently swabbed with it. Results are shown in Figure 22.

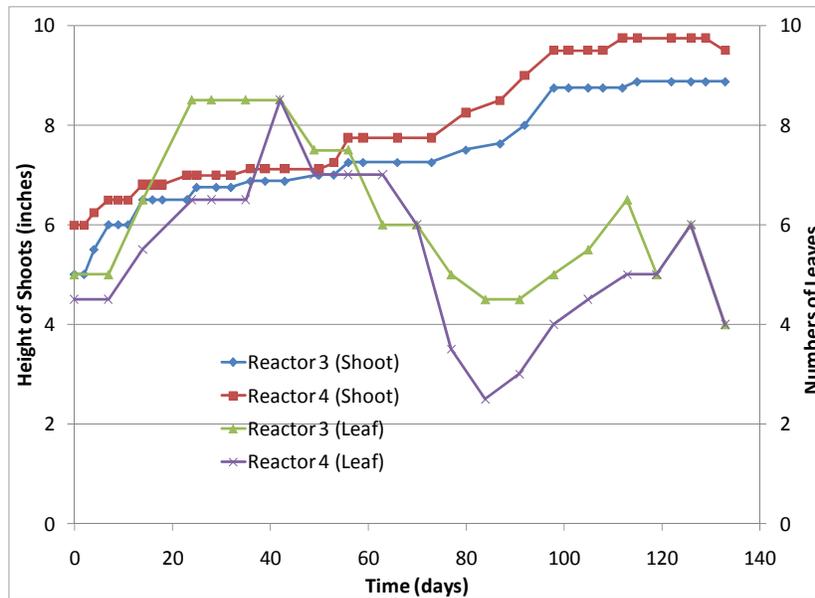


Figure 22. Height of shoots and the numbers of leaves of papayas.

As shown, shorter shoots but more leaves were found from the papayas planted in Reactor 3 which had the CAAs layer five inches below the top soil. However, it is not sure at the moment whether or not the initial physical conditions have influenced the results. That is, four identical baby papayas were obtained and planted to the Reactors but the Reactor 3 started with shorter shoot and more leaves in the beginning.

A chlorophyll meter (SPAD-502, Konica Minolta) was acquired in the middle of the experiment and the chlorophyll intensity was monitored on the leaves of papayas. Monitoring results showed a healthier growth of papayas in the Reactor 3 which had a CAAs layer than in the Reactor 4 which had a gravel layer (Figure 23).

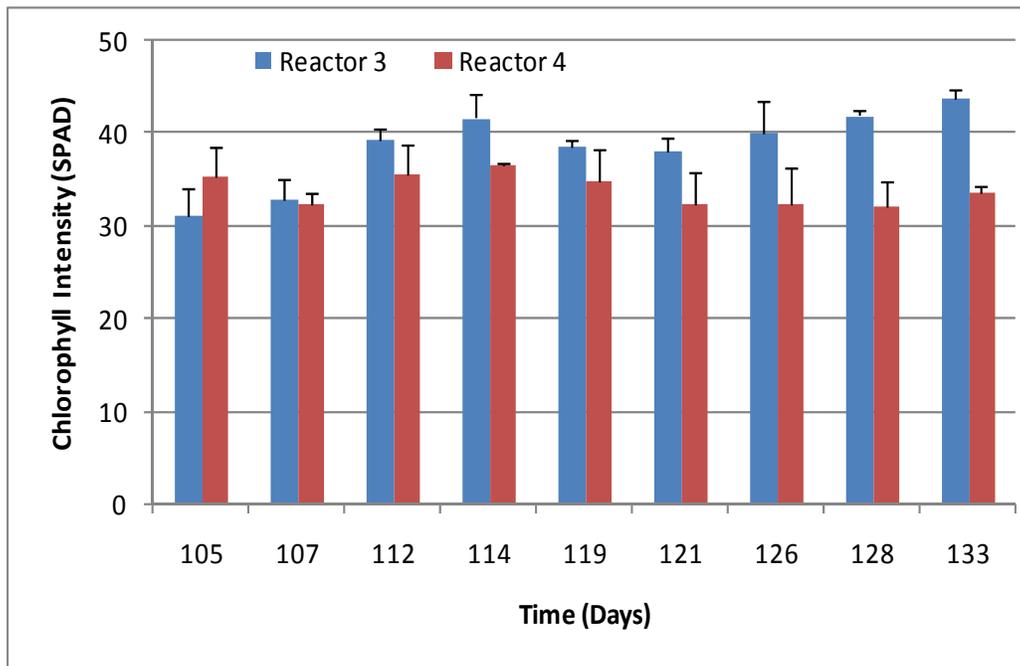


Figure 23. Chlorophyll intensity in the papaya leaves.

Beans: Beans were germinated almost the same time. First cotyledon was observed after 8 ~ 10 days. Likely, they started blossoming 29 ~ 31 days after seeding. The heights of shoots of the beans grown in the Reactor 4 were very dissimilar between two bean plants. The numbers of bean leaves were found very similar except for a bean grown in the Reactor 4 (Figure 24).

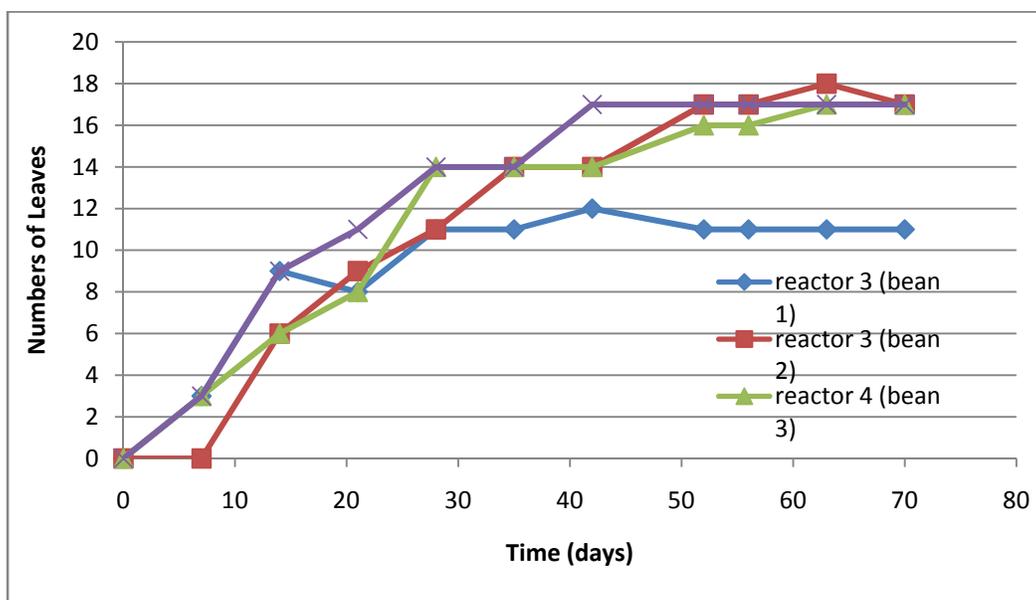
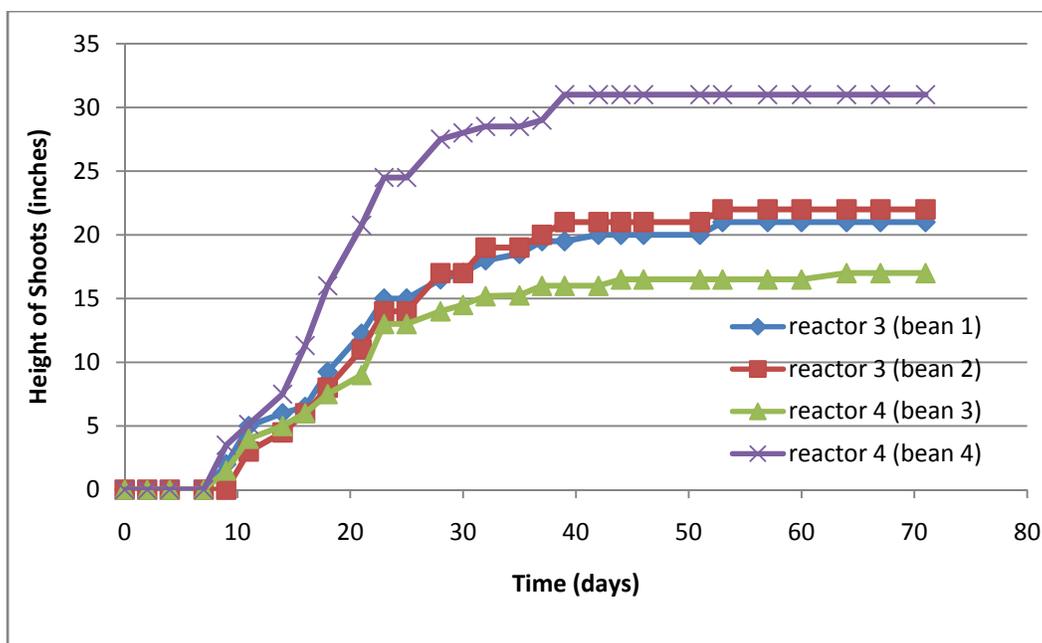


Figure 24. Height of shoots (top) and the numbers of leaves (bottom) of the beans.

After ~40 days, bean sacks were developed and their numbers and lengths were monitored (Figure 25). Data were varying much and did not show any significant trends. However, two beans grown in the Reactor 3 showed closer data points than those in the Reactor 4. Bean seed in the sacks were harvested at the end of experiment and extracted for Pb analysis by a HACH Digestion method. Extracted liquids were measured for Pb with an ion selective electrode and the results showed no Pb in the extractant.

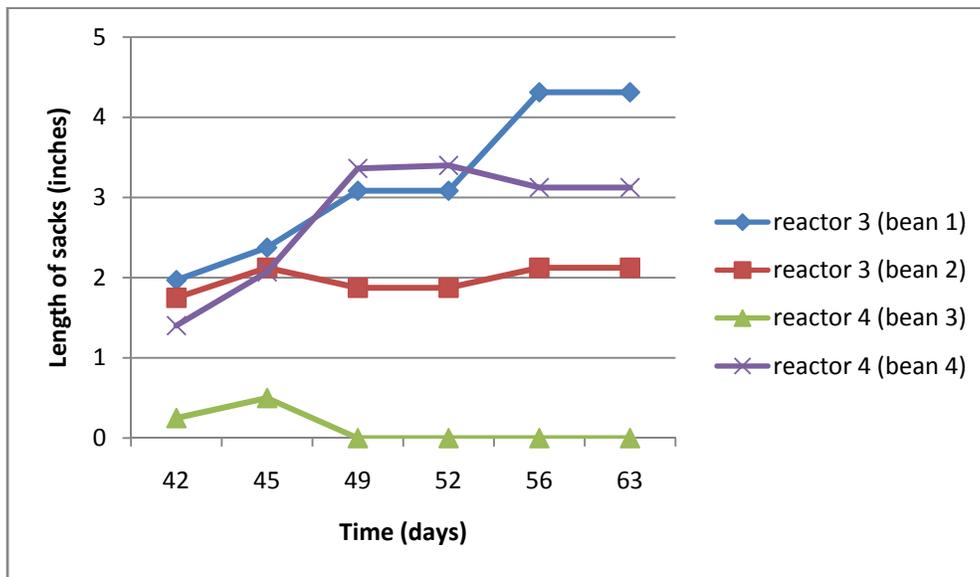
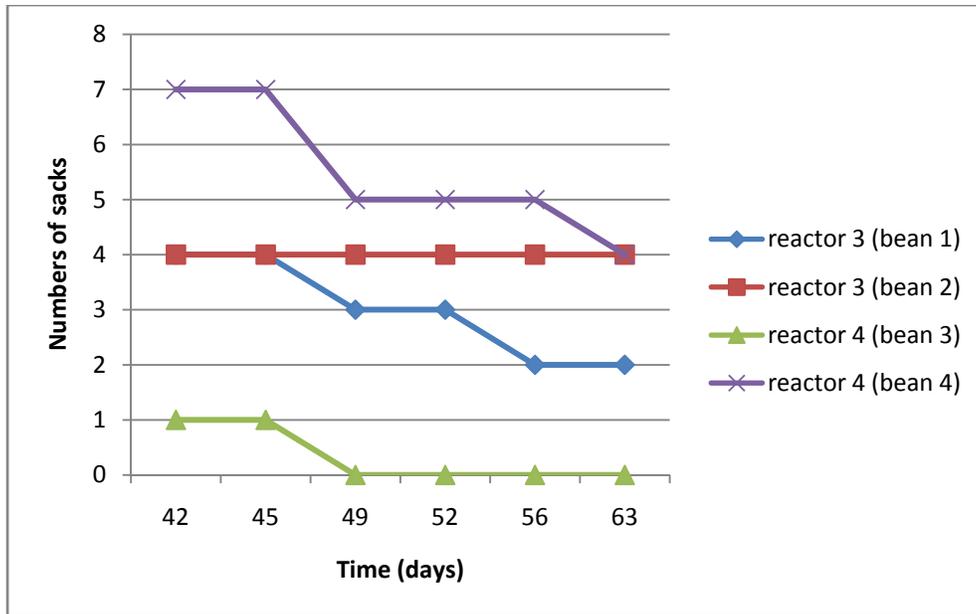


Figure 25. The numbers (top) and length (bottom) of bean sacks.

Pumpkins: Bean stalks were cut close to the roots after completion of the experiment. Then, two pumpkin seeds were planted in the same reactor (Reactors 3 and 4). In the Reactor 4 which had a gravel layer as a physical barrier 5 inches below the top soil, one seed did not germinate at all and the other one died after a month of growth. However, pumpkins germinated in the Reactor 3 have grown well (Figure 26).

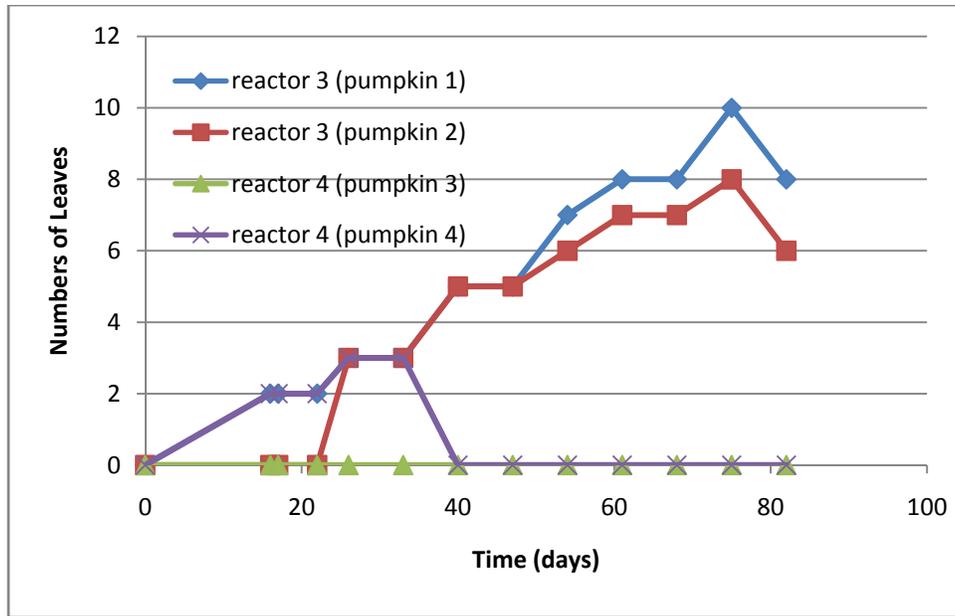


Figure 26. The numbers of pumpkin leaves.

On-going and Future Studies

A long-term water quality assessment with the different temperature settings and different backfilling configuration is currently being conducted. Experimental data and results will be presented in the next progress report.

In an experiment where the CAAs were used as an alternative daily cover for landfills, lower concentrations of nitrate were detected in leachate from the CAA-amended landfill reactor than from the control landfill reactor. As the restored land will be used for agricultural purpose, it is expected that farmers use fertilizers rich in nitrogen and phosphorus when they grow crops on the restored land. In these regards, future study will evaluate if the CAA-amended refilling can reduce nitrogen and phosphorus concentrations in the downstream water body due to topical fertilizer applications.

Seven different solid matrices have been used in the study. They were top soil, bottom soil, site soil, two different size CAAs, sand and gravel. Individual leaching tests will be further conducted to quantify their extent of contribution to the whole water quality parameters. Also, extensive soil characterizations will be conducted to assess physicochemical characteristics such as hydraulic conductivity, carbon, nitrogen and phosphorus contents, soil types, and particle distributions.

Native grass species to Santa Isabel (e.g., Tropical Fimbray) will be sampled on site and planted in the pots. The PI has been working with tropical fimbray in his another project studying fate and transport of organic chemicals (Feliciano et al., 2008). Plant experiment will be expanded to a feasibility study with other types of plants (e.g., papayas and plums). Later, scaled-up pots will be set up in the field experiment area of the Department of Civil Engineering and Surveying, UPRM. Subject to natural weather environments (e.g., precipitation, wind, evapotranspiration, sunlight, etc), survival, physiology, and growth dynamics of the grasses, seeds, and trees will be assessed in conjunction to the spatial and temporal biochemical characteristics of leachate (i.e., heavy metal concentrations, TOC concentrations,

pH, and THB counts). Natural weather environments will be monitored via a weather station located in the experiment area.

Result Disseminations

Preliminary results obtained from the current research were presented at the local and international conferences as follows:

- Hwang, S., Escobar, Z., Hernandez, V., Latorre, I., Hernandez, I., Fonseca, A., Del Moral, A. "Environmental Engineering Applications of Coal Combustion Byproducts Aggregates", 2008 International Conference on Environmental Science and Technology (ICEST), Houston, TX, Jul 28-31, 2008.
- Latorre, I., Hernandez, I., Fonseca, A., Hwang, S. "Restoration of Open-Pit Quarry to Bio-viable Land: Resource Recovery Approach", XIII Sigma Xi, University of Puerto Rico, Mayagüez, PR, April 10, 2008.
- Hernandez, I., Feliciano, I., Hwang, S. "Bio-viability on Restored Open Pit with Coal Ash Aggregate Amendment", 2009 World Of Coal Ash Conference, Lexington, KY, May 4-7, 2009.
- Latorre, I., Roman, D., Hwang, S. "Feasibility of Open Pit Restoration with Coal Ash Aggregates: Ground Water Quality Assessment", 2009 World of Coal Ash Conference (WOCA), Lexington, KY, May 4-7, 2009.
- Hwang, S., Latorre, I., Hernandez, I. "Groundwater Quality and Phyto-Viability from Restored Open Pit", 2009 AWWA Annual Conference & Exposition, San Diego, CA, June 14-18, 2009. (accepted)

References

- Feliciano, I., Hwang, S., Padilla, I. "Distribution of Explosives TNT and DNT with Surface Vegetation *Fimbristylis Cymosa*", 2008 AIChE Annual Meeting, Philadelphia, Pennsylvania, November 16 – 21, 2008.
- MDNR. (1992). A Handbook for Reclaiming Sand and Gravel Pits in Minnesota, Minnesota Department of Natural Resources, USA.
- Pando M., Hwang S. (2006) "Possible Applications for Circulating Fluidized Bed Coal Combustion By-products from the Guayama AES Power Plant". Technical Report. Civil Infrastructure Research Center, University of Puerto Rico at Mayagüez, PR

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	2	0	0	0	2
Masters	3	0	0	0	3
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Puerto Rico's House of Representatives Motion – A motion to congratulate and acknowledge the Institute for its public services in collaboration with the House Commission on Environment and Natural Resources Conservation.

Puerto Rico's House of Representatives Motion – A motion to congratulate Dr. Jorge Rivera-Santos, Director of the Puerto Rico Water Resources and Environmental Research Institute for its unselfish service on behalf of the environment, seeking viable alternatives for the protection and conservation of our natural resources.

Dr. Jorge Rivera-Santos received the AWWA's Fuller Award - George Warren Fuller Awards are presented annually by the AWWA to the sections' respective selected members for their distinguished service to the water supply field in commemoration of the sound engineering skill, the brilliant diplomatic talent, and the constructive leadership which characterized the life of George Warren Fuller.