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ST. JOHN EROSION STUDY

Final Report to the Water Resources Research Institute-

University of the Virgin Islands

1 March 1998 to 31 August 1999

Prepared by:

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1. Introduction

St. John, located approximately 80 km east of Puerto Rico, is the third largest of the island group that comprises the Territory of the United States Virgin Islands. This 50 km^2 island is well known for its pristine beaches and the richness of its marine environment. Virgin Islands National Park comprises about 54% of the total land area and 23 km^2 of its offshore waters (Figure 1). The National Park Service, local authorities and residents are increasingly concerned with the potential environmental impacts due to the rapid development on privately-owned lands.

Several studies on erosion have been conducted in St. John since the 1980's. Hubbard et al. (1987) found a decline in coral growth rates, and they concluded that this decline was due to higher erosion and sediment delivery rates during the plantation era. In addition to land use effects, Hubbard et al. noted that watershed size and bay geometry were primary controls on the impacts of land development. Nichols and Brush (1988) concluded that the effects of human activities in increasing sedimentation rates on the Reef Bay Swamp and Mandal Pond were slight, and that sediment delivery to these environments is controlled by the impact of hurricanes.

More recent studies have combined geomorphic analyses with direct estimates of sediment production rates from specific sources. MacDonald et al. (1997) questioned the significance of plantation-era erosion, and they pointed to the unpaved road network as the primary source of sediment on St. John. A road erosion model (ROADMOD) was developed based on limited field

data (Anderson and MacDonald, 1998), and the application of this model to two watersheds on St. John suggested that current sediment yields for some watersheds may be several times higher than during the plantation era.

Another study from mid-1996 to mid-1997 measured runoff and sediment production rates from undisturbed areas and road surfaces at both the plot and road segment scales (Sampson, 1999; MacDonald et al., 2000). These results showed that runoff from undisturbed planar hillslopes was produced exclusively during extreme precipitation events, and that this runoff was not accompanied by any measurable amount of sediment. On the other hand, plot-scale data indicated that the road surfaces often generated runoff from storms of 6 mm or more, and that annual erosion rates were as much as 10 to 15 kg m^{-2}. Data collected from silt fences at the road segment scale suggested sediment yields ranging from 0.1 to 7.4 kg per square meter of road surface per year. A comparison of data from comparable sites indicated that sediment yields at the road segment scale were only 13-25% of the sediment yields at the plot scale.

Even though these previous research efforts have provided some information on runoff and erosion processes on St. John, a more intense and longer-term field study was needed to better quantify and understand the key processes and sediment sources. The current study responds to this need, and the main objectives were to:

(1) measure runoff, sediment production, and sediment delivery rates from undisturbed areas;

(2) measure sediment production and sediment delivery from unpaved road surfaces, fillslopes, and cutslopes;

(3) construct empirical models to predict sediment production and delivery from undisturbed areas, unpaved road surfaces, fillslopes, and cutslopes;

(4) quantify runoff rates and sediment transport through the fluvial system at various scales, and evaluate the role of land use on the observed sediment concentrations;

(5) develop a GIS-based empirical sediment routing model for St. John, and evaluate its performance against other commonly-used models; and

(6) educate the public about erosion processes, and provide specific strategies to minimize the potential adverse effects of anthropogenic sediment sources.

This report will describe the field and laboratory work conducted in St. John between June 1998 and August 1999. Field work that took place during this time period can be divided into three main categories, and these are: precipitation and runoff response; sediment production and delivery from roads and hillslopes; and sediment transport through the fluvial network at scales ranging from low-order sub-catchments to higher-order watersheds. Since the funds from the current project helped to trigger other funds that allowed us to continue the project for an extended 1999-2000 field season, the emphasis of this report is on the design and data collection.

Hence the following sections first outline the general approach of the study, site selection, and field and laboratory methods. This is followed by as summary of the work performed in the field and in the lab, construction of the GIS coverages for developing a sediment routing model, and our efforts to disseminate the preliminary results and educate the public about local erosion problems. The final section discusses the preliminary analysis of data collected during the first part of the first field season, but the detailed results will be written up into three peer-reviewed journal articles in late 2000-early 2001 as part of Mr. Ramos-Scharron's Ph.D. dissertation.

2. Overall Approach, Site Selection, and Methodology

The overall project design is based on the concept of a sediment budget, and the ultimate goal is to develop a GIS-based sediment routing model for several watersheds in the island of St. John. More specifically, we are quantifying sediment production rates from different landscape units as well as sediment transport rates at different scales through the fluvial system. The spatial integration of these production and transport rates in a GIS format will allow us to route the movement of sediment through the landscape. Figure 2 is a generalized flowchart of the sediment routing model being developed in this study.

The different types of measurements can be divided into; (1) hydrologic measurements, and (2) sediment production and transport measurements. Hydrological measurements are needed because water is the primary detachment and transport mechanism. Because rainfall is the basic driver of runoff, erosion, and sediment transport, we have been measuring precipitation rates at different locations across St. John. We also have been measuring the runoff response at scales ranging from small plots to entire watersheds.

Sediment production measurements include erosion rates at the hillslope plot and road segment scales. Sediment transport measurements are being used to quantify the transport rate of sediment at the road segment, sub-catchment and watershed scales, and these data will be used to estimate sediment yields at each scale.

2.1. Hydrologic Measurements

Precipitation

Even though the small size of the island of St. John would suggest a relatively homogeneous distribution of precipitation, wind and orographic effects produce a precipitation gradient that may induce significant differences in erosion and sediment transport rates across St. John. Bowden and others (1970) used daily rainfall data to delineate five zones with average annual

precipitation ranging from 127 to 140 cm close to Bordeaux Mountain to as little as 90 to 100 cm in the East End area (Figure 3). Given this variability, we have installed five recording raingauges and one non-recording gauge to document the short-term variations in rainfall and provide the data to develop and test our runoff and erosion models. Two of these stations are in the wet climatic zone (127-140 cm per year), two in the moderate zone (114-127 cm per year), and one in the moderately dry zone (102-114 cm per year) (Figure 4). Table 1 provides a general description of the type of raingauges being used, while Figure 5 provides a monthly summary of the data collected from July 1998 to August 1999 for four of the five recording raingauges.

Natural hillslopes

Three plots were set up in 1996 to measure the magnitude and frequency of runoff from undisturbed hillslopes (Sampson, 1999). Two of these plots are on the western slopes facing Haulover Bay on the drier eastern portion of the island, and the third plot is in the lower Fish Bay catchment. The plots are located on planar hillslopes with gradients ranging from 23-31%. Due to the fact that no recording raingauge was installed in the proximity of Haulover Bay, runoff volumes will have to be related to daily rainfall from East End or recording rainfall data from the stations shown in Figure 2. 4

The plots are approximately 10 m long parallel to the slope and 4 m across. They are bounded by 15-cm aluminum flashing sealed with concrete (Sampson, 1999). The downhill end of the plot directs all runoff to a PVC pipe connected to one or more 100 liter plastic reservoirs connected in series. The plots are checked after large storms. If a measurable volume of runoff has accumulated in the plastic reservoirs, the volume is determined by measuring the depth of water in the pre-calibrated reservoir. These plots were not operational for most of the 1998 field season, but runoff samples with minor quantities of sediment were taken late in 1998 and in July 1999 (Table 4).

Road-segment scale runoff

Runoff rates at the road segment scale are being continuously measured at two sites using 8-inch cutthroat flumes, pressure transducers, and data loggers that record the water level in the flume at 5 to 15 minute intervals. The water levels are converted to discharge by standard equations. These data will allow us to quantify the runoff response of the road segments. We are particularly interested in using this data to determine the amount and intensity of precipitation needed to generate runoff from each road segment, the sediment transport capacity of the road surface runoff, and the time distribution of runoff as compared to the precipitation intensity during individual storm events. Suspended sediment data are also being collected at these sites, but this will be discussed in the next section.

The first site was installed 20 September 1998 on a ditch in Cocoloba Trail, a long and partially unpaved road in the lower Fish Bay catchment on the southern part of the island. Fifteen-minute rainfall data are available from the Fish Bay raingauge, which is approximately 0.9 km away from the flume on Cocoloba Trail, and stage is also being recorded at 15-minute intervals. An example of the data collected from a storm event is shown in Figure 6. More information regarding the operation of this station will be presented later in this report.

The second station was installed on the road leading to the Maho Bay Eco-Resort on 20 August 1999. The runoff response from this station will be correlated with the precipitation data collected in the Maho Bay raingauge, which is less than 50 m from the top of the road segment draining into the flume. Initial observations indicated that stage data needed to be taken more frequently to accurately quantify the runoff response at this site. As a result, both stage and precipitation data are being collected at 5-minute intervals.

Watershed-scale runoff response and sediment yield measurements

Potential evapotranspiration (PET) in the island of St. John is greater than monthly precipitation totals for most of the year (Bowden et al., 1970). The deficit of rainfall relative to

PET means that there are no perennial streams in St. John (MacDonald et al., 1997). Cosner (1972) estimates that only about 5-10 cm of annual rainfall is available for groundwater recharge and surface water runoff. The combination of steep slopes, shallow soils, and high intensity storms results in "flashy" runoff hydrographs with exceptionally steep rising and recession limbs.

The current hypothesis is that there is a complex precipitation threshold required to initiate runoff in the streams (known as *guts* in the Virgin Islands). Precipitation amount, intensity, and antecedent conditions have to be considered in order to model this system. Cosner (1972) suggested that the runoff-rainfall ratio for a station on Guinea Gut on the southwestern portion of St. John ranges from 0.1 to 15.1 percent. The processes by which runoff is generated are important because they directly affect how sediment is produced, stored, and transported through the landscape. While short-lived storms during dry periods are not likely to trigger runoff in the guts, these events are able to produce runoff on road surfaces, and thus initiate erosion. This sediment is then deposited on the hillslopes or in the guts until a large event triggers saturation overland flow and runoff in the streams (MacDonald et al., 2000). Hence large storm events are probably the primary mechanism for the sporadic delivery of sediment to the marine environment.

As described by MacDonald et al. (1997), U.S. Geological Survey (USGS) discharge and suspended sediment sampling stations were operated in both Fish Bay Gut and Lameshur Bay Gut from mid-1992 until early 1994. The high cost, logistical problems, and paucity of runoff caused the National Park Service and the USGS to discontinue both stations after less than two years. As part of the current project, a discharge and suspended sediment sampling station was installed during the 1998 field season at the former site of the USGS station in Lameshur Bay Gut. A second station was installed in Fish Bay Gut, but this was placed about 100 m downstream of the USGS site in order to capture more of the runoff and sediment from the

extensive unpaved road network in the Fish Bay watershed. Stage at each of these stations is being measured at 15-minute intervals by a pressure transducer and a data logger.

The data collected at these stations will be used for four different purposes: 1) quantify catchment-scale water yields; 2) determine the precipitation thresholds needed to initiate runoff on these streams; 3) calculate suspended sediment yields; and 4) calculate bedload transport rates. Data from the old USGS stations in Fish Bay, Lameshur, and the still active Guinea Gut station will also be incorporated into this analysis.

Both stations operated satisfactorily and complete runoff data sets were collected for several events in late 1998. Figures 7 and 8 show the measured stage during the latter part of the 1998 field season for Fish Bay Gut and Lameshur Bay Gut, respectively.

2.2. Sediment production and sediment transport

One of the main objectives of this study is to quantify sediment production rates from different landscape units on the surface of St. John. Landscape units are defined as areas with distinct sediment production rates. These different rates are induced by the interaction of the physical characteristics of the eroding surface with the factors controlling erosion processes; hence the relative importance of the controlling factors varies from surface to surface. For this landscape units have been classified into two broad categories: undisturbed and disturbed surfaces. Undisturbed surfaces of particular interest include topographically-convergent hillslopes close to channel heads, planar hillslopes, and areas at stream margins subject to treethrow processes. Disturbed surfaces include all components of the road prism (i.e., road tread, cutslope, and fillslope).

In order to construct a realistic sediment budget, one must quantify sediment production rates from each landscape unit. Since it is not possible to make measurements on all units, one must develop procedures to predict sediment production rates from unmeasured sites, and these must be based on the processes that erode and transport sediment to the stream network. These

procedures will be necessarily be based on empirical relationships, but the complexity of these relationships will vary according to the factors that induce erosion on the particular surface being modeled and our ability to identify and measure the controlling factors.

Natural hillslopes

Two different methods are being used to quantify sediment production rates from natural hillslopes. The first method is to simply collect all of the runoff and sediment produced from the undisturbed plots described in Section 2.1. Because the volume of runoff is being measured after large storms, it is relatively straightforward to also determine the amount of sediment being produced. If any sediment is observed in the bottom of the reservoir at the time of sampling, the water is agitated and a sample is collected. These samples are filtered, dried and weighed to determine the concentration of suspended sediment. The total sediment in the reservoir is calculated by multiplying the measured sediment concentration by the total volume of runoff. If there is sufficient sediment, a particle-size analysis will be conducted using the hydrometer method (Bowles, 1992). A small number of samples have been collected from these plots over the period covered by this report, but the lab analyses have not yet been completed.

The second method to quantify erosion rates from undisturbed areas uses silt fences to collect the sediment produced from unchanneled convergent areas. Three silt fences were installed in the Bordeaux Mountain area during the 1998 field season and two fences were established in the Maho Bay area in 1999. At the end of the time period included in this report no sediment had been trapped in any of these silt fences, even though overland flow had occurred in all of the areas from several high volume and high intensity precipitation events.

Road surface

The main objectives of the road tread component of this project are to: 1) quantify sediment production rates and the particle-size distribution of eroded materials; 2) identify the most

important factors controlling erosion from the road tread; 3) build an empirically-based model of sediment production rates using precipitation data and road tread characteristics; and 4) generate data to test the applicability of other road erosion models (e.g., U.S. Forest Service, 1981; Anderson and MacDonald, 1998; Elliot et al., 1998) and for comparisons to other published data (e.g., Reid, 1981; Reid and Dunne, 1984).

From previous studies (MacDonald et al., 1997; Anderson and MacDonald, 1998) and our initial field observations we hypothesized that the major controls on road tread erosion are road gradient, road drainage pattern (as a control on road drainage area), road age after construction or grading, road usage, and climatic zone. Access and logistical limitations meant that our road segment study sites were concentrated in three of the precipitation zones mapped by Bowden et al. (1970), and these are: 1) the wet zone of 127 to 140 cm/yr as represented by Bordeaux Mountain and the Catherineberg (John Head Road) areas; (2) the moderate zone of 114 to 127 cm/yr as represented by the Lameshur and Maho Bay areas; and (3) the moderately dry zone of 102 to 114 cm/yr as represented by the Lower Fish Bay catchment.

Road drainage area is believed to be the primary control on the amount of runoff from the road surface for a given rainfall event, while road gradient is hypothesized to be the primary control on the velocity of overland flow. The product of area times slope is commonly used as a surrogate for total shear stress (e.g., Anderson and MacDonald, 1998). For this reason the product of road surface area and road segment slope was the primary criterion for selecting the specific road segments to be monitored within each of the three precipitation zones (Figure 9). Within the moderate precipitation zone we were also able to identify road segments spanning three levels of road usage, and these were abandoned roads, road segments used primarily by light vehicles, and road segments subject to high level of both light vehicles and trucks. Road age after construction or grading was not considered when selecting the study segments, but we will be able to evaluate the effect of this factor because all roads, with the exception of most segments

along the John Head road, have been graded at least once during the July 1998-May 2000 period of study.

Sediment production from road segments is being measured by two different methods. The first method uses silt fences at the outlet of road drainage features (i.e., culverts or rolling dips) to trap the sediment being transported from the road surface (Sampson, 1999). Hence the first step towards installing the silt fences was to find sites where all the road surface runoff was being collected and discharged at one location. At these sites we installed fabric dams by driving 3-feet long pieces of rebar vertically into the ground. One edge of the filter fabric was fastened to the rebar, while the other end was laid out on the ground upslope of the sediment fence. The upslope edge is then secured with rocks or with u-shaped landscape staples, and this apron upslope of the dam greatly facilitates the identification and removal of the trapped sediment. Fourteen fences were installed in 1998 and six fences were added in 1999 in order to better sample the range of factors that are expected to control road surface erosion on St. John (Figure 9).

After the fences have been installed, they are visited about every two to four weeks to check on their condition. If a measurable amount of sediment has accumulated in the fence, this is shoveled into buckets and weighed in the field. A well-mixed sample of about 2-4 kg is collected and placed in water-tight bags. These samples are taken to the lab to determine percent moisture content and particle-size distribution. The field-measured weight is then corrected according to the measured moisture content. Sediment production is calculated by dividing the total dry weight by the road surface area contributing to the sediment trap. Table 5 summarizes the work done on individual silt fences from July 1998 to the end of August 1999 and lists the field-measured weights of sediment collected in each fence.

The second method to quantify road tread erosion rates was to measure runoff and suspended sediment. Section 2.1. described the establishment of runoff monitoring stations on Cocoloba Trail in the Lower Fish Bay area and the road leading to the Maho Bay Eco-Resort. Suspended sediment samples at these sites were collected either manually or with a pump sampler. The

collected samples were filtered, dried, and weighed. The sediment yields from each road segment were determined by multiplying the mass of suspended sediment times runoff and integrating over time. If the mass of suspended sediment was sufficient, the particle-size distribution is also being determined by the hydrometer technique (Bowles, 1992). Between 21 October and 16 December 1998 a total of 39 suspended sediment samples were collected from Cocoloba Trail, while 9 grab samples were collected from two different storm events in late August 1999 at the Maho Bay Camp road. None of these samples had been analyzed by the end of August 1999.

Cutslopes

This component of the study is designed to quantify sediment production rates from cutslopes and fillslopes. Cutslope and fillslope sediment production rates were believed to comprise only a small fraction of the total sediment produced from roads. As a result, only a relatively small portion of our efforts have been devoted to quantifying sediment production rates from these sites.

The cutslopes on St. John were grouped into three different types according to their heights. For practical reasons the field work has focussed on sediment production rates from the low and medium height cutslopes. Table 6 lists the cutslope and fillslope sediment production plots established from July 1998 to August 1999 and the sediment collected from each.

The low cutslopes were defined as 1-2 meters high, and these are the most common type of cutslopes on St. John. These cutslopes are predominantly soil, with only minor portions of bedrock. In order to calculate an average annual sediment production rate from this type of cutslope, two different methods are being used. First, silt fences have been placed at the bottom of selected cutslopes to directly capture the eroding sediment. Fence installation and measurement procedures are the same as described in the previous section.

The second method uses erosion pins to directly measure the loss of material from the cutslopes over time. The erosion pins used in this study were 30-cm pieces of rebar inserted

normal to the cutslope. A pre-determined length of the pin is left protruding from the surface. The distance from the end of the rebar to the cutslope surface is measured once a year to estimate the cutslope erosion rate. The mass of sediment removed by erosion is calculated by multiplying the average erosion rate in centimeters per year times the cutslope area and an estimated bulk density. At each site the erosion pins were placed in a grid of 3-4 vertical columns about 20-30 cm apart, with each column having 5-7 pins about 20-30 cm apart.

Medium-height cutslopes range from about 3 to less than 10 meters high, and these typically have a much higher proportion of bedrock. Most of the eroded material is coarse fragments from rockfalls triggered by high-intensity rainstorms. Since it was not practical to install and measure erosion pins in these cutslopes, sediment production rates are only being measured by silt fences at the bottom of each site.

The third type of cutslope are those greater than 10 m high, and these are composed mostly of bedrock. This type of cutslope is found primarily along certain sections of Centerline Road, which is a paved road traversing the central spine of the island. During intense rain events this type of cutslope is subject to occasional rockfalls or debris avalanches. The amount of material produced from these high cutslopes is difficult to measure because the debris is usually removed by road crews within a day. Since these high cutslopes are not common and are generally older, we are not attempting to measure sediment production or delivery rates from these sites.

In addition to directly measuring the amount of sediment produced by cutslopes, we must also know the proportion of cutslope erosion that is delivered to the stream network. The proportion of sediment delivered from cutslopes is controlled by the rate of sediment production, the distance between the sediment deposits and the inside ditch, and the transport capacity of the ditch. In order to estimate the proportion of cutslope sediment that leaves the road prism, the sediment from cutslopes has to be isolated from the sediment originating from the road surface, and this has to be done without disturbing the amount or pattern of drainage. Paved road segments provide the best opportunity to measure sediment delivery from cutslopes without

altering the site conditions, and for this reason we have installed silt fences to directly measure sediment yields from culvert outflows along paved roads in the Caneel Bay and Maho Bay areas.

The Caneel Bay site consists of one fence collecting sediment from a 50-m road segment with a 4-m high cutslope. The Maho Bay site consists of four silt fences located on a 300-m road segment with 4-m high cutslopes. At the Maho Bay site three 4-m long silt fences were also placed at the bottom of the cutslope. This combination of sediment production fences and sediment delivery fences will allow us to compare the amount of sediment being produced with the amount of sediment being delivered by the road drainage system. Trap installation, measurements, and analysis follows the procedure described for road treads.

Fillslopes

Fillslopes in St. John are of the sidecast type, in that they result from the sidecasting of material directly from the blade of bulldozers or graders, and there is generally no attempt to compact the material. The uncompacted surface and vegetation regrowth usually precludes the development of infiltration-excess overland flow. As a result, sediment production rates from fillslopes are expected to be minimal, and we are assuming that the sediment production rates from unrilled fillslopes are similar to the sediment production rates from undisturbed planar hillslopes. We did install one sediment trap set in 1998 below a recently sidecasted fillslope, and this did not yield any sediment for several months. Fillslopes that are subject to road tread runoff tend to develop deep rills as a result of the concentrated runoff during the larger storm events. In the case of the fillslope fence installed in 1998, a change in the road drainage pattern directed runoff onto this fillslope and induced surface erosion by rilling (see Table 6 for information on this plot).

Streambanks

Sediment production rates from erodible streambanks are being measured from pins installed at several locations. The details of pin installation, measurement, and analysis are similar to the erosion pin networks used on cutslopes. Erosion pin grids have been installed on streambanks in lower Fish Bay Gut, lower Little Fish Bay Gut, lower Lameshur Bay Gut, and Jossie Gut in the Reef Bay catchment. Since only longer-term data will be collected by this approach, no results are available for the time period covered by this report.

Sediment transport along low-order streams

The amount of sediment transported from first-order catchments is also being measured with sediment traps. One such sediment trap was installed in a first-order tributary of the Reef Bay Gut during the first phase of this project, and this proved that these traps can withstand relatively large flow events from areas of approximately 0.15 km^2. However, a similar trap in a second-order stream with a much larger drainage area was destroyed by high flows in October 1998. Thus we have limited this component of the study to first-order streams.

During the 1999 field season two more traps were installed on first-order streams in the Reef Bay watershed, and two traps were placed on first-order tributaries of Gibney Gut, which drains northwards into Hawksnest Bay. The original trap in Reef Bay was emptied once in December 1998 and again in July 1999. No measurements had been taken from the other traps by the end of August 1999.

Sediment yields in higher-order streams

Sediment yields in higher-order streams are being evaluated by the collection of suspended sediment samples from the gauging stations set up in Lameshur Bay Gut and Fish Bay Gut (Section 2.1). The suspended sediment samples collected during the 1998 field season are summarized in Table 3. Some of these samples were analysed in early 1999 at the Water Resources Research Institute lab at the University of the Virgin Islands, but the results were

misplaced and are currently lost. We were also hoping to directly measure bedload tranport rates, but this has proven impractical in the larger streams due to the flashy runoff and difficulty of sampling deeper, high-velocity flows associated with high discharge events.

2.3. Development of GIS coverages

For our GIS-based sediment routing model we need spatially-explicit maps of the roads and stream network. For each road and stream segment we also need to measure or be able to predict key attributes. The road network and drainage points are being mapped with a GPS unit. For each road segment we are making detailed field maps of the road drainage pattern. From these data we can calculate road drainage area, slope, and the area-slope product. We are also collecting data on the characteristics of each cutslope in order to estimate their contribution to sediment yields at each road drainage point.

There is also a large field component associated with the development of the stream layer. For each stream segment we need to quantify those factors that control the sediment transport and storage capacity. Hydraulic and geomorphic parameters such as stream gradient, hydraulic radius, streambed roughness, and stream type are being determined by a combination of mapping and surveying. Empirical relationships will then be used to extrapolate these attributes to those stream segments that were not directly measured. The initial design for the road and stream coverages was developed under this project, but most of the field work was conducted after August 1999.

2.4. Educational Outreach

A very important part of this project is to disseminate our findings to the public, land managers, and private landowners. A greater awareness of road erosion issues should help stimulate further actions to reduce road erosion, while the communication of our technical findings can help landowners and land managers determine the most effective use of a given

expenditure. To this end we have been in regular communication with organizations such as the Department of Natural Resources (DPNR), University of the Virgin Islands (UVI), Virgin Islands National Park, Biological Resources Division of the U.S. Geological Survey, Natural Resources Conservation Service, Island Resources Foundation, and Friends of Virgin Islands National Park. We have also conducted a series of more formal presentations and interviews, and a partial list of these include:

- Presentation in the Water Resources Research Institute Seminar Series, UVI St. Croix Campus, 10 December 1998;
- Active participation in the DPNR Fish Bay Watershed Committee, July-December 1998;
- Conducted two field trips for the Fish Bay Homeowners Association in December 1998;
- Conducted a field trip for Chuck Weickert (Interim Chief of Resource Management for the VI National Park) and Julien Harley (Chief of Coastal Zone Management in St. John and current St. John Administrator);
- Interviewed by Amy Roberts for an article on the *Tradewinds* newspaper, April 1999;
- Conducted a field trip for Leo Preston, Natural Resource Conservation Service;
- Interviewed by Gail Karlsson for an article in the *St. John Times*, August 1999;
- Presentation to the Board of the Friends of the V.I. National Park, 1 September 2000.

3. Preliminary results and analysis

This following sections summarize some of the initial findings with respect to: road surface sediment production; sediment production from fillslopes, cutslopes, and paved roads; natural erosion rates from topographically convergent areas; and sediment transport and sediment delivery within the stream network. It is important to note that this analysis is preliminary, and that the representativeness of some of the data is subject to question because they were collected over a wet season with above average precipitation.

3.1. Road surface sediment production

3.1.1. Annual Erosion Rates

The data collected during this study provides some initial insight regarding the hypothesized controls on runoff, erosion, and sediment yields from different landscape units and at different scales. Table 7 lists the physical characteristics, traffic levels, and erosion rates for nine of the road segments established as part of this study. Figure 10 shows annual erosion rates for these same plots calculated from the data collected from July 1998 to August 1999. When extrapolated to annual values, the erosion rates ranged from 4 to 28 kg m^{-2} yr^{-1}, and this is substantially larger than the values for road segments estimated in MacDonald et al. (2000). Figures 11a-e plot the annual erosion rates from these road segments against five key factors—contributing road drainage area, average road slope, total precipitation, the product of road drainage area times slope, and the road ditch area times the average ditch slope.

With respect to road drainage area, our original hypothesis was that larger drainage areas should generate more runoff and hence higher erosion rates. However, Figure 11a shows a weak negative relationship between annual erosion rates and road drainage area. Additional data and analyses will be needed to clarify the reasons for this inverse relationship, but there are several factors that could help explain the observed pattern. First, the study by Sampson (1999) showed

that sediment yields at the plot scale of 20-60 m^2 were several times larger than sediment yields at the road segment scale of 200-800 m^2. This decline in sediment yields with increasing spatial scale is also consistent with most other studies of erosion and sediment yields, as increasing the spatial scale increases the opportunity for infiltration and sediment storage (e.g., Bunte and MacDonald, 1999). In the case of road erosion on St. John, the observed negative relationship is probably due in part to the deposition of eroded sediment within the road prism.

Figure 11b shows that the annual road erosion rate tends to increase with increasing road gradient. This is consistent with our hypothesis and erosion studies in other areas (e.g., Luce and Black, 1999). Further analysis of the data in Table 7 indicates that there is a weak negative correlation between road drainage area and average slope. This means that the road segments with larger areas tended to have lower slopes, and this may help explain why the larger road segments tended to have lower erosion rates (Figure 11a).

Figure 11b also shows that one road segment (SP-MB-Camp) had a much higher erosion rate than would have been expected from its average slope of 12.5%. This road segment is unique for several reasons, and these differences provide some additional insight into the likely influence of other factors on road surface erosion rates. First, this road is the only moderately-steep unpaved road that is subject to relatively high traffic by both heavy trucks and light vehicles. The reason for this high traffic load is that this segment leads to a popular holiday camp, and this means that the camp has to be regularly serviced by water supply trucks, group taxis, other supply trucks, and garbage trucks. Many of the guests also rent their own vehicles, and this further increases the traffic along this road segment (Table 7). This high traffic load is probably the primary reason for the second unique factor, which is the frequency of regrading. To the best of our knowlege, this is the only unpaved road on St. John that is graded at least twice a year, and a higher frequency of road grading should result in higher sediment yields (e.g., Luce and Black, 1999). Third, this segment does have one of the highest area-slope products (Table 7).

Figure 11c is a plot of annual erosion rates against total precipitation. In this plot the segments in the wetter zones (Bordeaux Mountain and John Head Road) are labelled as BM and JH, respectively, while the segments from the drier climatic zones (Fish Bay and Lameshur Bay) are labelled as FB and LB, respectively. We would expect that annual erosion rates should increase with increasing precipitation, but Figure 11c shows no such trend. Since the infiltration capacity and runoff rates from road segments should be relatively similar, it is clear that other factors, such as slope and traffic, are more important controls on road surface erosion rates than annual precipitation. We should also note that the Lameshur Bay site, which was originally thought to be in the moderate precipitation zone, received slightly less precipitation than the Fish Bay site, and this affects the sample sizes in the different strata as outlined in Figure 9.

Figure 11d is a plot of annual erosion rates against the areally-weighed product of road drainage area and gradient. Our hypothesis was that the area-slope product should be positively correlated with erosion (Anderson and MacDonald, 1998), but this trend is only weakly apparent in Figure 11d. Part of the reason for this poor relationship is that two segments with high area-slope products have low annual erosion rates (SP-JH-B and SP-LB-B, respectively). The low erosion rate in the first of these two segments may be due to the fact that this segment is older and rarely graded. Hence this segment is more heavily armored than most of the other segments, and the lack of fines would contribute to a lower erosion rate. The second road segment with an unusually low erosion rate is a segment in Lameshur Bay. The problem with this segment is that the sediment trap was often overtopped, and the pattern in Figure 11i suggests that the measured sediment yield was substantially underestimated.

Figure 11e is a plot of annual erosion rates against the area-weighted product of ditch drainage area times gradient. The roads on the extreme left-hand side of this graph were segments that did not have an inside ditch. As expected, this plot shows no general trend. These data and our field observations suggest that if road runoff is diverted to a stable ditch, road

segments with large drainage areas and steep slopes may have a substantially lower erosion rate than similar road segments where the road runoff flows along the road surface.

3.1.2. Road surface sediment production as a function of precipitation

The previous section analysed road segment erosion rates for the entire monitoring period. Since the total erosion for each road segment was based on as many as nine individual measurements, the accumulated sediment for each measurement period can be plotted against the precipitation associated with that period. By doing this for each road segment it is possible to more accurately evaluate the role of precipitation in controlling sediment yields.

Figures 12a-i show that there generally is a positive relationship between the amount of sediment produced from a given road segment and precipitation. In most cases the relationship appears to be relatively linear (e.g., Figures 12a, c, d), while for a couple of road segments the increase in sediment yield with precipitation appears to be more non-linear (Figures 12b, g). The strongly non-linear relationship for one of the segments in Lameshur Bay (Figure 12h) may be due to the fact that the runoff is diverted into an improvised, unarmored ditch, and the amount of runoff is a strongly nonlinear function of the amount of precipitation. Thus the smaller rain events probably generate little runoff at the road segment scale, while the larger storms generate large amounts of runoff that can pick up much of the loose sediment left along the side of the road after grading.

For several of the segments there appears to be a disproportionate amount of sediment from the period that included Hurricane Georges (e.g., Figures 12 a, b, g). We believe that these higher erosion rates are due to the amount and intensities of precipitation recorded during this event. Our recorded maximum 1-hour precipitation values ranged from 1.6 cm at the Fish Bay raingauge to 2.0 cm at the Lameshur Bay gauge. These relatively high intensities, when combined with wetter antecedent conditons, probably generated a disproportionate amount of runoff and road

surface erosion. Future analyses of these data will attempt to evaluate the relative importance of total precipitation, antecedent moisture conditions, and precipitation intensity.

Several of the road segments had little or no relationship between segment sediment yields and precipitation (e.g., Figures 12e, h, i). We have already noted that the sediment trap for one segment in Lameshur Bay (SP-LB-B) was often overtopped. The data for this segment show a horizontal trend because the measured values probably represent the maximum capacity of the sediment trap rather than the actual sediment production (Figure 12i). The lack of any significant trend for one of the Fish Bay plots (SP-FB-Marina-End, Figure 12e) may also be due to the problems in accurately measuring sediment production from this site. In this case we had to install a vertical rubber strip to serve as a cross-drain, and the runoff collected from the road surface was then directed across a fillslope to the sediment trap. The high erosion rates associated with relatively small rainfall values may be due to the initial erosion from water flowing across this fillslope. The sediment production data was also compromised by the fact that the cross-drain slope was inadequate to transport all the sediment eroded from the road surface, and the filter fabric dam was vandalized in late 1998.

This discussion and our preliminary analyses indicate that the specific site conditions can greatly influence the amount of runoff and sediment production. Another issue is the potential interaction between variables, as the slope of the relationship between precipitation and sediment production tends to be steeper for those segments with a higher slope-area product. This would be consistent with the general trend shown in Figure 11d, but the assessment of each individual factor is again complicated by the complex interactions between factors and the inherent limitations of sample size. Nevertheless, these preliminary data suggest that, at least in some cases, segment characteristics and total precipitation can be used to predict erosion rates at the road segment scale, and these relationships should be useful for predicting the likely erosion rates for different road segments under varying meteorologic conditions.

3.2. Fillslope and cutslope sediment production

Table 6 summarizes the data collected from the fillslope plot and the cutslope plots. The fillslope plot along John Head road (FP-JH-1) did not produce any sediment until a large storm event changed the pattern of runoff and directed some of the road surface runoff onto the fillslope. The resulting erosion rate was comparable to the sediment production rate from road surfaces. These data clearly show that road surface runoff should either be directed runoff away from the fillslopes, or that energy dissipators must be installed so that the runoff is not able to freely incise into unconsolidated fillslopes. This site also illustrates the difficulty of characterizing erosion rates when the basic causal factors can change greatly over time.

The cutslope plot data (Table 8) show that there is a great deal of variability in the measured erosion rates, and there is not a clear difference in erosion rates between the low and moderate height cutslopes. Figure 13 provides a comparison between erosion rates from three road surface plots and those from six different cutslope plots. The data also show that sediment production rates for some cutslopes are comparable to those from the road surface.

The data from the sediment traps along paved roads shows that a surprisingly large amount of sediment was being produced from the cutslopes and delvered to the sediment traps. Cutslope sediment production as measured by the short fences along a 0.29 km section of paved road was 6.3 kg/m^2 per year. Since the average cutslope height along this road is about 4 m, the total annual sediment production from cutslopes along this road segment can be estimated as 7.3 tons. The sediment traps along this segment yielded just over 3.0 tons/yr, or more than 10 tons/yr per kilometer of road. The ratio of sediment yield to sediment produced indicates that slightly more than 40% of the sediment produced from the cutslopes was delivered to the sediment fences by road runoff.

These results suggest that, in some cases, cutslope sediment production rates are comparable to sediment production rates from the road surface. The delivery of this material to a road drainage location can be difficult to assess. For unpaved roads the amount of sediment that is

delivered to a drainage location will depend on the location of the base of the cutslope relative to road surface flowpaths, the transport capacity and competence of the road runoff, and the particle-size distribution of the material eroded from the cutslopes. Since most roads have an inside ditch at the base of the cutslope, much of the material eroded from the cutslopes will be delivered directly into the ditch. Hence much of the cutslope erosion is readily available for transport, and we might expect that most of the finer material will be delivered to the road drains. For paved roads we would expect an even higher delivery ratio due to the greater amounts of runoff and limited potential for sediment storage in the much smoother inside ditches. While the overall importance of cutslopes cannot yet be assessed, it is clear that they can contribute a substantially higher proportion of the road-related sediment than originally predicted.

3.3. Sediment production from undisturbed, vegetated plots

The plots on vegetated planar hillslopes did not produce any measurable sediment during the first year of this project, even though several precipitation events did generate runoff. This confirms earlier assertions that sediment production rates from these areas are very low (e.g., MacDonald et al., 1997; Sampson, 1999). The low sediment production rates are probably due to both the paucity of runoff and the surface protection afforded by vegetation and rocks (Anderson, 1994). These data are important because they provide the basis for comparison to the measured erosion rates from unpaved roads, cutslopes, and fillslopes.

3.4. Sediment delivery rates from a first-order sub-catchment and implications for larger scales.

The sediment trap in the first-order stream in the Reef Bay catchment provides information on the ability of small, high-gradient streams to transport the sediment being delivered to them. In this case the 0.15 km^2 catchment includes a 0.58-km section of Bordeaux Mountain Road.

This road is relatively steep and located at or just below the ridge that forms the upper boundary of the first-order catchment. The road drains into a swale that was probably originally unchannelled, but is now a small channel. A total of 14.1 tons of sediment were collected from this trap during the first year of this study, and this converts to approximately 94 tons/km^2. If we assume that all of this sediment was derived from the road, this is equivalent to an erosion rate of 24 tons/yr per kilometer of road. Since this value is very close to the erosion rates calculated from other roads in the same area, this implies that the sediment delivery ratio for road-related sediment in these types of streams is close to unity.

At a larger scale the delivery of sediment from a road to the marine environment may be affected by the path the sediment follows. Table 9 lists five different scenarios or cases with examples of each. The last column provides a qualitative indication of the proportion of sediment that is likely to reach the marine environment and the possible implications. Key controls on the rate of sediment delivery include the frequency, duration, and magnitude of runoff events, as these provide the basic transport capacity. This runoff must then be routed into and through the channel network, and the channel characteristics will influence both the transport capacity and potential for sediment storage.

MacDonald et al. (1997) argued that most of the sediment delivered into the stream network will be delivered to the mouth of the guts as a result of the high magnitude of runoff events and the relatively steep and confined channels. This presumption should be tested against the data being collected under this project. Similarly, this project is quantifying the primary anthropogenic sediment sources and their respective controls. These data, together with the watershed-specific assessments of the road and stream networks, will provide the basis for a multi-scaled understanding of sediment production and delivery on St. John. This information can then be used to guide management decisions and design the sediment control strategies that are urgently needed to protect the resources that are integral to the economy and character of St. John.

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FIGURES

Figure 1

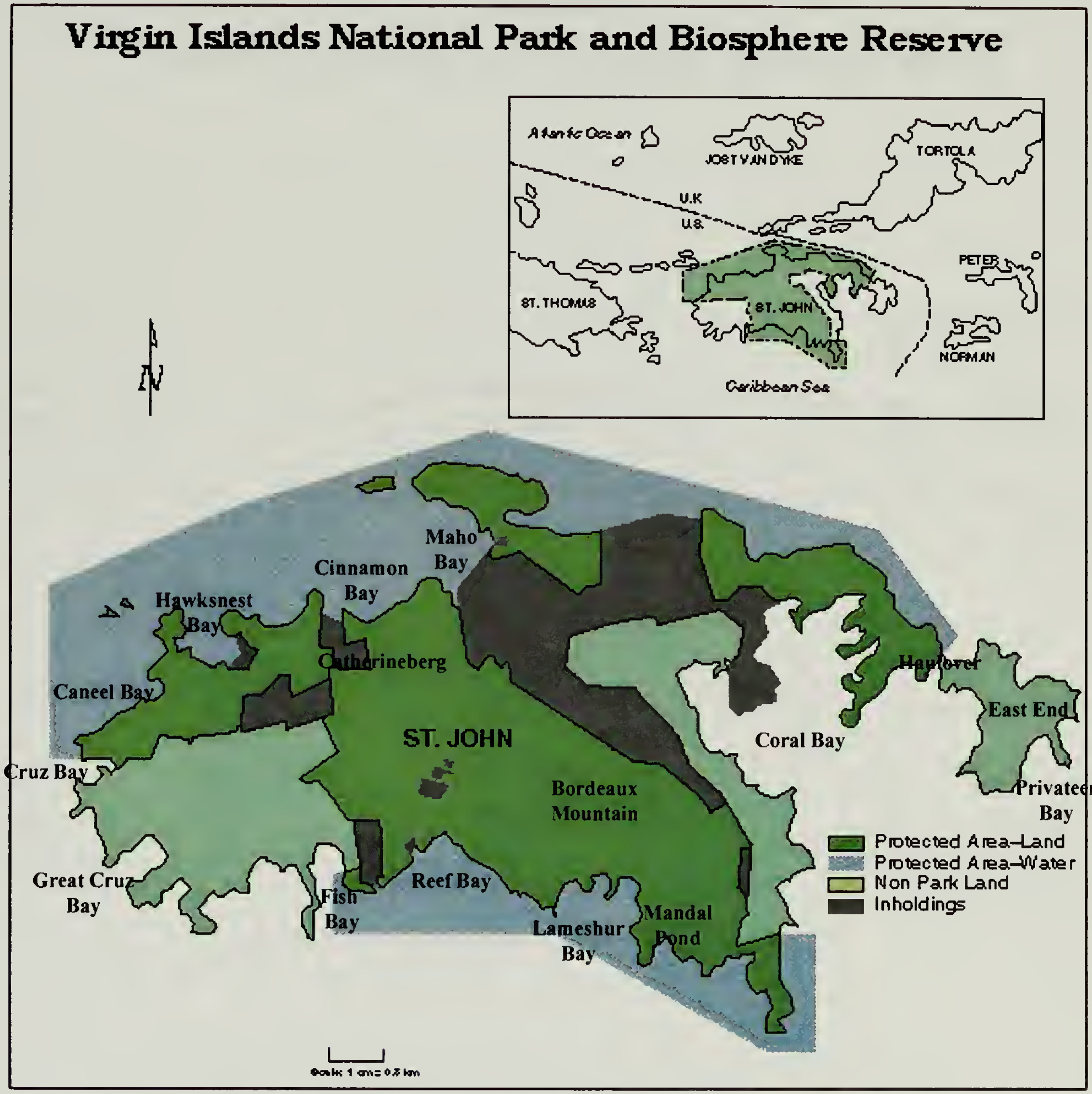

Virgin Islands National Park and Biosphere Reserve
Atlantic Ocean
JOST VAN DYKE
TORTOLA
U.K
U.S.
ST. THOMAS
ST. JOHN
PETER
NORMAN
Caribbean Sea
N
Maho Bay
Cinnamon Bay
Hawksnest Bay
Catherineberg
Caneel Bay
Cruz Bay
ST. JOHN
Bordeaux Mountain
Coral Bay
Haulover
East End
Privateer Bay
Great Cruz Bay
Fish Bay
Reef Bay
Lameshur Bay
Mandal Pond
Protected Area–Land
Protected Area–Water
Non Park Land
Inholdings
Scale: 1 cm = 0.5 km

Figure 2.
General Structure of Sediment Routing Model

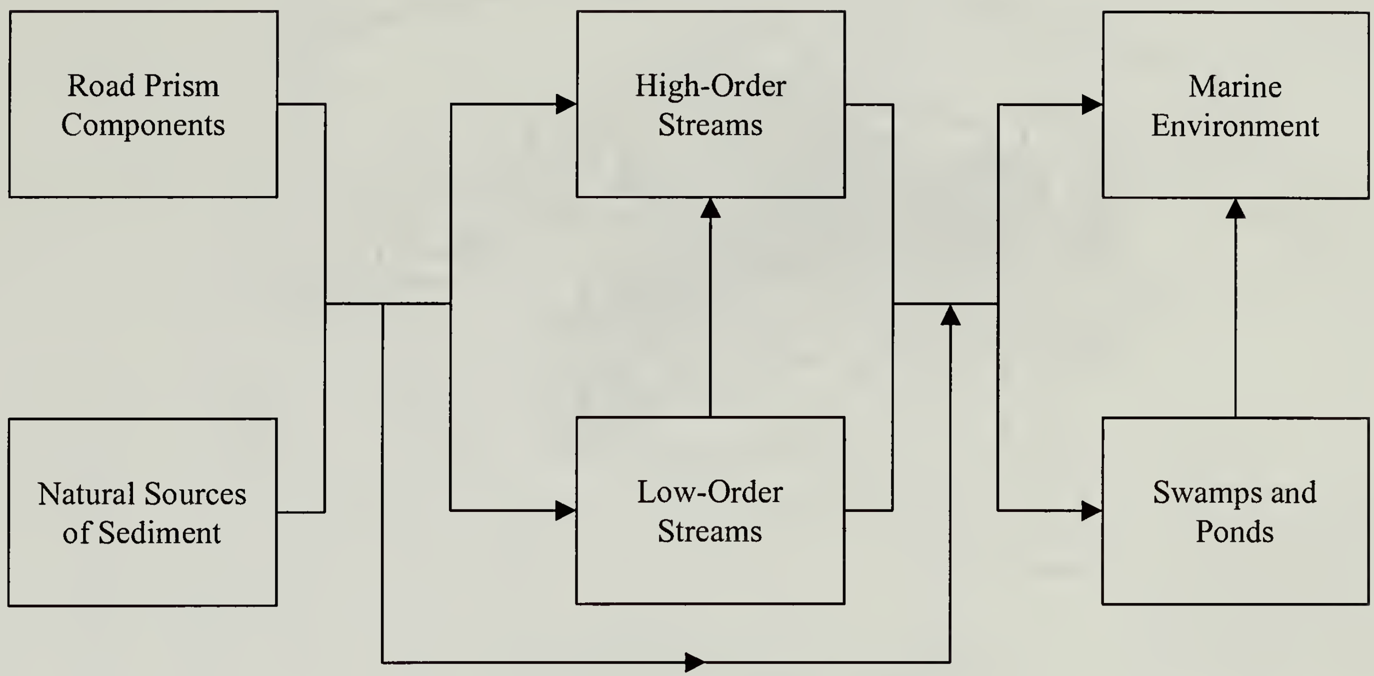


Figure 3. Average annual precipitation for St. John, US Virgin Islands (Bowden et al., 1970)

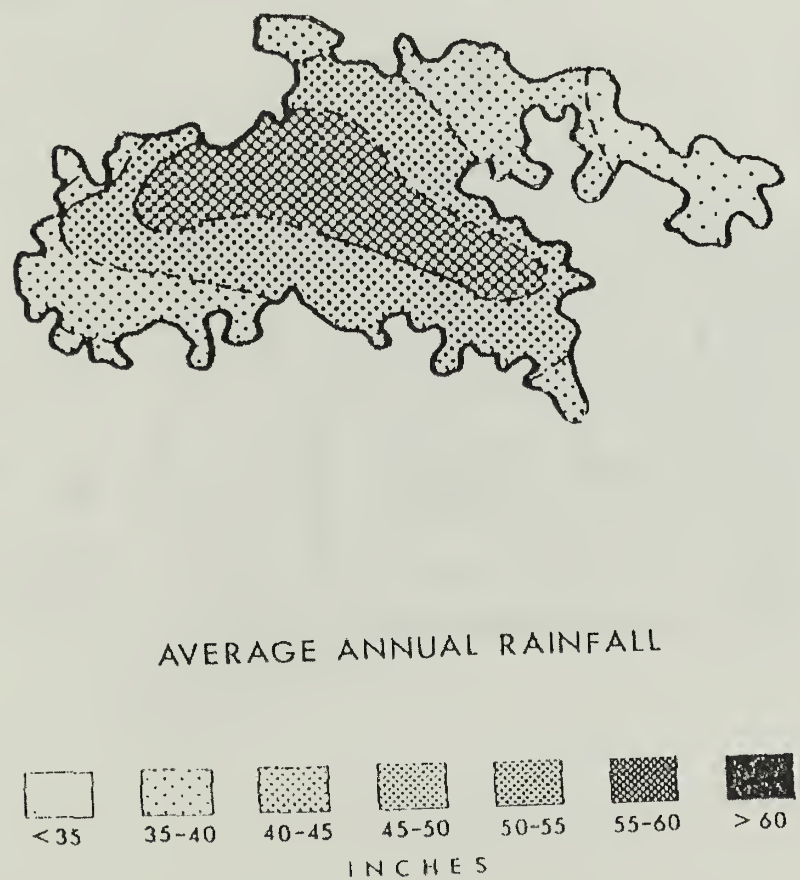


Figure 4. Approximate locations of study sites for the St. John Erosion Study

Figure 5. Comparison of Monthly Data for Four Raingage Stations in St. John for the Period of July 1998 to August 1999

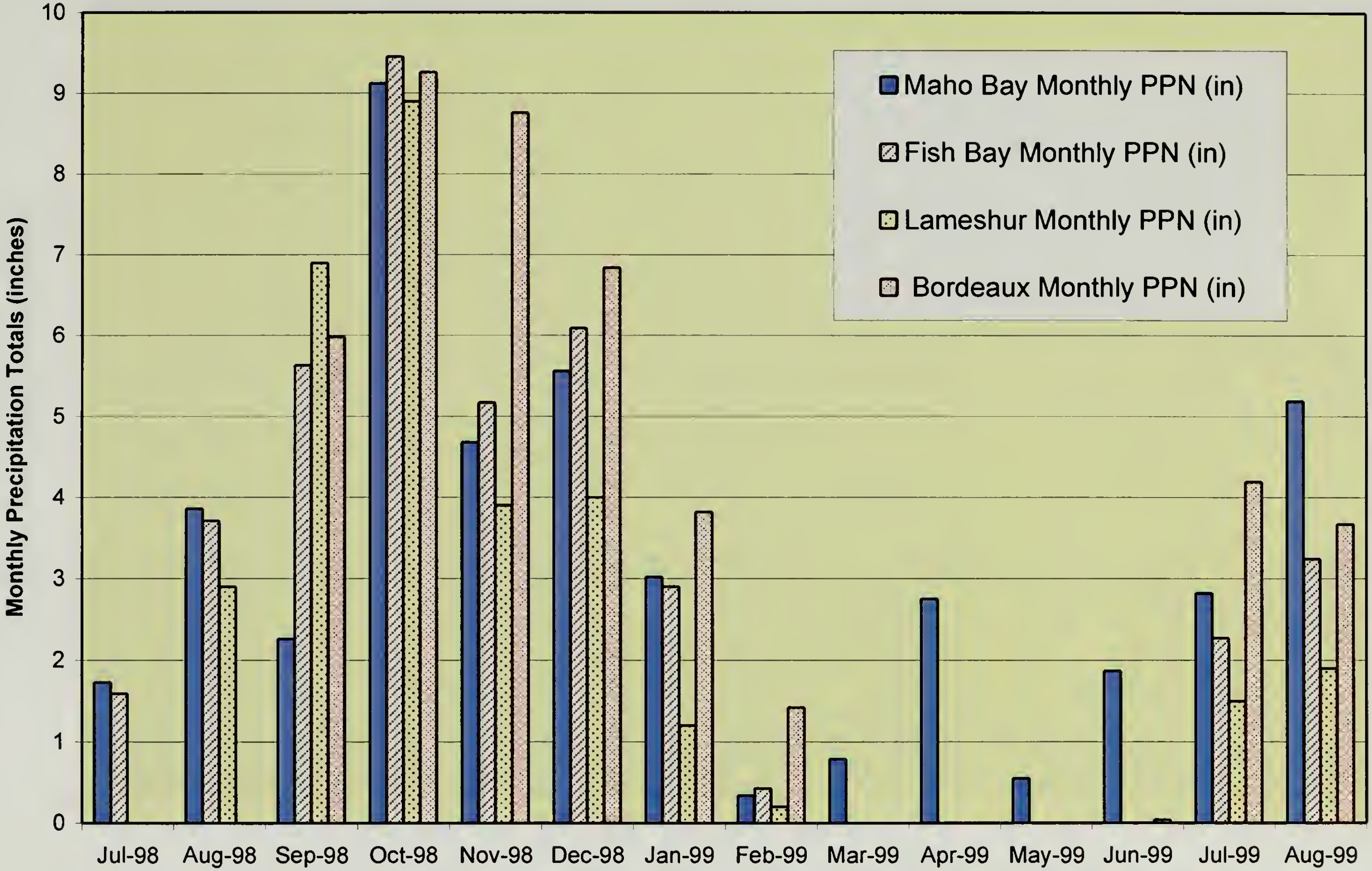


Figure 6. Flume stage and hyetograph example for Cocoloba Trail (24 October 1998)

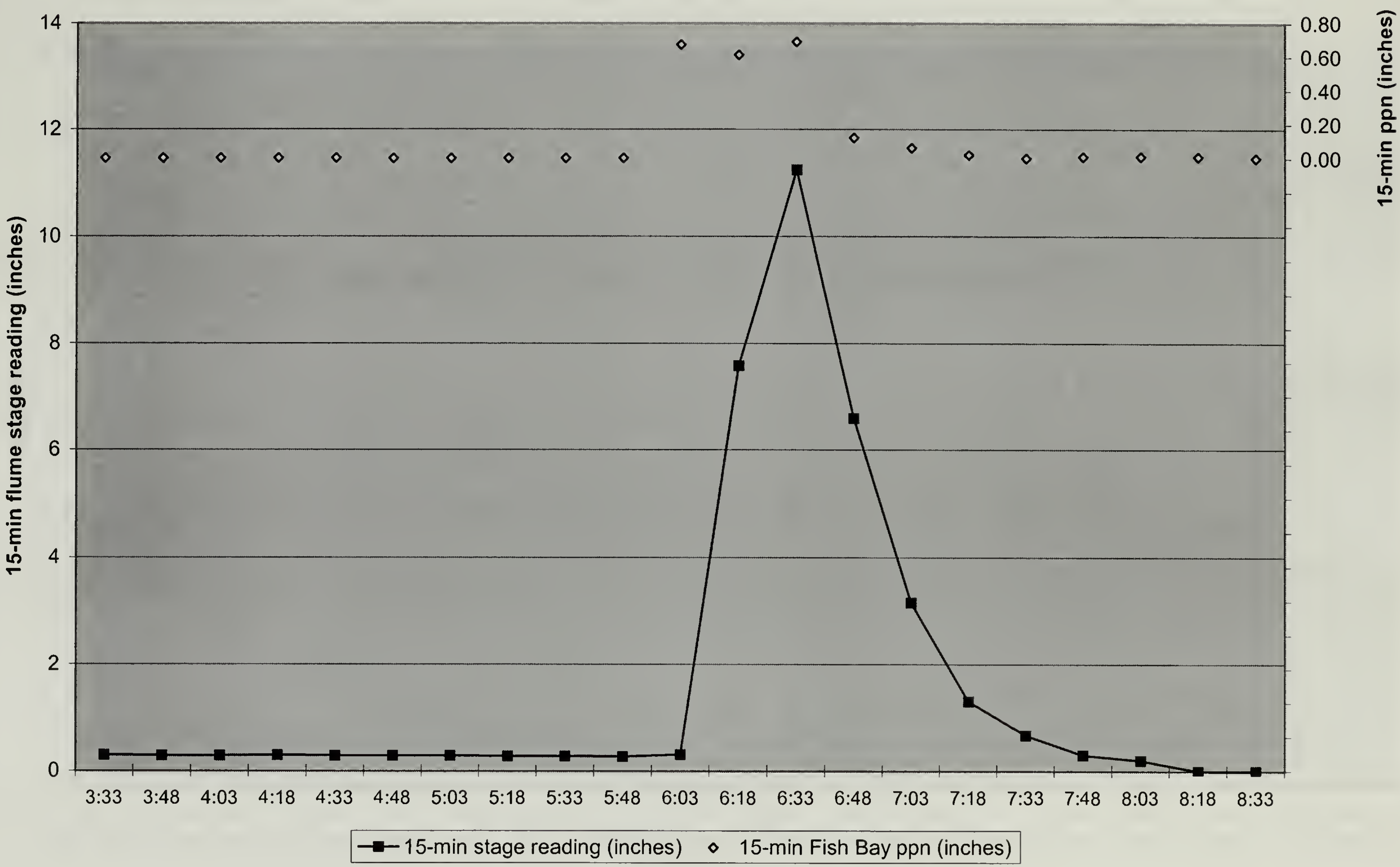


Figure 7. Fish Bay Gut Stage Readings
21 October to 16 December 1998

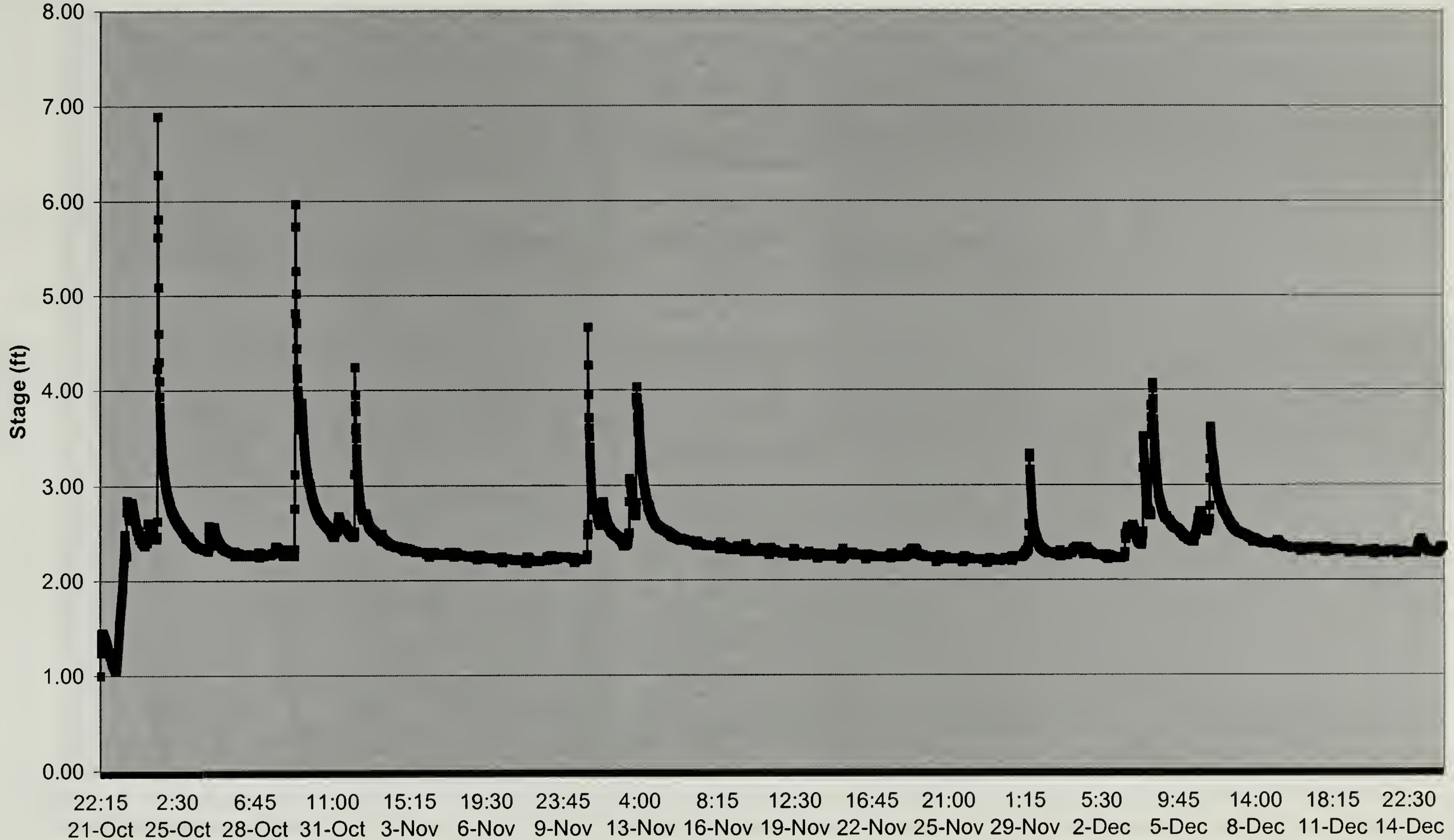


Figure 8. Lameshur Bay Gut Stage
21 September to 11 December 1998

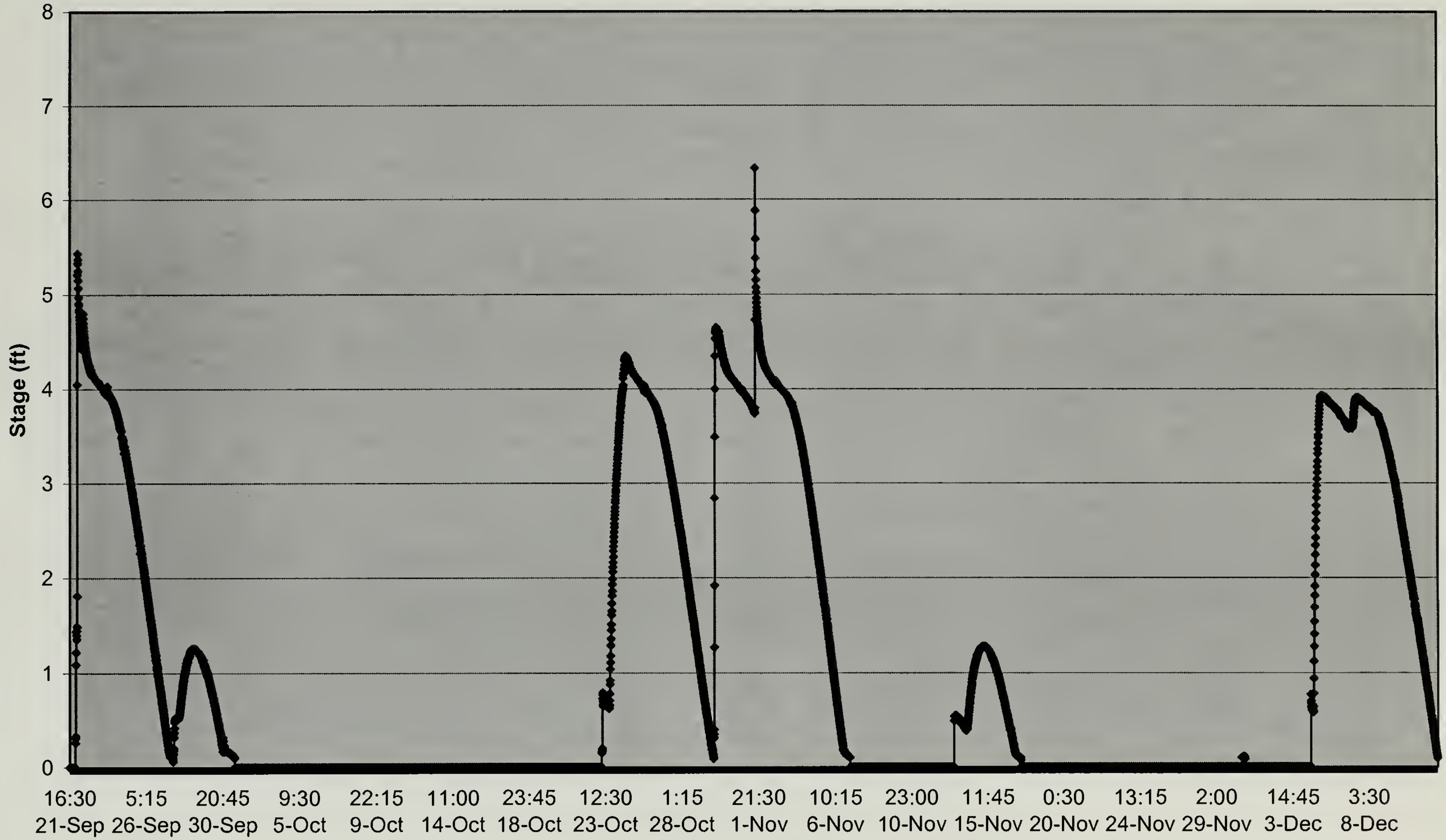


Figure 9. Site Selection Design for Road Tread Erosion Plots

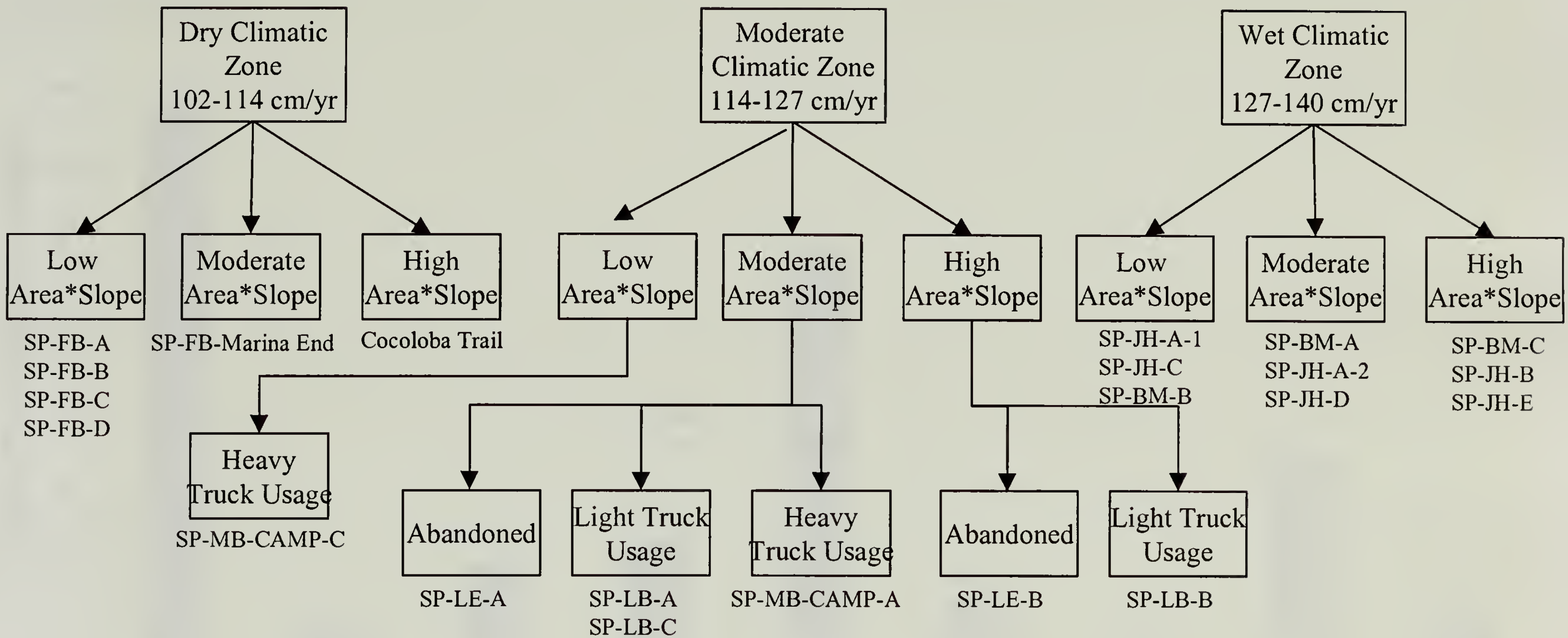


Figure 10. St. John Erosion Study- Annual Erosion Rates for Nine Road Surface Erosion Plots

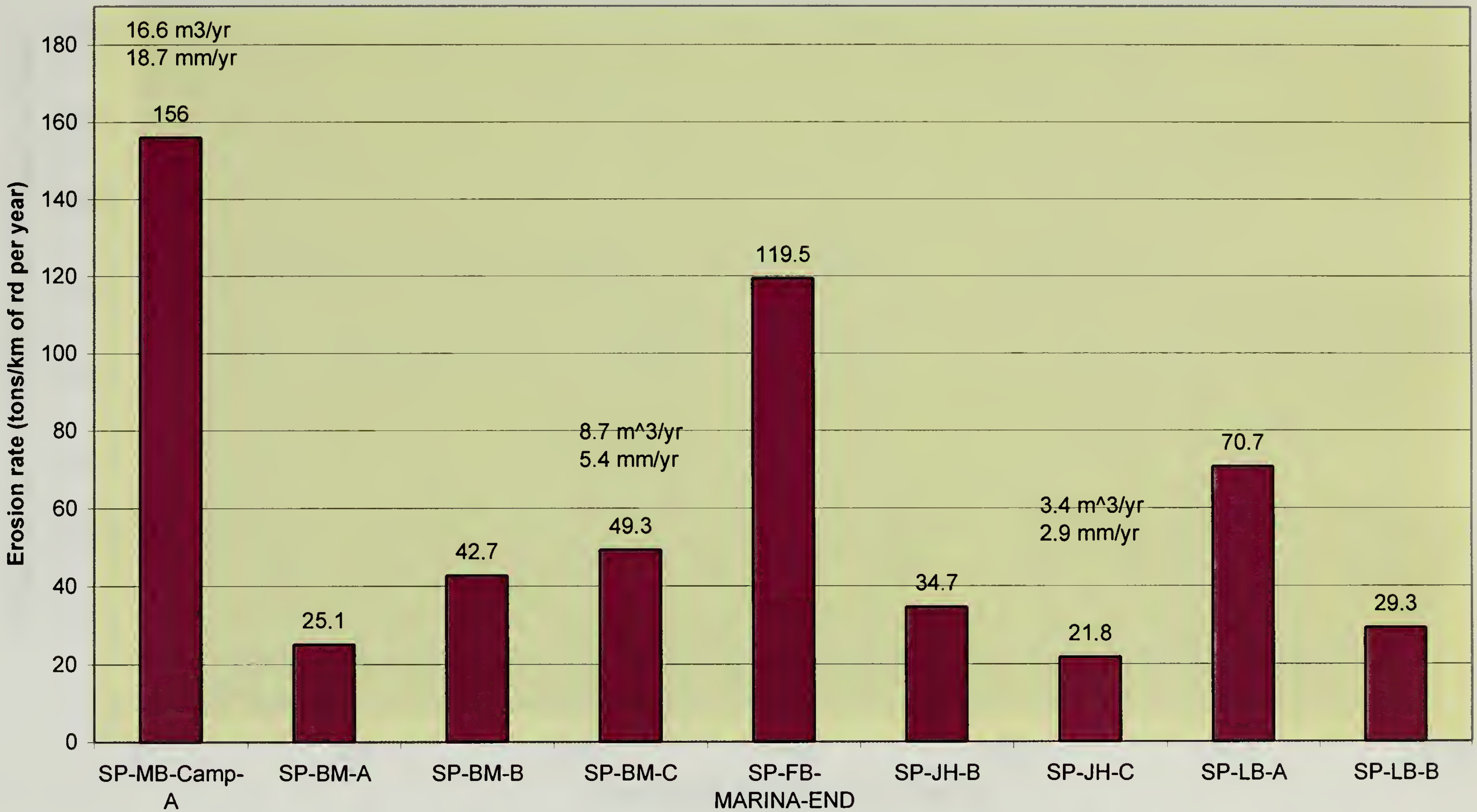


Figure 11a. Plot of annual erosion rate vs. total road drainage area

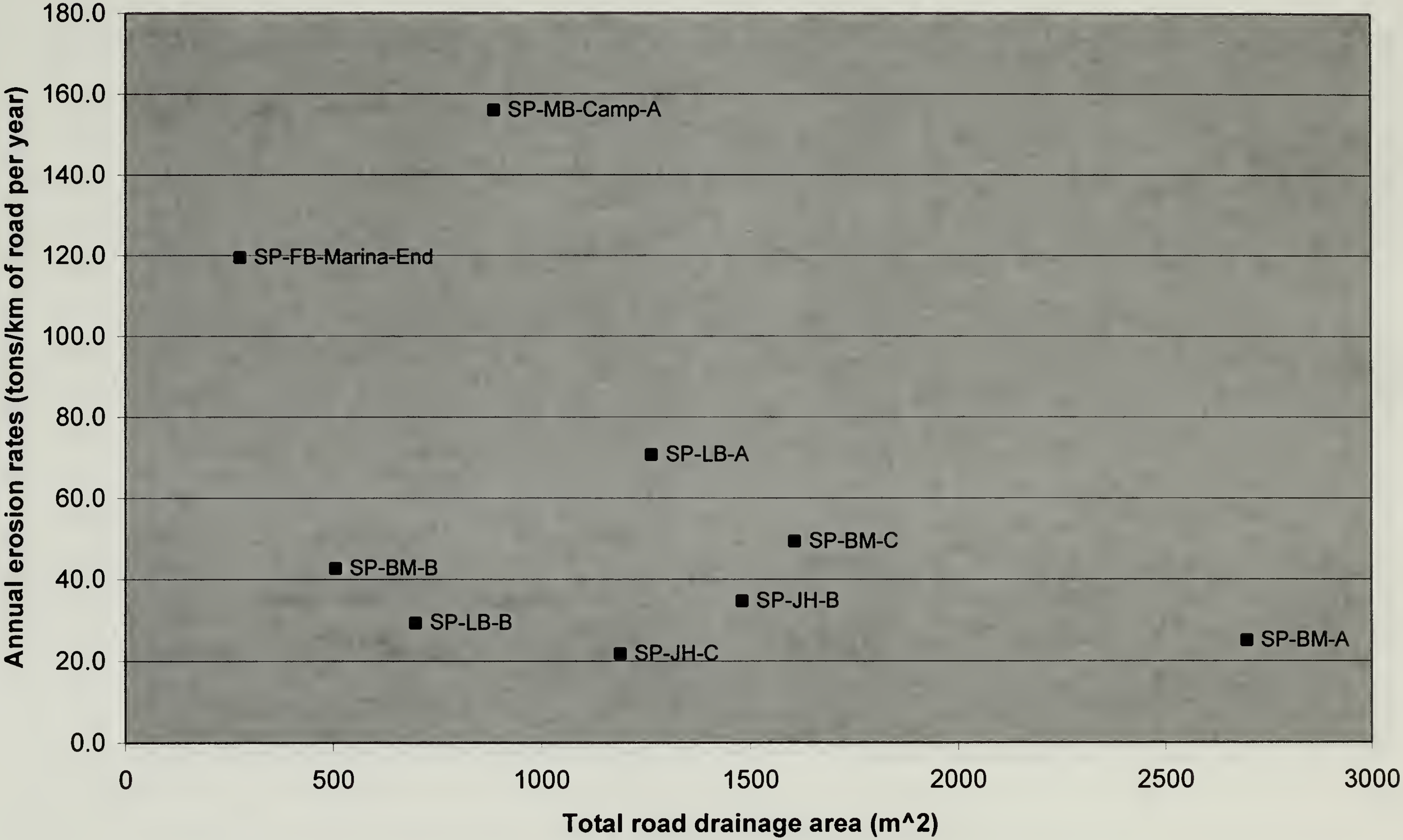


Figure 11b. Annual erosion rates vs. area weighed average slope

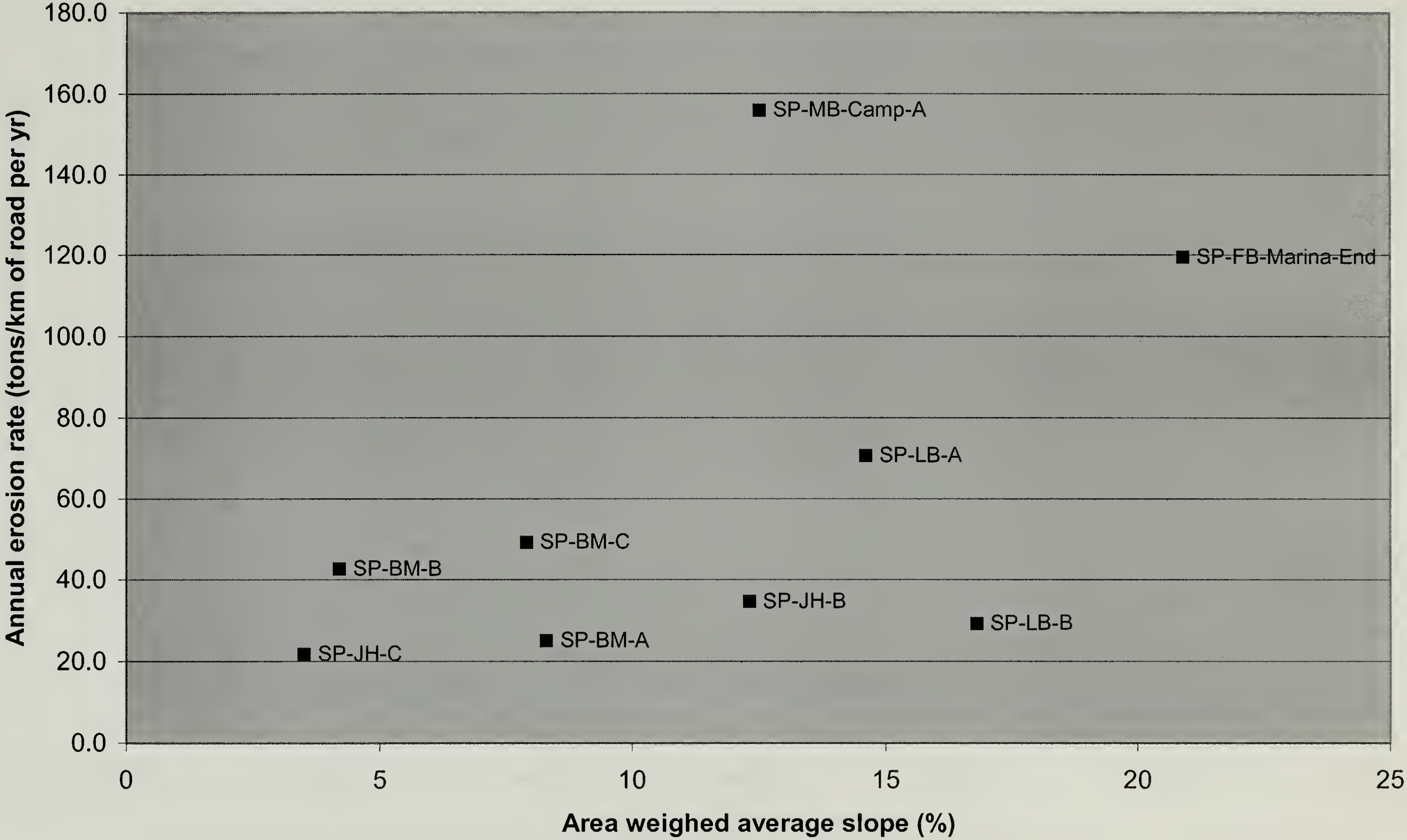


Figure 11c. Plot of annual erosion rate vs. total precipitation

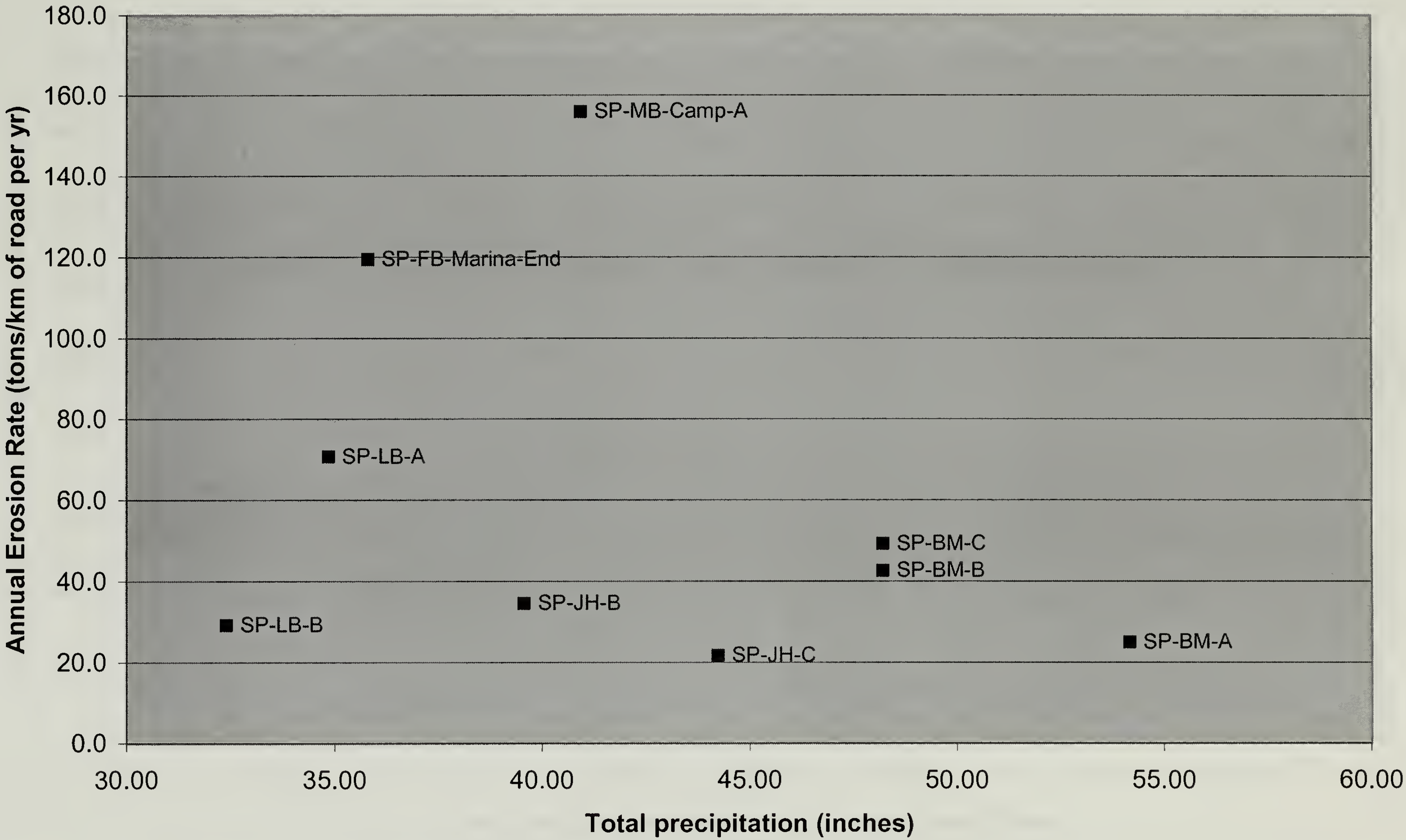


Figure 11d. Plot of annual erosion rates vs. Area-weighed road drainage area times gradient

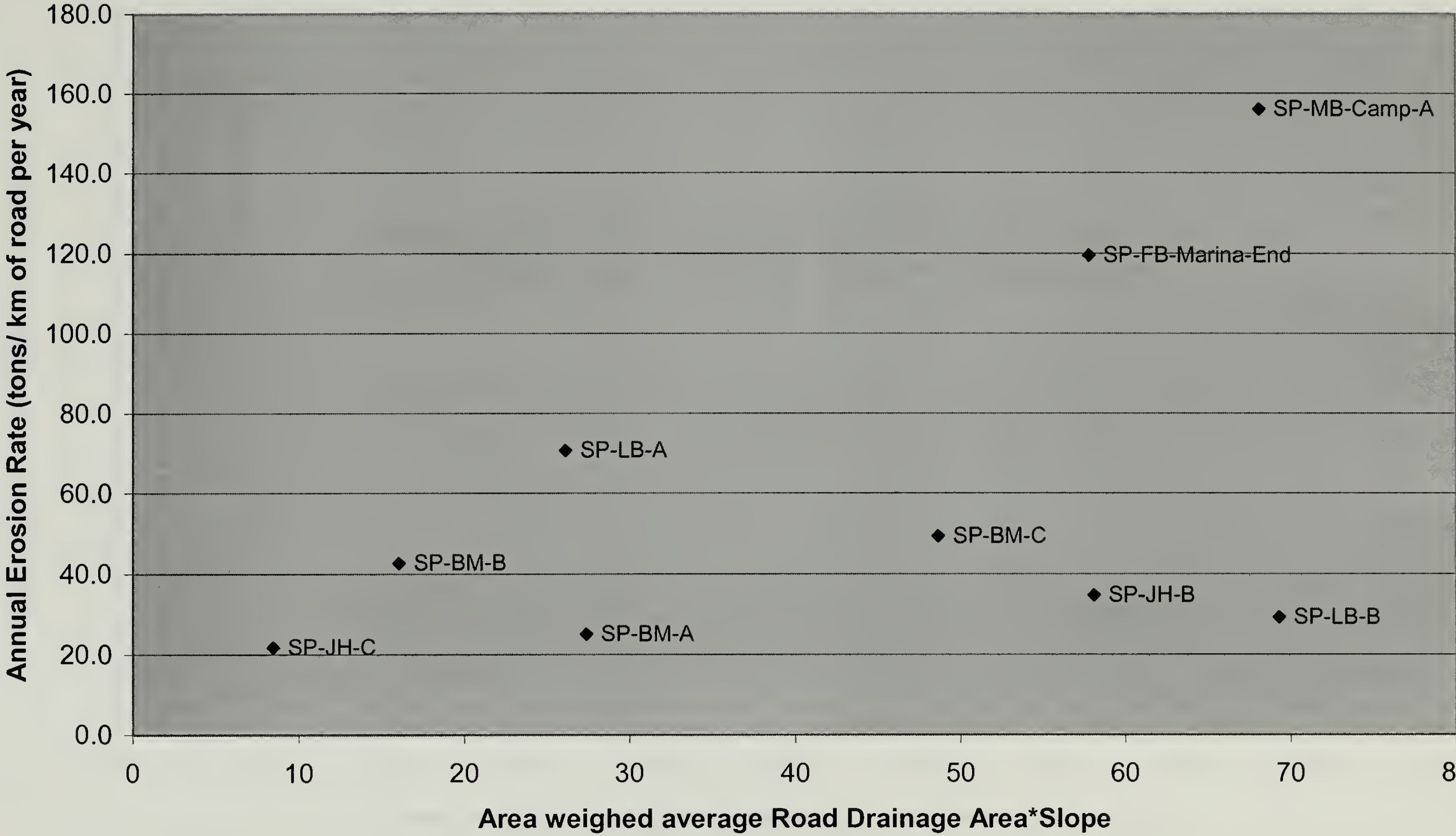


Figure 11e. Plot of Erosion Rate and Area-weighed average ditch drainage area times slope

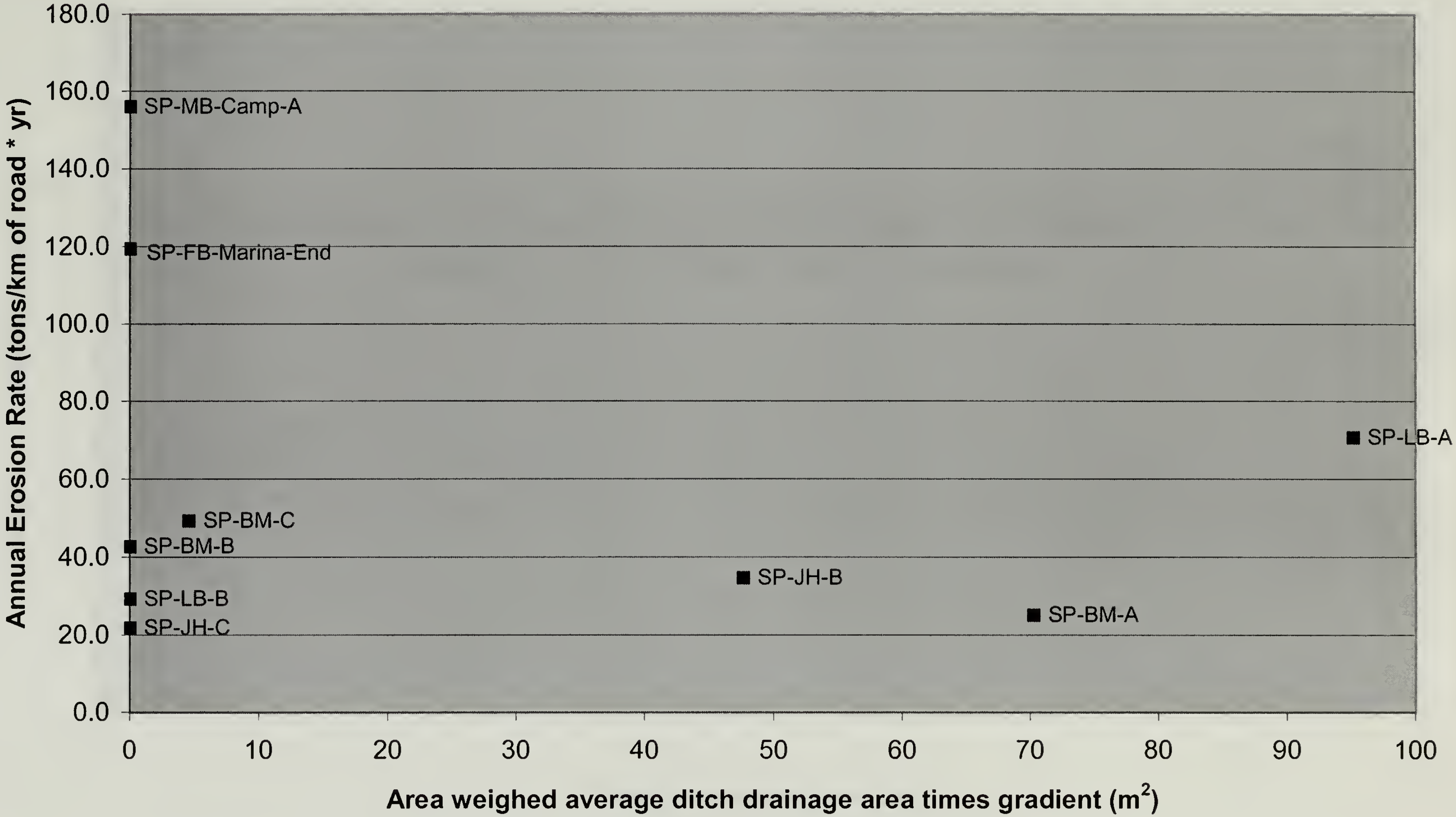


Figure 12a. Plot of sediment production vs. total precipitation for road surface plot SP-MB-Camp-A

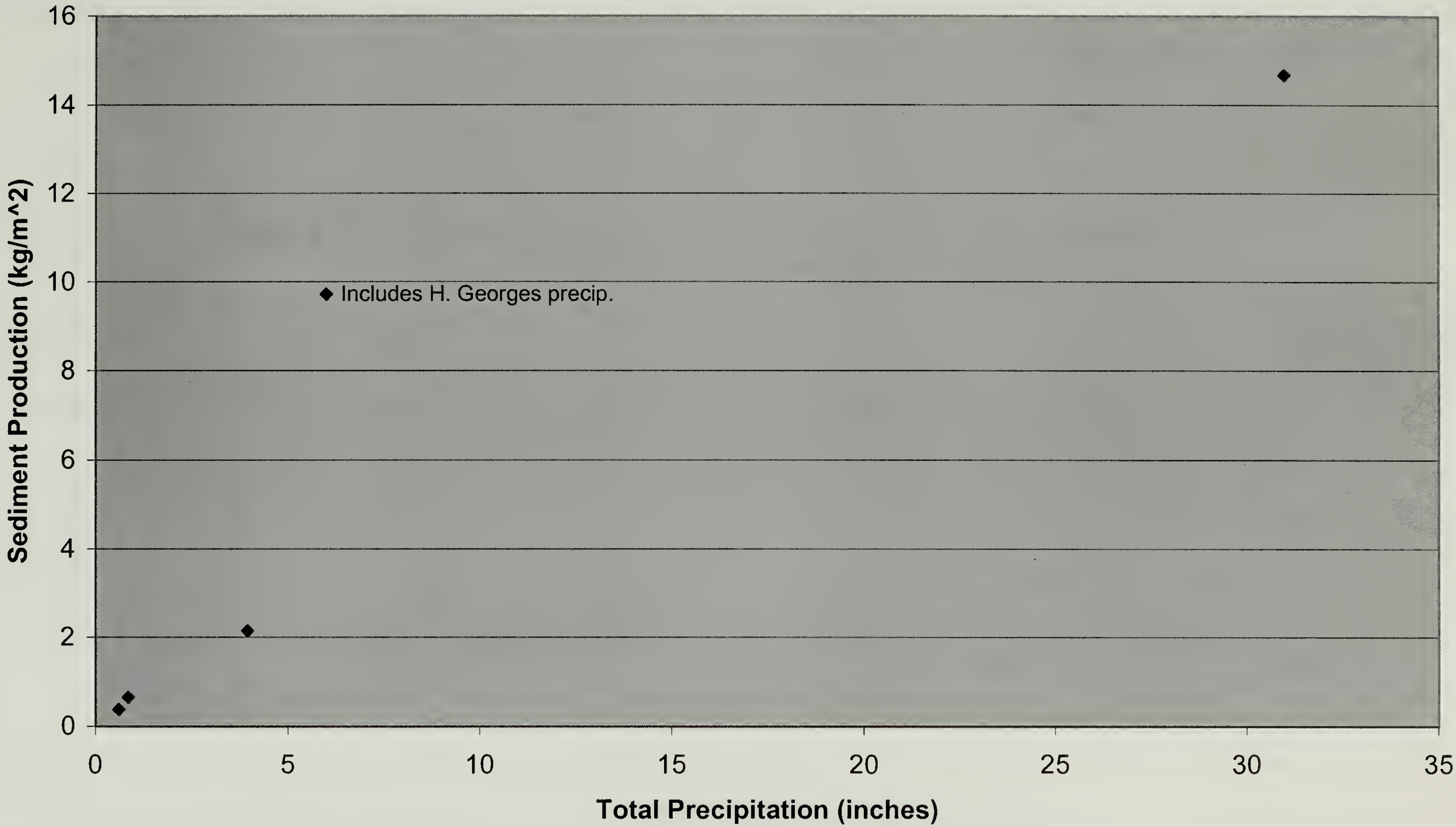


Figure 12b. Plot of sediment production vs total precipitation for road surface plot SP-BM-A

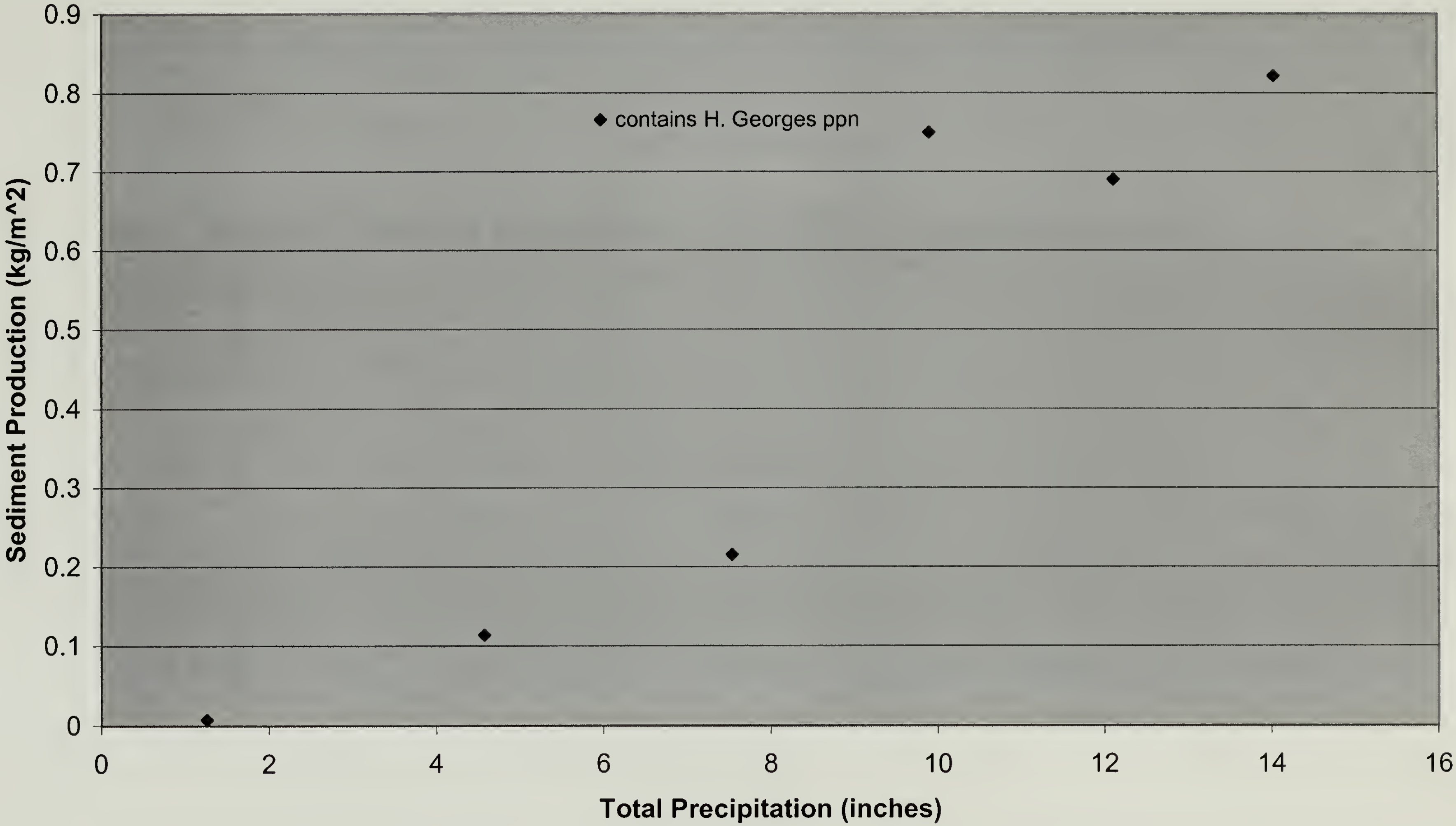


Figure 12c. Plot of sediment production vs. precipitation totals for road surface plot SP-BM-B

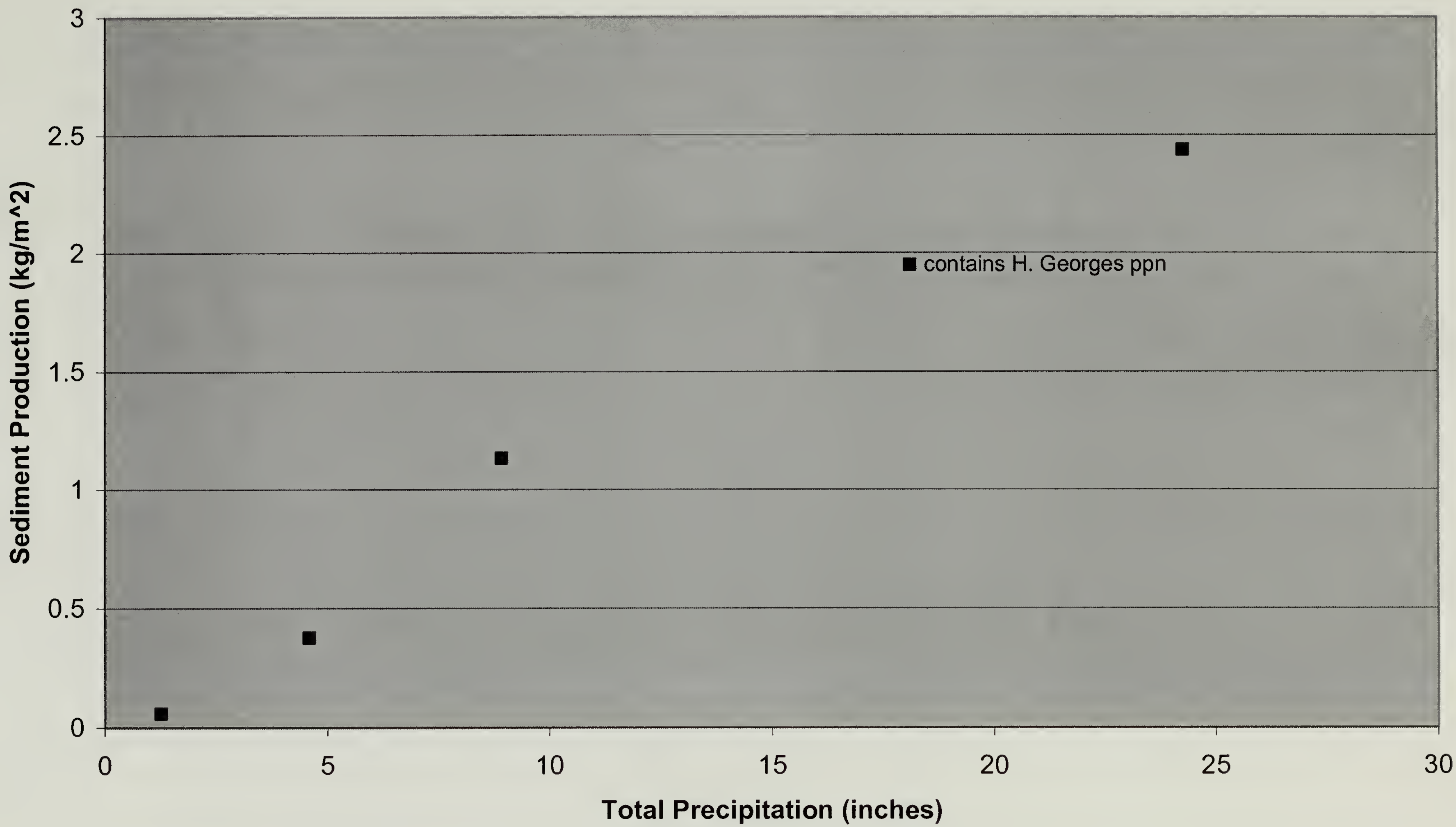


Figure 12d. Plot of sediment production vs total precipitation for road surface plot SP-BM-C

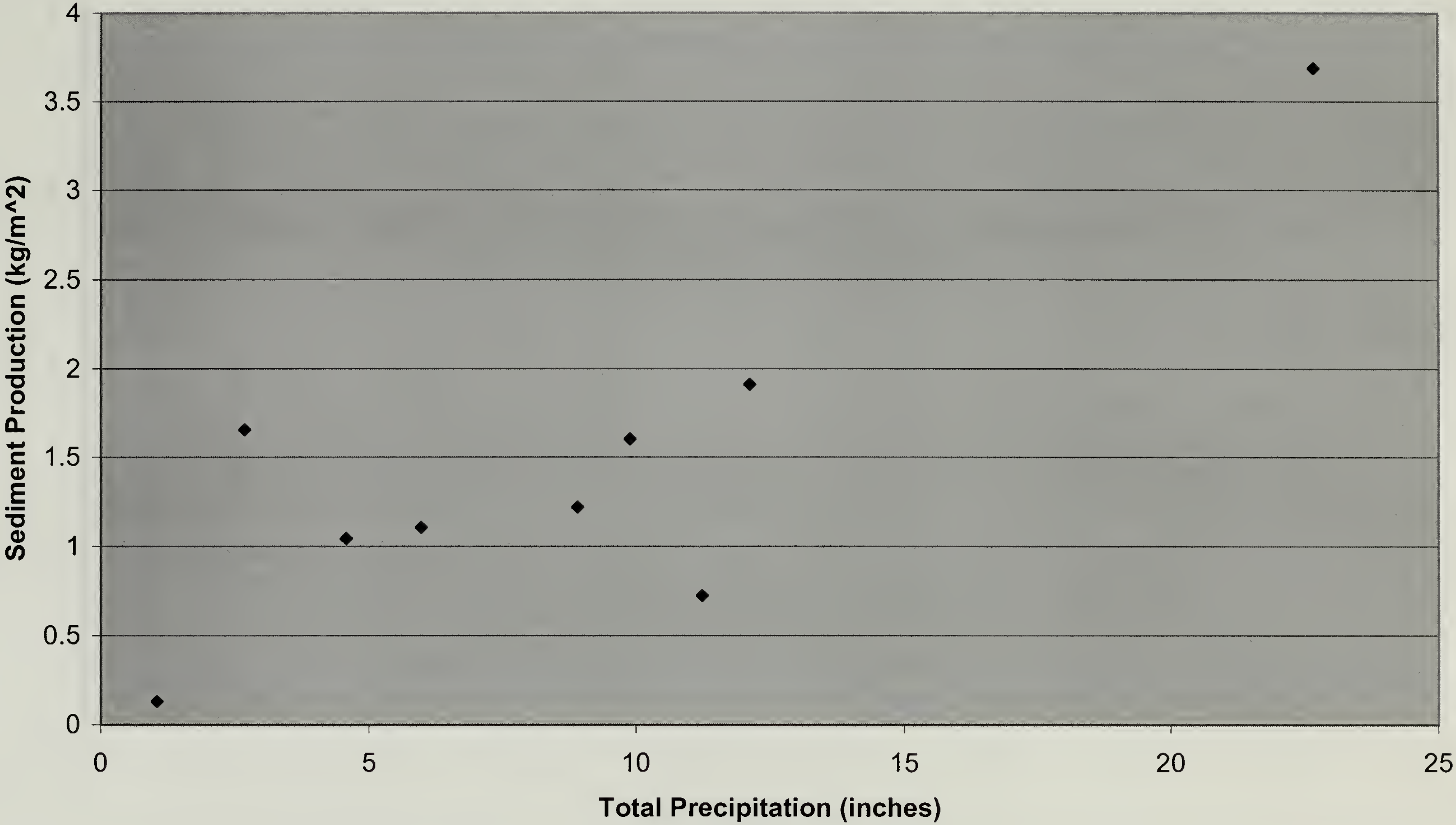


Figure 12e. Plot of sediment production vs. total precipitation for SP-FB-Marina-End

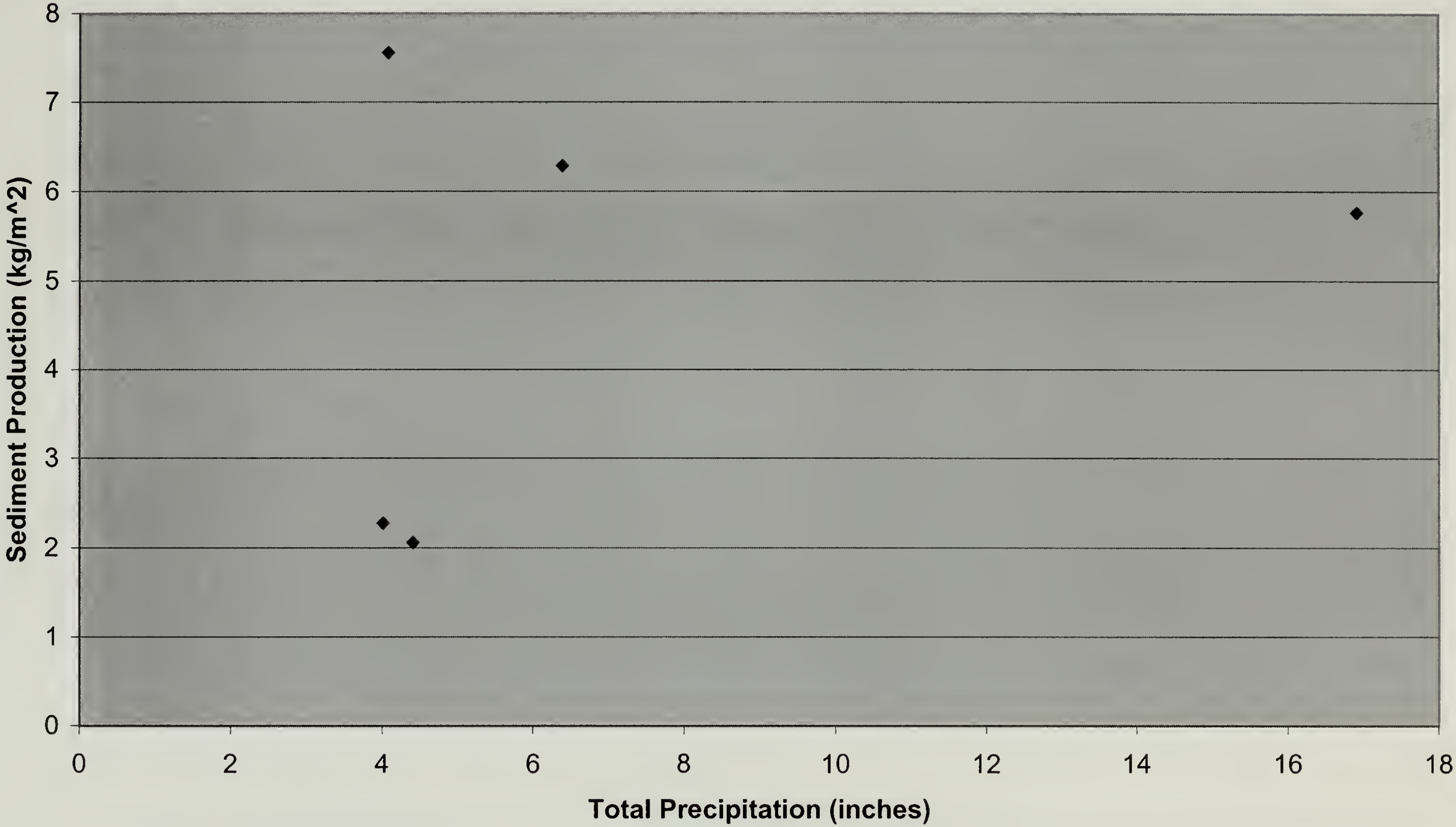


Figure 12f. Plot of sediment production vs total precipitation for road surface plot SP-JH-B

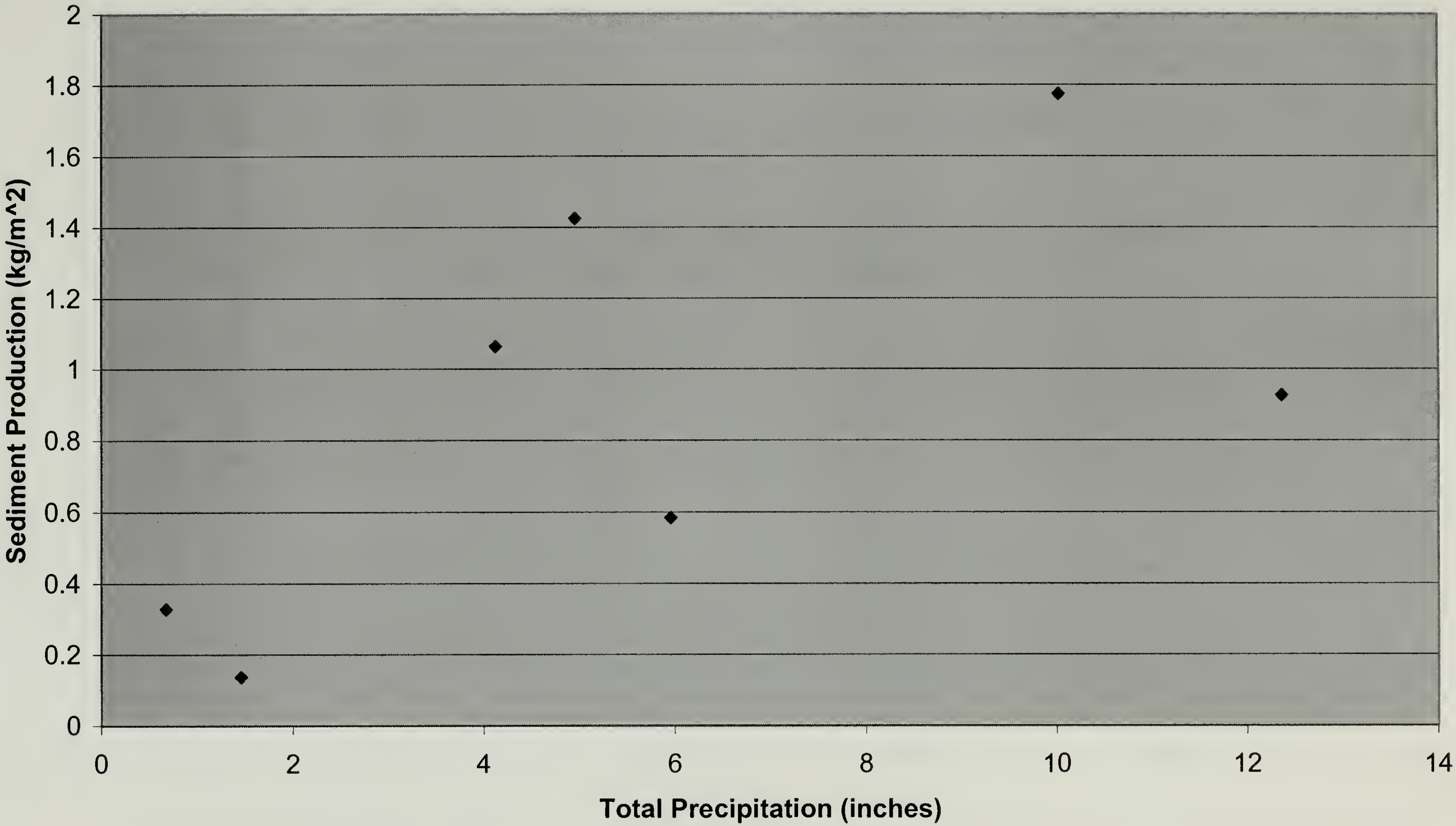


Figure 12g. Plot of sediment production vs. total precipitation for road surface plot SP-JH-C

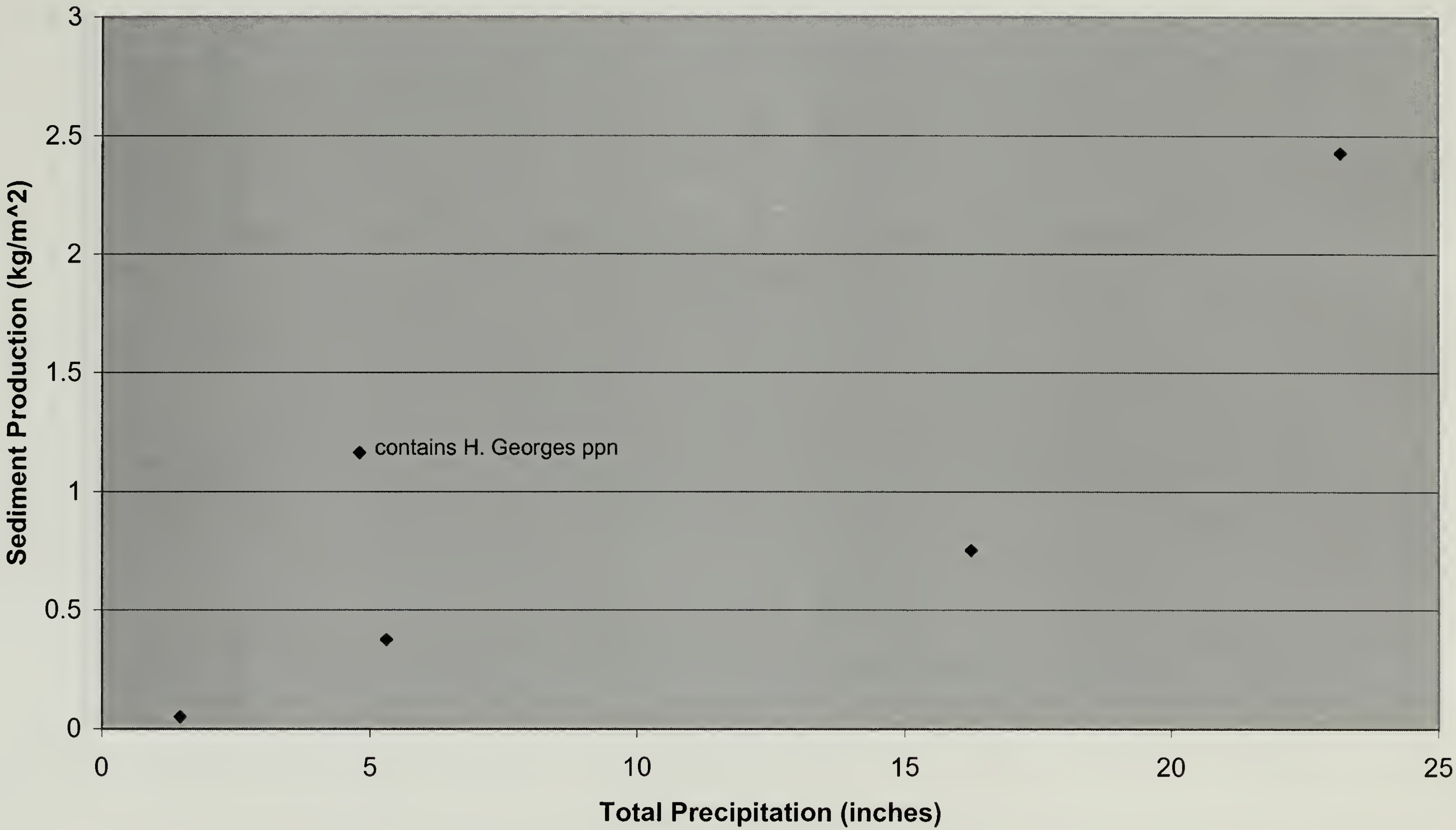


Figure 12h. Plot of sediment production vs. precipitation totals for road surface plot SP-LB-A

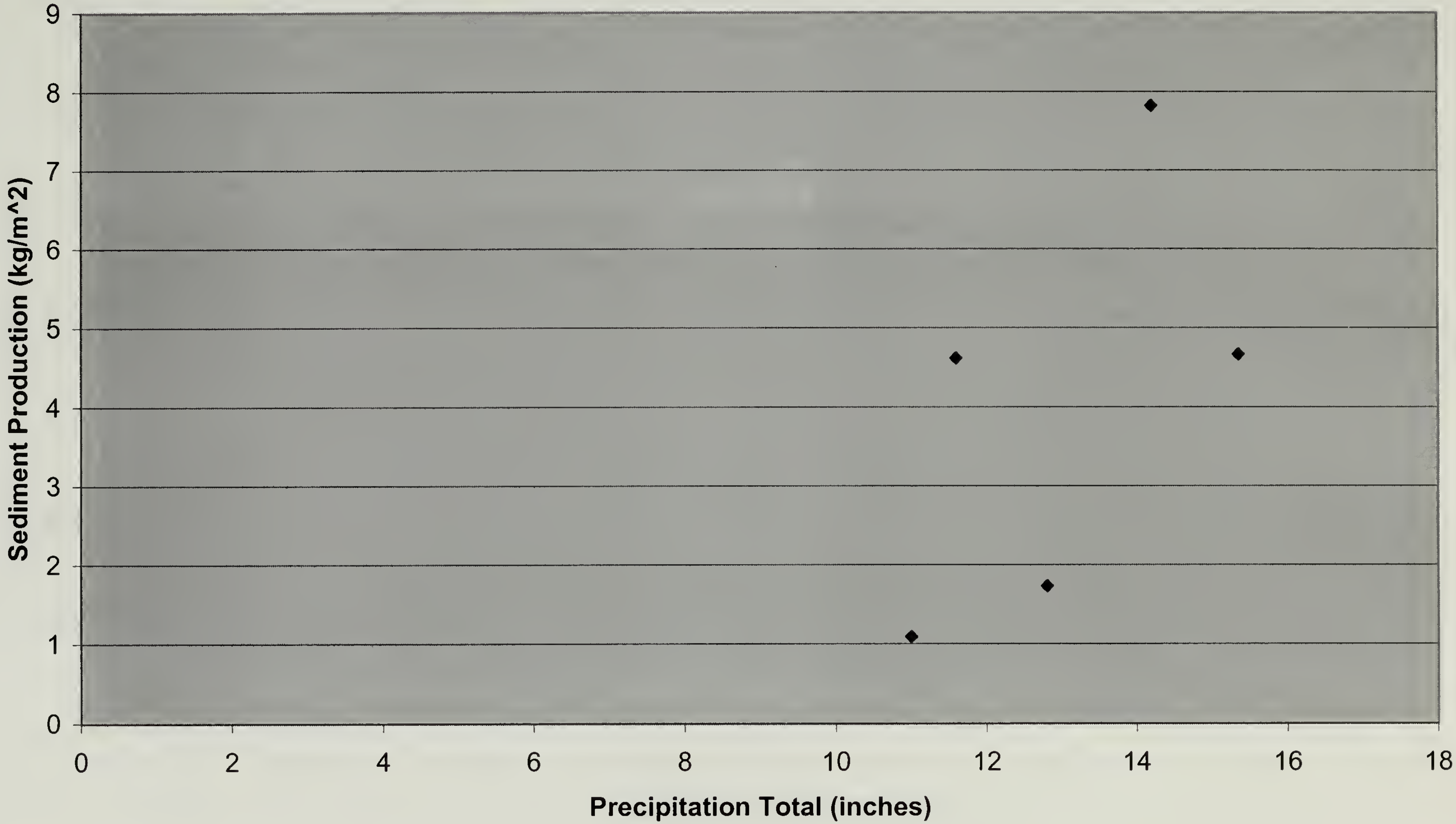


Figure 12i. Plot of sediment production vs. precipitation totals for road surface plot SP-LB-B

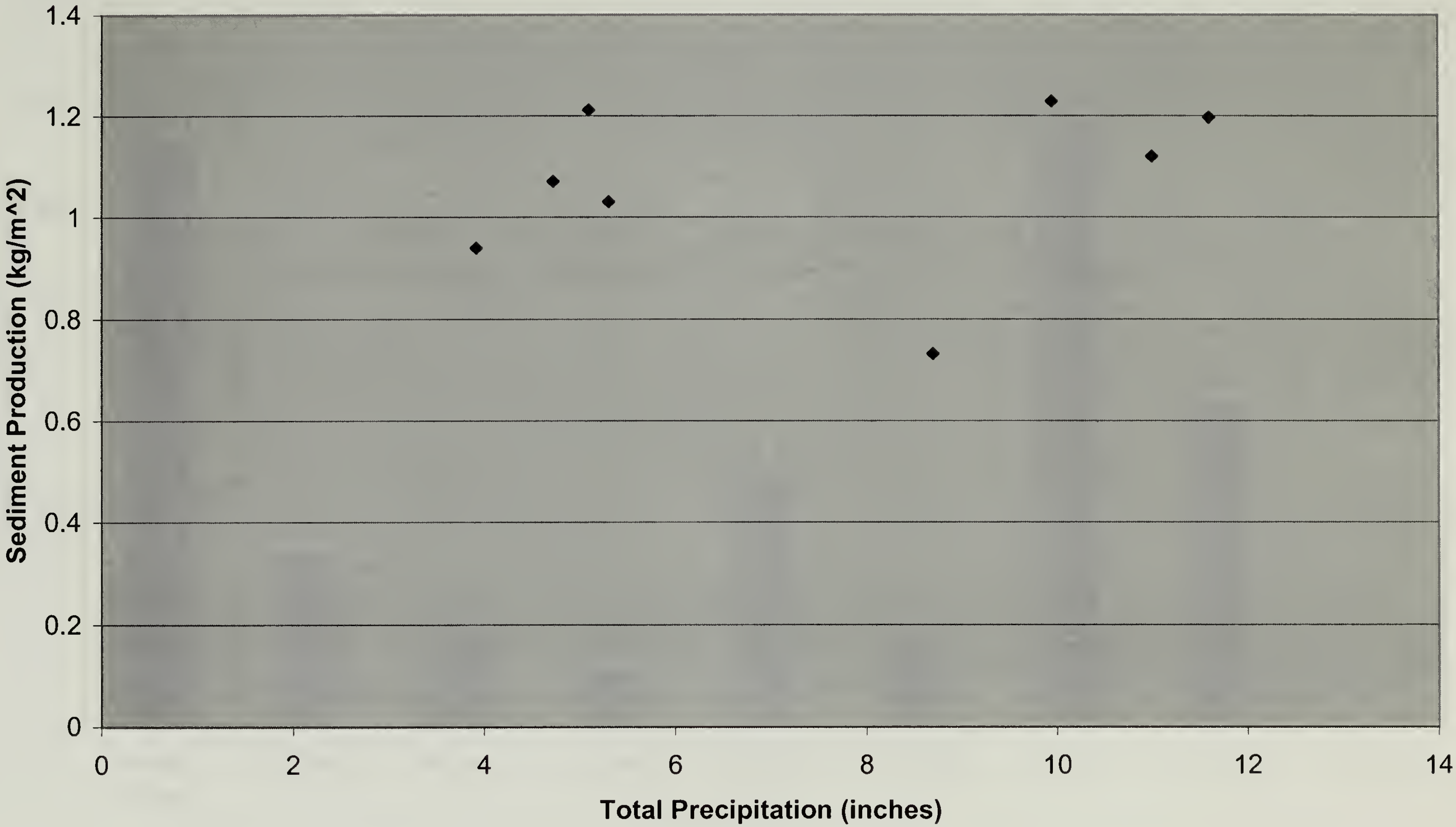
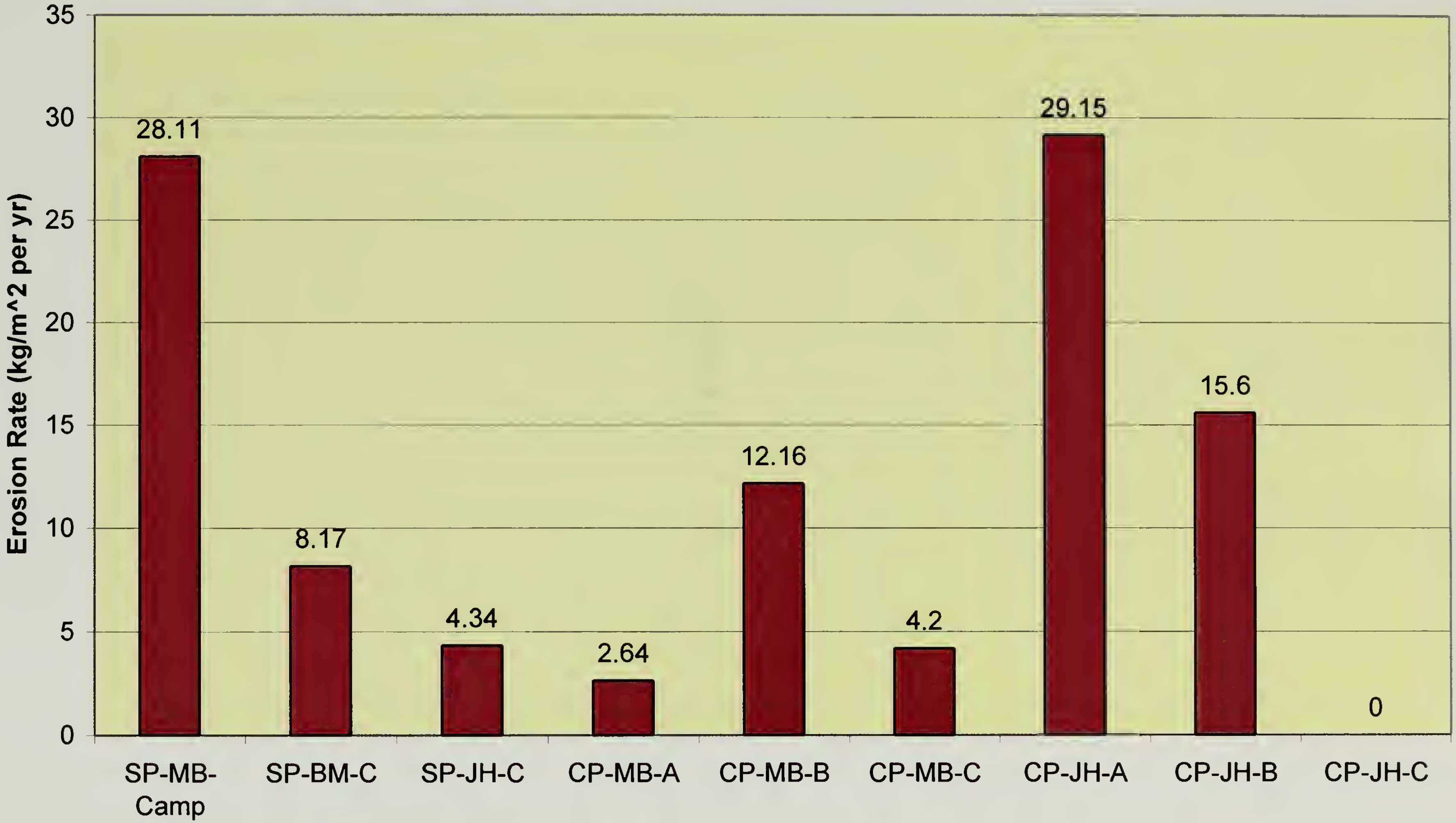


Figure 13. Annual Erosion Rate Comparison Between Road Surfaces and Cutslopes



TABLES

Table 1. Rain gauge network in St. John.

Station Name	Climatic Zone	Rain gauge type
Maho Bay Camp	114-127 cm per year	Weighing bucket- 0.01" resolution in 1-hour intervals
Fish Bay	102-114 cm per year	Tipping bucket- 0.01" resolution in 15-minute intervals
Lameshur Bay	114-127 cm per year	Tipping bucket- 0.10" resolution in 15-minute intervals
Catherineberg (John Head Road)	127-140 cm per year	Weighing bucket- 0.01" resolution in 1-hour intervals
Bordeaux Mountain	127-140 cm per year	Tipping bucket- 0.02" resolution in 15-minute intervals
Cocoloba Trail- Lower Fish Bay	102-114 cm per year	Non-recording wedge-shaped Tru-Check raingauge

Table 2. Monthly data for four recording raingauge stations in St. John for the time period July 1998 to August 1999.

Month and Year	Maho Bay Monthly Totals (inches) & Comments	Fish Bay Monthly Totals (inches) & Comments	Lameshur Bay Monthly Totals (inches) & Comments	Bordeaux Mntn Monthly Totals (inches) & Comments
Jul-98	1.73 Installed Jul 13	1.59 Installed Jul 20	No data	No data
Aug-98	3.86	3.71	2.9 Installed Aug 19	No data
Sep-98	2.26 H. Georges not included	5.63	6.9	5.98 Installed Sep 14 Resolution of 0.02 in.
Oct-98	9.12	9.45	8.9	9.26
Nov-98	4.68	5.17	3.9	8.76
Dec-98	5.56	6.09	4	6.84
Jan-99	3.02	2.9	1.2	3.82
Feb-99	0.34	0.43 Data collection interrupted Feb 8	0.2 Data collection interrupted Feb 8	1.42 Data collection interrupted Feb 28
Mar-99	0.79	No data	No data	No data
Apr-99	2.75 No data for Apr 23 1800hrs- Apr 29 1300 hrs	No data	No data	No data
May-99	0.55	No data	No data	No data
Jun-99	1.87	No data	No data	0.04 Data collection reestablished June 28
Jul-99	2.82 No data for Jul 29 1200 hrs to end of month	2.27 Data collection reestablished Jul 12	1.5 Data collection reestablished Jul 12	4.19 Resolution of 0.01 in. begins July 12
Aug-99	5.18 No data for Aug 1 0000hrs- Aug 3 0700 hrs	3.24	1.9	3.67

Table 3. Summary of watershed-scale suspended sediment data collected during the 1998 field season.

Station Name	Date Samples Collected	Number and type of samples	Sample status
Lameshur Bay Gut	21 September 1998	22 (pump sampler)	22 analyzed
	23 October 1998	24 (pump sampler)	24 analyzed
Fish Bay Gut	23 October 1998	1 (dh-48 sampler) 1 (pump sampler)	0 analyzed 1 analyzed
	24-25 October 1998	1 (dh-48 sampler) 13 (pump sampler)	1 analyzed 13 analyzed
	26 October 1998	1 (pump sampler)	1 analyzed
	28 October 1998	1 (dh-48 sampler) 1 (pump sampler)	1 analyzed 1 analyzed
	30 October 1998	21 (pump sampler)	21 analyzed
	1 November 1998	14 (pump sampler)	14 analyzed
	11 November 1998	16 (pump sampler)	14 analyzed
	12 November 1998	1 (dh-48 sampler) 2 (pump sampler)	1 analyzed 2 analyzed
	13 November 1998	6 (pump sampler)	6 analyzed
	13-17 November 1998	2 (pump sampler)	2 analyzed
	29 November 1998	6 (pump sampler)	3 analyzed
	3-4 December 1998	1 (dh-48 sampler) 12 (pump sampler)	1 analyzed 12 analyzed
	5 December 1998	6 (pump sampler)	6 analyzed

Table 4. Summary for undisturbed bounded plots for July 1998 to August 1999.

Plot	Date	Comments	Sample status
Haulover Fenced Plot	July 25, 1998	Plot initially checked and fixed	n/a
	November 19, 1998	Container overturned and disconnected; no samples	n/a
	December 18, 1999	One 0.5 L sample collected	analyzed early 1999
	July 9, 1999	Two 0.5 L samples collected	no lab analysis conducted
Haulover Unfenced Plot	July 25, 1998	Plot initially checked and fixed	n/a
	November 19, 1998	Two 0.5 L samples collected	analyzed early 1999
	December 18, 1998	One 0.5 L sample collected	analyzed early 1999
	July 9, 1999	Container disconnected; no samples	n/a
Fish Bay Plot	July 25, 1998	Plot initially checked and fixed	n/a
	November 12, 1998	Container broken; no sample collected; new container set	n/a
	December 5, 1998	Two 0.5 L samples collected	analyzed early 1999
	August 10, 1999	Two 0.5 L samples collected	no lab analysis conducted

Table 5. Summary of road surface erosion plots installed for the St. John Erosion Study from 1 July 1998 to 31 August 1999.

Plot Description	Code Name	Age/Usage	Date Collection started	Measurements Date (wet weight in lbs)
On last Marina Drive road segment leading to dock	SP-FB-Marina-end	Graded in 1997 Low usage	8/18/98	9/10/98 (1707) 10/7/98 (1464) 10/27/98 (4237) 11/11/98 (5565) 3/27/99 (4341)
On Marina Drive-eastern end of unpaved road	SP-FB-A	Old road-graded in late 1998 High (light vehicles)	7/10/98	Not enough sediment for a measurement
On Marina Drive-eastern end of unpaved road	SP-FB-B	Old road-graded in late 1998 High (light vehicles)	7/10/98	Not enough sediment for a measurement
On Marina Drive-between main and little Fish Bay guts- Rob Sampson's silt fence	SP-FB-C	Old road-graded in late 1998 High (light vehicles)	?	7/16/98 (736)
On Marina Drive-between main and little Fish Bay guts	SP-FB-D	Old road-graded in late 1998 High (light vehicles)	7/10/98	Not enough sediment for a measurement
Cocoloba Trail-on ditch close to junction with Z-Road	SP-FB-Coco	Old road Moderate usage	7/27/98	8/3/98 (221) 9/10/98 (3293) Trap removed in September 1998
Middle-steep section of John Head Road-includes new driveway-Sampson's JH-2 plot	SP-JH-A	Freshly graded in 1998 Low usage	7/3/98	8/4/98 (946) 8/19/98 (1523) 9/8/98 (3505) 9/28/98 (9218) became SP-JH-A-1 & SP-JH-A-2 in 10/19/98
Road surface plot- Lower portion of SP-JH-A	SP-JH-A-1	Graded in 1998 Low usage	10/19/98	10/28/98 (5542) 4/8/99 (3302) 6/29/99 (1732) 8/31/99 (893)
Upper portion of SP-JH-A	SP-JH-A-2	Low usage	10/19/98	10/29/98 (5371) 2/15/99 (4151) 7/15/99 (4349)

Table 5. Summary of road surface erosion plots installed for the St. John Erosion Study from 1 July 1998 to 31 August 1999 (cont.).

Plot Description	Code Name	Age/Usage	Date Collection started	Measurements Date (wet weight in lbs)
Upper steep section of John Head Road- Sampson's JH-1 plot	SP-JH-B	Old Low usage	7/8/98	8/4/98 (562) 8/19/98 (1248) 9/8/98 (4428) 9/30/98 (5698) 11/3/98 (6317) 3/1/98 (3343) 6/29/99 (2194) 8/31/99 (1919)
Upper gently sloping section of John Head Road close to Catherineberg Ruins	SP-JH-C	Old Moderate usage	7/8/98	8/4/98 (192) 9/8/98 (1332) 9/29/98 (4240) 3/26/99 (7110)
Upper steep section of John Head Road at cross drain in front of parcel 3-14	SP-JH-D	Old Low usage	7/15/99	8/31/99 (599)
Upper steep section of John Head Road located at a recently unclogged culvert at upper section of SP-JH-B	SP-JH-E	Old Low usage	7/16/99	8/31/99 (1284)
Road leading to ranger house on Lameshur Bay	SP-LB-A	Old Low usage	7/31/98	10/7/98 (3440) 11/17/98 (14671) 7/8/99 (22040)
On Route 107 leading to Lameshur Bay close to Mandal Pond	SP-LB-B	Old-graded early 1999 Low usage	7/31/98	10/7/98 (2026) 11/18/98 (2047) 1/5/99 (2026) 7/9/99 (2228)
On Route 107 leading to Lameshur Bay close to Mandal Pond	SP-LB-C	Old-graded early 1999 Low usage	7/17/99	Not enough sediment for a measurement
Road leading to Maho Bay Campground	SP-MB-Camp	Road graded in June and December 1998 Heavily used (heavy truck usage)	7/6/98	7/22/98 (906) 8/5/98 (1540) 9/1/98 (5181) 10/5/98 (25622 a & b) 8/6/99 (35164 a)

Table 5. Summary of road surface erosion plots installed for the St. John Erosion Study from 1 July 1998 to 31 August 1999 (cont.).

Plot Description	Code Name	Age/Usage	Date Collection started	Measurements Date (wet weight in lbs)
Along Route 108 on Bordeaux Mountain (close to Lameshur Bay trail head)	SP-BM-A	Old-graded in November 1998 Moderate usage	7/28/98	8/10/98 (64) 9/17/98 (959) 10/1/98 (5503) 11/4/98 (5278) 12/16/99 (6008) 7/2/99 (6084) 8/31/99 (1646)
Along Route 108 on Bordeaux Mountain	SP-BM-B	Old-graded in November 1998 Moderate usage	7/28/98	8/10/98 (113) 9/17/98 (741) 11/4/98 (3622) 7/1/99 (4541)
Along Route 108 on Bordeaux Mountain	SP-BM-C	Old-graded in November 1998 Moderate usage	7/28/98	8/10/98 (605) 9/17/98 (4693) 10/1/98 (4769) 11/4/98 (8425) 12/16/98 (6968) 3/28/99 (3558) 7/1/99 (6883)
Located at an abandoned road (probably on L' Esperance road)	SP-LE-A	Old Abandoned	To be installed in October	
Located at an abandoned road (probably on L' Esperance road)	SP-LE-B	Old Abandoned	To be installed in October	

Table 6. Summary of cutslope and fillslope erosion plots used for the St. John Erosion Study as of 1 September, 1999.

Plot Description	Code Name	Characteristics of plot area	Date Collection started	Measurements Date (wet weight in lbs)
Fillslope Plot-New fillslope on middle steep section of John Head Road. Measurements taken after road runoff from SP-JH-A was diverted into the fillslope	FP-JH-1	New fillslope (sidecast material from new home construction)	7/24/98	11/2/98 (5540)
Cutslope Sediment Production Plot- Lower section John Head Road	CP-JH-A	Old	8/6/98	No measurements taken at this time
Cutslope Sediment Production Plot- Lower section John Head Road	CP-JH-B	Old	8/6/98	7/9/99 (315)
Cutslope Sediment Production Plot- Lower section John Head Road	CP-JH-C	Old	8/6/98	7/9/99 (628)
Cutslope Sediment Production Plots- Abandoned driveways off the road leading to Maho Bay Campground	CP-MB-Camp Upper	Old (low cutslope)	8/6/98	10/15/98 (43)
Same as above	CP-MB-Camp Lower	Old (low cutlslope)	8/6/98	10/15/98 (55)
Cutslope Sediment Production Plots- On one-way section of Northshore Road leading West	CP-MB-A (upper)	Old (high cutslope)	7/23/98	07/19/99 (196)
Same as above	CP-MB-B	Old (high cutslope)	7/23/98	7/19/99 (770)
Same as above	CP-MB-C (lower)	Old (high cutslope)	7/23/98	7/20/99 (280)
Cutslope Sediment Delivery Plots- Below culverts on one-way section of Northshore Road leading West	CSDP-MB-A (upper)	Old	7/22/98	10/15/98 (323) 7/19/99 (320)
Same as above	CSDP-MB-B	Old	7/22/98	7/19/99 (1525)
Same as above	CSDP-MB-C	Old	7/22/98	7/20/99 (1284)
Same as above	CSDP-MB-D (lower)	Old	7/22/98	10/15/98 (1682) 7/20/99 (1374)
Cutslope sediment delivery trap- On Northshore Road in the Caneel Bay area	CSD-CB-A	Old (high cutslope)	7/11/98	Not enough sediment for measurement
Cutslope Sediment Production Plot- On upper sections of road leading from Susannaberg to Hawksnest Bay	CP-SU-A	Old (low cutslope)	9/1/99	No measurements at this time.
Same as above	CP-SU-B	Old (low cutslope)	9/1/99	No measurements at this time.

Table 7. Summary of data collected for several road surface erosion plots from 1998 to 1999.

Trap Id	Drainage Area (m^2)	Avg. Gradient (%)	Avg. Width (m)	Road Area*Slope (m^2)	Ditch Area*Slope (m^2)	Traffic Rate (vehicles/day)	Total PPN (inches)	Period used for erosion rate calculation	Erosion rate (kg/m^2 yr)	Erosion rate (tons/km yr)
Sp-mb-camp-a	888	12.5	5.55	68.13	0	268 (Jan-Feb) 107 (Sept)	40.94	5 Aug 98- 6 Aug 99	28.11	156.0
Sp-bm-a	2697	8.3	6.61	27.38	70.26	9	54.16	5 Aug 98- 31 Aug 99	3.80	25.1
Sp-bm-b	506	4.2	6.93	16.07	0	156	48.20	28 Jul 98- 1 Jul 99	6.16	42.7
Sp-bm-c	1607	7.9	6.00	48.63	4.59	156	48.20	28 Jul 98- 1 Jul 99	8.17	49.3
Sp-fb-end	276	20.9	5.00	57.79	0	4	35.80	18 Aug 98- 27 Apr 99	23.90	119.5
Sp-jh-b	1481	12.3	5.57	58.07	47.66	No data	39.57	8 Jul 98- 29 Jun 99	6.23	34.7
Sp-jh-c	1188	3.5	5.03	8.45	0	71	44.23	8 Sept 98- 24 Sept 99	4.34	21.8
Sp-lb-a	1265	14.6	5.23	26.14	95.17	2 (estimate)	34.85	31 Jul 98- 8 Jul 99	13.52	70.7
Sp-lb-b	698	16.8	5.65	69.30	0	23	32.40	18 Nov 98- 15 Nov 99	5.18	29.3

Table 8. Summary of data collected for fillslope and cutslope plots for 1998-1999 field season.

Plot Id	Total Area (m^2)	Total Sediment Produced (kg)	Erosion rate (kg/m^2)
FP-JH-A	97.1	2076	21.38
CP-MB-A	33.6	89	2.64
CP-MB-B	26.04	316	12.16
CP-MB-C	28.56	120	4.20
CP-JH-A	8.37	244	29.15
CP-JH-B	7.94	124	15.6
CP-JH-C	7.84	0	0

Table 9. General description of the different sediment routing settings found in St. John.

Sediment Routing Setting	Examples	Comments
Case I		
Sediment source directly connected to the marine environment	1) Lameshur Bay road section leading to ranger station 2) Salt Pond "trail"	Amount of sediment delivered is usually less than in other cases (typically only a single source of sediment), but suspended sediments are delivered very frequently and undiluted into the marine ecosystem
Case II		
Sediment source directly connected to a swamp/detention pond which is then connected to the marine environment	1) Lameshur Bay road section going from Mandal Pond down to Great Lameshur Bay 2) Last end of Marina Drive in the Lower Fish Bay area	Amount of sediment delivered to the marine environment is reduced due to settling in the swamp environment and the low frequency of events in which sediment is delivered to the bay; unknown effects of sediments in the swamp ecosystem
Case III		
Sediment source directly connected to a low-order stream which drains directly into the marine environment	1) Sections of the Haulover Bay development 2) Susannaberg development area in the Upper Gibney Gut sub-catchment	Sediment delivery rates into the marine environment may be high due to sediment transport efficiency of low-order streams and the lack of any swamp environment that might aid in sediment retention.
Case IV		
Sediment source connected to any part of the fluvial network of a high-order watershed which drains directly into the marine environment	1) Old and recent development along centerline road in the perimeter of Battery Gut and the main Fish Bay Gut (includes areas on Catherineberg, Adrian, and Susannberg Estates)	Sediment delivery rates into the marine environment might be high due the large area covered by this type of fluvial network, which allows a high number of potential sediment delivery points; frequency of runoff events that deliver sediment is expected to be similar to Case III, but the duration of such events is expected to be longer.
Case V		
Sediment source connected to any part of the fluvial network of a high-order watershed which drains into a swamp/detention pond before entering the marine environment	1) Portions of the Bordeaux Mountain road that drain into the Reef Bay watershed 2) Little Fish Bay Gut sub-catchment	Quantities of sediments delivered to the marine environment is reduced due to settling in the swamp environment and to a reduced frequency of events in which sediment is delivered; unknown effects of sediments in the swamp ecosystem.