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Watershed Management to Meet Water Quality Standards by Using the Vetiver System in Southern Guam

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Abstract

Sedimentation as the result of runoff is the principle human-caused threat to the environment in general and the water quality in particular in the Pacific island of Guam. Runoff water is characterized by flash floods of high velocity but short duration. The rapid flow is attributed to low soil infiltration, a high proportion of rain converted to overland flow, and scanty or absent vegetation cover due to wildfires. In the areas where protective vegetation cover is lowest, the soil is subjected to the high shearing force by such an overland flow.

Erosion damage is a serious problem to the environmental ecosystem of the island. Sediment lost to erosion clogs rivers, lakes, and waterways. Erosion and sedimentation loss are also a major source of water-quality problems in Guam. Sedimentation provides a vehicle for the transport of agricultural chemical residues into the canals, streams, rivers and eventually the near-shore ecosystems, where it damages coral reefs.

The objective of the project reported here was to assess the sediment-loading rate to the near-shore coral reef originating from the upland watershed. The effectiveness of vetiver systems (VS) as a sediment trap and its effect on quality of the water leaving the upland watershed was evaluated. Four plots (22 x 1.5 m) were laid out on a uniformly sloped (12%) watershed for estimation of sedimentation rates. Each plot was equipped with 20 cm high flume wall that separated its surface from those of the other plots and their surroundings. Flumes are equipped with cone-shaped weirs that directed the runoff and sediments into a collecting tank beneath the weirs.

In order to evaluate the effect of different soil surface management on erosion and quantify the sedimentation and turbidity of the runoff water from each plot, the following treatments were examined at this particular watershed: (i) Natural vegetation 'as it is' treatment, (ii) 'VS' treatment as a restoration technique, (iii) 'controlled burn' treatment, (iv) 'exposed surface-no-cover' treatment

The above-mentioned treatments represent a wide range of conditions that are present in a typical watershed area in southern Guam.

Keywords: *Vetiver system, sediment loading rate, water quality, coral reef.*

Introduction

Guam is the southern island of the Mariana chain in the western Pacific. It is 2,600 km east of Manila, Philippines, and about the same distance south of Tokyo. The inland is about 48 km long and 6 to 9 km wide. The southern part of the Guam is mostly volcanic, mountainous and deeply bisected by many rivers. The northern part of the inland is coralline, relatively flat and devoid of rivers (Muniappan *et al.* pers. comm.).

Volcanic and mountainous southern Guam is prone to soil erosion by water. Because of severe erosion of the soil in the upstream during heavy rains, it is quite common to note muddy

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freshwater mixing with the seawater at the river mouth damaging the coral reefs. Guam receives about 2,200 mm of rain per year and over 75% of it falls from June to November (Muniappan *et al.* pers. com.). Forest fires are frequent during the dry season (December to May) causing bare soil to be exposed to sunlight as well as rainfall, which cause severe erosion on these areas (Khosrowpanah 1991).

Runoff water in Guam is characterized by flash floods of high velocity but short duration (Young 1988; GEPA 1986). The rapid flow is attributed to low soil infiltration, high proportion of rain converted to overland flow, and scanty or no vegetation cover due to wildfires. In the areas that protective vegetation cover is at its minimum, and the soil quality is poor (low organic matter content) the soil is subjected to the high shearing force of such an overland flow.

Through soil removal or sediment deposition and nutrient removal, erosion alters the inherent physical and chemical properties of soils (Lal 1987; Lal *et al.* 1997; Nearing *et al.* 1994). This alteration may result in degradation, in turn affecting the environment as well as the processes that regulate the productivity and sustainability of an ecosystem.

The on-site damage from erosion is indeed a problem to environmental ecosystem of the island especially in the southern regions. Sediment loss due to erosion clogs rivers, lakes, and waterways. It reduces the water storage capacity of reservoirs and canals and increases flooding. In addition, erosion and sedimentation loss are a major source of water-quality problems in Guam. Sedimentation is also damaging to the near-shore coral reef ecosystem.

Sedimentation from terrestrial runoff is the principle anthropogenic threat to Guam and the other Pacific Islands water resources and the near shore coral reef ecosystems. Non-point source (NPS) pollution as the consequence of sedimentation is one of the most significant threats to near shore water quality as well as coral reef ecosystems in Guam (Richmond 1993).

The impact of sediment-laden runoff on fringing coral reefs has been the subject of intensive research, yet knowledge of the effects remains qualitative (Wolanski *et al.* 2003). Because sediment can literally bury coral, sedimentation is a major cause of mortality in the initial life stages of hard corals (Wolanski *et al.* 2003). Sediments can effectively reduce recruitment rates and at higher concentrations affects a range of life history parameters in juvenile and adult corals (Richmond 1994). Over the last few decades, increases in population and changes in land use have led to significant increases in surface runoff and associated decline in water quality impacting the coastal reef ecosystem threatening the well being of the coral reefs (NRCS 1996; Richmond 1994; 1995).

Control of soil erosion resulting from intensive rainfall during the rainy season is an important and challenging task for the soil scientists, conservationists and foresters in these areas. The task for soil scientists and soil conservationists is to select, employ and evaluate effective vegetative systems forming dense hedge on the contour, having strong and dense leaves and stems while being resistant to: wildfire, drought, flood, insect and disease resistant. Among the plants considered for this purpose is the vetiver. It is a dense, bunch-type grass with stiff stems, an extremely strong root system (up to 4.6 m deep), and grows to the height of 1.5 m. Vetiver does not spread by stolen or rhizome, and does not produce fertile seed, hence poses no danger to become a weed (Wiecko, pers. comm.). The crown of the vetiver is located 10-20 cm under the soil surface, which makes it resistant to fire and grazing wildlife (Wiecko, pers. comm.). There are no reports of vetiver as being a host to diseases, insects and other pests (Wiecko, pers. comm.). It grows on all continents in tropical and subtropical regions, tolerates a wide range of soil pH and low fertility, and does well even on very shallow, rocky soils. It is both a xerophyte and a hydrophyte, and once established it can withstand drought, flood, and long periods of water logging (Wiecko, pers. comm.). It does not compete with other plants and it has associated nitrogen-fixing mycorrhiza, which would explain its green growth throughout the year. When planted 10-12 cm apart, it will form a dense 38-50 cm wide permanent hedge capable of trapping the sediment hence stopping the soil erosion *in situ*.

In this study we will evaluate the effect of the vetiver system (VS) on sedimentation in order to develop mitigation technique for soil erosion from the upstream watershed in southern Guam. Also, the effect of different soil surface conditions will be evaluated in this study.

Objectives

The specific objectives of the project are among the following:

1. Quantify sediment loss from the study plots in order to estimate the sedimentation from the entire watershed under investigation.
2. Evaluate the effect of different soil surface condition on erosion and sediment loss and provide recommendations for the restoration of the degraded land (watershed).
3. To evaluate the effectiveness of VS as sediment trap to mitigate sediment transport of a typical watershed in southern Guam.

Material and Methods

Field Evaluation for Soil Erosion and Sediment Loss Assessments

This on-going project commenced in May 2003 with the initial surveying and identification of possible projects sites for erosion monitoring and analysis.

Four plots each 22 x 1.5 m was laid out on a uniformly (12%) sloped watershed. Each plot was equipped with a 20-cm high flume wall that separated it from other plots and the surrounding slope. The flumes ended in cone-shaped weirs, in turn attached to end troughs that extended 20 cm into collecting tanks beneath the weirs, where runoff and sediments were collected.

Soil texture analysis from the site at the beginning of the experiment revealed that the soil under study contains 54.4% clay, 20.7% silt and 24.9 % sand making it a clay soil. The organic matter content of the soils under study was determined to be 3.9% on average (Table 1).

In order to evaluate the effect of different soil surface management on erosion and quantify the sedimentation and turbidity of the runoff water from each plot, the following treatments were examined at this particular watershed area:

a) Natural vegetation ‘as it is’ treatment.
b) The ‘VS’ treatment.
c) The ‘controlled burn’ treatment.
d) Tilled or ‘exposed-surface’ treatment with no soil-cover.

The above-mentioned treatments or soil surface conditions represent a wide range of conditions that are present in a typical watershed area in southern Guam.

The treatment with the native natural vegetation condition (‘as it is’) was used as a control for comparison purposes. The native Vegetation on the study plots was the savanna, typical of southern Guam. This savanna is for the most part a xeric ecosystem that is dominated by grasses, low shrubs, and scattered small trees, but wetland and limestone species are also found there (Raulerson 1979, Stone 1970).

The VS treatment was used as a restoration technique in order to evaluate the effect of VS on sediment trapping and the water quality conditions affected by these systems. The vetiver was planted in hedgerows of approximately 4 m apart while sunn hemp was planted between the hedgerows as a green manure in order to provide the initial nitrogen requirement for the grass. This treatment was particularly used to quantify the sedimentation and turbidity of runoff water from the treatment plot in order to develop best management practices to alleviate the impact of sedimentation and turbidity on near shore coral reef ecosystem.

The ‘controlled burn’ condition represents the erosion from land denuded of vegetation commonly by intentionally set savanna wildfires in southern Guam.

In the ‘exposed surface – ‘no-cover’ treatment the plot was tilled and the soil surface was left with no vegetation cover in order to expose the soil surface to rain-drop impact at all times to represent the degraded bare soils of southern Guam, known as badlands. The purpose of this treatment was to assess the sedimentation and turbidity on near shore coral reefs attributable to runoff from these severely eroded and exposed soil surfaces in watersheds in southern Guam.

The runoff from each plot was collected in a tank installed beneath the weir at the bottom end of each flume and the runoff was measured at each sampling event as described. The capacity (1.7 m^3) of the storage (catchment's) tank was based on 100% runoff from a 24-hour storm event that occurs within each ten-year cycle. The weirs at the end of the flumes are attached to an end trough, which is extended 20 cm into the storage tank. Storage tanks are placed beneath the collector troughs to collect the runoff from each plot and runoff was measured before tanks were drained for the subsequent events. A set of suspended sediment samplers were installed in each tank for the measurement of sediment discharged from the flumes. In addition to the samples from the sediment samplers for turbidity analysis and sediment quantification, sub-samples from the runoff water in the tanks were taken after the water in the tank was stirred using high-pressured stirrer. Both samples were combined for final sedimentation analysis.

Samples as well as sub-samples were collected twice a week during the wet season (July – December) and once a week during the dry season (December – June). Samples were brought to the lab and allowed to sit for 72 hours. When the sediments were settled, most of the water was drained and the sample was transferred into a beaker and dried at 75^{o}C for 48 hours then weighed to determine the sediment content collected for each treatment plots. Turbidity was measured from separate samples by using a Hatch 2100 instrument for each treatment plots.

Result and Discussion

As shown in Fig. 1, during the dry season (January – June) almost all the treatments behaved similarly and the amount of sedimentation was minimal. The small amount of sediment eroded from the VS plot resulted mainly from tilling before the vetiver grass was planted; the vetiver grass did not become fully established until late April 2004. In general, not much sediment was produced from any of the treatment plots from February 2004 to June 2004, mainly due to low rainfall through out this dry season. During the rainy season, however, the VS plot showed much less erosion than the others – less than one third that from the natural-vegetation plot and less than 1% of that from the bare-surface plot (Table 2). Soil erosion, and the differential between the VS plot and the bare-surface plot, was greatest after major storm events (Fig. 1). The same trend is visible in Fig, 2; the amount of sedimentation was the lowest in runoff water from the VS plot and highest in the 'bare-surface' plot. Although the average rainfall was about the same during the months of June and August, the sedimentation from the 'bare surface' plot was considerably higher in August due to the higher intensity of a major storm event that occurred in this month. Again it was shown that the VS treatment was the most effective in sediment trapping as an erosion control during a major storm event (Fig. 1).

The VS plot also produced the lowest turbidity measurements (Fig. 3). Fig. 4, depicting samples collected after a major storm event, shows the differences dramatically.

At the end of the study the organic-matter content of the soil was higher than at the beginning on both the 'VS' plot and the 'controlled-burn' plot; it was lower on the other two treatments (Table 1).

Results have shown that VS effectively reduced the amount of sedimentation as compared to plot with 'bare soil surface' and/or other plots with different treatment at the watershed under study. The result from this study also has shown that the VS not only is an effective measure for erosion control but also improves water quality downstream (Fig. 4), hence protecting coral reef from muddy waters in southern Guam. In short, as described by Xia and Shu (2003), vetiver, due to its unique characteristics, such as higher biomass, fast growth, and strong root system, has been documented to play an important role in water quality improvement due to reducing soil erosion at the watershed level. Also, the VS has been documented to play an important role for reclaiming degraded land for sustainable development and environmental integrity (Xia and Shu 2003).

Concluding Remarks

The results from this case study show that the VS effectively reduced soil erosion and the amount of sedimentation particularly as compared to areas of bare soil. The VS is not only effective for erosion control but also improves the quality of runoff water (Fig. 4) downstream, reducing sedimentation in near-shore waters and protecting coral reef from the detrimental effects of storm runoff.

In short, vetiver grass, due to its unique characteristics, such as higher biomass, fast growth, and strong root systems, has been documented to play an important role in reducing soil erosion as well as in reclamation of degraded land for sustainable development and environmental integrity.

In summary, restoration of natural resources in Guam and environmental protection in the island are achievable if the techniques described implemented properly.

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Table 1. Characterization of the soil before and after the experimental treatments

Initial soil characteristics				Management practices	Soil characteristics as affected by study treatments			
Ave. OM Content (%)	Ave. % soil texture				Ave. % soil texture			Ave. OM content (%)
	Clay	Sand	Silt		Clay	Sand	Silt	(%)
3.9	54.4	24.9	20.7	Burned	57.2	20.5	22.3	5.1
3.9	54.4	24.9	20.7	Vetiver	51.8	28.2	20.0	5.4
3.9	54.4	24.9	20.7	Bare Soil	54.8	26.1	19.1	3.0
3.9	54.4	24.9	20.7	Natural	56.8	25.7	17.5	3.8

Table 2. Annual soil loss from each plot with different treatments.

Size and slope of the study plots				Management Practices (soil surface conditions)	Soil loss (tons/ha/yr)
Area (ha)	Length (m)	Width (m)	Slope (%)		
0.0037	21.95	1.5	12	Controlled Burn	14.13
0.0037	21.95	1.5	12	Vetiver System	1.47
0.0037	21.95	1.5	12	Bare Soil	104.75
0.0037	21.95	1.5	12	Natural Condition	5.22

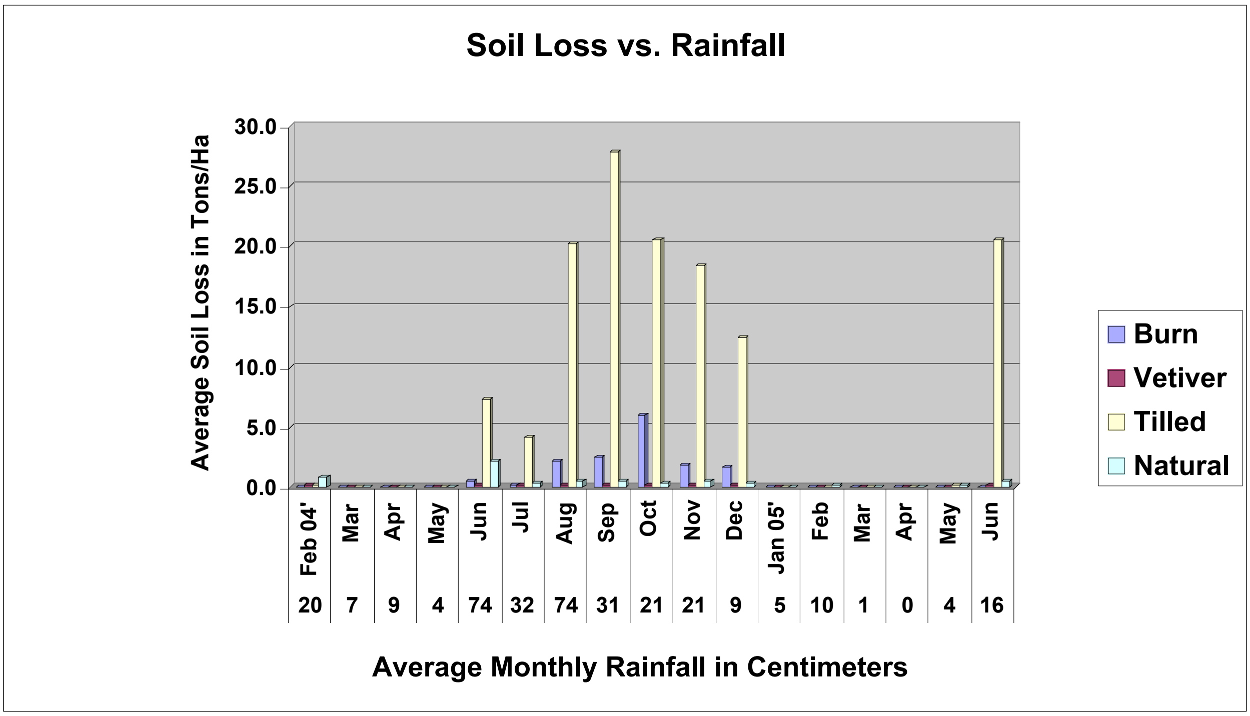

Fig. 1. Average monthly rainfall and resulting sedimentation from plots with different treatment

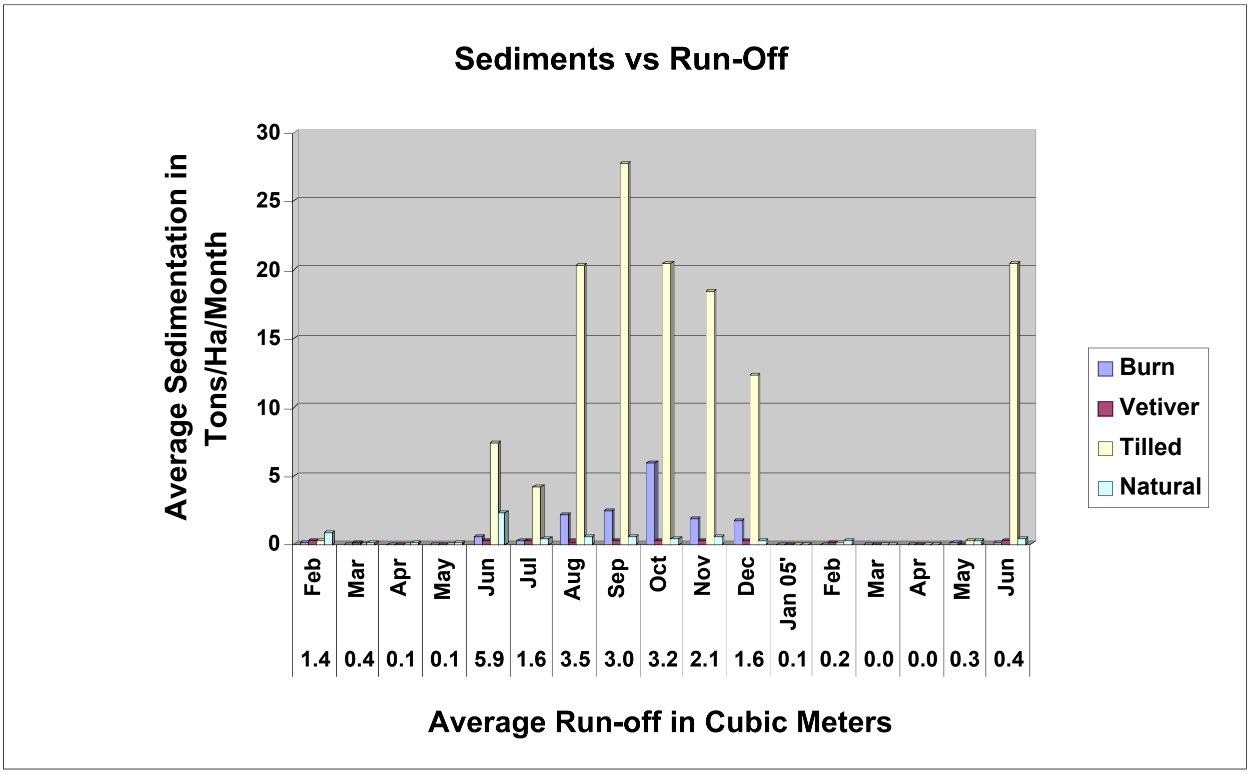

Fig. 2. Average monthly runoff and resulting sedimentation from plots with different treatment

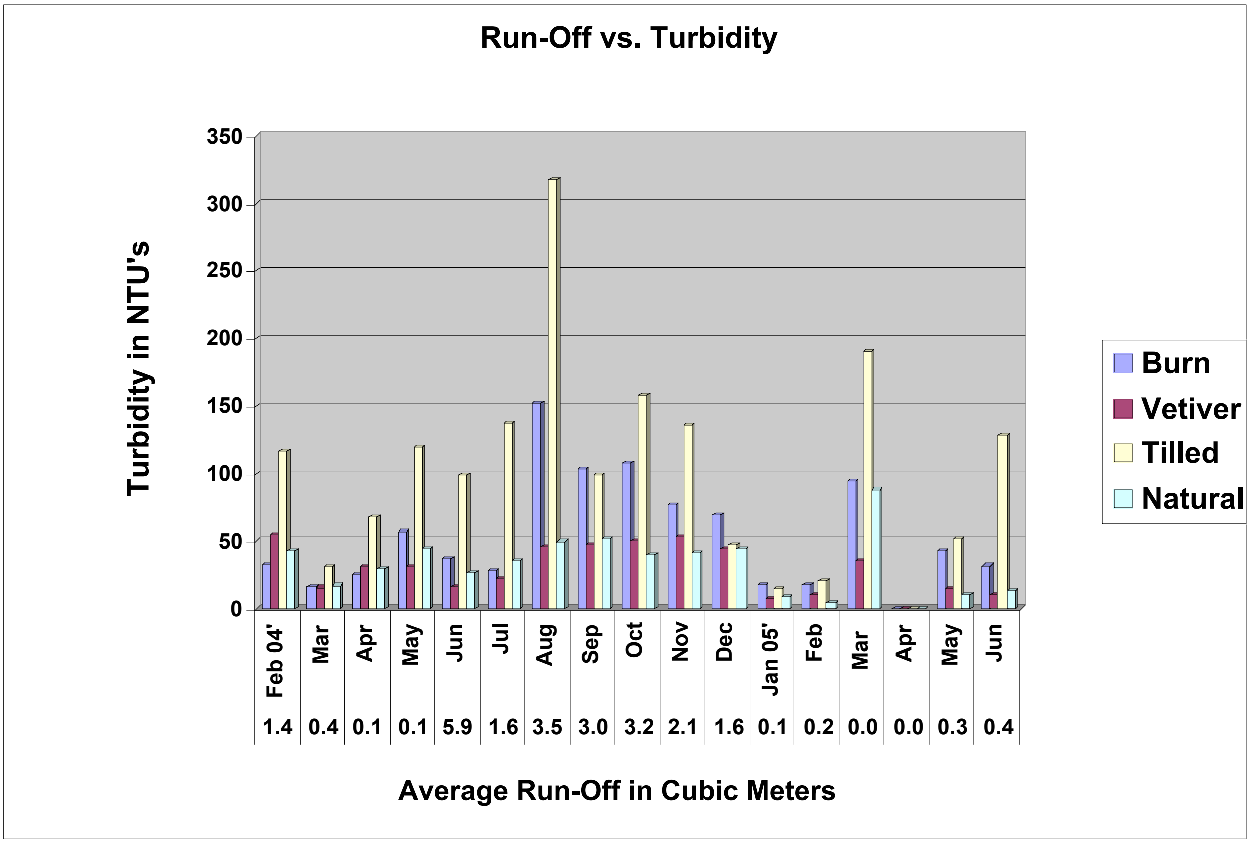

Fig. 3. Average monthly rainfall and resulting turbidity measurement from plots with different treatment

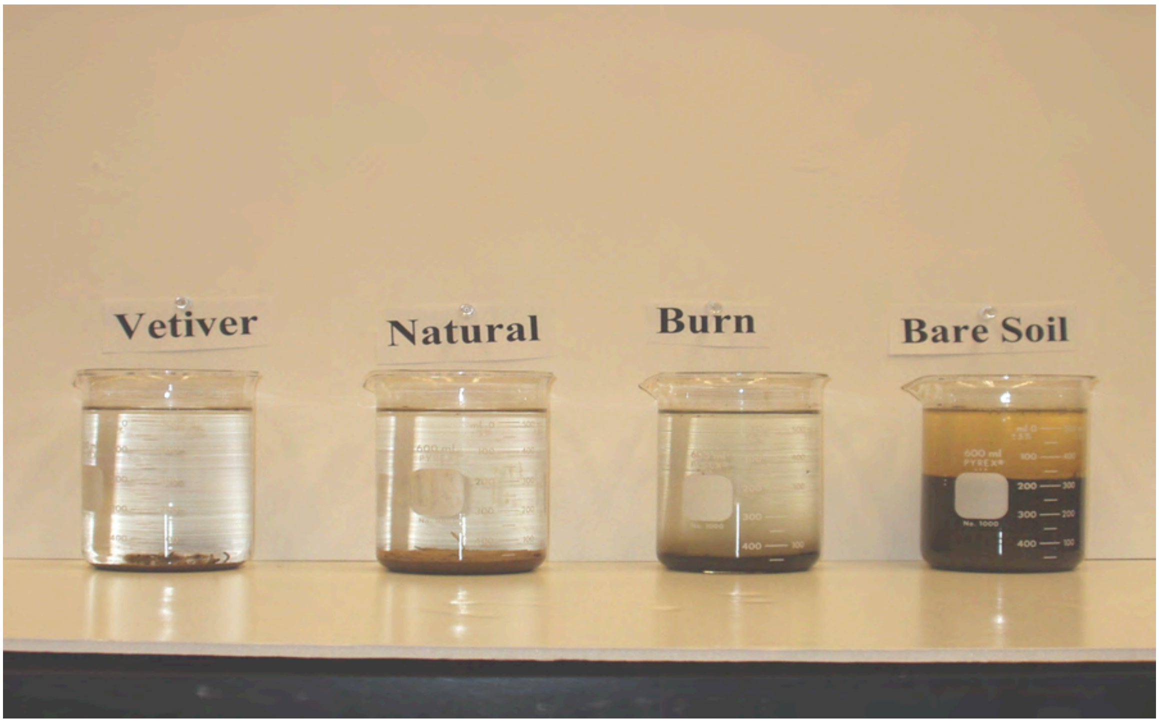

Fig. 4. Water quality is affected from a major storm event by showing the amount of sedimentation from each treatment plots