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Tampa Bay Estuary Program

IMPACTS OF ATMOSPHERIC DEPOSITION ON STORMWATER QUALITY

FINAL REPORT

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FINAL REPORT

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1. EXECUTIVE SUMMARY

The overall goal of this project was to better differentiate the influence of atmospheric deposition on surface water quality, particularly nitrogen loads in stormwater runoff. Understanding the relative contributions of atmospheric sources versus land-based sources of pollutant loads to Tampa Bay would strengthen the basis for informed management actions currently being defined through the TBNEP-Tampa Bay Comprehensive Conservation and Management Plan (CCMP).

This project had two major objectives: estimating the total nitrogen loads in stormwater runoff contributed from atmospheric deposition versus all other sources for sampled urban/residential basins in the Tampa Bay Watershed; and estimating the retention rates of nitrogen for these basins.

Stormwater sampling from two urban residential study watersheds utilizing automated sampling equipment allowed us to determine non-point source nitrogen loadings using standard techniques of composite sampling. Wet and dry atmospheric deposition sampling at the nearby Gandy Bridge Intensive Atmospheric Deposition site allowed us to quantify inputs from those sources.

Mass Balance Perspective

A coarse mass balance was prepared to provide a general perspective of the magnitude of atmospheric sources in relation to other nitrogen fluxes in the study watersheds. The mass balance indicated that total atmospheric sources amounted to approximately 5-6% of the annual nitrogen input loading to the watershed, with roughly equal contributions from wet and dry deposition. Stormwater discharge loadings of nitrogen from the watershed were of similar magnitude as the wet atmospheric loadings to the watershed, amounting to 3% of the total watershed output. On a mass balance basis, cumulative dry atmospheric deposition and undischarged wet atmospheric deposition inputs are not clearly implicated as a likely major source for stormwater loadings.

Analytical Relationships

The study examined the potential contributions of wet and dry atmospheric nitrogen deposition on stormwater quality both separately and in combination, but succeeded only in identifying clear relationships for wet atmospheric inputs.

Overall Watershed Performance

The stormwater discharge load may be entirely attributable to atmospheric wet deposition loads via both direct discharge and indirect cumulative watershed processes. On an overall numerical basis, nearly all of the annual watershed stormwater discharge loading can be accounted for by the annual atmospheric wet deposition nitrogen loading. If this overall relationship proves meaningful and is not simply a numerical coincidence, it implies that an equilibrium situation potentially exists within these watersheds and the primary driving force behind the nitrogen discharged in stormwater is the excess wet input from atmospheric sources. Under this scenario, the nature of the rainfall – runoff process dictates that only a fraction of the nitrogen discharge is directly attributable to the atmospheric source. The remainder of the stormwater nitrogen discharge could conceivably stem almost entirely from the wet atmospheric inputs through indirect time-lagged watershed processes that eventually result in removal from the watershed of this quantity of nitrogen as excess in an equilibrium system. Although the mass balance indicates that this retained component comprises only a small fraction of the overall watershed nitrogen stores, it is sufficient to account for the entire remainder of the stormwater discharge loading.

Event-based Analysis

On an event-by-event mass throughput basis, approximately 15 - 20% of the total annual rainfall volume and, by inference, 15 - 20% of the associated atmospheric wet deposition nitrogen loading is discharged from the basin immediately as runoff. The remaining 80 - 85% of the atmospheric wet deposition nitrogen input is assumed to be attenuated at least temporarily within the basin, entering the normal nutrient cycle and becoming indistinguishable from other elements of the watershed stores of nitrogen.

The stormwater discharge nitrogen loading from the study watersheds is composed 28% from direct atmospheric wet deposition sources and 72% from in-watershed sources on average during any particular storm event. In-watershed sources during a given storm event include cumulative amounts of previous dry atmospheric deposition and the non-discharged wet atmospheric deposition from previous events. No clear relationship could be identified between these cumulative retained atmospheric nitrogen sources and stormwater discharge loadings during this study.

If the relationship identified for the study watersheds holds true in other watersheds, particularly in similar urban residential areas, the relationship to determine the directly-attributable atmospheric wet deposition contribution to total stormwater discharge loads is:

Percentage directly-attributable atmospheric wet deposition load = (Watershed Runoff Coefficient x Atmospheric Wet Deposition load / Stormwater Discharge load) x 100

The results of the study are directly applicable to similar older urban residential areas with less than lush yards (i.e moderate to low levels of maintenance). The study results for direct contributions of wet atmospheric nitrogen deposition should be transferable to other vegetated areas with reasonable success by following the general rule outlined above.

2. INTRODUCTION

The overall goal of this project was to contribute to the growing body of knowledge regarding the influence of atmospheric deposition on surface water quality, particularly stormwater runoff nitrogen concentrations. Understanding the relative contributions of atmospheric sources versus land-based sources of pollutant loads to Tampa Bay will strengthen the basis for informed management actions currently being defined through the TBNEP Tampa Bay Comprehensive Conservation and Management Plan (CCMP). In particular, a Nitrogen Management Strategy is currently being developed and implemented by the participating members of the TBNEP Management Conference, and this information will assist these members in objectively dividing nitrogen load reduction responsibilities.

Members of the project team have assisted the TBNEP in developing a Nitrogen Management Strategy for Tampa Bay using an objective approach and the best available data wherever possible. The partitioning of stormwater nitrogen loads between atmospheric and land-based sources has been identified as an important data gap during apportioning of annual reductions to individual governments and other entities, and this project will help to fill this data gap.

This project had two major objectives:

- estimating the total nitrogen loads in stormwater runoff contributed from atmospheric deposition versus all other sources for sampled urban/residential basins in the Tampa Bay Watershed; and

- estimating the retention rates of nitrogen for these basins.

This project consisted of two major tasks: the collection of field data and the analysis of those data. Measured precipitation volume and quality data were obtained from the Gandy Bridge site, and measured stormwater quality data were collected from two locations near the Gandy Bridge site.

These data were used to estimate the proportion of the atmospheric deposition nitrogen loading delivered to the study site that contributes to nonpoint source loadings, and the proportion of the atmospheric deposition nitrogen load that is retained (attenuated) in the watershed. Additionally, the proportion of the total nonpoint source nitrogen load from the drainage basin that is directly or potentially attributable to atmospheric deposition was estimated. A coarse mass balance was prepared to place the atmospheric inputs and stormwater discharges in perspective.

Nitrogen loading estimates to Tampa Bay due to atmospheric deposition were previously determined as part of the total estimated loadings to the bay for 1985-1991 (Zarbock et al., 1994). Wet deposition was estimated during that study by utilizing precipitation and nutrient concentration data collected at the National Atmospheric Deposition Program site at Verna Wellfield, and dry deposition estimates were determined by multiplying wetfall estimates by a regionally-derived ratio determined by the Florida Acid Deposition Study. These estimates determined that atmospheric deposition directly to the bay's surface may account for about 29% of the total nitrogen load to the bay.

Given the relative importance of this load in comparison with the total nitrogen load to the bay, it was determined that a more accurate estimate of atmospheric deposition of nitrogen to the bay's surface was necessary. The TBNEP, Hillsborough, Pinellas, and Manatee counties, and the Florida Department of Environmental Protection, asked that the bay be included as an EPA Great Waters Program. The Tampa Bay Atmospheric Deposition Study (TBADS), after approval by the EPA Great Waters Program, was begun in the spring of 1995, and resulted in data collection beginning in August 1996, and continuing through the present, with plans for sampling through 1999. The issues determined to be addressed by the TBADS were

- estimation of the extent of water quality impacts from atmospheric deposition directly to the surface of the bay and that due to stormwater runoff, and
- identification of sources of atmospheric nitrogen and toxic materials deposited to the bay and its watershed.

To determine the estimates of atmospheric nitrogen deposition to the bay, participants in the TBADS recommended a sampling site on the eastern end of the Gandy Bridge, which was approved by the NOAA/Great Waters participants. Data collected at this site, in concert with meteorological data collected at a mid-bay site, have been analyzed to derive the amount of nitrogen being directly deposited to the bay surface (Pribble and Janicki, 1998).

Previous estimates of atmospheric deposition directly to the surface of Tampa Bay yielded a contribution of 27% of the total nitrogen load to the bay over the 1985-1991 time period (Zarbock et al., 1994). Based on the estimates of atmospheric deposition as described in Pribble and Janicki (1998), the contribution of atmospheric deposition to total nitrogen loading to the bay, using the 1985-1991 estimates for other loading sources, is 23%, or 1.7×10^6 lbs/yr to the bay surface of approximately 255,000 acres.

Nutrient loadings to the watershed, and thus to stormwater, from wet deposition may be assumed to be the same as that to the bay's surface, as the physical mechanisms of wet deposition are not appreciably different to a water body and to the land surface. Dry deposition of nutrients to the bay surface, however, is dependent upon not only atmospheric concentrations of nutrients, but upon physical characteristics of the atmosphere and water body as well (Pribble and Janicki, 1998; Valigura, 1995). Dry deposition calculated based upon the method described in Valigura (1995) to a water body is likely to be very different, given the same atmospheric concentrations of chemical species, than that to a terrestrial surface. Several factors are apparent which may lead to this difference. The amount of surface area available within a unit of ground area may be considerably greater than that in a unit of water body area, due to the three-dimensional characteristics of terrestrial surfaces (grass, trees, buildings) and the approximately two-dimensional surface of the water. The question of how to best handle dry deposition on a variety of three-dimensional substrates and accurately estimate the nature and amounts of material that is actually subject to washoff and transport is a matter of continuing research and debate.

Effects of wind on dry deposition to a water body can be estimated, serving as an aid to deposition, whereas for terrestrial surfaces, winds may serve to resuspend previous deposits and autochthonous materials and remove them from a unit area, as well as aiding in the deposition of allochthonous materials. From discussions held with scientific advisors to the TBADS, however, there appear to be no universally accepted methods for estimating dry deposition to a terrestrial surface. Until better methods are developed and implemented, the modeled dry deposition to a water surface, as described in Pribble and Janicki (1998), are utilized here to estimate contributions of atmospheric deposition to stormwater nutrient loadings to the bay.

3. STORMWATER SAMPLING PROGRAM

The objective of the stormwater sampling program was to measure input rainfall amounts, runoff discharge amounts, and to conduct chemical analyses of the runoff discharge to allow calculation of pollutant loads.

3.1. SITE SELECTION

3.1.1. Criteria for Site Selection

The watershed sampling sites were selected based on the basin meeting a defined set of criteria. The watershed selection criteria were:

- **Drainage basin size**
- **Homogeneity of land use**
- **Proximity to Gandy Bridge Atmospheric Deposition Monitoring Site**
- **Avoidance of backwater conditions**
- **Sufficient flow for sample collection**
- **Accessible sampling site within the basin**

- **Drainage basin size** -- The size of the drainage basin was important for several reasons. First, the basin was required to be large enough to generate sufficient runoff to sample on a regular basis. Second, larger drainage basins often do not have homogeneous land use, as needed to meet the analytical criteria. Finally, large basins often have more internal processes that may make the accurate prediction of hydrologic and pollutant inputs and outputs more difficult. For this reason, it was desired to select drainage basins to sample that were large enough to generate sufficient runoff, yet not so large as to be too complex or heterogeneous for the analysis.

- **Homogeneity of land use** -- Our proposal for this work included several different approaches for selecting the land use composition and number of representative sampling sites. Because residential land use is the most common urban land use in most of the major basins in the Tampa Bay Watershed, it was decided to evaluate residential land use as representative of urban development. In addition, if the mass balance approach was to be used, added certainty could be placed on identifying and quantifying sources and sinks of nitrogen within a single land use. Thus, site selection was also based on identifying a drainage area with predominance, if not totality, of residential land use.

- **Proximity to Gandy Bridge Atmospheric Deposition Monitoring Site** -- A central assumption for this work was that precipitation quality data from the Gandy Bridge site would be used for the analysis. Thus, it was imperative that the area selected for stormwater sampling be close enough to that site to make valid the assumption that the rainfall data collected at the Gandy Bridge site was representative of the monitored basins. Although the monitored site was only 0.8 miles from the Gandy site, significant variation in rainfall depth was observed.

- **Avoidance of backwater conditions** -- The area near the Gandy Bridge site has relatively low topography with little relief, and much of the coastal storm drainage system is subject to tidal inflows and backwater. To enable accurate discharge measurements to be made, and to obtain representative water quality samples, the sampling site was most desirably located to avoid tidal inflows and backwater effects to the greatest extent possible.

- **Sufficient flow for sample collection** -- As stated above, the selected drainage basins had to be large enough to generate sufficient runoff for frequent sample collection. Meeting this criteria was dependent on both the size and land use of the basin, and the configuration of the runoff conveyance at the sampling site. For example, if a moderately sized basin must be sampled in a large conveyance, a runoff discharge flow that may be suitable for sampling in a smaller conveyance may not sufficiently fill the larger conveyance to obtain good stormwater samples. It was assumed that a minimum runoff depth of four inches within the conveyance to be sampled would be sufficient for sample collection.

It was necessary at the project outset to establish a minimum desired rainfall event expected to yield adequate stormwater runoff flow for sampling such that a sufficient number of these events would predictably occur within the proposed sampling period. Water resources literature typically assigns approximately the first 0.2 inches of rainfall to "initial abstraction" for urban land uses. This includes wetting the ground and vegetation and filling minor depressions prior to the initiation of runoff. Thus, standard practice suggests that a minimum rainfall event of greater than 0.2 inches is necessary to generate any runoff.

Based on a review of long- term (1933 through 1995) precipitation records from Tampa International Airport, an average of just over two rain events of one inch or greater occurs during each of the wet season months (June through September), and an average of one or less occurs during each of the dry season months. An average of over four rain events of one-half inch or greater occurs in each of the wet season months, and one to two such events occur during each of the dry season months. It therefore seemed reasonable to set a minimum desired rainfall event at between 0.2 and 0.5 inches to ensure that adequate runoff for sampling would be generated. Some variation within the desired range could be expected depending on antecedent moisture conditions and the configuration and dimensions of the conveyance that was to be sampled (pipe or ditch).

- **Suitable sampling site** -- To obtain good samples using automated sampling equipment, a suitable sampling location must be available. To be acceptable, a site must have a functional stormwater conveyance (e.g., a manhole or inlet to a piped system, or an open channel). In addition, access must be available to locate instrumentation at the site and to drive a vehicle close to the site. Finally, the site must be secure. This includes consideration for equipment and instrumentation safeguarding, and for field personnel safety while approaching, working at, and leaving the site.

3.1.2. Site Characterization

The main criterion for site selection, proximity to the Gandy Bridge site, required that any drainage basin selected for sampling be located within a short distance of the east Gandy Bridge Causeway. The purpose of this criterion was that precipitation quality data collected at the Gandy Bridge site could then be used to represent conditions at the stormwater sampling site with some certainty. To accommodate this criterion, the project team selected two basins located within the nearby Norma Park area.

The City of Tampa recently conducted a drainage study of the Norma Park area, which includes portions of south Tampa at and adjoining the Gandy Bridge site. The study (CDM, 1990) focused on flooding problems rather than water quality, but provided a detailed assessment of subbasin delineation, surface water drainage patterns, drainage infrastructure, land use and soils characteristics, and other information. In addition, the study included surface water modeling of the Norma Park area. Results of the study (area characterization, modeling, and field data collected for model set up and calibration) proved useful for the subject investigation.

Based on the above criteria, two sites were selected as most appropriate to monitor to determine the impact of atmospheric deposition on stormwater quality. These sites are located on Figure 3-1 and are discussed in greater detail below.

3.2. Description of Sampling Sites

Both sampling sites were very similar in character. Photos 1 and 2 provide some typical views in these residential areas.

3.2.1. Site 1

Site 1 (Bay Vista): This sampling site is located east of Manhattan Avenue and west of Dale Mabry Highway, south of Euclid Avenue at Bay Villa Avenue. The sampled basin encompasses approximately 54 acres, and consists of approximately 95% residential and 5% open area associated with an institution (school). The stormwater drainage pattern is generally from east to west, then south toward Bay Villa Avenue (Figure 3-1).

Stormwater is conveyed through the basin via overland flow, along streets without storm drains, via stormwater pipe network and discharges to an open-channel concrete lined ditch. The sampling site was located in a manhole with an 18 inch pipe.

- **Proximity to Gandy Bridge Atmospheric Deposition Monitoring Site** -- The basin is approximately 1.5 miles from the Gandy Bridge site.

- **Drainage basin size** -- The basin includes approximately 54.0 acres. This was of sufficient size to generate stormwater for sampling, as discussed below.

- **Homogeneity of land use** -- The basin consists of 95 % residential and 5% open area land use. The residential land use is of similar uniform density (single family with 5 - 8 lots per acre) throughout the basin.

- **Avoidance of backwater conditions** -- The sampling site is located relatively far inland and tidal inflows during high tide were not observed during field reconnaissance.

- **Sufficient flow for sample collection** -- A minimum rainfall event of between 0.2 and 0.5 inches was initially anticipated as required to ensure that adequate runoff for sampling was generated. Based on preliminary calculations using the SCS Runoff Curve Number Method, a 0.5 inch rain with a curve number of 80 would result in approximately 0.1 inch of runoff. A 50-acre basin would thus generate approximately 4,500 cubic feet of runoff. If the runoff hydrograph lasted for one hour past the end of rain (not unlikely given the developed nature of the basins), then average flows reaching approximately 1.0 to 1.5 cubic feet per second (cfs), with peak flows of 2.5 to 3.0 cfs would be generated. This was sufficient to reach the four-inch depth required for sampling, so the flow criteria were met. Stormwater sampling results indicated that the initial assessment was correct.

- **Suitable sampling site** -- The site has a functional stormwater conveyance (piped system to ditch), and access is available to locate instrumentation at the site and to drive a vehicle close to the site. Being on school grounds, the site is also relatively secure.

3.2.2. Site 2

Site 2 Fair Oaks: This sampling site is located east of Westshore Boulevard and west of Manhattan Avenue, at the intersection of Trask and Lawn Avenue. The basin to be sampled includes approximately 17.9 acres, and consists exclusively of residential land use. The stormwater drainage pattern is generally from east to west then north of Fair Oaks to a main storm drain (Figure 3-1).

Stormwater is conveyed through the basin via overland flow, along streets without storm drains, and a stormwater pipe network that discharges to a main storm drain via an 18 inch pipe. The sampling site was located at a manhole on Lawn Avenue.

- **Proximity to Gandy Bridge Atmospheric Deposition Monitoring Site** -- The basin is approximately 0.8 miles from the Gandy Bridge site.

- **Drainage basin size** -- The basin includes approximately 17.9 acres. This was of sufficient size to generate stormwater for sampling, as discussed below.

- **Homogeneity of land use** -- The basin consists entirely of residential land use, all of similar density (single family with approximately 5 - 8 lots per acre) throughout the basin.

- **Avoidance of backwater conditions** -- Although the sampling site is located relatively close to the bay, tidal inflows were not observed at the proposed sampling site during field reconnaissance on high tide.

- **Sufficient flow for sample collection** -- As stated above, a minimum rainfall event at between 0.2 and 0.5 inches was initially stipulated to ensure that adequate runoff for sampling is generated. Based on preliminary calculations using the SCS Runoff Curve Number Method, a 0.5-inch rain with a curve number of 80 would result in approximately 0.1 inch of runoff. A 17.9 acre basin would thus be expected to generate approximately 1,500 cubic feet of runoff. If the runoff hydrograph typically lasted for about one hour past the end of rain (not unlikely given the developed nature of the basin), then average flows reaching approximately 1.0 to 1.5 cubic feet per second (cfs), with peak flows of 2.5 to 3.0 cfs should be generated. This would be sufficient to reach the four inch depth of flow in the pipe desired for sampling, so the flow criteria were met.

- **Suitable sampling site** -- The site has a functional stormwater conveyance (piped system with a manhole), and access was available to locate instrumentation at the site and to drive a vehicle close to the site. The site was also relatively secure.

3.3 Stormwater Sampling Methodology

Storm water samples were collected using ISCO automated samplers. One sampler was installed at each site. Each sampler recorded water level (measured by bubbler), and was activated to collect a minimum sample (100 ml) based on flow intervals. Prior to sampler installation and programming, a stage-discharge relationship (rating curve) was developed for each sampling site through repeated measurement of flow and associated water level through the system. Establishing a stage-discharge relationship would allow flow to be estimated by observing the water level elevation. The sampler could then be programmed to initiate sampling at a given flow increment based solely on changes in water level over time.

Samplers had PVC lines installed to reach the stormwater flow at a minimum of one inch above the conveyance bottom. No strainer was used, and the sample collection line was faced downstream to minimize clogging by leaves and other large particulate material. The sample collection lines were purged automatically between each sample.

Samples were composited to obtain one flow-weighted composite sample for each runoff event. This limited analytical costs while providing a good representation of the total load from individual runoff events.

The samplers were checked daily. Field personnel collected all water samples associated with runoff events (up to one composite sample per 24-hour period). Because of the limited size, abundant impervious surface, and well-developed drainage infrastructure, runoff hydrographs from the basins were expected to peak and recede rapidly. Thus, it was not anticipated that extended periods would be spent at the sites during sampling events. Field monitoring for the CDM (1990) study suggested that most runoff from typical storm events (0.5 to 1.5 inches) discharged from the basins in one hour or less after the cessation of rainfall. This pattern was generally observed in practice, although continuous low flow discharges sometimes continued for many hours after the majority of the discharged had passed.

Samples were tested for specific conductance in the field, then fixed prior to shipment to Thornton Laboratory. Samples were delivered for analysis within specified holding time limits.

Photo 3 shows the ISCO automated sampling equipment used during this project.

Photo 4 shows the sampling probe installation from a test site during a trial run early in the project. Final sampling installations at both sampling sites were located within 18 inch diameter pipes.

3.4. Sampled Stormwater Parameters

The objective of this study was to investigate the influence of atmospheric deposition of nitrogen on stormwater runoff quality, and to estimate the relative proportion of nitrogen from atmospheric sources that is retained in the watershed and that enters the runoff stream. For these purposes, composite stormwater runoff samples were analyzed for TKN, NO_2/NO_3, and specific conductance.

The nitrogen species when summed yielded a reasonable estimate of TN concentration, and the specific conductance helped to identify potential contamination of the stormwater stream by other sources.

Samples were tested for specific conductance in the field and then fixed/preserved prior to shipment to Thornton Laboratory. Samples were delivered for analysis within specified holding time limits. All sampling was conducted in strict accordance with the EPA approved Quality Assurance Project Plan.

In some cases, runoff discharge from storm events continued into a second day (typically due to either very large events or multiple episodes of rainfall over an extended time). Due to the way the samplers were programmed, additional composite samples were also collected on the second day throughout a portion of the discharge hydrograph. This information provided a basis for better estimation of concentrations throughout the entire discharge period and ultimately provided some unique observations.

The ISCO samplers were checked and serviced daily. Field personnel recorded daily rainfall totals and collected all water samples associated with runoff events (up to one composite sample per 24-hour period). Because of the limited subbasin sizes, abundant impervious surface, and well-developed drainage infrastructure, runoff hydrographs from the basins tended to peak and recede fairly rapidly.

3.5. Qualifying storm events

Qualifying events to be used in the analysis were those for which a complete data set was available. This required recorded rainfall totals from both the Gandy atmospheric sampling site and the watershed stormwater sample site and successful sample collection and chemical analysis. Secondary considerations included reviewing the distribution of sampling intervals within the discharge hydrograph to assure that a representative sample had been obtained and comparing rainfall totals at the site with the Gandy record to assure that similar rainfall had been received.

Sample collection and analysis occurred 80 times at Site 1 and 33 times at Site 2. Thirty nine of the samples at Site 1 could not be used because no rainfall event had occurred or site rainfall depth was not recorded. Likewise, 4 of the samples at Site 2 were invalid for similar reasons. Causes included simple sampler malfunction or flows generated by lawn irrigation or car washing that were sufficient to trigger the sampler.

A further 8 samples at Site 1 and 8 samples at Site 2 were censored due to problems with aligning rainfall amounts and other data collection difficulties. Sample data were discarded because rainfall was not collected (did not occur or was not recorded) at Gandy, there was significant disagreement between site rainfall and Gandy rainfall, or field data records were not retrievable (computer failure) and discharge volumes could not be calculated. No samples were rejected due to poor distribution of sampling aliquots throughout the hydrograph.

This initial data screening effort resulted in identifying 33 qualifying sampling events at Site 1 and 21 qualifying sampling events at Site 2. In the remaining data set, multiday events occurred 6 times at Site 1 and 5 times at Site 2. Corresponding rainfall, runoff and analytical values were composited to support the loading analysis. Following the calculated composite preparation, the final data set consisted of 26 samples at Site 1 and 16 samples at Site 2. This data set was used to conduct rainfall and discharge volume analyses.

When results of the rainfall chemical analysis at Gandy were received, additional events were eliminated from the comparative analysis because analytical data were not available for atmospheric wet deposition. The final data set for the qualitative analyses that compared atmospheric wet deposition and stormwater discharge consisted of 17 events at Site 1 and 11 events at Site 2. The final data set for analyses that compared total atmospheric deposition (wet + dry) included 12 samples from Site 1 and 5 samples from Site 2 due to data gaps in the dry deposition results. The data attrition experienced during this study is unfortunately fairly typical for studies of this type and underscores the frustrations and difficulties in acquiring comparative field data from several different sources.

3.6. Rainfall Data

Stormwater sampling site rainfall data were collected using a standard pole-mounted plastic gauge installed at each site. The site rainfall gauges had a capacity of 5 inches of rainfall, which unfortunately proved to be insufficient when 6.93 inches were recorded at the Gandy station during a 24-hour period on September 26-27, 1997. This event proved to be one for which atmospheric wet deposition results were unavailable, also due to insufficient volume in the sample collector.

3.6.1. Relationship between Rainfall at Gandy and Sampling Sites

Although Sites 1 and 2 were located 1.5 and 0.8 miles from the Gandy site, respectively, rainfall totals observed did not always agree closely between the two sites or between the sites and Gandy. On several occasions, no rainfall would be observed at one or another gauge although significant rainfall was noted at the other locations. This is reflective of the locally highly variable rainfall typical of Florida's roaming thunderstorm cells. Rainfall totals shown are for either 24 hour or 48 hour periods corresponding to the sampled events. A number of events lasted longer than 24 hours due to continuous rainfall and corresponding extended discharge. In these cases, daily rainfall totals were summed to provide an overall event total.

Table 3-1 summarizes the rainfall received at Gandy and Site 1 for the qualifying events prior to further culling for date-matching with the atmospheric deposition samples. Table 3-2 provides the same summary information for Site 2. It should be noted that the events are dated on the day the sample was collected (typically at 8 – 9 AM) and the figures reflect the rainfall during the previous 24 hour period. Figures 3-2 and 3-3 provide a graphical comparison of Gandy rainfall with rainfall measured at each study site.

The overall rainfall totals measured at the Gandy bulk precipitation sampler were about 10% less than the rainfall totals measured at the study sites. In general, the larger events were almost consistently lower while the smaller events exhibited significant variability.

3.6.2. Stormwater Discharge Flow Data Calculation

Stormwater runoff samples were collected using ISCO automated samplers that recorded water level and used preprogrammed stage-discharge relationships (rating curves) to calculate instantaneous and cumulative flow. All data were recorded in sampler memory for later download. Strip chart recordings of discharge hydrographs annotated with sampling intervals were also produced. Independent measurements were made during the project to confirm the stage-discharge relationship using a velocity meter and depth gauge.

Following a review of the collected data, it was determined that unique site conditions and quirks of the instrumentation precluded using the instrument-calculated flow data directly in further calculations, although water level recordings were deemed reliable with some limitations. Recurring problems with the level sensors returning to a true zero position resulted in the instruments continuously calculating and accumulating a small 'flow' when none was actually occurring, resulting in relatively large errors in the instrument-reported cumulative discharge flow volumes. In addition, a continuing sedimentation problem at Site 1 caused by a break in a pipe joint further aggravated the flow calculation problem. Although city crews repeatedly flushed and cleaned the pipe and eventually located and repaired the problem, many of the monitored events at this site were impacted by the erroneous calculated flow recordings. In this case, the pipe was partially blocked, reducing the effective flow area.

The problem with flow data was overcome during the data reduction effort by using the instrument's water level recordings and manually recalculating the instantaneous and cumulative flow using the same ratings and Manning's friction factor based pipe flow calculation that had initially been programmed into the autosamplers. In the case of the partially blocked pipe at Site 1, the effective pipe flow area was recalculated for each reported flow interval (15 minute data) to make the correction. The depth of sediment in the pipe was available from non-discharging periods before and after the event, allowing us to estimate the approximate sediment depth for each flow interval during the event. Typically the sediment depth would increase or decrease slightly during smaller events but would be nearly flushed away during larger events.

Flow ratings of the pipe conveyances were confirmed by two methods. One method used a hand-held flowmeter to record discharge for comparison with the ISCO calculated discharge. Figures 3-4 and 3-5 show the results obtained at Sites 1 and 2, respectively. The results agree reasonable well. The greatest difficulty in this approach was aligning the manually collected data time-wise with the pre-timed recordings of the ISCO 3230 unit.

The second method employed installing a Doppler velocity meter (ISCO 4150) to directly record flow velocity. Such units were installed for a short time at both sample sites. Good results were obtained at Site 1, but no useful data were gained from Site 2 due to water level sensor malfunction that reported all flow depths as 0.3 feet. Unfortunately, the problem was not discovered until after the equipment had been removed from the site and data were downloaded from the instrument. This effort was supplementary to the above flow rating process and was intended to confirm the previous results.

Figure 3-6 shows the results obtained at Site 1. It is interesting to note that essentially full pipe flow is exhibited even when surcharged conditions existed (depth greater than the pipe diameter of 1.5 feet in the manhole). This indicates that there was no major backwater effect, such as from tidal influences or other causes, to limit discharges from the system and that the primary control was the size of the conveyance. This performance confirmed previous field observations that indicated such effects were not anticipated. The result also confirmed that water level recordings from the ISCO composite samplers could reliably be used to calculate stormwater discharge flows. Despite the lack of confirming data, field observations did not indicate any reason to suspect that Site 2 functioned any differently than Site 1 and water level data from this site were also considered reliable for flow calculations (within the limitations discussed above). This result also indicated that data from large events causing surcharged conditions could be included in further analysis. Based on the project approach, the possibility existed that data from large events would potentially be eliminated from further analysis due to the inability to reliably determine discharge flows and volumes from water level recordings alone.

Tables 3-1 and 3-2 summarize the total cumulative discharge volume for each event at Site 1 and Site 2, respectively. Separate and combined rainfall totals and cumulative discharge volumes are shown for multi-day events. These events are discussed further below.

Figures 3-7 and 3-8 provide a comparison of the rainfall observed and the runoff volume generated at Site 1 (54.0 acres) and Site 2 (17.9 acres), respectively. Site 2 in particular appears to have some inherent depressional or other storage capacity that varyingly impacts the start of discharge depending on antecedent moisture conditions. For example, 0.5 inches of rain produces anywhere from about 250 to 4200 cubic feet of discharge at different times. The greater discharges occur during an extended wet period in December 1997. Similarly, rainfalls in the 2+ inch range variously produce under 10,000 or over 20,000 cubic feet of runoff. The low discharge event was preceded by a month long dry period that saw only about 0.7 inches of total rainfall.

3.7. Stormwater Nitrogen Load Calculation

Determining the total nitrogen load in stormwater runoff was straightforward but relied on several key assumptions. The most important assumption was that the composite sample was representative of the entire discharge volume. The measured concentrations obtained from the composite samples were assumed to be representative of the entire discharge period for the purpose of calculating loads.

A complication when applying this approach involved handling of the longer discharge events. Several events at each site spanned a two-day time period of continuing discharge and were also sampled twice (once each day). In those cases, the analytical results from the two composite samples were weighted in proportion to the observed rainfall for each day to develop representative concentrations and loadings for the entire period of discharge. Although it is not strictly correct that the runoff would be directly proportional to the rainfall, there was no reasonable way to further differentiate the exact contribution of each portion of rainfall.

A review of the multi-day discharge hydrographs revealed the general trend that rainfall occurring during the second day was usually of smaller magnitude. Stormwater discharge resulting from the previous day's rainfall continued during the second day. This formed the basis for treating the entire period of continuous discharge as a single event with multiple periods of rainfall and combining the results. Due to the approach used in assigning the analytical values to portions of the entire runoff discharge volume on the basis of the rainfall amount observed, the calculated composite analytical result may slightly favor the results from the first day's sampling. The reason the results may be biased stems from the fact that rainfall occurring when the ground is saturated typically generates greater runoff in proportion to the rainfall amount. This is not expected to have introduced much additional uncertainty in the results because the composite samples obtained typically spanned only approximately 4 – 6 hours during each sampling cycle in any case. Only those events with greatly different analytical results for the two samples would be significantly affected by potential error in assigning portions of the discharge volume for the composite calculation. Although the composite sampling time frame was sufficient for many storm hydrographs for shorter events and performed well to sample the bulk of the period of greatest discharge, long periods of extended low flow discharge are not well represented in the composite sample.

Tables 3-1 and 3-2 provide a summary of the composite sample nitrogen species concentrations for the events observed at Sites 1 and 2, respectively. The events for which sample results were further composited to apply to the entire multi-day discharge volume are shown highlighted in the table, followed by the calculated composite results that were later used in further calculations. Regarding the multi-day discharge events, it is interesting to note that 2 of the 6 sample sets at Site 1 and 3 of the 5 sample sets at Site 2 showed higher nitrogen concentrations during the second sampling of the total discharge and on some of those occasions the increase was fairly significant (see Tables 3-1 and 3-2). This suggests that extended saturated conditions in the watershed can sometimes allow additional nitrogen to enter solution for discharge. This contradicts, at least some of the time, the popular notion that the 'first flush' from a storm is the always the portion most worthwhile to capture and treat. The first flush contains the majority of the suspended solids and associated pollutants, but it is apparent that soluble components may appear at increased concentrations later in the event discharge stream.

The sampling protocol followed during this project did not allow us to determine whether this concentration increase might also have been evident during the tail end of the shorter discharge hydrographs. This topic could be addressed by conducting discrete sampling and analysis throughout the entire period of discharge. In examining the record in greater detail, there is no apparent general correlation between the duration of the events and the ultimate composite concentration observed by the methods used during this study.

Figures 3-11 and 3-12 provide a summary of monthly stormwater discharge loadings from Site 1 and 2, respectively. The totals are not all-inclusive because one or more events may be missing from the record at each site (notably August 1997 data from Site 2) because they were eliminated from the analysis as described in Section 3.5. A striking feature of both plots is the tremendous loadings generated during December 1997 while heavy El Niño rains saturated the area.

4.0 ATMOSPHERIC SAMPLING PROGRAM

The objective of the atmospheric deposition data collection and analysis for this project was to determine the amount of total nitrogen loadings to the watershed of the bay resulting from direct deposition to the watershed.

4.1 Atmospheric Sampling Methods

Data collection at the Gandy site and the meteorological station (see Figure 4-1) commenced in August 1996, with the first measurements of atmospheric nitrogen species and meteorological data on August 7, 1996. Collection of wet deposition data for nitrogen began on August 13, 1996 (Pribble and Janicki, 1998).

Analyses of wet deposition samples yield values of ammonium, chloride, sulfate, potassium, magnesium, specific conductance, orthophosphate, nitrate, sodium, calcium, and pH. In addition to the wetfall samples, rainfall amounts are taken from an on-site rain gauge. Wetfall samples were collected at least once weekly, and often more frequently.

For collection of data needed for calculation of the dry deposition of nutrient species to the bay, and, as we assume, to the watershed, the meteorological site in Tampa Bay provides input to the NOAA buoy model (Valigura, 1995) to determine deposition velocities of particulates from 1-2 mm and for nitric acid (gaseous). The relevant physical parameters are wind speed, air temperature, water temperature, and relative humidity. The dry deposition sampling apparatus consists of a dual flow-through system containing annular denuders, for gaseous components measurement, and a nylon filter system, for collection of particulates. Sampling is done for a 24-hour period every six days, with a pumping rate of 10 liters/minute over the 24 hours. The samples are analyzed for gaseous and particulate nitrate, sulfate, and ammonia.

4.2 Quality Assurance

Wet deposition sampling is done following the protocols developed by the National Atmospheric Deposition Program (NADP) Atmospheric Integrated Research Monitoring Network (NADP/AIRMoN). A wet bucket collects rainfall samples, and samples of greater than 10 ml are sent to the Central Analytical Laboratory (CAL) of the Illinois State Water Survey, where the samples are analyzed utilizing the same methods as those used by the NADP/AIRMoN program.

Dry deposition is sampled using the denuders and filter packs for determination of gaseous and particulate nitrogen concentrations in the atmosphere. The denuders and filter packs are sent to QST (formerly Environmental Science and Engineering) for analysis.

Meteorological data as collected at the site in Tampa Bay are reviewed for data anomalies. Given that meteorological data are averaged from 1 second data for every 30 minutes, with atmospheric concentrations averaged over 24 hours, elimination of isolated data anomalies does not greatly impact calculation of 24-hour deposition rates.

4.3 Data Reduction

For wet samples that span several days between collections, the measured wet deposition is evenly distributed over the days for deposition calculation. To determine the wet deposition of nutrient species, the concentrations of various nitrogen species are determined, and the total mass flux due to wetfall is the product of the chemical concentration in the rainfall, the rainfall depth, and the surface area of the watershed.

Determination of dry deposition is not such a straightforward calculation. Concentrations of various nitrogen species in the atmosphere are determined, and deposition velocities for the various nutrient components to the bay, and thus, by the assumptions of this effort, to the watershed, are determined utilizing the buoy model developed by NOAA. The NOAA model uses as input meteorological data collected near the intensive deposition sampling site.

For the purposes of calculating dry deposition, the measured concentrations taken every six days are allowed to represent the concentrations on the day of sampling, and on the previous 2.5 days and the following 2.5 days. The concentrations of the various chemical species in the atmosphere are then multiplied by the appropriate deposition velocity, the surface area of the watershed, and the time period over which the deposition velocity is calculated, to determine the total flux of each nutrient species.

The sum of the wet mass flux and the dry mass flux of nitrogen species to the bay and its watershed represents the deposition of nitrogen due only to those nitrogen species converted by the annular denuders to nitrate and ammonium, in addition to the particulate forms of nitrogen collected by the nylon filter pack and the nitrate and ammonium from the wet deposition.

4.4 Nitrogen Deposition

Rainfall data collected at the Gandy site are shown in Figure 4-2 for July 1997 through December 1997. The total nitrogen concentration in the wet sample during each rainfall event is displayed in Figure 4-3 for the same time period. The product of the rainfall depth and the total nitrogen concentration yields the associated deposition of nitrogen for each rainfall event, shown in Figure 4-4. The relationship between rainfall and wet nitrogen deposition at the Gandy site is shown graphically in Figure 4-5. This relationship is linearly fit with a line by the equation

Wet N-flux (g/m^2) = Rainfall (m) x 0.2593 + 0.0013,

with a coefficient of determination (r^2) of 0.40. This fit is only applicable for the period from July through December, 1997.

Atmospheric concentrations of nitrogen species were determined from data collected every six days at the Gandy site for August 1996 through December 1997. Meteorologic data were collected for the same time period, and used to determine dry nitrogen deposition fluxes to the surface of the bay (Pribble and Janicki, 1998), and to the land surface following the assumptions of this study. The monthly wet, dry, and total nitrogen fluxes for the available data are displayed in Figure 4-6. It is important to note that wet deposition data were not obtained for some of the larger events due to sampler overflow. The recording rain gage at the site has a maximum level beyond which the gage overflows. The samples for which this occurs are noted in the NADP database, with the corresponding measurement from the Belfort rain gage at the same site. These events were disqualified from the data to be analyzed because of the lack of a sample volume measurement. Notably, September and December data are underestimated.

Wet deposition totals for each sampled month, from August 1996 through December 1997, are shown in Table 4-1. For the one full year of data, 1997, the total wet deposition of nitrogen is 356 mg/m^2 (3.18 lb/acre). Table 4-1 also shows the total monthly dry nitrogen deposition for the August 1996 through December 1997 period. For 1997, the total dry deposition of nitrogen is 387 mg/m^2 (3.45 lb/acre). Total nitrogen deposition to the surface of the bay in 1997 was approximately 743 mg/m^2 (6.63 lb/acre) (Pribble and Janicki, 1998). Table 4-2 shows a more detailed breakdown of the monthly dry deposition data for gaseous N and particulate N.

5.0 PROJECT APPROACH

The general project process and analytical procedure that was initially defined for application during the data analysis provided a means to evaluate the overall transfer of nitrogen from atmospheric deposition through the watershed to the stormwater discharge. By looking primarily at apparent overall watershed transfers of nitrogen from only the measured atmospheric inputs to the stormwater discharge, the method was intended to avoid a requirement to understand and characterize watershed processes in detail while still determining the cause and effect relationship. The approach implied that atmospheric nitrogen inputs are a major source of nitrogen inputs to the watershed, of roughly the same order of magnitude in total as all other inputs. The approach assumed that a clear relationship between total wet and dry deposition and the stormwater discharge loading would be readily identifiable but this ultimately proved not to be the case. As originally presented, the initial analytical method suffered from a number of limitations if only wet or dry deposition were to be considered in relation to stormwater discharge loadings and if atmospheric inputs proved to be a minor input to the watershed on a mass basis. As a result the initial project approach underwent some refinement during the course of the analyses.

The approach was modified to include the mass balance to provide the proper perspective for the apparent overall watershed atmospheric deposition loading-stormwater discharge loading balance. Available monthly data were summarized, but seasonal or monthly comparison analyses of atmospheric deposition and stormwater discharges could not be prepared because the data set was incomplete and the results from the remaining limited data would have little meaning. The atmospheric loading versus stormwater discharge loading analysis was expanded beyond the overall watershed transfer approach to consider event-by-event watershed throughput on the basis of the volume of runoff generated.

5.1 Constraints, Limitations and Uncertainty

Constraints

The project encountered a number of constraints. Limited resources were available so that it was not possible to instrument and study many different watersheds with different land uses as initially desired. Alternatives to maximize the information obtained such as less frequent grab sampling from watersheds covering a variety of land uses were considered. The final consensus was that more intensive efforts at fewer locations would provide a better database. Two similar watersheds both representing typical established urban single family residential land use were studied. The study watersheds had to be located near to the atmospheric deposition sampling location so that data obtained at that site would be reasonably transferable to the study watersheds. Additional constraints and site selection criteria are discussed previously.

Limitations

Primary limitations of the analysis include the inability to reliably collect and analyze 'ideal' samples from each and every storm event during the study period. Equipment problems, human error, and Mother Nature always conspire to result in the loss of potentially useful information despite best intentions and best efforts. For example, sample collection containers at the atmospheric site proved too small resulting in discarding data from all of the large rainfall events. Due partly to the El Niño conditions, there were a significant number of large events successfully sampled for stormwater for which no atmospheric data were available. Partly as a result of the unusual weather conditions, rainfall gauges were also undersized for the largest events observed. In hindsight, fully automated equipment of greater capacity should have been used.

The scope of the study precluded detailed field characterization of each element of the watershed nitrogen material balance or the complete water balance. For example, the many landowners could not be interviewed in detail to ascertain exact fertilizer application amounts and timing nor the number and habits of pets.

The results of laboratory chemical analyses are always subject to limitations in sampling methodology, sample processing and handling, and accuracy of the analytical method. Composite sampling techniques, regardless of the approach used, are limited. For example, equal aliquots sampled at flow-proportioned intervals over the course of a few hours during the period of greatest discharge, as was done, may provide different results than flow proportional samples drawn continuously throughout the entire period of discharge. Alternative sampling methods can require equipment of far greater capacity and may incur greatly increased analytical costs, if, for example, each sample aliquot is to be analyzed. Such considerations can make certain approaches cost prohibitive.

Another limitation involves the nitrogen species composition that constitutes 'Total Nitrogen' from the atmospheric sampling protocol and the stormwater loading sampling protocol. The atmospheric sampling program under NADP provides analysis of ammonia and nitrate. Stormwater sampling includes analysis of TKN (essentially ammonia and organic-N) and the nitrite-nitrate group.

Barring a yet-to-be designed isotopic doping and tracer study or other advanced technique, there is as yet no way to directly attribute the actual nitrogen molecules appearing in stormwater discharge to any particular ultimate source. Some of the watershed stormwater discharge can be directly related to atmospheric input, but much of the overall watershed loading and discharge relationship is implied and relies on inferential techniques.

Uncertainty

A major assumption underlying the analysis is that atmospheric deposition loads observed at the Gandy Bridge site are representative of conditions at the sampled basins. Because both sampled basins are within two miles of the Gandy Bridge site, this assumption seems reasonable, but it does introduce some uncertainty to the results. Uncertainty also arises from assumptions regarding the drainage basin delineations and characterization of the storm drain system. Other sources of uncertainty apply to specific portions of the analytical and mass balance approaches.

The mass balance is relatively uncertain because only fairly coarse estimates are available for major watershed fluxes. As demonstrated above, many sources of data must be used to complete the mass balance. Each source and sink of nitrogen requires an independent source of data, and each data set has a level of uncertainty (often unknown) associated with it. Assumptions from data obtained on a state-wide, regional, or national level must often be used for the study area, as little if any local information exists. In addition, examination of lawn conditions and surveys of neighborhood residents were used to estimate patterns in fertilizer application. These types of surveys often yield tenuous results because many homeowners do not keep records or do not clearly remember when, how much or what type of fertilizer they used. Because fertilizer is a significant source of nitrogen in the basins, the uncertainty associated with these data could greatly reduce the accuracy of the mass balance. For these reasons, the mass balance approach should be viewed as a means to assess the order of magnitude for various pathways of nitrogen transport as a comparative measure against which to gauge the components containing atmospheric sources.

For the study results to be widely applicable, it must be assumed that the data collected are representative of underlying long-term conditions at the sites. Normal variations in rainfall will cause some uncertainty in this assumption. The extraordinary El Niño weather conditions encountered during a portion of the study require the reader to use caution in applying the results to normal weather conditions.

6.0 MASS BALANCE

To complete the mass balance, all of the major nitrogen sources, pathways, reservoirs, and sinks for the study watersheds are identified and quantified. The mass balance was completed as a method of determining non-atmospheric contributing sources of nitrogen to the watershed. These other sources of nitrogen, may include:

- leaking sanitary sewer pipes,
- particulate organic nitrogen such as tree leaves and grass clippings,
- fertilizer application, and
- animal waste.

The nitrogen entering the basin was delivered into the soil, onto grass lawns, or onto impervious surfaces. Within the basin, nitrogen in the soil is taken up by grass, and grass die-back contributes to soil nitrogen. It is assumed that soil, grass, and impervious surfaces also provide a reservoir of nitrogen within the basin. Directly connected impervious areas (DCIA), from which runoff reports directly to the drainage system, are of primary concern. Runoff from other impervious areas is intercepted by grass and soil areas. It is assumed that rainfall on the watershed causes some of the nitrogen on the DCIA, in and on the soil, and in grass particles to be washed off-site, contributing to the NPS load through runoff.

Other potential pathways of nitrogen out of the system include infiltration to groundwater, and biomass removal such as bagged grass clippings. Nitrogen (N_2) may also be lost to the atmosphere from the soil through denitrification.

The mass balance required all of the above sources, pathways, reservoirs, and sinks to be quantified. The following sections describe how this was completed. Data required for the mass balance included:

- **Rainfall volume and timing** -- Rainfall data were available for the Gandy Bridge site. Additionally, a rain gauge was installed in each basin. The daily totals obtained for each basin were compared with the Gandy Bridge records. Rainfall data from the Gandy Bridge site were used with chemistry data and estimates of dry deposition to estimate total atmospheric loads (L_{AD}). These data were developed by others as part of the TBNEP/Great Waters Intensive Atmospheric Deposition Sampling Program.

- **Atmospheric deposition chemistry** -- Nitrogen concentrations in rainfall, and estimates of dry deposition were obtained from the Gandy Bridge site. It was assumed that these data were representative of conditions at the sampled basins. Chemistry data, rainfall records, and estimates of dry deposition were used to estimate total atmospheric loads (L_{AD}). These data were collected by others as part of the TBNEP/Great Waters Intensive Atmospheric Deposition Sampling Program. The procedures followed for collecting and analyzing wet and dry atmospheric deposition data is summarized in Section 4.

- **Runoff volume and timing** -- On-site monitoring provided a continuous record of stormwater runoff and any apparent base flow. The procedure for collecting and reducing hydrologic data is discussed in Section 3. Measured runoff volume was used with runoff chemistry data to estimate total nonpoint source loads (L_T) from the monitored basins.

- **Runoff chemistry** -- On-site monitoring provided water quality data for stormwater runoff and any apparent base flow. The procedure for collecting and analyzing stormwater quality data is discuss in Section 3. Measured runoff volume was used with runoff chemistry data to estimate total nonpoint source loads (L_T) from the monitored basins. Composite samples for each runoff event during the sampling period (as described in Section 3) were used to represent the event-based runoff volume and concentration. The event composite concentration was multiplied by the total flow volume determined for each event to calculate an event-based nitrogen load for each basin.

The above data were the central information sources used to support the analytic approach, as discussed below. Additional information was required to characterize other potentially significant sources of nitrogen inputs to the basin to support the mass balance approach. These data included the following:

- **Estimates of fertilizer uptake rate by plants (grass, shrubs)** -- Data on reported uptake rates of nitrogen by grass and shrubs were obtained from literature sources. Tree uptake rates were not explicitly included, because the deeper root system of trees can obtain nutrients from groundwater and thus are not solely dependent on fertilizer as a nutrient source. There was otherwise only a very limited amount of landscaping and shrubbery present in the study watersheds. Data on reported uptake rates of nitrogen by grass and shrubs were used to estimate the proportion of applied nitrogen that is incorporated into biomass within the study area. The watershed characteristics indicated that the primary vegetative component was turf grass. Literature values for turf grasses showed various annual nitrogen uptake ranges from about 100 to 600 lb N/acre-year. As the range was so variable and the plants likely respond directly to amounts available, this component was used to complete the mass balance. Plant uptake was assumed to amount to about 105 lb N/acre-year for the study watersheds.

- **Estimates of total number and type of non-human mammals present in the study area** -- A windshield inspection was completed to estimate the number and type of animals in the study area (dogs, cats, and other common mammals).

Hillsborough County Animal Services provided an estimate of pet animal populations that are summarized in Table 6-1. 1998 figures were used in the calculations.

Additional estimates were provided by Animal Services to identify the number of households owning pets and are summarized in Table 6-2.

Figures were also provided for birds, horses and cows. Pet birds were not explicitly considered as a nitrogen source because they are not typically released from captivity. No horses or cows were observed to be residing within the study watersheds.

Site 1, with about 164 residential lots, was estimated to have approximately 88 dogs and 99 cats. Site 2, with about 62 residential lots, was estimated to have approximately 34 dogs and 37 cats.

- **Estimates of non-human mammal waste production (lb./day for dogs, cats, etc)** -- Values for waste production by non-human mammals found in the study area were obtained from Dr. Richard Hill of the UF Veterinary School. Dr. Hill provided additional information to allow estimation of areal loadings from cats and dogs. Waste generation was expressed in lb./individual of species that were observed to commonly appear in the watershed. Cats consume approximately 200 cal/day in their diets, containing approximately 30% protein (17 g). Approximately 16% of the protein is nitrogen, which is passed unchanged by the animal. This yields about 2.74 g N passed per animal/day. Dogs consume approximately 1000 cal/day in their diets, containing approximately 25% protein. Approximately 16% of the protein is nitrogen, which is passed unchanged by the animal. This yields about 11.4 g N passed per animal/day.

The net loading to vegetated areas amounts about 22.4 lb N/acre-year for Site 1 and 26.7 lb N/acre-year for Site 2. A figure of 25 lb N/acre-year was assumed for the mass balance.

- **City of Tampa records of leaky sanitary sewer pipes in the area** -- City inspectors periodically inventory sewer lines for leaks. City records and field data collections were reviewed to determine if any significant leaks were present in the study area. No evidence of leaks (infiltration) into the storm sewer system was identified and no evidence of any base flow discharge from the basins was observed during the monitoring period. Infiltration from sanitary sewers could be discounted as a potential source of nitrogen loadings within the study area during the course of the project and a value of 0 was assumed for the mass balance.

Although sanitary sewers posed no problem in the study area, this is not universally true. A current study underway in the City of Sarasota has identified a single worst case leakage point of approximately 2 - 3 gallons per minute (gpm) for a 20 foot section of pipe (PBSJ memorandum, 1998).

Potential infiltration is considered during the design of both storm and sanitary sewer systems to ensure that sufficient conveyance and/or treatment capacity will be available in worst case conditions. Typical design values range from less than 2 to approximately 5 gpm per mile of 18 inch pipe.

- **Estimates of particulate organic nitrogen deposition rates (leaf litter, grass clippings, etc) --** The most commonly occurring types of trees and turf grasses in the study area were identified, and literature values for detritus deposition rates (clippings, leaves, twigs, etc.) were obtained. Data on nitrogen content in grass, shrubs, and trees were also researched. Grass clippings are the major sources within the study watersheds and are produced at a rate of about 100 lb dry weight/acre-month during the regular nine month mowing season. Nitrogen ranges from about 2 – 6 % of the clippings on a dry weight basis. If 4 % nitrogen content is assumed, and adjusting for grassed area within the watershed, about 36 lb N/acre/year are recycled.

- **Estimates of fertilizer application frequency and rate --** Data on typical or recommended application rates, timing, and fertilizer type were obtained from the County Extension Service, retail home improvement outlets and from neighborhood surveys. The neighborhoods were surveyed to determine how many residents apply fertilizer, when and how frequently it is applied, what type of fertilizer is most commonly used, and what application rates are typically used. The mass of nitrogen in the fertilizer applied within the study area was estimated on an annual basis.

Field inspection of the monitored watersheds provided the observation that the watersheds were approximately 60% bahiagrass and 40% St. Augustine lawns. Lawns comprised approximately 90 - 95% of each yard. Field observations from Sites 1 and 2 are summarized in Tables 6-3 and 6-4, respectively. Table 6-5 provides a definition of the lawn maintenance levels used in the ratings. Fertilizer application rates accompanying the lawn maintenance levels are shown in Table 6-6. Using these levels and rates, the estimated fertilizer application rate assumed for the mass balance was 61 lb N/acre-year based on the overall characteristics of the two watersheds. As noted, the watersheds exhibited low to moderate levels of lawn maintenance overall. Moderate to high levels of lawn maintenance as exhibited in other residential areas could more than double loadings to the watershed from fertilizer application.

- **Estimates of biomass removed from the study area** -- Based on neighborhood surveys, the proportion of grass clippings and landscape trimmings that are bagged and removed from the study area was estimated. Field observations and interviews with several local lawn services indicate that essentially no biomass is removed from the watersheds. Current costs and regulations for landfill disposal have resulted in the situation that none of the lawn services provide bagging and removal services. Field observation confirmed that nearly all organic material is left in place or composted on site. This potential nitrogen sink (removal from watershed) is insignificant for the study watersheds and a value of 0 was assumed for the mass balance.

- **Estimates of denitrification, ammonia volatilization and nitrogen fixation for the study area** – Several literature sources were consulted to derive estimates for these nitrogen removal processes applicable to the mass balance. Guidelines provided in the Process Design Manual for Land Treatment of Municipal Wastewater (EPA, 1981) indicate that denitrification is facilitated by high levels of organic matter in the soil, high soil cation exchange capacity characteristic of fine-textured and organic soils, alternating saturated and unsaturated soil moisture conditions and warm temperatures. Denitrification losses are typically conservatively estimated in the range of 15 to 25% of the applied nitrogen (measured losses ranged from 3 to 70%). After considering conditions in the watershed and the meteorological conditions experienced during the study, a value of 20% was used to complete the mass balance. The Design Manual suggests that for fairly sandy soils, ammonia volatilization losses should be considered already included in the denitrification losses. Nitrogen fixation rates can account for up to 200 lb/acre per year in certain circumstances. The Design Manual cautions that with constant nitrogen input a new equilibrium will be reached and net storage accumulation will be zero. The study watersheds are mature residential areas and a net storage accumulation of zero was assumed for the mass balance.

A rough estimate of magnitude of soil nitrogen storage can be made from analysis of urban residential sediments (1750 mg/kg) cited in Water Quality Assessment: Screening Procedure (EPA, 1985) and some non-urban Florida soil samples (1000 mg/kg) recently analyzed by BCI. Assuming a 3 foot root zone for healthy turf grass, this amounts to about 14,000 to 23,000 lb/acre of nitrogen storage in the soil accessible to plants.

- **Estimates of groundwater losses for the study area** – Recent studies performed by project team members and associates indicates that there is essentially no contribution to deep groundwater aquifers within the area containing the study watersheds. The shallow surficial aquifer may provide some seepage input to Tampa Bay, but this pathway is not thought to constitute a significant output from the study watersheds.

Mass Balance Results

The overall mass balance attempted to generally account for overall inputs and outputs within the monitored basins. This is intended to provide a perspective for how atmospheric deposition inputs and stormwater losses rank in magnitude in comparison to other watershed nitrogen pathways and the potential existing storage within the watershed. The watersheds are mature, relatively unchanging, residential areas that are basically in equilibrium with respect to nitrogen and are not expected to have any major increasing internal storages. Figure 6-1 provides a simplified overall nitrogen balance for the watershed showing inputs and outputs.

Fertilizer inputs (61 lb N / acre/year) form the largest single external source of nitrogen, followed by animal wastes (25 lb N / acre/year). Biomass recycling (36 lb N / acre/year) forms part of the internal cycle that can function as an export in other watersheds where, for example, grass clippings are removed. Wet atmospheric input is about 4 lb N / acre/year. Dry atmospheric input is about 3 lb N / acre/year. As noted above, the study watersheds exhibited moderate to low levels of lawn maintenance. Fertilizer loading could be significantly higher in other urban residential watersheds. As noted, plant uptake and dieback can be highly variable, covering a wide range in response to available inputs. These components represent important elements of the watershed internal nutrient cycle.

It is interesting to note that denitrification overshadows stormwater runoff as the most significant output of nitrogen from the basin. If denitrification (20 lb N / acre/year) and stormwater discharge (4 lb N / acre/year) are considered as the major external outputs from the watershed, the mass balance indicates that stormwater discharge comprises less than 20% of the net losses.

7.0 ANALYTICAL APPROACH RESULTS

To relate atmospheric deposition of nitrogen to nitrogen loading in stormwater runoff, a determination of nitrogen deposition for each stormwater runoff event was made. In addition, dry nitrogen deposition, which may be an additional component of stormwater runoff nitrogen loading to the bay, was estimated. The wet, dry, and total atmospheric deposition of nitrogen was then compared to the stormwater nitrogen loading from the watersheds.

To determine nitrogen concentrations in rainfall events that resulted in stormwater runoff events at the two watersheds, stormwater samples collected from the watersheds were date-matched with wet atmospheric samples from the Gandy Site. Because the rainfall amounts differed between Gandy and each study site, measured concentrations of nitrogen from the Gandy Site wet samples were applied to the rainfall amounts at the two sites, so that a total wet atmospheric deposition of nitrogen was determined for each watershed. This approach assumed that, although rainfall amount received at Gandy and each site varied somewhat, the concentration of nitrogen in the rainfall was essentially the same at all locations. The total number of date-matched samples for Site 1 was 17, with 11 date-matched samples from Site 2.

Dry atmospheric deposition of nitrogen was estimated by applying the cumulative dry nitrogen deposition, as calculated from the Gandy Site data and the meteorological data (Pribble and Janicki, 1998), from the end of the rainfall event back to the end of the preceding rainfall event.

Tables 7-1 and 7-2 summarize the area-normalized wet atmospheric deposition and stormwater discharge loadings used in the following analyses. Tables 7-3 and 7-4 provide a similar summary showing concentrations and total mass loadings. Tables 7-5 and 7-6 provide a summary of atmospheric and stormwater loadings.

'Rainfall Volume' is calculated by applying the depth of rainfall recorded at the stormwater sampling site to the surface area of the watershed.

'Stormwater Volume' is calculated as described in Section 3 from the automatic sampler data. Depth of flow in the pipe was recorded every 15 minutes. Depth was used in conjunction with the Manning's equation for pipe flow to develop a volumetric flow rate (cfs) for the interval, with corrections applied as needed to account for partial blockage by sediment.

The area-weighted total nitrogen loadings are calculated as follows:

'Rainfall Loading' is determined by applying rainfall concentration to the rainfall volume to generate a total mass loading and then dividing by the watershed area to develop the area-weighted loading.

'Runoff-Volume Normalized Rainfall Loading' considers the volume of runoff in the state that it entered the watershed as rainfall to determine the associated loading. For example, at Site 2 the July 12, 1997 event brought 2,576,208 liters of rain of which 55,162 liters discharged, or about 2% (ratio of stormwater runoff discharge to rainfall of 0.02). The 55,162 liters of runoff form a portion of the rainfall that represents an area-weighted loading in this case of 0.003 lb/acre. Understanding of this concept may be aided by the realization that just as the remaining 98% of the incoming rainfall is physically prevented from discharging from the watershed by the fact that it has infiltrated into the soil or has become impounded, so likewise has the associated nitrogen. Placing the input load on this basis (only the input amount associated with the water that is ultimately discharged) allows us to evaluate the relationship between the nitrogen load that was initially present in the water when it entered the watershed and the nitrogen load that is present when the same volume of water is discharged as stormwater. The results are described in Section 7.2

The 'Stormwater Runoff Loading' is derived by applying the stormwater concentration to the stormwater volume to generate a total mass loading and then dividing by the watershed area to generate an area-weighted loading.

The 'Incremental Loading' is calculated by subtracting the 'Runoff-Volume Normalized Rainfall Loading' (i.e. the amount initially present in the runoff volume when it entered the watershed) from the 'Stormwater Loading (i.e. the amount present in the runoff volume when it discharged from the watershed). This represents the net loading added to the runoff while it passed through the watershed.

7.1 Overall Watershed Relationship of Wet Atmospheric Deposition Load and Stormwater Discharge Load

Watershed-specific plots of stormwater nitrogen load as a function of wet nitrogen deposition are shown in Figures 7-1A and 7-2A, for Sites 1 and 2, respectively. The linear best fit equation for Site 1 is

$L_{SW} = 0.6136*L_{AD}$, with a coefficient of determination (r^2) of 0.84,

and for Site 2 is

$L_{SW} = 1.216*L_{AD}$, with an r^2 of 0.89.

Here, L_{SW} is the stormwater area-normalized nitrogen loading (lb/acre) and L_{AD} is the area-normalized atmospheric wet deposition of nitrogen (lb/acre).

The slopes of the lines (0.6136 and 1.216) represent the apparent transfer coefficients of the atmospheric source, as theorized by the original analytical approach, to the stormwater discharge for Site 1 and Site 2. The apparent difference in the relationship shown for the two watersheds is mostly an artifact of differences in the final sets of sample data available for the loading comparison rather than significant differences in watershed function during the study.

Combining events from both watersheds results in the relationship graphically illustrated in Figure 7-3A. The linear best-fit equation is

$L_{SW} = 0.9118 * L_{AD}$, with an r^2 of 0.78.

The slope of the best-fit line for the two watersheds combined, 0.91, represents the apparent overall transfer coefficient of the atmospheric load, or that fraction of wet nitrogen deposition accounted for via the stormwater nitrogen loading.

The 91% transfer coefficient of the atmospheric wet deposition of nitrogen suggests that 91% of the nitrogen deposited via wet deposition is accounted for in the stormwater nitrogen loading, although the nitrogen in the stormwater loading is not necessarily the same nitrogen as was deposited in rainfall.

The total wet deposition at the Gandy Site from July through December, 1997, utilizing analyzed samples from the Gandy site for concentration data and rainfall, was 267 mg N/m^2 (2.39 lb/acre), or approximately 75% of the total annual wet nitrogen deposition of 356 mg/m^2 (3.18 lb/acres) for 1997 at the Gandy site (Pribble and Janicki, 1998). As noted previously, data for some events primarily in September and December were not available so the actual totals would have been greater.

The methods used to determine nitrogen concentrations in the rainfall on the two watersheds resulted in only some of the actual measured rainfall events being utilized for this analysis (those that occurred simultaneously with rainfall events at the Gandy site that were analyzed for concentration data). Assuming that the total annual nitrogen loadings to the two watersheds are similar to that estimated at Gandy, and that approximately 99% of the nitrogen deposited via rainfall is represented in the stormwater runoff from the two sites, total annual stormwater nitrogen loadings from the two watersheds are estimated at 352 mg/m^2 (3.14 lb/acre). An alternate estimate of the annual stormwater load based on scaled-up stormwater discharge data (50 inches normal rainfall total / 30 inches study rainfall total x study loading) yields approximately 4 lb/acre-year.

The extrapolated annual estimates should be used with caution because they do not take into account possible variations at other times of year.

7.2 Overall Watershed Relationship of Rainfall Runoff-Volume Normalized Wet Atmospheric Deposition Load and Stormwater Discharge Load

The overall relationship described above indicates that all stormwater discharge may be numerically accounted for by wet atmospheric loads. This overall relationship may indicate that the watershed is an equilibrium system in which the discharges are controlled by the 'excess' inputs from wet atmospheric deposition. Alternatively, the apparent relationship may simply be coincidence.

We know, however, that this one-to-one relationship cannot hold true during a particular event because the rainfall that does not discharge from the basin is physically prevented from surface discharge by infiltration into the soil or by impoundment. The remaining rainwater discharges as runoff. On the assumption that the wet atmospheric nitrogen load is similarly partitioned into a retained fraction and a discharged fraction, the relationship between the wet atmospheric nitrogen loads associated only with the portion of the rainfall volume that ultimately discharged as runoff was examined versus the stormwater discharge loads. To reiterate, the plots are labeled 'volume normalized' because they represent the input loading and discharge loading for the same volume of water, i.e. the rainfall runoff volume in the state that it entered the watershed and in the state that it left the watershed.

The linear best fit equation for Site 1 is

$L_{SW} = 3.5228*L_{ADRV}+0.007$, with a coefficient of determination (r^2) of 0.922,

and for Site 2 is

$L_{SW} = 3.5475*L_{ADRV}+0.0092$, with an r^2 of 0.998.

In this case, L_{SW} is the stormwater area-normalized nitrogen loading (lb/acre) and L_{ADRV} is the area-normalized atmospheric wet deposition of nitrogen (lb/acre) normalized to the runoff volume. These results are shown in Figures 7-4A and 7-5A for Sites 1 and 2, respectively.

Combining events from both watersheds results in the relationship graphically illustrated in Figure 7-6A. The linear best-fit equation is

$L_{SW} = 3.5456*L_{AD}+0.0082$, with an r^2 of 0.983.

These figures are plotted with axes reversed in Figures 7-4B, 7-5B and 7-6B to allow ready determination of the fraction of the stormwater loading directly accounted for by the nitrogen associated with the runoff upon input to the watershed. For Site 1, Site 2 and the combined sites, the fraction is 0.262, 0.281, and 0.277, respectively. Thus, atmospheric wet deposition directly accounts for an overall 28% of the nitrogen appearing in the stormwater discharge load.

On the assumption that the relationship shown represents the direct wet atmospheric nitrogen contribution, the remaining nitrogen load is derived from the watershed during the runoff process. Plotting the incremental watershed load against the stormwater discharge load allows us to determine that overall

$L_{SW} = 1.3803*L_{IW}-0.0027$, with an r^2 of 0.9975.

Here, L_{SW} is the stormwater area-normalized nitrogen loading (lb/acre) and L_{IW} is the area-normalized incremental watershed load of nitrogen (lb/acre). Conversely, the incremental watershed load accounts for 72% of the stormwater discharge load. These results are shown in Figures 7-9A and 7-9B for the combined sites. Figures 7-7A and B, and 7-8A and B show similar independent results for Sites 1 and 2, respectively.

7.3 Overall Watershed Relationship of Total Atmospheric (wet + dry) Nitrogen Deposition Load and Stormwater Discharge Load

In an attempt to relate stormwater runoff nitrogen loads to possible cumulative effects of total (wet + dry) atmospheric nitrogen deposition, analyses similar to those described above were completed for the sum of wet and dry atmospheric deposition. Daily dry deposition values, as estimated from atmospheric nitrogen concentrations and air-to-water deposition velocities, were summed between rain events at the watersheds, then added to the wet deposition of nitrogen for each event. These estimated total atmospheric deposition nitrogen loads did not account for any of the various differences which may result in different dry deposition rates of nitrogen over land and water (as discussed previously).

Total (wet + dry) atmospheric nitrogen deposition values were only estimated for those events for which both wet and dry deposition values were available. Given data gaps in dry deposition as referred to in Table 4-1, only 12 events were utilized from Site 1 and only 5 events were utilized from Site 2. For the combination of the data from both watersheds, the relationship between stormwater loading of TN and total (wet + dry) atmospheric deposition is shown in Figure 7-10. The r^2 from the best linear fit between these data from the combination of both watersheds is only 0.04. Given these data and the lack of fit between them, no conclusions may be drawn as to the relationship between total (wet + dry) atmospheric deposition of nitrogen and nitrogen loading in stormwater. For 1997, the total dry deposition of nitrogen was 387 mg/m^2 (3.45 lb/acre), with 232 mg/m^2 (2.07 lb/acre) occurring from July through December.

The assumption that dry deposition of nitrogen to a terrestrial environment is the same as that to the surface of Tampa Bay is not supported or rejected by this analysis. Any dry deposition of nitrogen to the surfaces of the terrestrial environment may be assimilated by vegetation, and thus not available for entrainment in the stormwater runoff. Likewise, however, nitrogen particles reaching the surfaces of the watersheds through dry deposition may not remain within the watersheds, but may be resuspended and displaced. Neither course may be determined from this analysis.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Event-by Event Analysis

Identifying the actual source of all stormwater loadings proved to be beyond the discrimination of the current study. The results of this study allow us to view atmospheric nitrogen sources in proper perspective as a minor component of the overall watershed nitrogen mass balance but as a potentially major contributor to the ultimate nonpoint discharge from the watershed. This study has shown through the event-by-event analysis that overall 28% of the stormwater discharge loading is directly attributable to atmospheric wet nitrogen deposition through the runoff process. Additional contributions from both wet and dry atmospheric deposition sources to stormwater discharge loadings are likely but could not be quantified during this study.

It is evident that the amount of nitrogen leaving the watersheds via stormwater runoff over the period of this study is very similar to the amount of nitrogen being delivered to the watersheds via rainfall. It must be noted that this analysis does not track individual molecules of nitrogen-containing compounds through the watershed, but only determines that the amount of nitrogen leaving the watersheds through stormwater runoff is very similar to the amount being delivered through rainfall.

Overall Relationship

To explain the near balance between atmospheric wet deposition loadings and the stormwater discharge loadings, it is possible that there are fundamental matters of watershed equilibrium such as nutrient availability and plant uptake efficiency and the time scale of rainfall and runoff processes that need to be further considered. If the entire source is ultimately atmospheric, a large part of the process is indirect and requires accumulation within the basin. One alternative is that the atmospherically-derived input loads are preferentially removed during future events. Another alternative is that the atmospheric loads constitute an excess in watershed systems that are essentially at equilibrium. However, the apparent relationship may simply be a numerical coincidence.

Cumulative Wet and Dry Deposition

Although no direct relationship was found during the study between cumulative dry deposition as determined by the methods described, it is possible that the accumulation of both excess wet deposition and the dry deposition, or some fraction, might relate directly to the observed stormwater discharge. Such an analysis would require complete wet, dry, and stormwater discharge data sets so that a lagged multiple regression can be performed. In addition, it would be appropriate to 'age' the accumulated nitrogen on at least a daily basis during this analysis, possibly by means of a first order decay function, to account for losses due to denitrification and other mechanisms.

The conclusions derived from the collected data during this project support the standard understanding of terrestrial nitrogen processes. The majority of the stormwater loading derives from in-watershed sources that include previously deposited atmospheric nitrogen rather than from direct atmospheric sources for the urban residential watersheds studied. Atmospheric nitrogen sources that are not discharged immediately contribute a small amount to the overall watershed standing crop and are thus subject to dissolution, transport and discharge during future storm events.

Recommendations

The primary recommendation is that similar studies should be conducted in other Tampa Bay area watersheds that represent the other major land uses contributing significant non-point discharges to the Bay. The atmospheric deposition program remains in place and data continues to be collected, providing the opportunity to gain knowledge of the atmospheric deposition – stormwater discharge relationship in additional watersheds. Future studies should span at least a full year of sample collection to better address issues of variability by season. Measures should be put in place to overcome some of the equipment limitations encountered during this effort. Alternative methods of dry deposition collection should be explored that better simulate the interaction of substrate and washoff as experienced in the terrestrial environment. A more complete serial data collection would allow greater opportunity to identify possible relationships between cumulative dry deposition, cumulative non-discharged wet deposition, and subsequent stormwater discharge loading.

Smaller supplemental studies that would define the boundaries of potential atmospheric contributions could be performed.

Parking Lot Study

A parking lot, for example, that generates nearly 100% runoff might reasonably be expected to show stormwater discharge loadings reflective of 100% of the atmospheric deposition (wet and dry) for that particular surface material (typically asphalt concrete) plus any directly introduced watershed loadings such as materials falling from vehicles. A useful study to differentiate introduced loadings would compare an active parking lot with an inactive parking lot, perhaps at a defunct mall or shopping center. An inactive parking lot would form one extreme that could produce data characterizing the net and cumulative atmospheric contribution. Study results would be directly applicable to significant acreages of runoff producing area throughout the Bay's watershed and much of the information could be translated directly to estimation for general road and highway surfaces. Rooftops constitute another prevalent urban material that could be readily instrumented for concise study of atmospheric sources.

Equilibrium Vegetated Plot Study

A set of plot studies (i.e. established turf grass lawns) could be conducted to test the apparent study result that wet atmospheric loadings appear to control the stormwater discharge loadings when the system is at equilibrium. Determining stormwater nitrogen loadings under different rates of fertilization (i.e. selecting existing lawns that receive different levels of maintenance) could provide a means to determine whether the watershed discharge loads are equilibrium-controlled or vary more in response to fertilization levels. Most previous plot studies have shown increases in discharge with increases in fertilizer loadings, but it is not known whether any of the plots had been established long enough to reach equilibrium.

PHOTOS

Photo 1 Typical View of Residential Area in Study Watershed

Photo 2 Typical View of Residential Area in Study Watershed

Photo 3 ISCO Automatic Sampling Equipment used during study

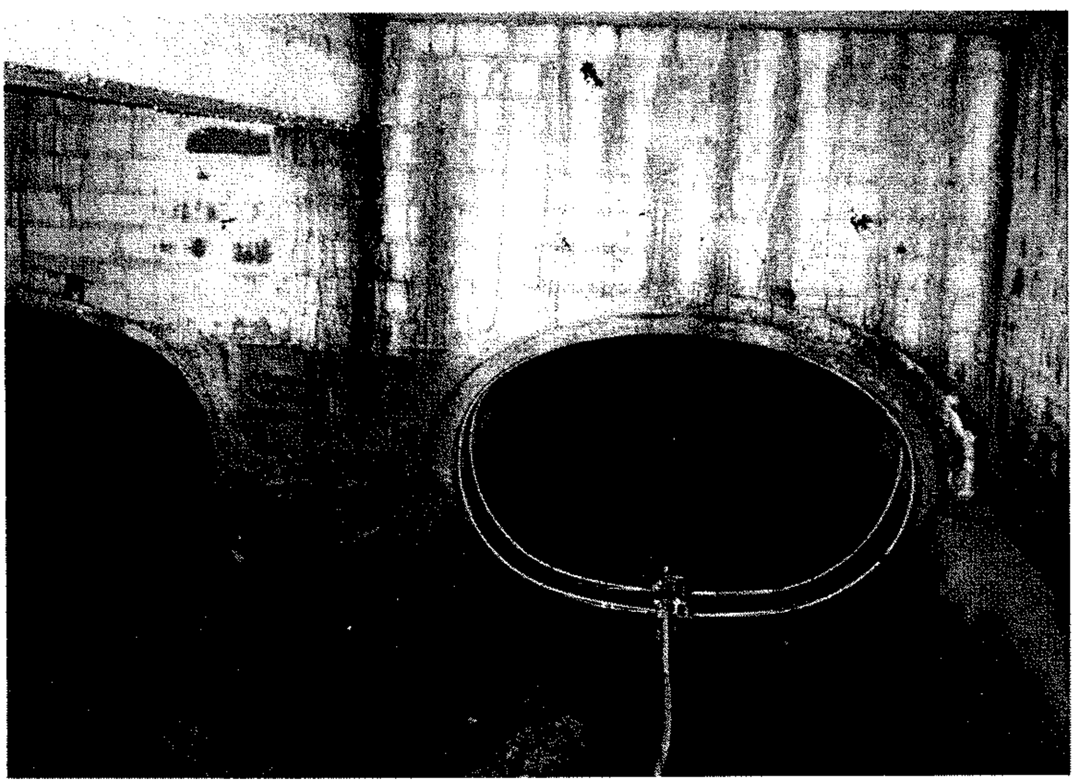

Photo 4 View of Typical Sampler Line Installation in Storm Sewer

TABLES

Table 3-1 Site 1 Event Data Summary

Month	Day	Year	Site	Rainfall at site (inches)	Rainfall at Gandy (inches)	Runoff Volume (ft^3)	TKN (mg/l)	NO2NO3 (mg/l)	TN (mg/l)	Specific Conductance (umhos/cm)	Rainfall Ratio
7	11	1997	1	0.4	0.1	2,543	2.10	0.71	2.81	175	
7	12	1997	1	0.4	2.48	6,020	2.50	0.64	3.14	120	
7	21	1997	1	0.1	0.58	658	bdl	0.28	0.28	220	
7	22	1997	1	0.4	0.4	7,493	0.56	0.81	1.37	82	
7	23	1997	1	0.3	0.44	4,055	1.40	1.20	2.60	120	
8	3	1997	1	0.2	0.19	2,496	1.00	0.34	1.34	100	
8	4	1997	1	0.4	0.45	5,584	0.71	0.30	1.01	100	
8	5	1997	1	0.1	0.14	2,441	0.57	0.06	0.63	170	
8	6	1997	1	0.7	1.08	11,574	0.57	0.22	0.79	70	
8	8	1997	1	0.6	0.18	9,868	0.72	0.36	1.08	62	
9	18	1997	1	0.2	0.61	2,162	3.10	1.70	4.80	152	
9	27	1997	1	5	6.93	*	0.94	0.19	1.13	45	0.81
9	28	1997	1	1.2	0.82	293,515	0.49	0.12	0.61	1223	0.19
9	28	1997	1	6.2	7.75	293,515	0.85	0.18	1.03	273	
10	17	1997	1	0.4	0.3	8,705	2.20	0.75	2.95	150	
10	18	1997	1	0.3	0.05	*	1.10	0.31	1.41	80	0.60
10	19	1997	1	0.2	0.25	9,063	0.72	0.21	0.93	100	0.40
10	19	1997	1	0.5	0.3	9,063	0.95	0.27	1.22	88	
10	25	1997	1	0.15	0.08	1,016	0.55	0.32	0.87	480	
10	27	1997	1	0.9	2.05	*	0.94	0.22	1.16	40	0.41
10	28	1997	1	1.3	0	64,072	1.10	bdl	1.10	68	0.59
10	28	1997	1	2.2	2.05	64,072	1.03	0.22	1.12	57	
11	1	1997	1	1.7	1.85	62,715	0.26	0.21	0.47	100	
11	15	1997	1	0.2	0.05		0.64	0.61	1.25	340	
11	30	1997	1	0.5	0.4	9,943	0.45	0.15	0.60	120	
12	1	1997	1	0.3	0.2	2,435	0.45	0.29	0.74	220	
12	4	1997	1	1.4	1.25	*	0.87	0.22	1.09	78	0.93
12	5	1997	1	0.1	0.06	36,586	0.26	0.53	0.79	838	0.07
12	5	1997	1	1.5	1.31	36,586	0.83	0.24	1.07	129	
12	10	1997	1	0.3	0.25	5,749	1.40	0.38	1.78	200	
12	11	1997	1	2.7	2.44	114,112	0.91	0.28	1.19	127	
12	13	1997	1	4.1	2.7	*	1.00	0.43	1.43	220	0.87
12	14	1997	1	0.6	0.9	225,168	1.30	0.46	1.76	120	0.13
12	14	1997	1	4.7	3.6	225,168	1.04	0.43	1.47	207	
12	15	1997	1	0.1	0.05	7,290	1.50	1.20	2.70	410	
12	26	1997	1	0.7	0.76	12,403	1.20	0.30	1.50	120	
12	27	1997	1	4.3	3.7	*	1.20	0.58	1.78	430	0.98
12	28	1997	1	0.1	0.05	155,833	2.80	0.74	3.54	310	0.02
12	28	1997	1	4.4	3.75	155,833	1.24	0.58	1.82	427	

* Runoff discharge continuous for multiday event. Cumulative totals for rainfall and discharge used.

bdl = below detection limit

Notes: 'Rainfall Ratio' derived from rainfall and used to weight relative contribution of chemical analyses

Table 3-2 Site 2 Event Data Summary

Month	Day	Year	Site	Rainfall at site (inches)	Rainfall at Gandy (inches)	Runoff Volume (ft^3)	TKN (mg/l)	NO2NO3 (mg/l)	TN (mg/l)	Specific Conductance (umhos/cm)	Rainfall Ratio
7	12	1997	2	1.4	2.48	1,948	2.60	0.62	3.22	70	
7	20	1997	2	1.1	1	2,273	bdl	0.36	0.36	66	
7	22	1997	2	0.5	0.4	347	1.70	0.62	2.32	98	
8	3	1997	2	0.4	0.19	207	2.00	bdl	2.00	140	
9	27	1997	2	5	6.93	*	1.30	0.16	1.46	55	0.83
9	28	1997	2	1	0.82	110,359	0.72	0.57	1.29	156	0.17
9	28	1997	2	6	7.75	110,359	1.20	0.23	1.43	72	
10	28	1997	2	2.2	2.05	9,267	0.97	0.19	1.16	200	
11	14	1997	2	2.2	2.5	*	0.81	0.12	0.93	300	0.92
11	15	1997	2	0.2	0.05	22,246	2.20	0.28	2.48	550	0.08
11	15	1997	2	2.4	2.55	22,246	0.93	0.13	1.06	321	
11	30	1997	2	0.5	0.4	258	1.00	0.29	1.29	220	
12	4	1997	2	1.7	1.25	*	1.10	0.21	1.31	160	0.94
12	5	1997	2	0.1	0.06	7,460	1.30	0.23	1.53	361	0.06
12	5	1997	2	1.8	1.31	7,460	1.11	0.21	1.32	171	
12	10	1997	2	0.3	0.25	110	2.10	0.60	2.70	420	
12	11	1997	2	2.6	2.44	23,698	1.20	0.26	1.46	233	
12	12	1997	2	0.8	0.6	4,049	1.70	0.27	1.97	480	
12	13	1997	2	3.8	2.7	*	2.00	0.22	2.22	380	0.88
12	14	1997	2	0.5	0.9	90,207	0.91	0.27	1.18	137	0.12
12	14	1997	2	4.3	3.6	90,207	1.87	0.23	2.10	352	
12	25	1997	2	0.5	0.6	3,110	1.40	0.74	2.14	300	
12	26	1997	2	0.5	0.76	4,235	2.20	0.20	2.40	410	
12	27	1997	2	2.5	3.7	*	1.70	0.17	1.87	300	0.96
12	28	1997	2	0.1	0.05	107,873	2.00	0.33	2.33	430	0.04
12	28	1997	2#	4.4	3.75	107,873	1.71	0.18	1.89	305	

* Runoff discharge continuous for multiday event. Cumulative totals for rainfall and discharge used.

2# Rainfall total from Site 1 used because it appears to be a better estimate of what was received in the basin.

bdl = below detection limi

Notes: 'Rainfall Ratio' derived from rainfall and used to weight relative contribution of chemical analyses

Table 4-1. Monthly deposition of nitrogen.

Year	Month	Wet N Deposition ($mg/m^2/month$)	Dry N Deposition ($mg/m^2/month$)	Total N Deposition ($mg/m^2/month$)
1996	8	18.3	37.1[a]	55.4
1996	9	5.4	34.9	40.2
1996	10	8.8	14.4[b]	23.2
1996	11	7.3	51.4	58.6
1996	12	0.6	37.2	37.8
1997	1	4.9	26.1	30.9
1997	2	6.9	22.0	28.9
1997	3	7.0	24.9	31.9
1997	4	94.0	24.1	118.1
1997	5	15.2	24.2	39.5
1997	6	30.4	33.4	63.8
1997	7	88.0	14.0[c]	102.0
1997	8	22.1	8.8[d]	30.8
1997	9	37.6	41.0[e]	78.6
1997	10	14.9	91.3	106.3
1997	11	7.9	68.7[f]	76.6
1997	12	26.7	8.2[g]	34.9

a - Missing August 1 0:00 - August 7 18:30, 1996
b - Missing October 11 15:00 - October 25 10:00, 1996
c - Missing July 16 12:30 - July 31 23:30, 1997
d - Missing August 1 0:00 - August 11 14:00, and August 24 3:30 - August 25 3:00, 1997
e - Missing September 24 0:00 - 23:30, 1997
f - Missing November 20 0:00 - 23:30, 1997
g - Missing December 14 4:30 - 7:30, and December 18 23:30 - December 31 23:30, 1997

Table 4-2 Monthly dry deposition of nitrogen.				
Year	Month	Dry Gaseous N Deposition ($mg/m^2/month$)	Dry Particulate N Deposition ($mg/m^2/month$)	Total Dry N Deposition ($mg/m^2/month$)
1996	8	36.1	1.02	37.1[a]
1996	9	33.6	1.24	34.9
1996	10	13.9	0.50	14.4[b]
1996	11	50.0	1.35	51.4
1996	12	36.0	1.23	37.2
1997	1	24.5	1.51	26.1
1997	2	21.0	1.01	22.0
1997	3	22.9	2.05	24.9
1997	4	22.1	2.02	24.1
1997	5	21.6	2.63	24.2
1997	6	31.6	1.79	33.4
1997	7	12.6	1.37	14.0[c]
1997	8	8.3	0.47	8.8[d]
1997	9	38.9	2.07	41.0[e]
1997	10	82.1	9.28	91.3
1997	11	61.4	7.37	68.7[f]
1997	12	7.4	0.81	8.2[g]

a - Missing October 11 15:00 - October 25 10:00, 1996
b - Missing July 16 13:30 - July 31 23:30, 1997
c - Missing August 1 0:00 - August 11 14:00, August 24 9:30 - August 25 3:00, 1997
d - Missing September 24 1:00 - 23:30, 1997
e - Missing November 20 1:00 - 23:30, 1997
f - Missing December 14 4:30 - 7:30, 1997
g - Missing December 18 23:30 - December 31 23:30, 1997

Table 6-1 Hillsborough County Animal Services estimated Pet Animal Populations

Projection Year	1997	1998	1999	2000	2001	2005
Human Population	915,900	928,300	940,800	953,500	966,400	1,026,100
Housing Units	399,800	405,300	410,500	416,100	421,500	447,400
Canine Population	213,509	216,446	219,223	222,214	225,098	238,929
Feline Population	239,028	243,316	245,425	248,773	252,002	267,487

Table 6-2 Hillsborough County Animal Services Estimates of Pet Ownership

Species	% of Housing Units Owning	Average Number Owned Per Housing Unit
Canines	31.6	1.69
Felines	27.3	2.19

Table 6-3 Watershed Site 1 Vegetation - Field Observations

Gutter System	
Average yard is 90% lawn	
Typical House Size:	1400 - 1600 square feet
Bahiagrass lawns	60%
St. Augustine lawns	40%
Lawn Maintenance levels	
High	10%
Moderate	50%
Low	40%

Table 6-4 Watershed Site 2 Vegetation - Field Observations

Drainage Ditches	
Average yard is 95% lawn	
Typical House Size:	1200 - 1400 square feet
Bahiagrass lawns	60%
St. Augustine lawns	30%
Mixed (Bahia, St. Aug, other)	10%
Lawn Maintenance levels	
High	10%
Moderate	30%
Low	60%

Table 6-5 Definition of Lawn Maintenance levels (for this project):

High	
Visual indicators	Thatch present, dark green color, good coverage, few weeds (except dollar weed, which is sign of excessive watering)
Maintenance assumptions	Fertilized two to four times per year with a quick-release fertilizer formulated for lawns (N=17, 25 or 30), mowed regularly, likely to apply herbicides and pesticides frequently
Moderate	
Visual indicators	No thatch, healthy appearance, good coverage, few weeds
Maintenance assumptions	Fertilize twice a year with slow-release fertilizer (i.e. Lesco 15-15-15)
Low	
Visual indicators	Coverage sparse in areas, weeds present throughout yard
Maintenance assumptions	Do not fertilize, or perhaps once a year with inexpensive, all-purpose water soluble 6-6-6 fertilizer or with a quick release lawn formulation (16-4-8)

Table 6-6 Fertilizer application rates

High	(assume 30% N, 3x/year)	157 lb. N / acre-year
Moderate	(assume 15% N, 2x/year)	87 lb. N / acre-year
Low	(assume 6% N, 1x/year)	42 lb. N / acre-year

Table 7-1 Site 1 Total Nitrogen Loading Summary Data

Event Date	Rainfall Volume (liters)	Stormwater Volume (liters)	Ratio SW/Rain	Rainfall N Loading (lb/acre)	Runoff-Volume Normalized Rainfall N Loading (lb/acre)	Stormwater Runoff N Loading (lb/acre)	Incremental N Loading (lb/acre)
7/11/97	2,220,515	72,030	0.03	0.0892	0.0029	0.0083	0.0054
7/12/97	2,220,515	170,484	0.08	0.0400	0.0031	0.0219	0.0188
7/22/97	2,220,515	212,192	0.10	0.0313	0.0030	0.0119	0.0089
7/23/97	1,665,386	114,851	0.07	0.0877	0.0060	0.0122	0.0061
8/3/97	1,110,257	70,699	0.06	0.0105	0.0007	0.0039	0.0032
9/18/97	1,110,257	61,232	0.06	0.0577	0.0032	0.0120	0.0088
10/17/97	2,220,515	246,529	0.11	0.0986	0.0110	0.0297	0.0187
10/19/97	2,775,643	256,658	0.09	0.0142	0.0013	0.0128	0.0114
10/25/97	832,693	28,769	0.03	0.0345	0.0012	0.0010	-0.0002
11/30/97	2,775,643	281,597	0.10	0.0112	0.0011	0.0069	0.0058
12/1/97	1,665,386	68,966	0.04	0.0104	0.0004	0.0021	0.0017
12/5/97	8,326,930	1,036,109	0.12	0.0518	0.0065	0.0453	0.0388
12/10/97	1,665,386	162,820	0.10	0.0212	0.0021	0.0118	0.0098
12/11/97	14,988,473	3,231,653	0.22	0.0864	0.0186	0.1570	0.1384
12/15/97	555,129	206,454	0.37	0.0140	0.0052	0.0228	0.0175
12/26/97	3,885,900	351,260	0.09	0.0322	0.0029	0.0215	0.0186
12/28/97	24,425,660	4,413,177	0.18	0.5241	0.0947	0.3279	0.2332

Table 7-2 Site 2 Total Nitrogen Loading Summary Data

Event Date	Rainfall Volume (liters)	Stormwater Volume (liters)	Ratio SW/Rain	Rainfall N Loading (lb/acre)	Runoff-Volume Normalized Rainfall N Loading (lb/acre)	Stormwater Runoff N Loading (lb/acre)	Incremental N Loading (lb/acre)
7/12/97	2,576,208	55,162	0.02	0.1400	0.0030	0.0219	0.0189
7/20/97	2,024,164	64,362	0.03	0.1020	0.0032	0.0108	0.0075
7/22/97	920,074	9,830	0.01	0.0391	0.0004	0.0028	0.0024
8/3/97	736,059	5,862	0.01	0.0210	0.0002	0.0014	0.0013
11/30/97	920,074	7,296	0.01	0.0112	0.0001	0.0012	0.0011
12/5/97	3,312,268	211,273	0.06	0.0622	0.0040	0.0344	0.0304
12/10/97	552,045	3,129	0.01	0.0212	0.0001	0.0010	0.0009
12/12/97	1,472,119	114,670	0.08	0.0309	0.0024	0.0278	0.0254
12/25/97	920,074	88,079	0.10	0.0278	0.0027	0.0232	0.0206
12/26/97	920,074	119,939	0.13	0.0230	0.0030	0.0355	0.0325
12/28/97	8,096,654	3,054,976	0.38	0.5241	0.1978	0.7103	0.5125

Table 7-3 Site 1 Total Nitrogen Chemistry Summary Data

Site 1: 54 acres

Event Date	Rainfall Volume (liters)	Rainfall N Conc. (mg/l)	Rainfall N Loading (lb)	Rainfall N Loading (lb/acre)	Stormwater Volume (liters)	Stormwater N Conc. (mg/l)	Stormwater N Loading (lb)	Stormwater N Loading (lb/acre)
7/11/97	2,220,515	0.98	4.82	0.0892	72,030	0.03	0.45	0.0083
7/12/97	2,220,515	0.44	2.16	0.0400	170,484	0.08	1.18	0.0219
7/22/97	2,220,515	0.35	1.69	0.0313	212,192	0.10	0.64	0.0119
7/23/97	1,665,386	1.29	4.73	0.0877	114,851	0.07	0.66	0.0122
8/3/97	1,110,257	0.23	0.57	0.0105	70,699	0.06	0.21	0.0039
9/18/97	1,110,257	1.27	3.11	0.0577	61,232	0.06	0.65	0.0120
10/17/97	2,220,515	1.09	5.33	0.0986	246,529	0.11	1.60	0.0297
10/19/97	2,775,643	0.13	0.77	0.0142	256,658	0.09	0.69	0.0128
10/25/97	832,693	1.01	1.86	0.0345	28,769	0.03	0.06	0.0010
11/30/97	2,775,643	0.10	0.60	0.0112	281,597	0.10	0.37	0.0069
12/1/97	1,665,386	0.15	0.56	0.0104	68,966	0.04	0.11	0.0021
12/5/97	8,326,930	0.15	2.80	0.0518	1,036,109	0.12	2.44	0.0453
12/10/97	1,665,386	0.31	1.15	0.0212	162,820	0.10	0.64	0.0118
12/11/97	14,988,473	0.14	4.67	0.0864	3,231,653	0.22	8.48	0.1570
12/15/97	555,129	0.62	0.76	0.0140	206,454	0.37	1.23	0.0228
12/26/97	3,885,900	0.20	1.74	0.0322	351,260	0.09	1.16	0.0215
12/28/97	24,425,660	0.53	28.30	0.5241	4,413,177	0.18	17.71	0.3279

Table 7-4 Site 2 Total Nitrogen Chemistry Summary Data

Site 2: 17.9 acres

Event Date	Rainfall Volume (liters)	Rainfall N Conc. (mg/l)	Rainfall N Loading (lb)	Rainfall N Loading (lb/acre)	Stormwater Volume (liters)	Stormwater N Conc. (mg/l)	Stormwater N Loading (lb)	Stormwater N Loading (lb/acre)
7/12/97	2,576,208	0.44	2.51	0.1400	55,162	3.22	0.39	0.0219
7/20/97	2,024,164	0.41	1.83	0.1020	64,362	1.36	0.19	0.0108
7/22/97	920,074	0.35	0.70	0.0391	9,830	2.32	0.05	0.0028
8/3/97	736,059	0.23	0.38	0.0210	5,862	2.00	0.03	0.0014
11/30/97	920,074	0.10	0.20	0.0112	7,296	1.29	0.02	0.0012
12/5/97	3,312,268	0.15	1.11	0.0622	211,273	1.32	0.62	0.0344
12/10/97	552,045	0.31	0.38	0.0212	3,129	2.70	0.02	0.0010
12/12/97	1,472,119	0.17	0.55	0.0309	114,670	1.97	0.50	0.0278
12/25/97	920,074	0.25	0.50	0.0278	88,079	2.14	0.42	0.0232
12/26/97	920,074	0.20	0.41	0.0230	119,939	2.40	0.63	0.0355
12/28/97	8,096,654	0.53	9.38	0.5241	3,054,976	1.89	12.71	0.7103

Table 7-5 Site 1 Summary of Atmospheric and Stormwater Loadings

Event Date	Atmospheric N Deposition Wet (lb/acre)	Dry (lb/acre)	Total (lb/acre)	Stormwater N Loading (lb/acre)
7/11/97	0.0892	0.0251	0.1143	0.0083
7/12/97	0.0400	0.2127	0.2527	0.0219
7/22/97	0.0313			0.0119
7/23/97	0.0876			0.0122
8/3/97	0.0105			0.0039
9/18/97	0.0577	0.3326	0.3903	0.0120
10/17/97	0.0986	0.5068	0.6054	0.0297
10/19/97	0.0142	0.0403	0.0545	0.0128
10/25/97	0.0345	0.0775	0.1120	0.0010
11/30/97	0.0112	0.2995	0.3107	0.0069
12/1/97	0.0104	0.0022	0.0126	0.0021
12/5/97			0.0124	0.0453
12/10/97	0.0212	0.0101	0.0314	0.0118
12/15/97	0.0140	0.0079	0.0219	0.0228
12/26/97	0.0322			0.0215
12/28/97	0.5243			0.3279

Table 7-6 Site 2 Summary of Atmospheric and Stormwater Loadings

Event Date	Atmospheric N Deposition Wet (lb/acre)	Dry (lb/acre)	Total (lb/acre)	Stormwater N Loading (lb/acre)
7/12/97	0.1400	0.2070	0.3469	0.0219
7/20/97	0.1020			0.0108
7/22/97	0.0392			0.0028
8/3/97	0.0210			0.0014
11/30/97	0.0112	0.2995	0.3107	0.0012
12/5/97			0.0177	0.0344
12/10/97	0.0212	0.0101	0.0314	0.0010
12/25/97	0.0278			0.0232
12/26/97	0.0230			0.0355
12/28/97	0.5243			0.7111

FIGURES

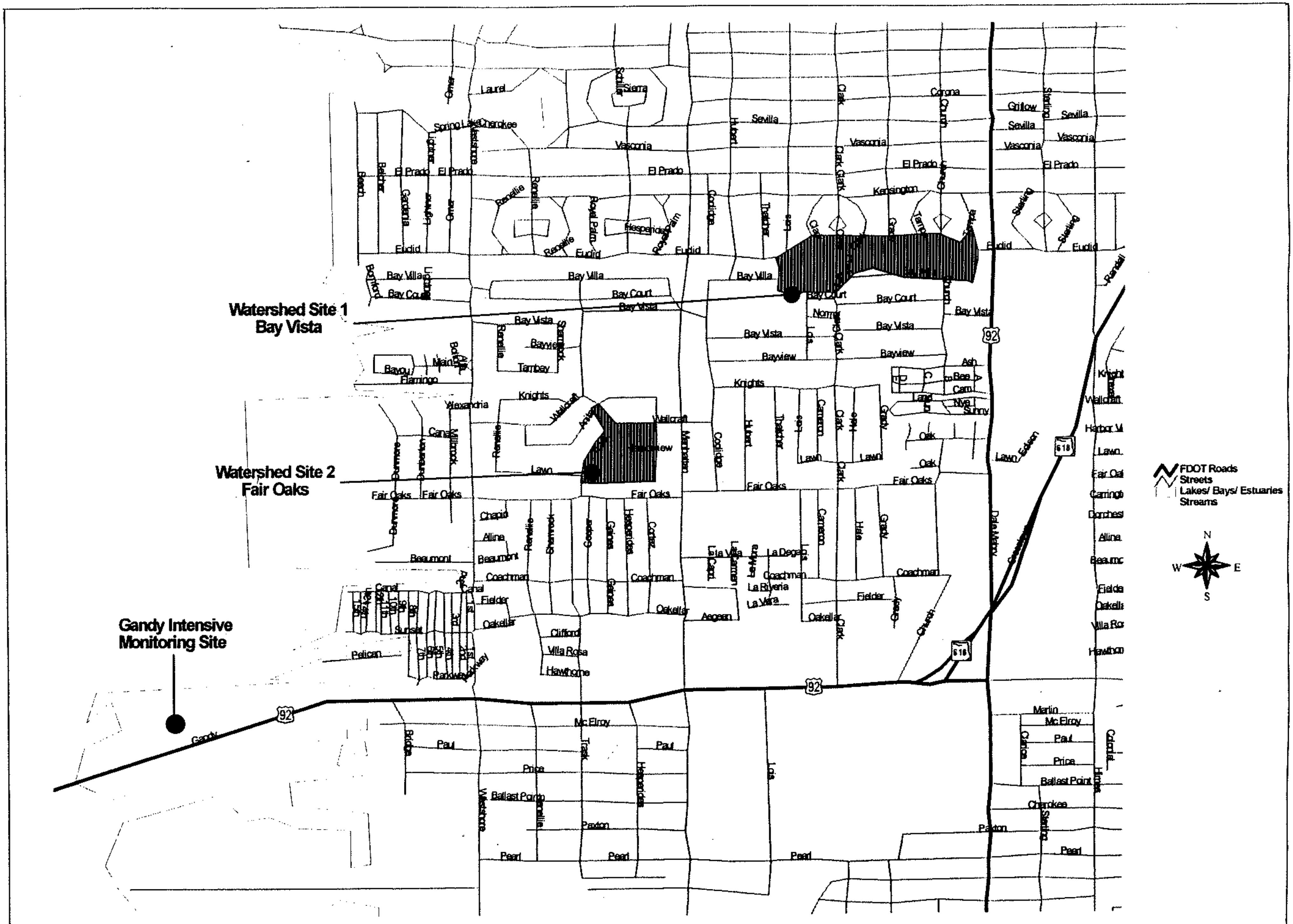

Figure 3-1. Watershed Study Site Location Map

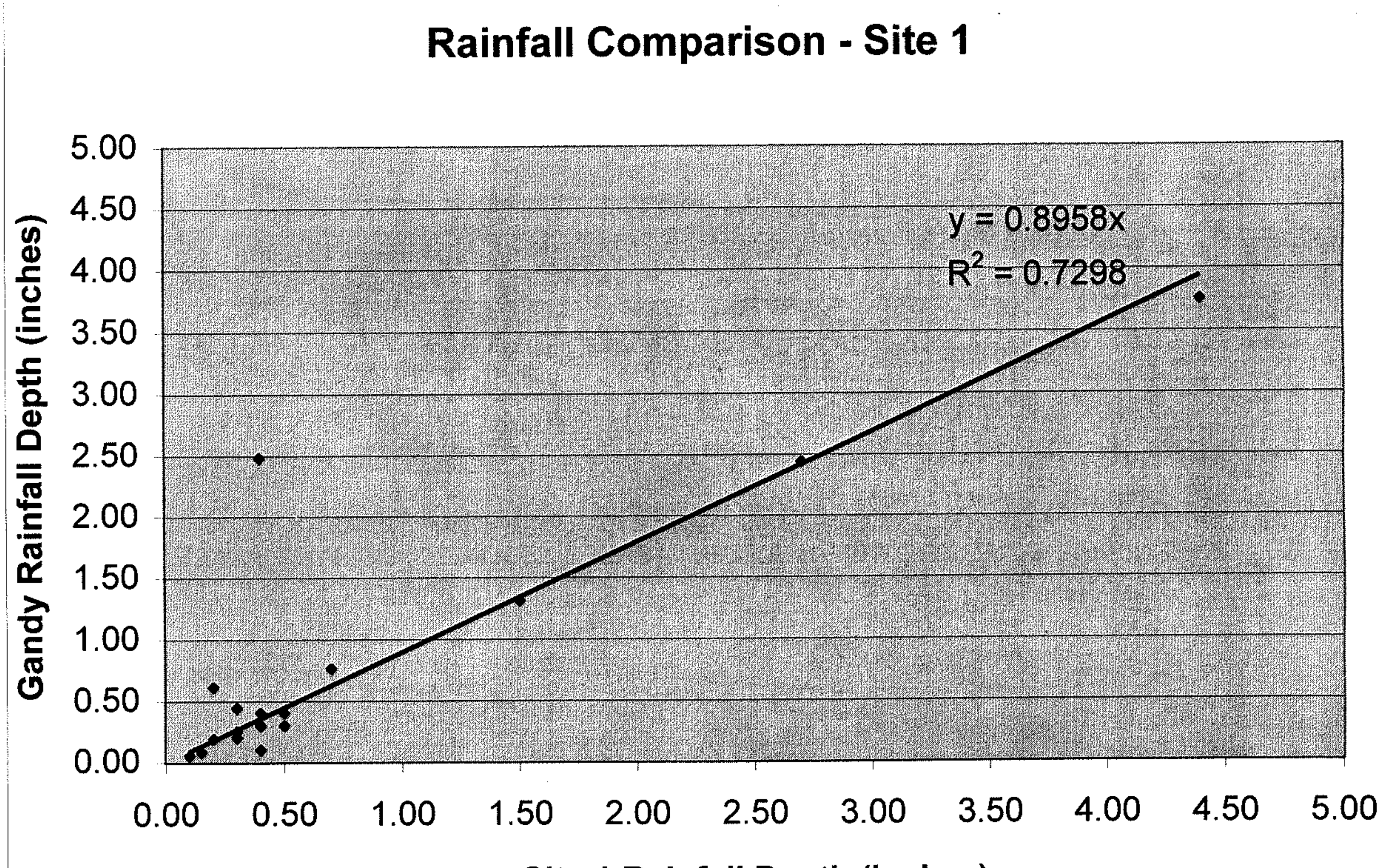

Figure 3-2 Site 1 Rainfall Comparison

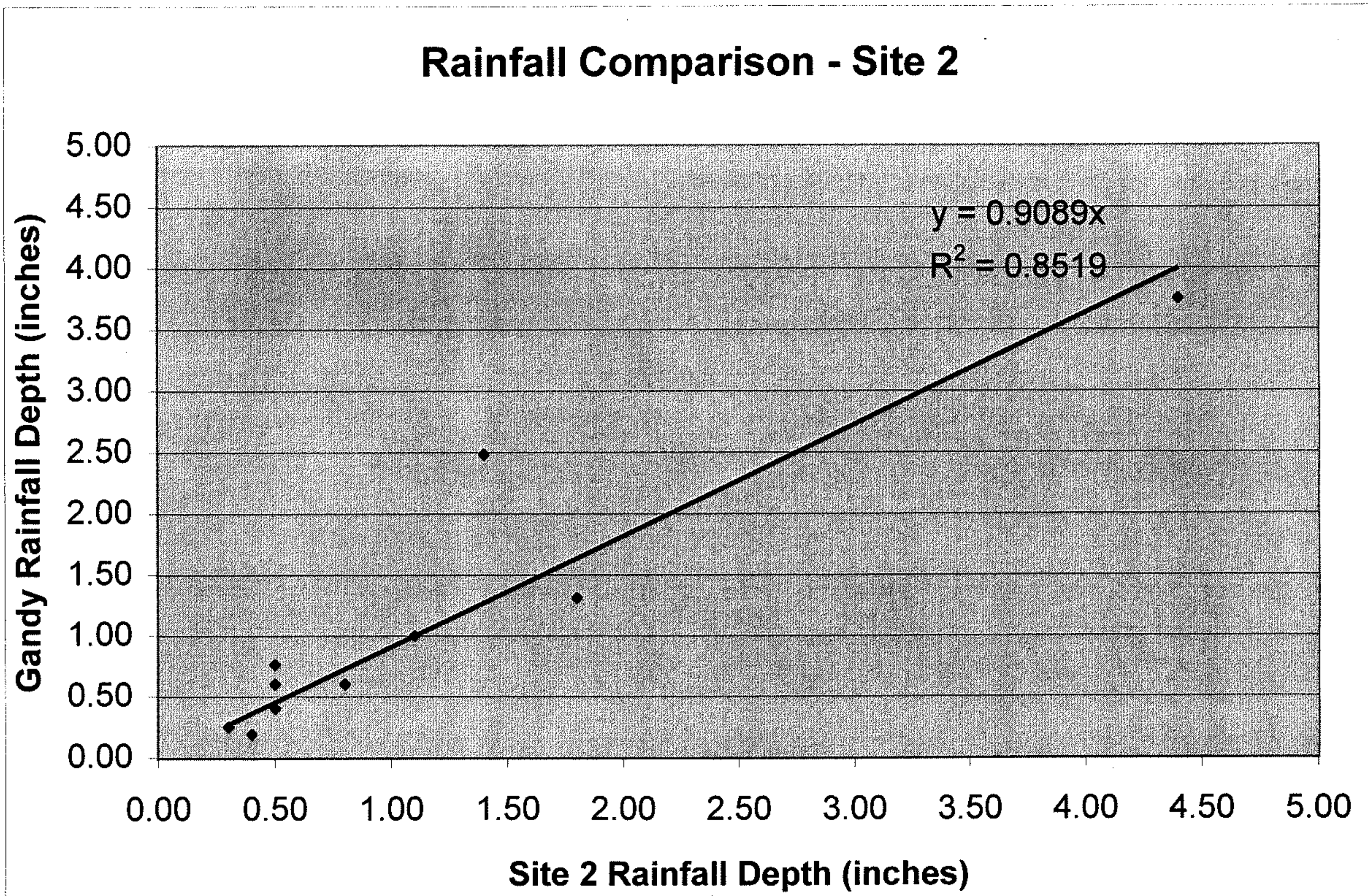

Figure 3-3 Site 2 Rainfall Comparison

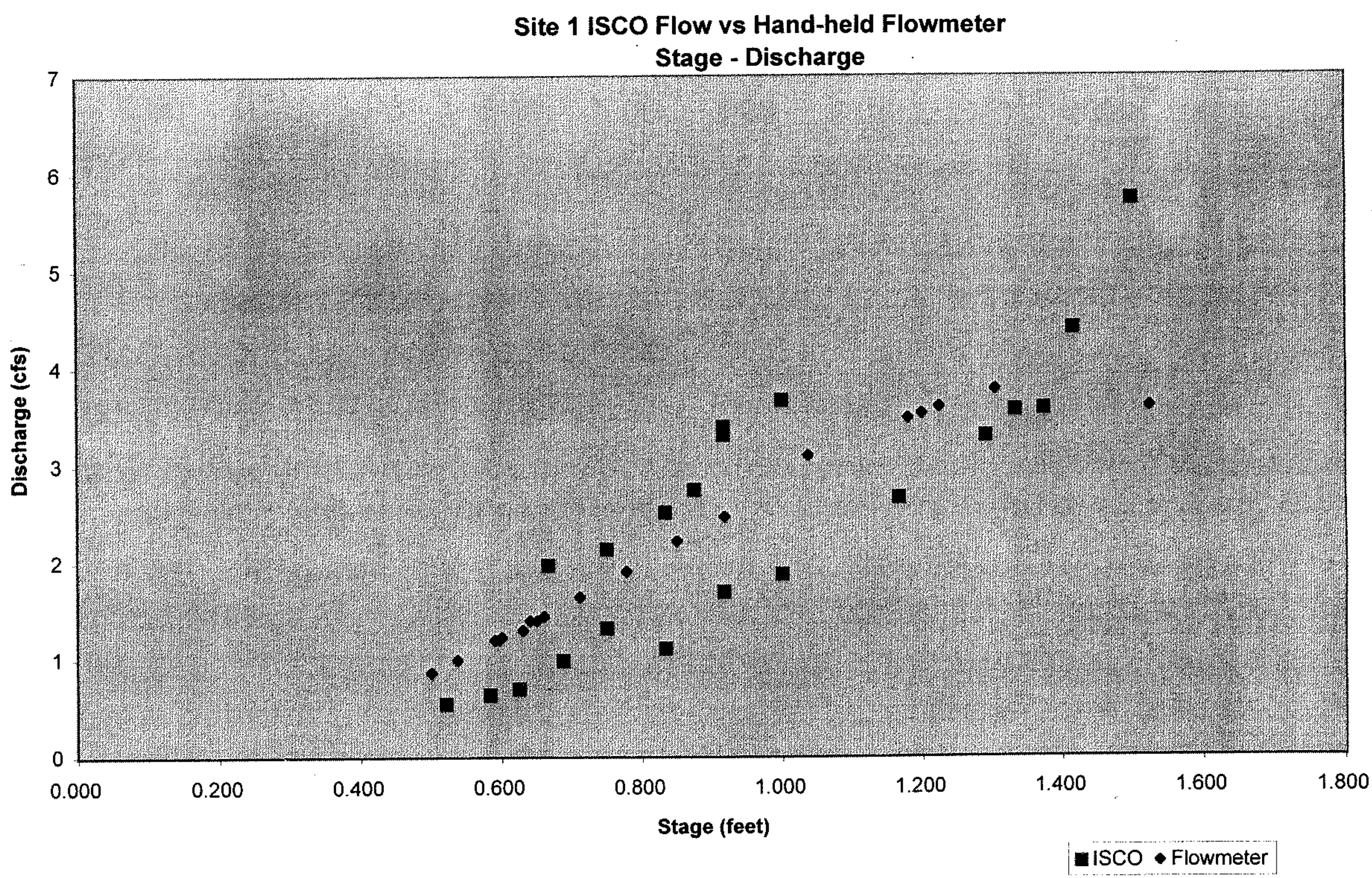

Figure 3-4 ISCO and Flowmeter Stage-Discharge Comparison

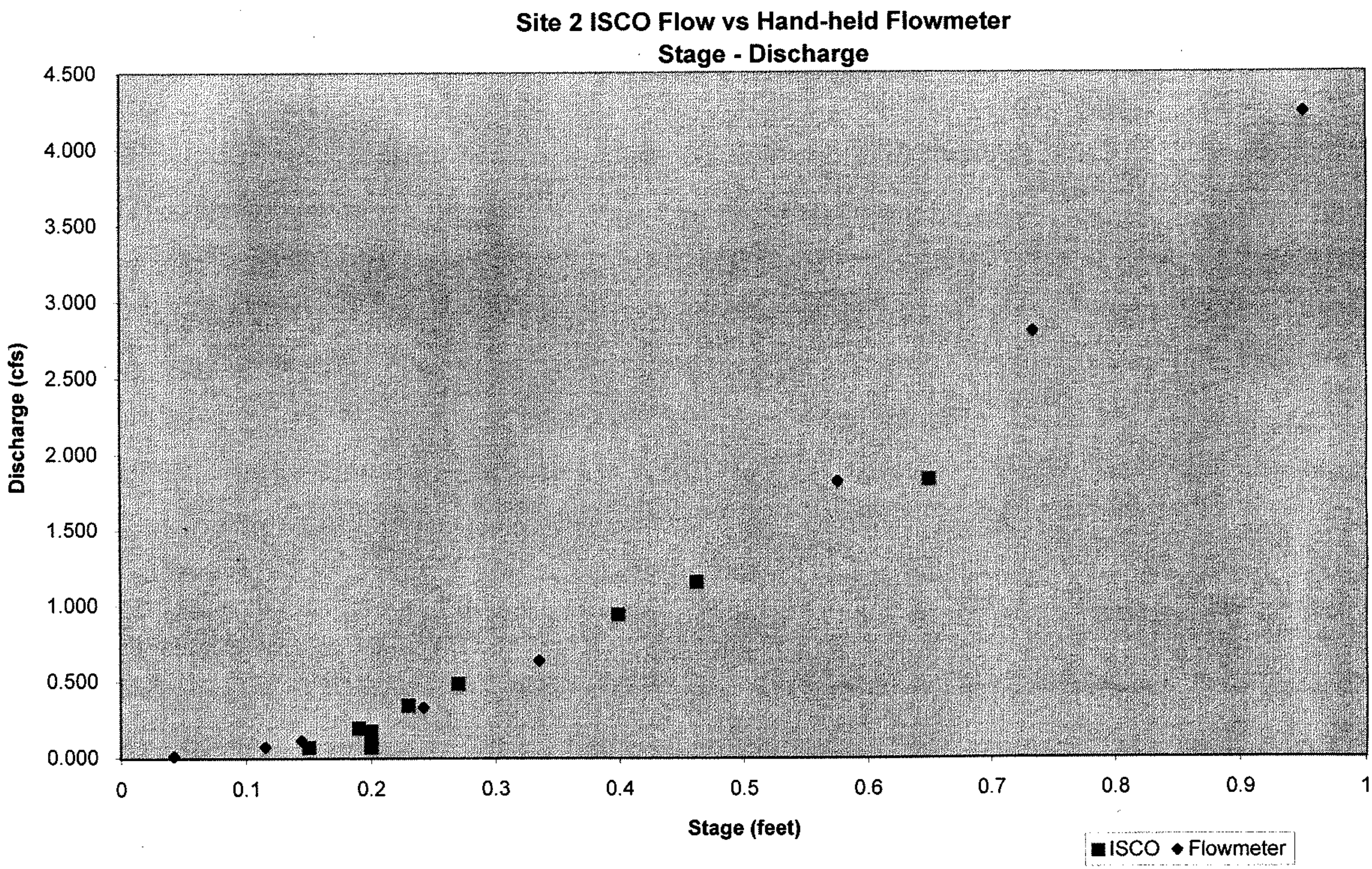

Figure 3-5 ISCO and Flowmeter Stage-Discharge Comparison

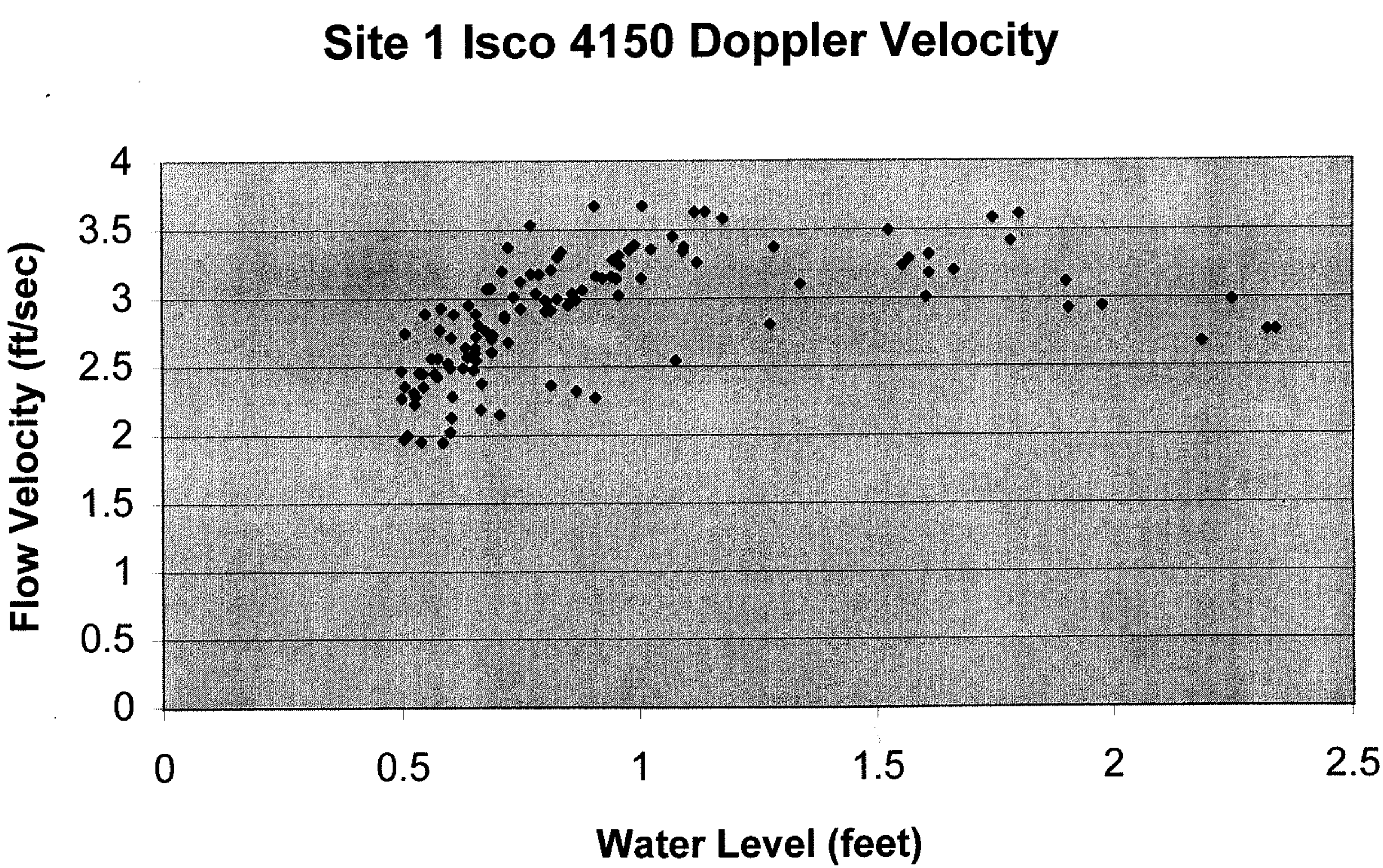

Figure 3-6 Site 1 Doppler Velocity Measurements

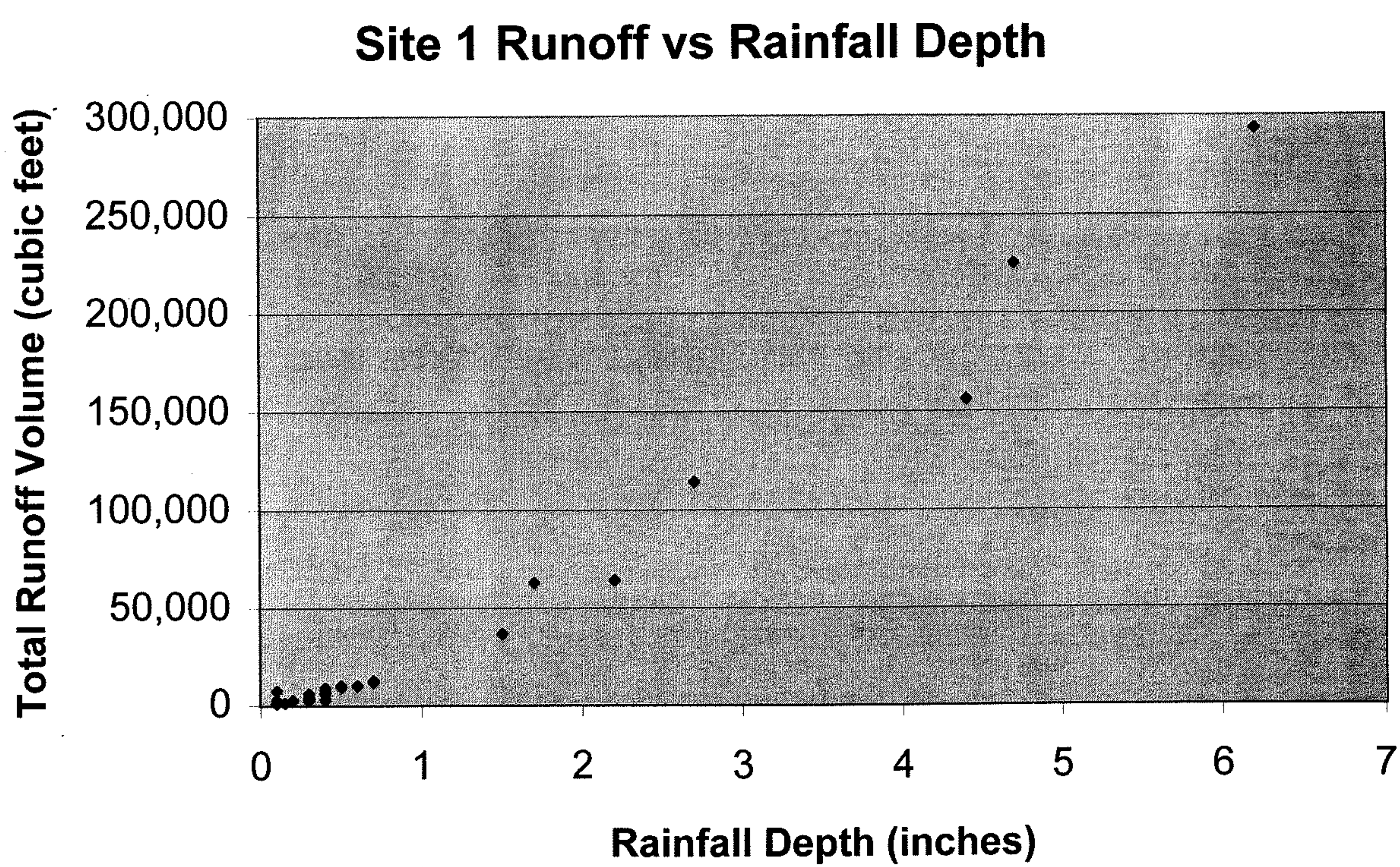

Figure 3-7 Site 1 Rainfall and Runoff Comparison

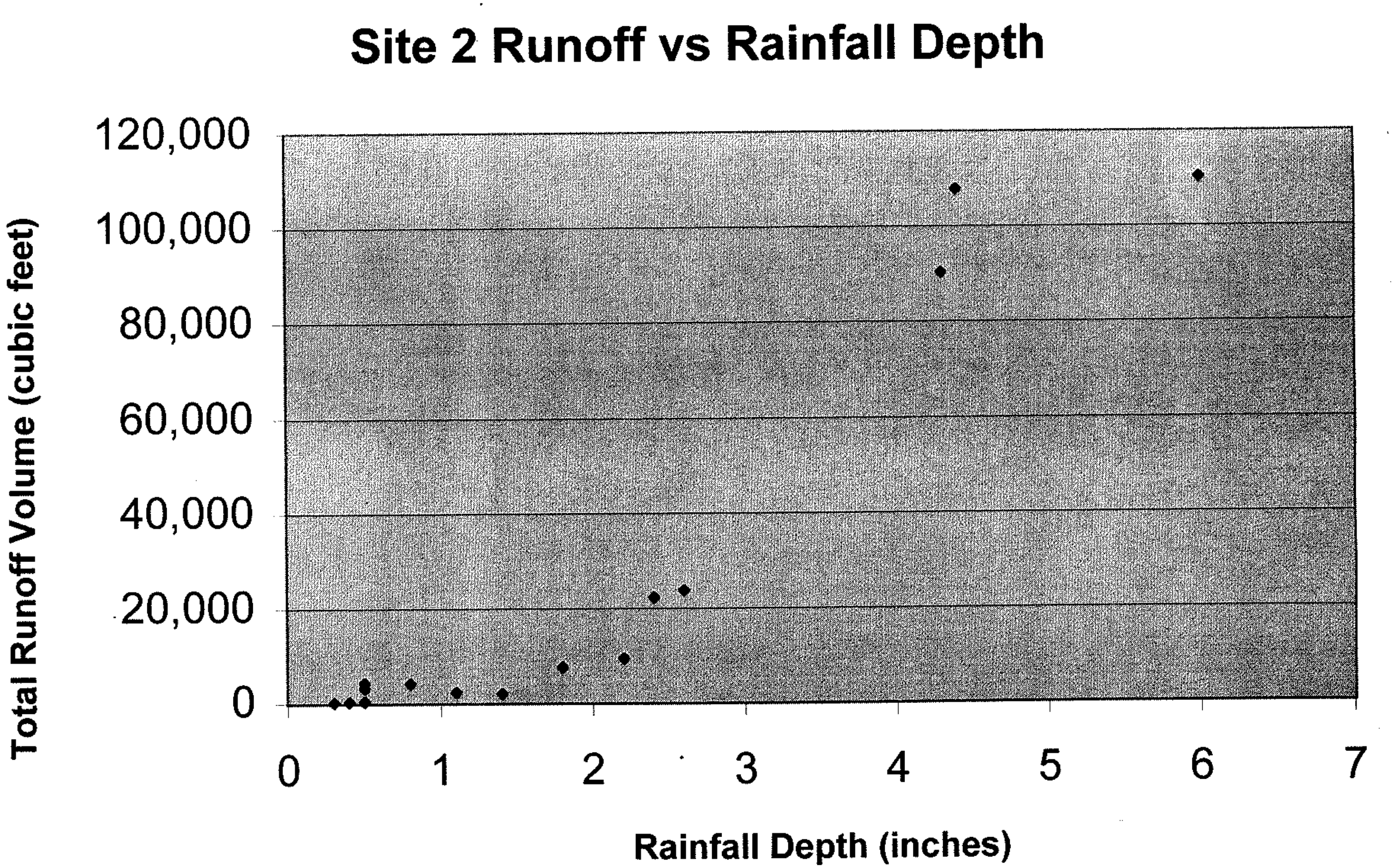

Figure 3-8 Site 2 Rainfall and Runoff Comparison

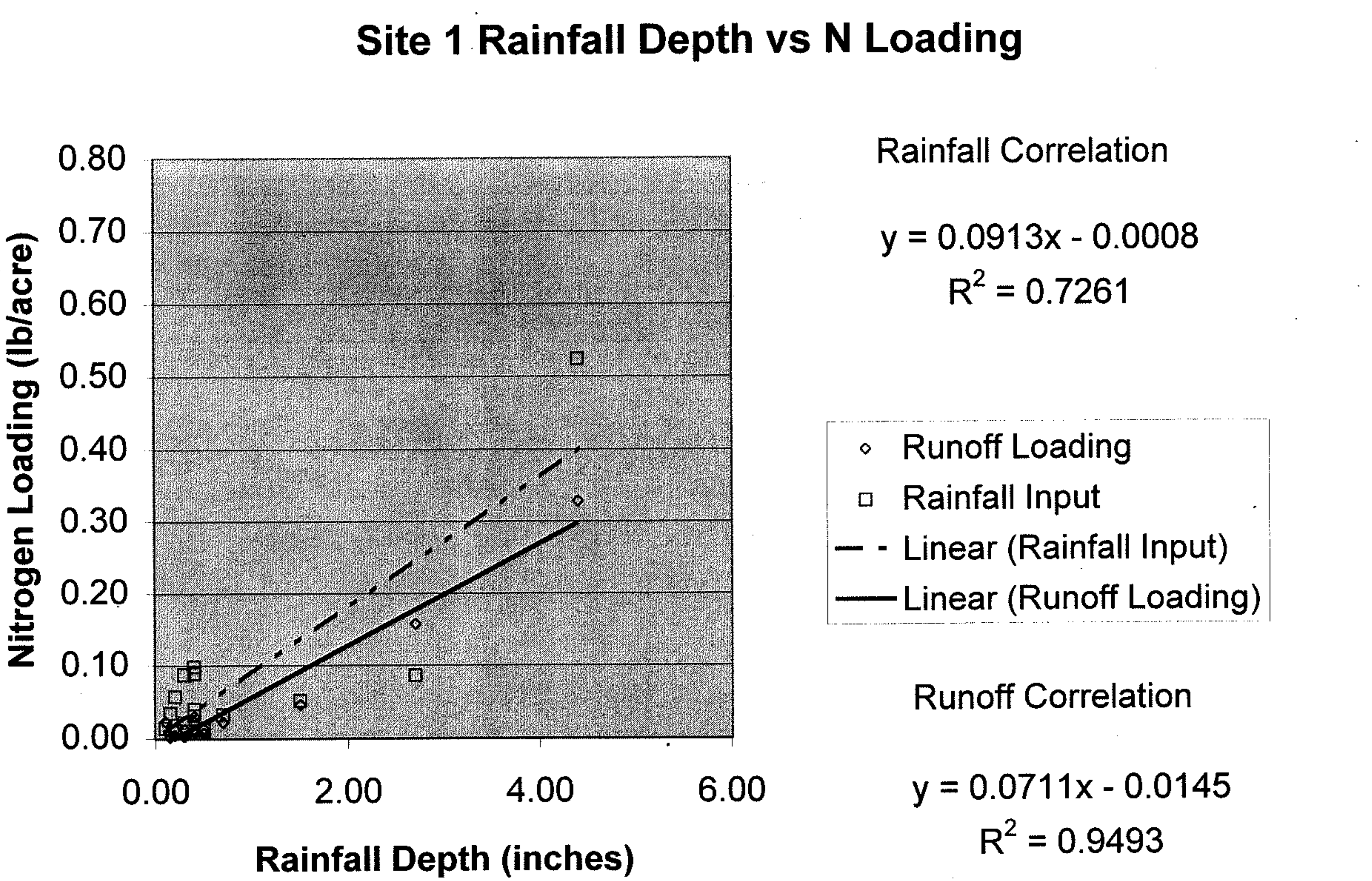

Figure 3-9 Site 1 Rainfall Depth vs N Loading

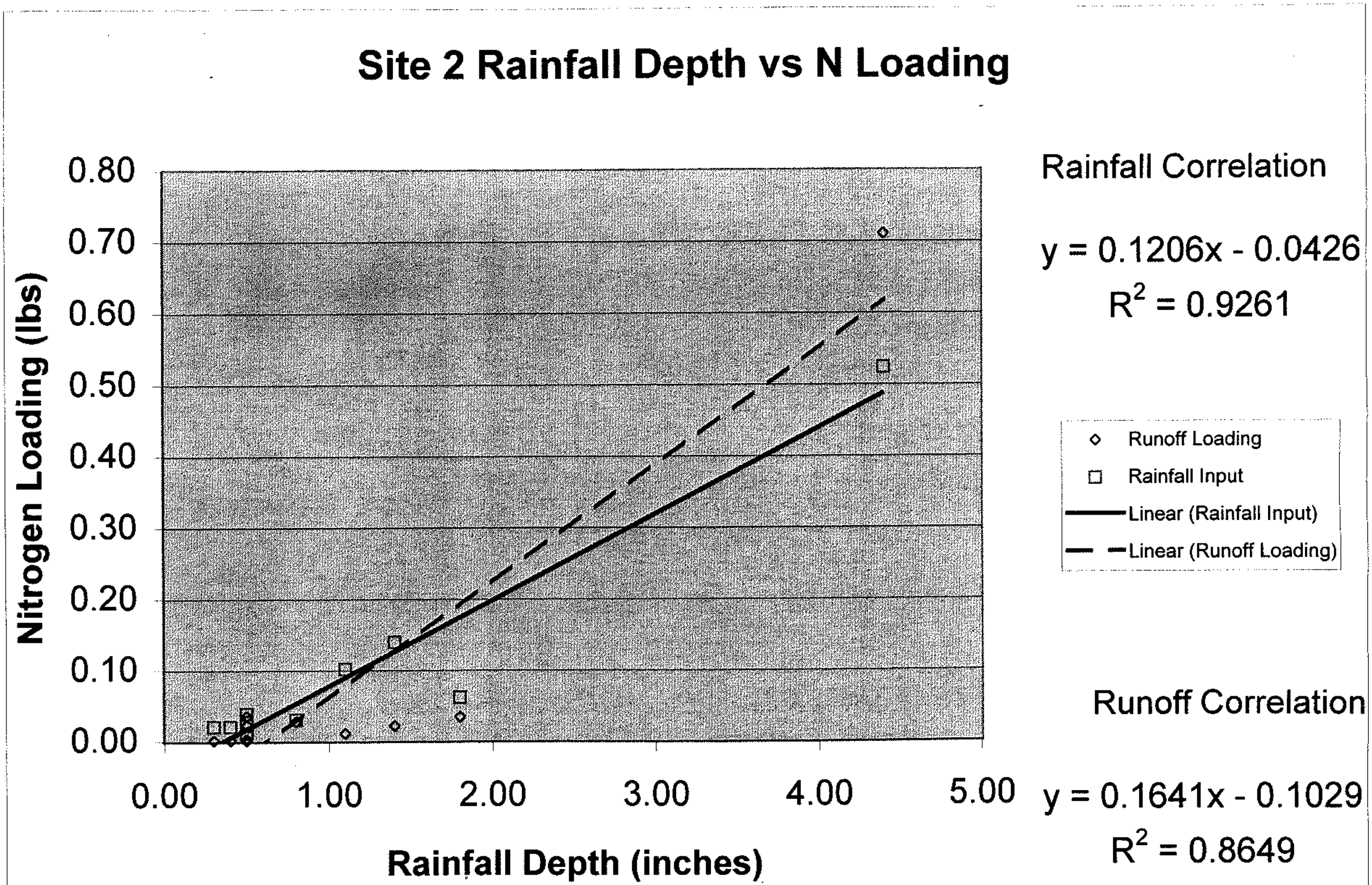

Figure 3-10 Site 2 Rainfall Depth vs N Loading

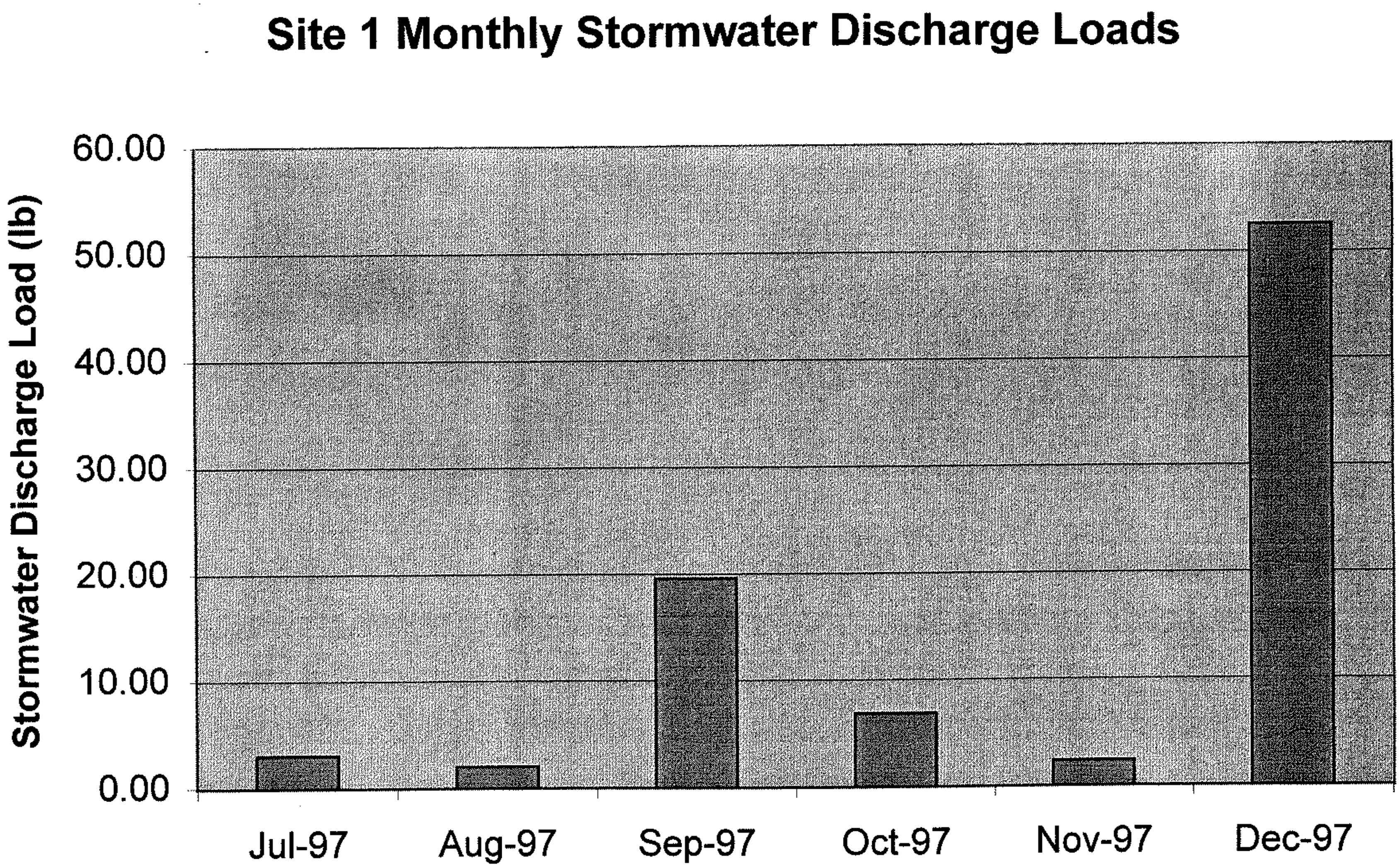

Figure 3-11 Site 1 Monthly Stormwater Discharge Loads

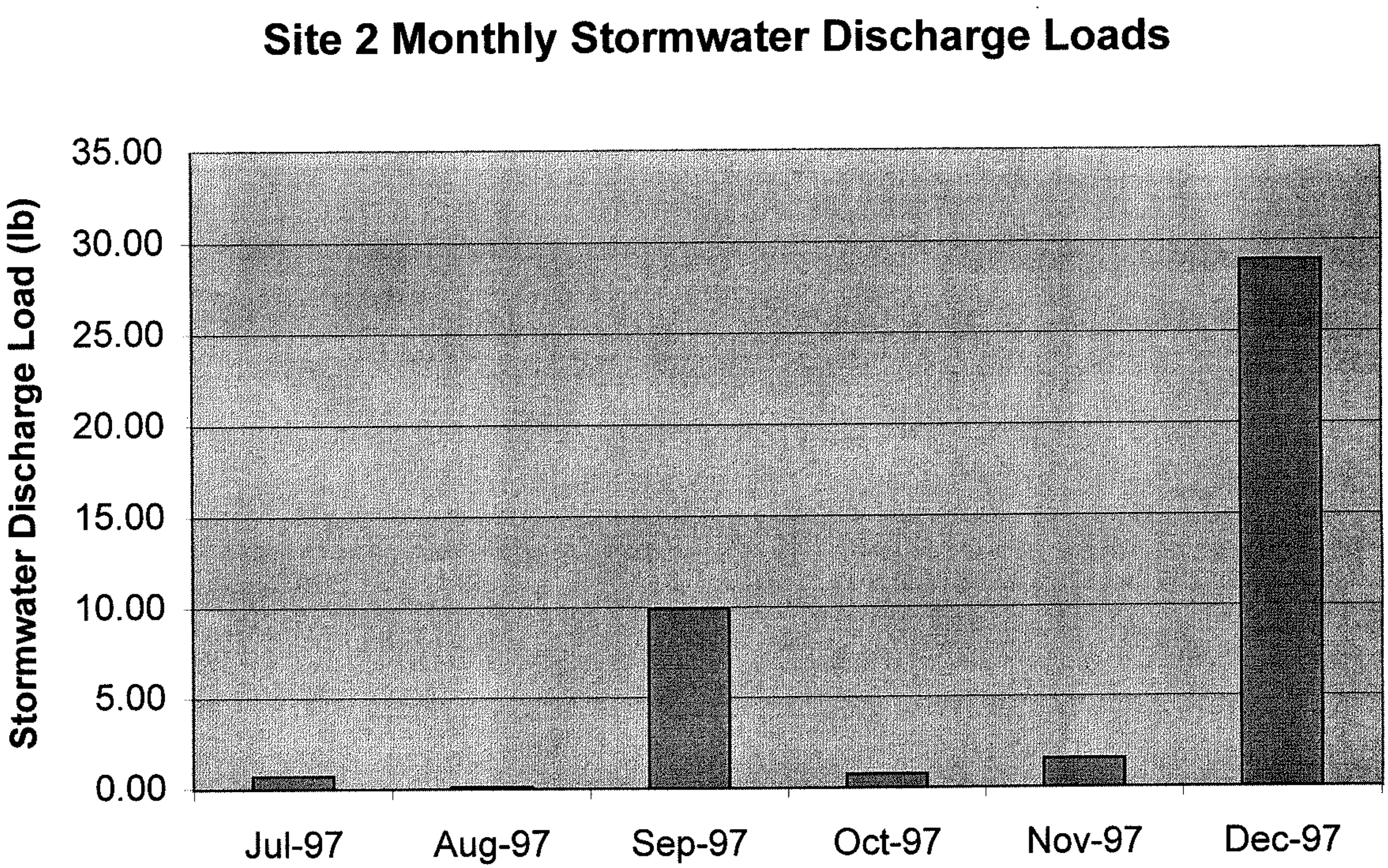

Figure 3-12 Site 2 Monthly Stormwater Discharge Loads

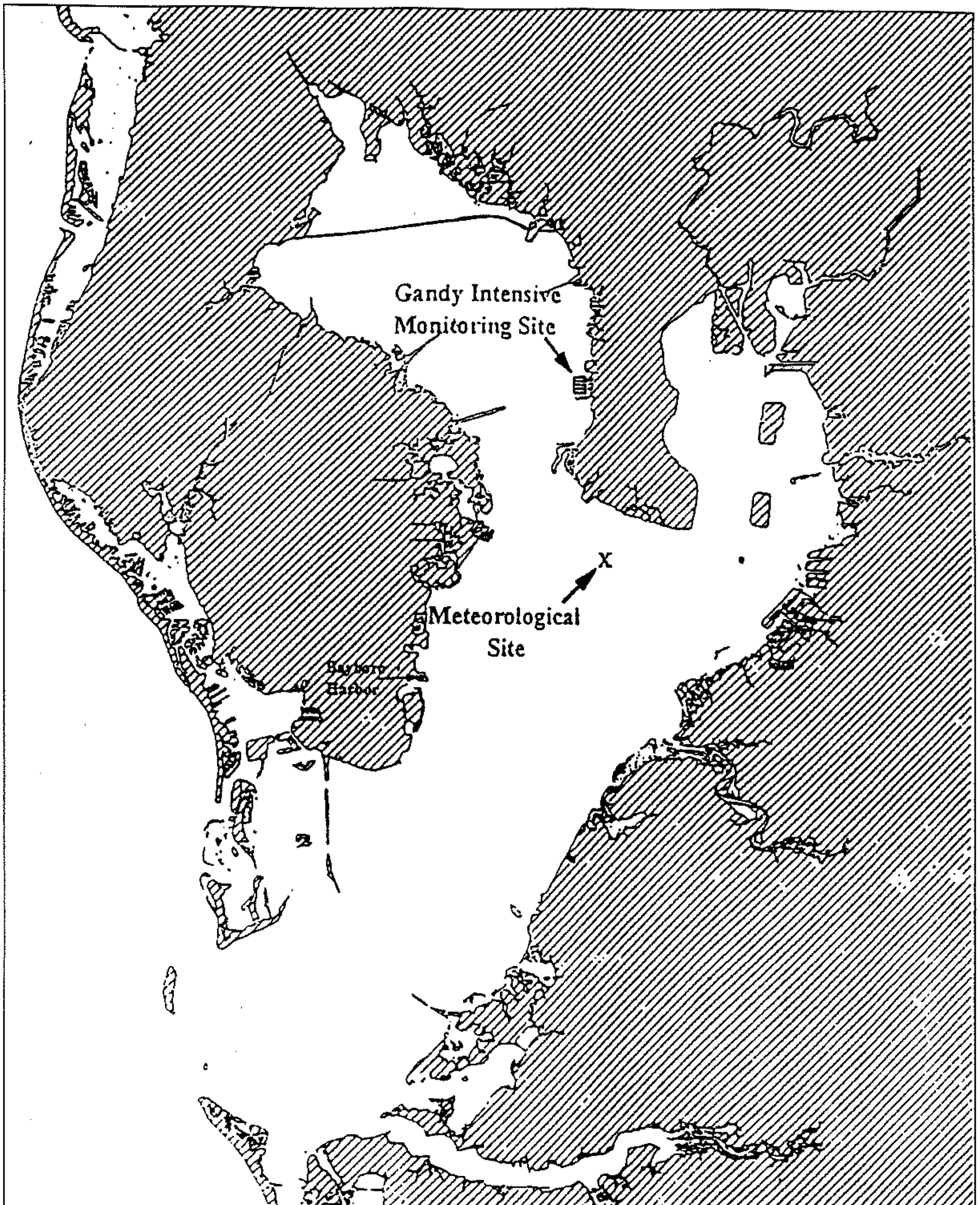

Figure 4-1. Locations of the Gandy Intensive Monitoring Site and the Meteorological Site.

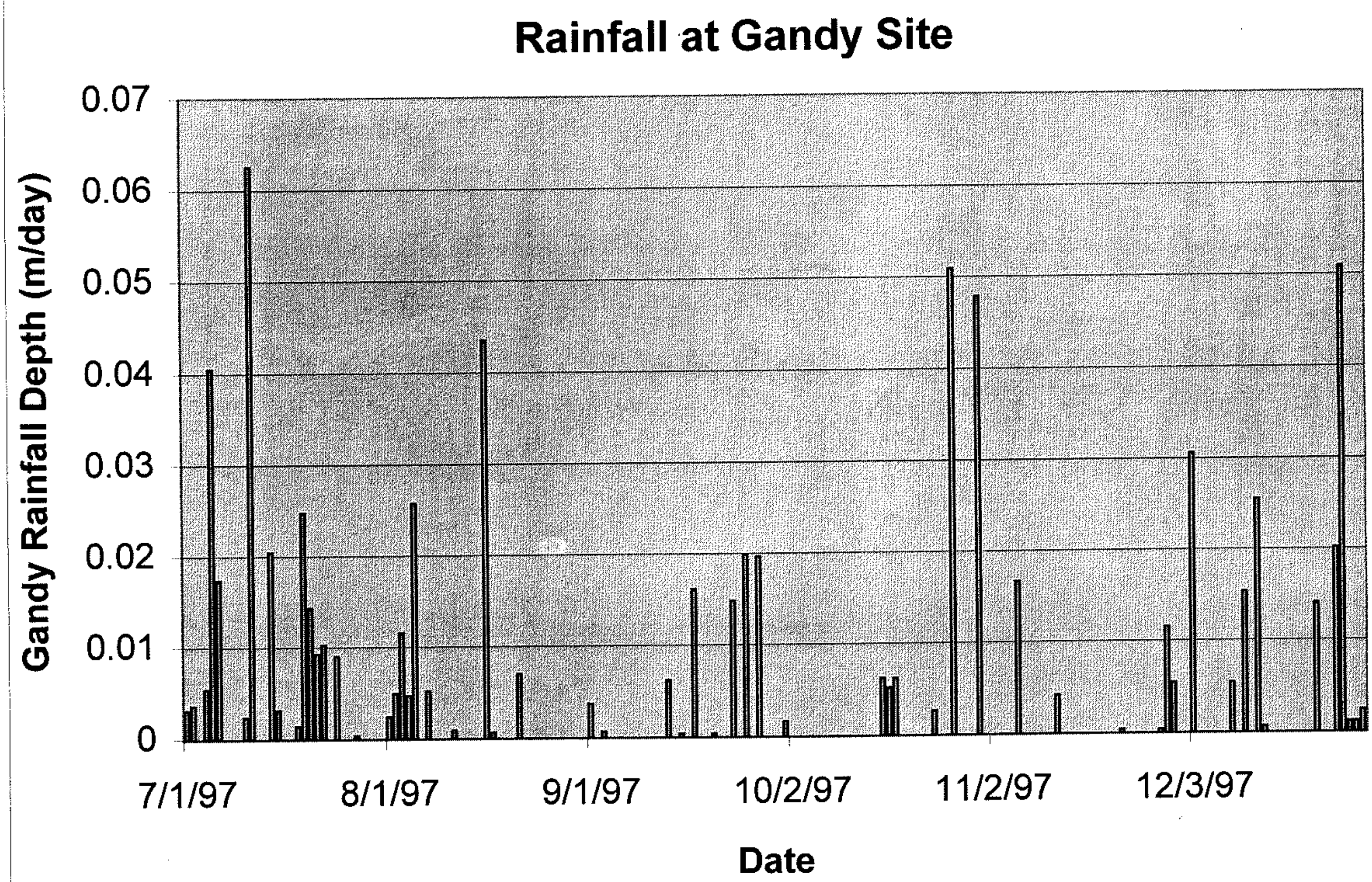

Figure 4-2 Rainfall at Gandy Site from analyzed samples

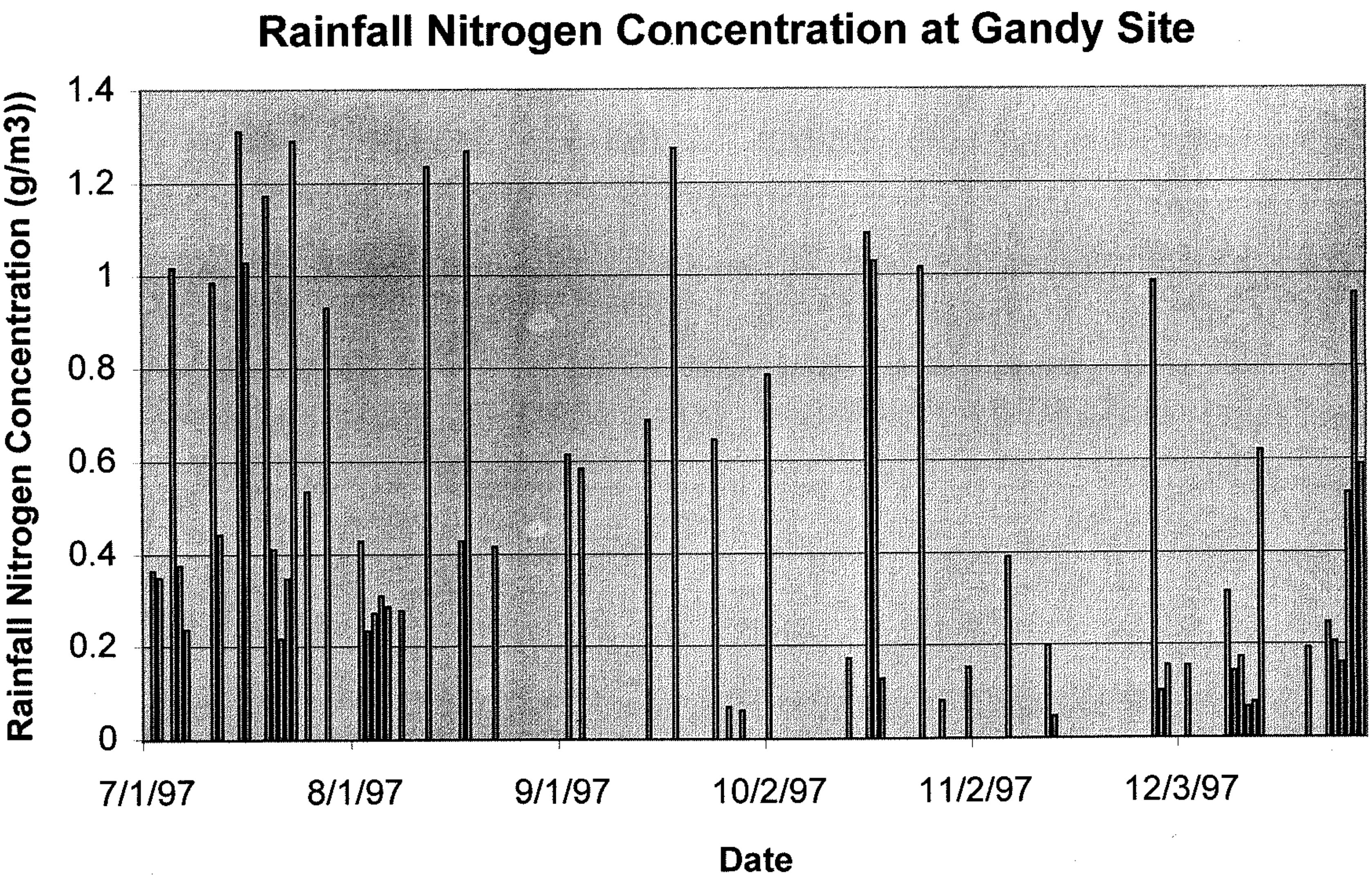

Figure 4-3 Nitrogen Concentration in Rainfall at Gandy Site

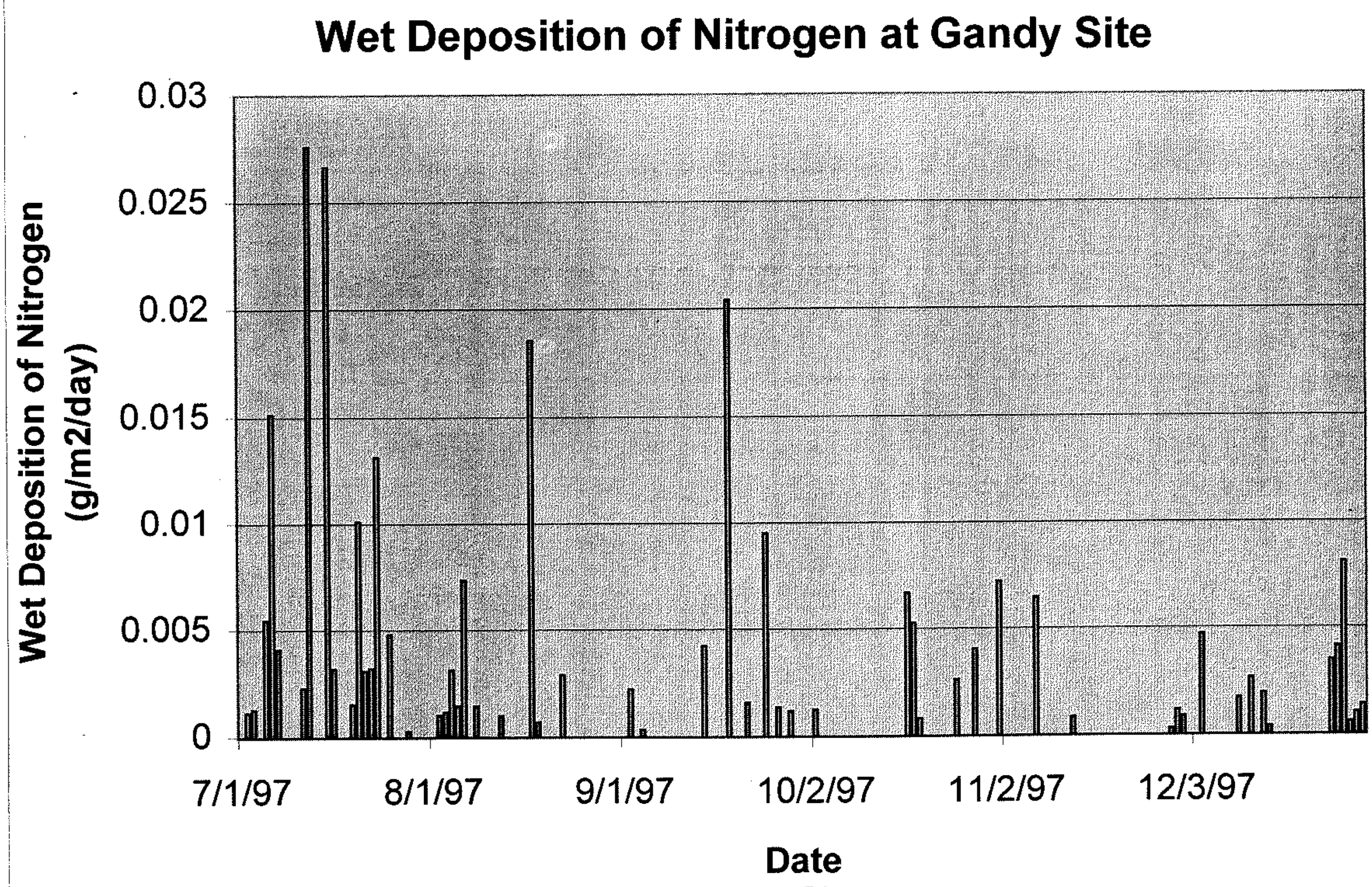

Figure 4-4 Wet Deposition of Nitrogen at Gandy Site

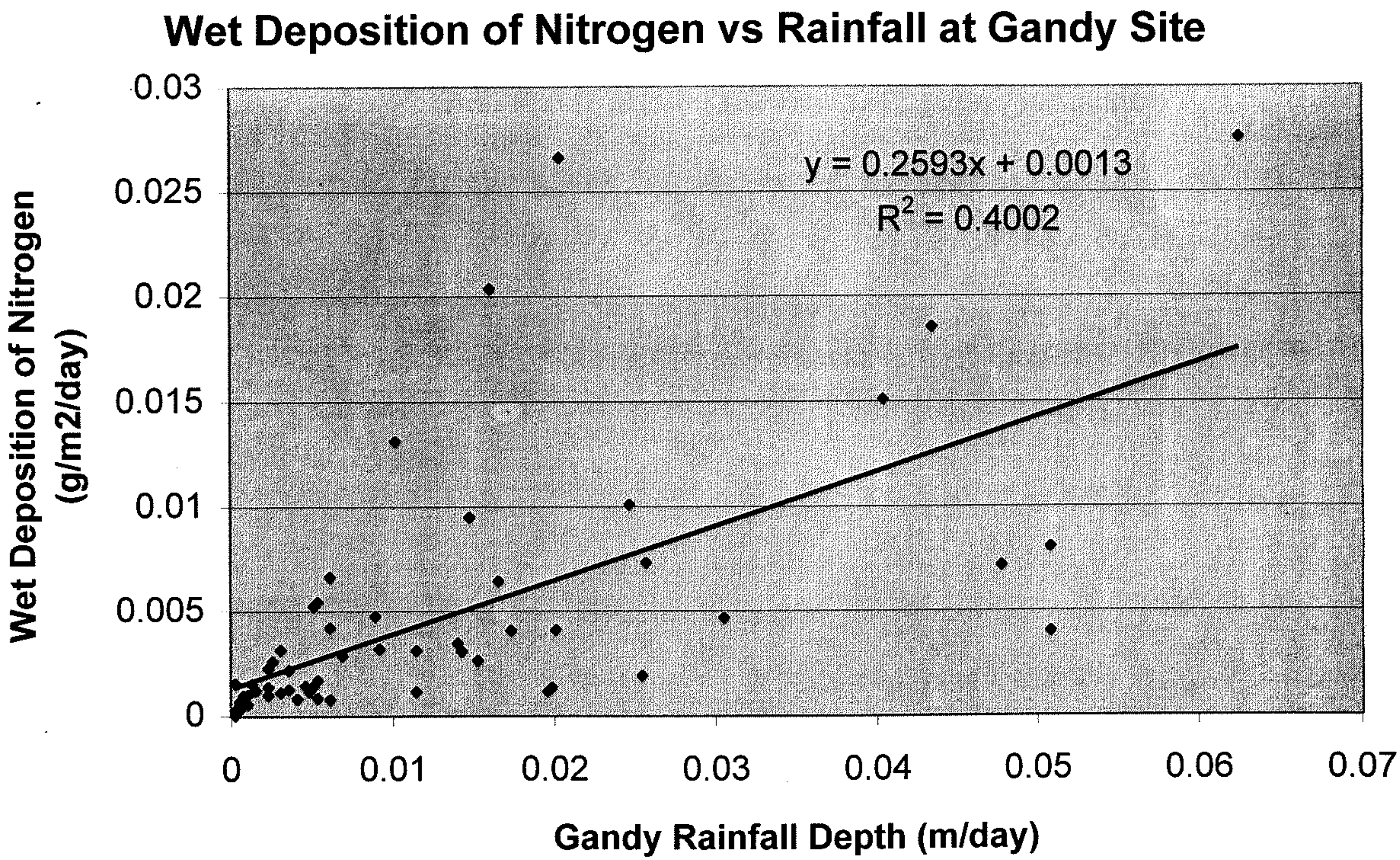

Figure 4-5 Relationship Between Wet Deposition of Nitrogen and Rainfall at Gandy Site

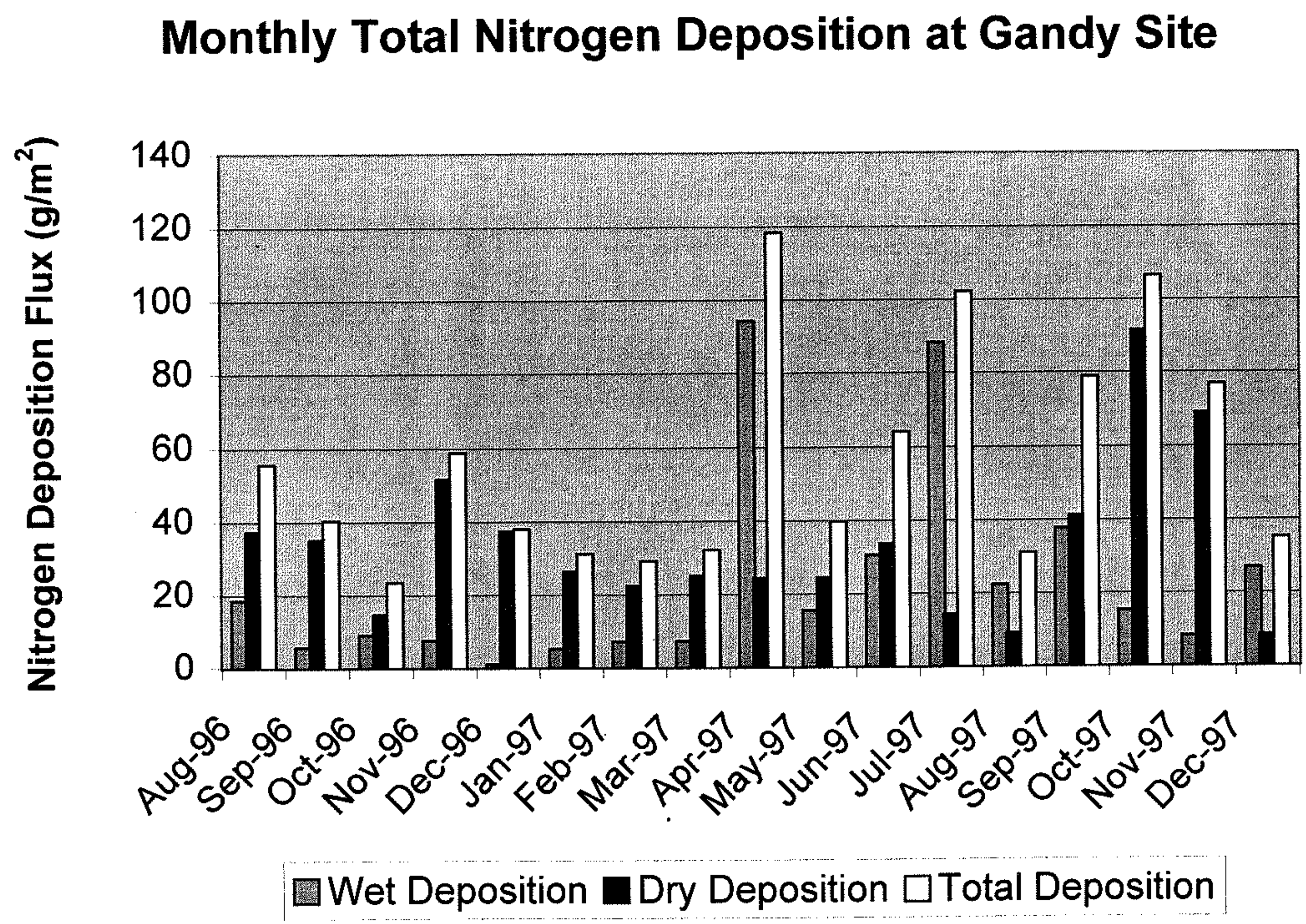

Figure 4-6 Monthly Total Nitrogen Deposition Fluxes at Gandy and Meteorological Site

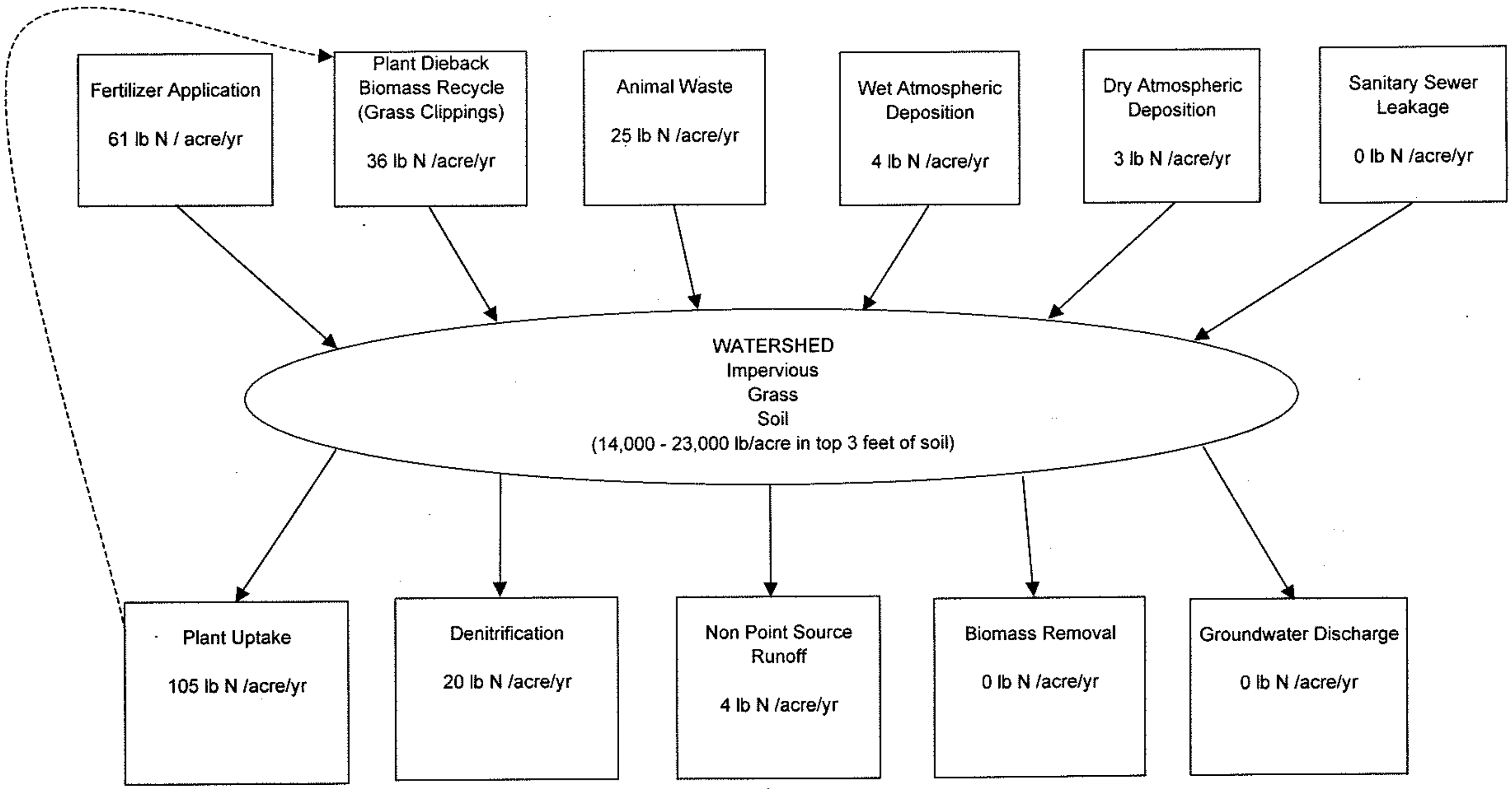

Figure 6-1 Simplified Urban Residential Watershed Nitrogen Mass Balance

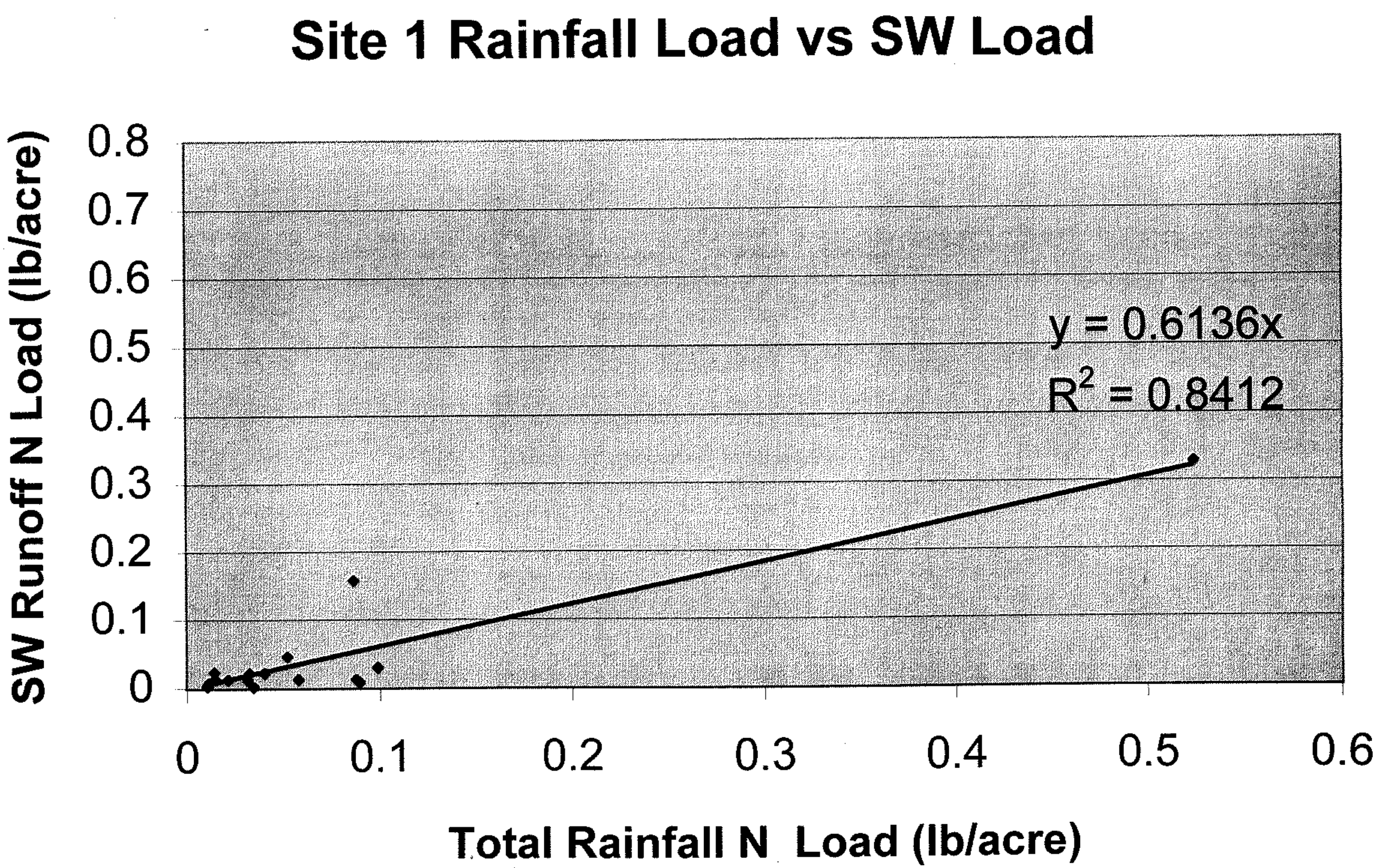

Figure 7-1A Site 1 Rainfall vs Stormwater N Loads

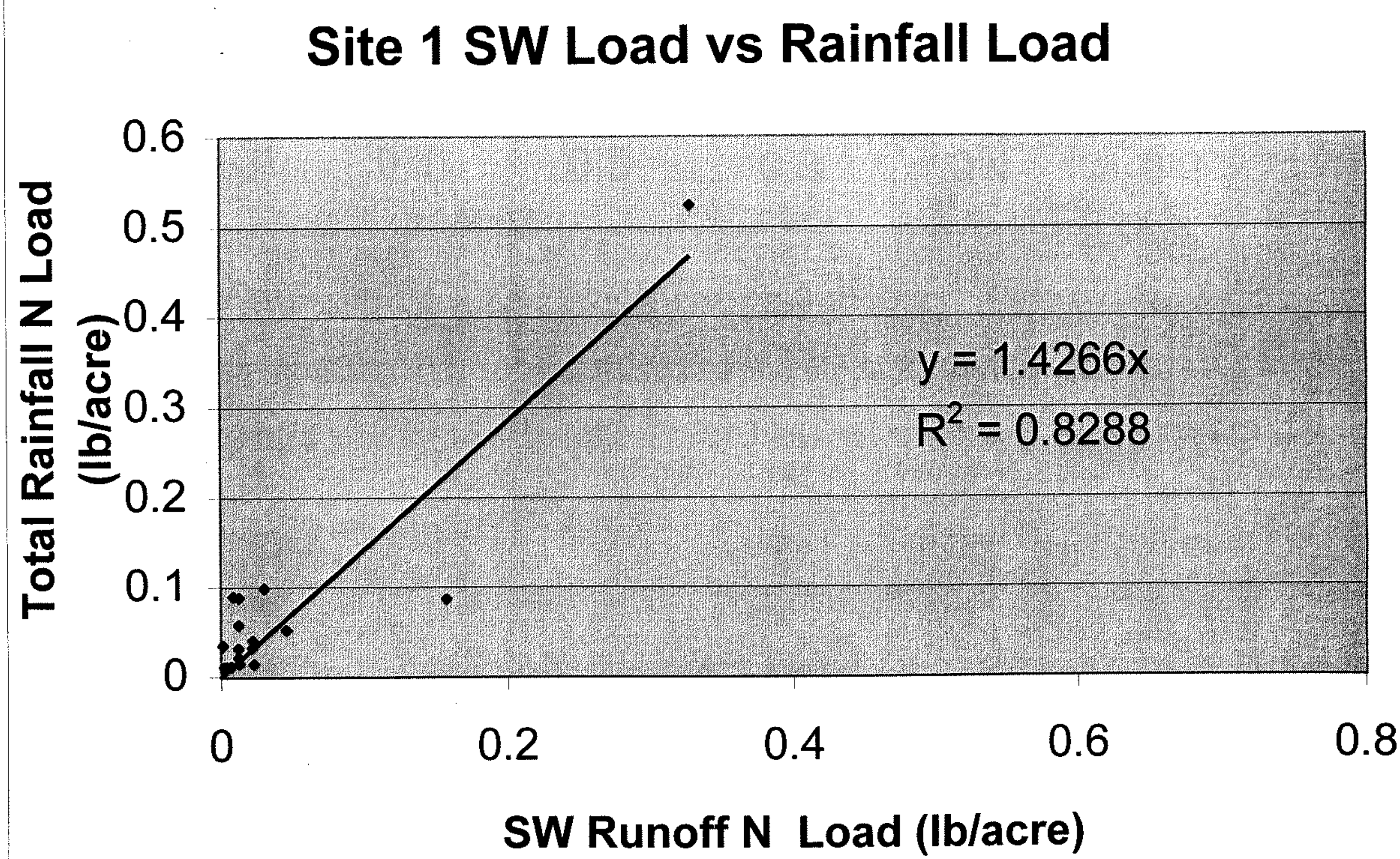

Figure 7-1B Site 1 Stormwater vs Rainfall N Loads

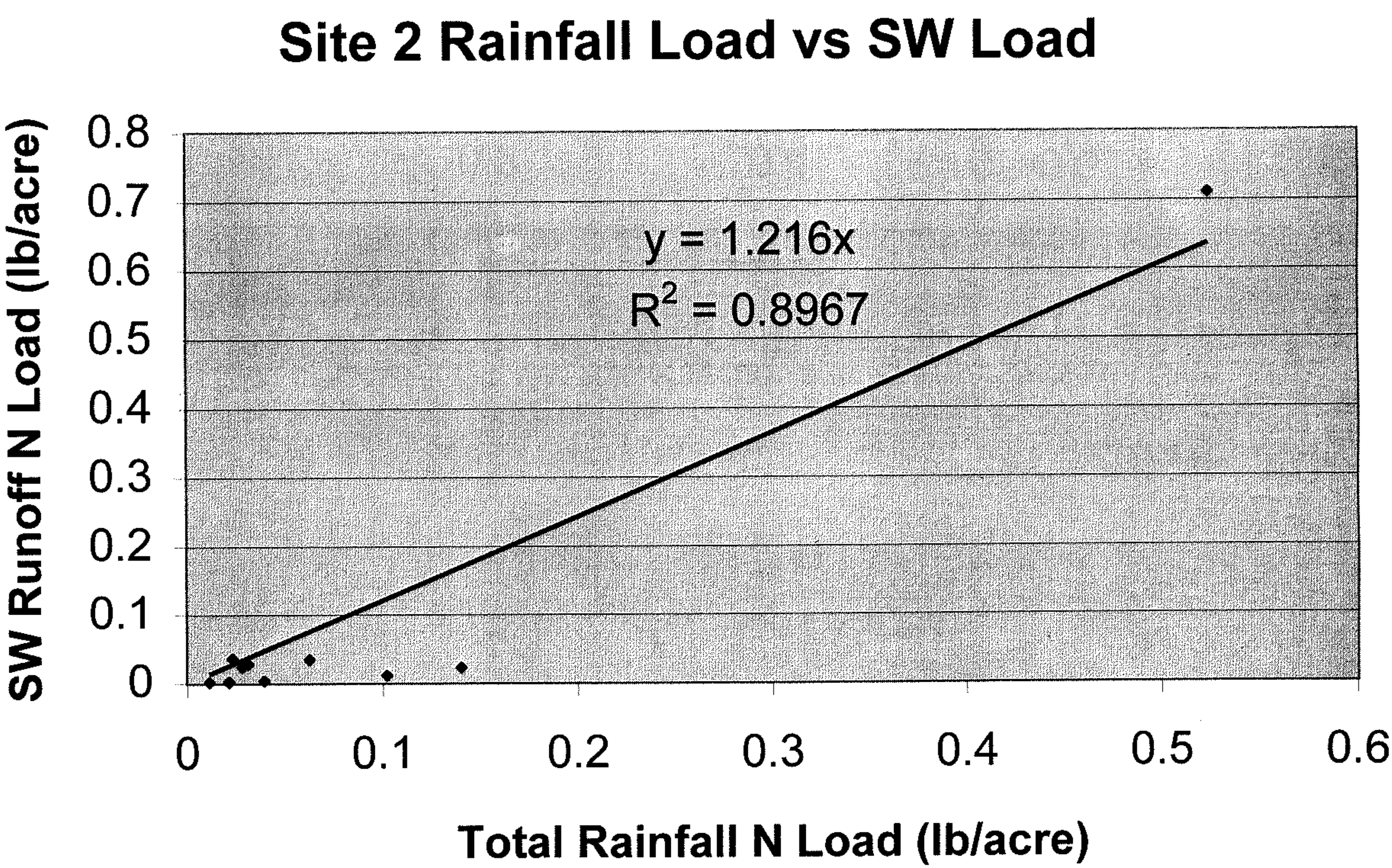

Figure 7-2A Site 2 Rainfall vs Stormwater N Loads

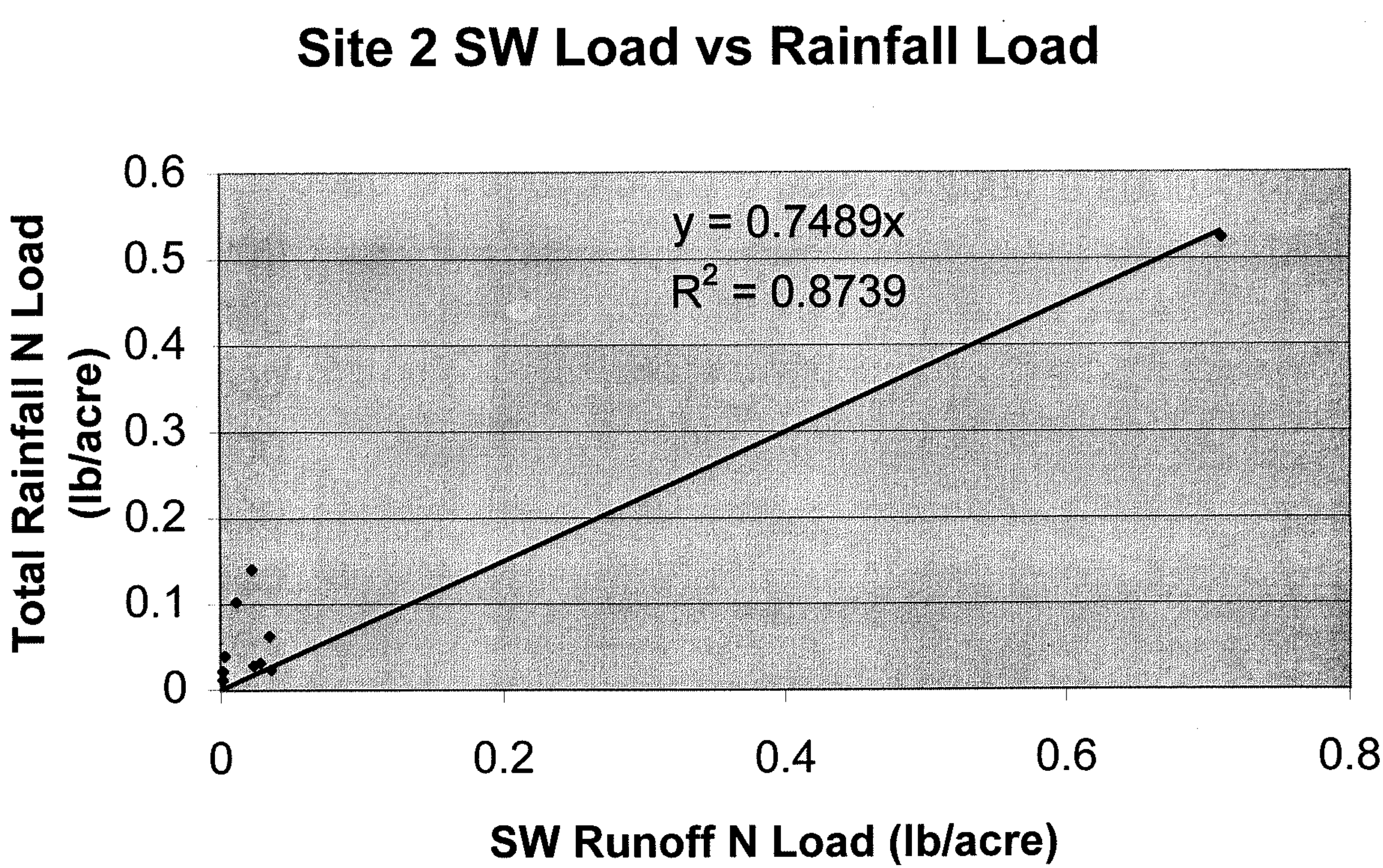

Figure 7-2B Site 2 Rainfall vs Stormwater N Loads

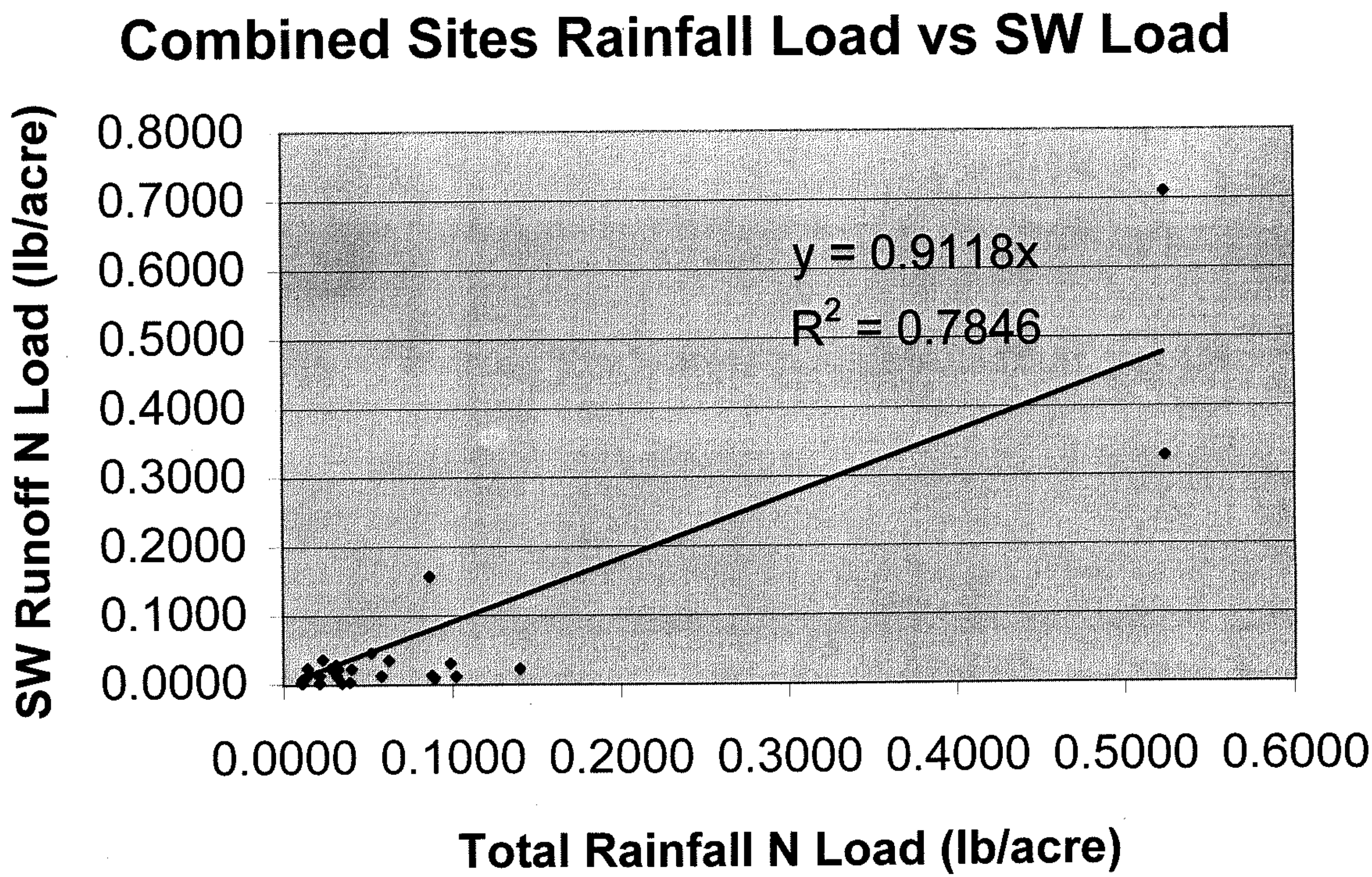

Figure 7-3A Combined Sites Rainfall vs Stormwater N Loads

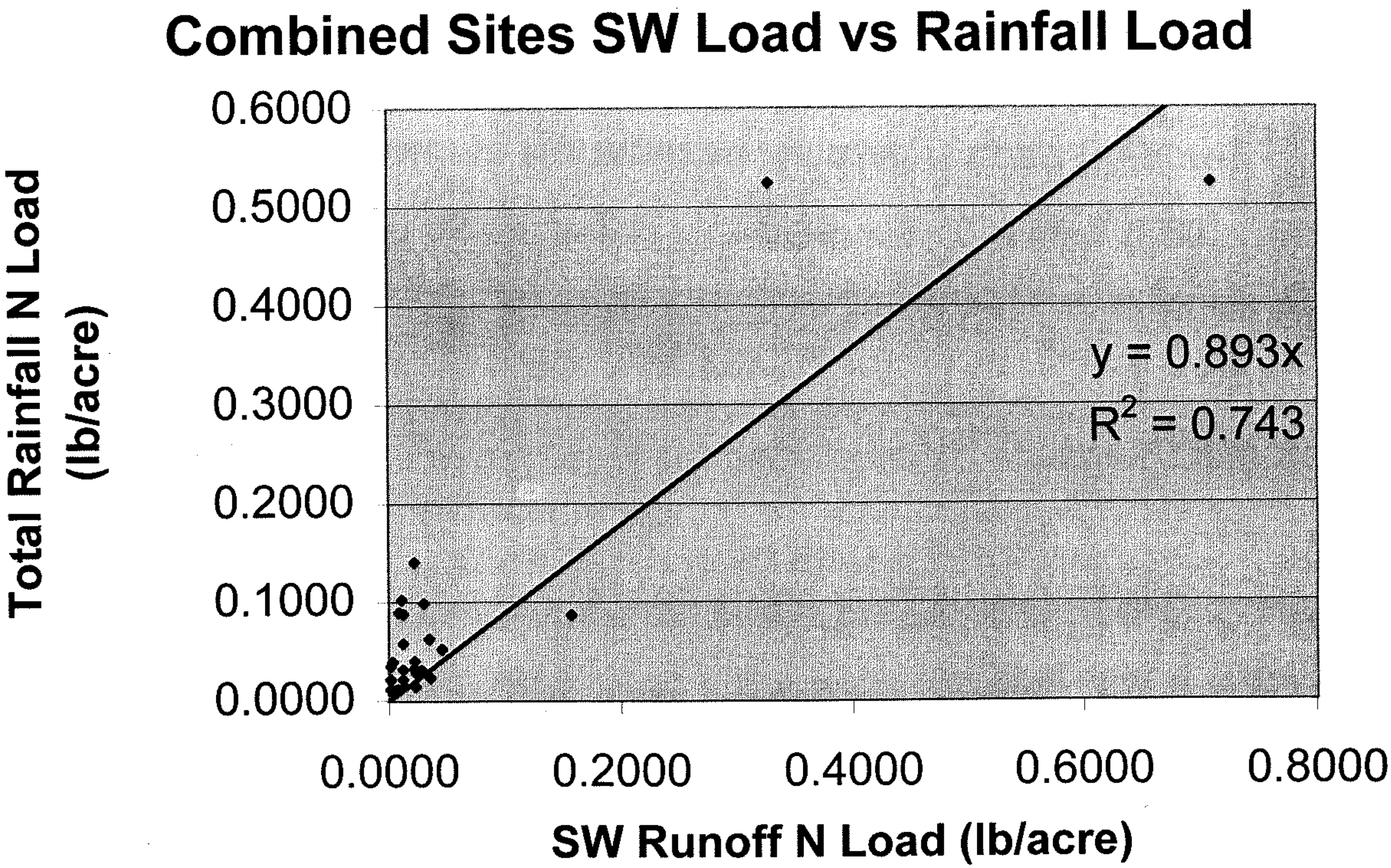

Figure 7-3B Combined Sites Rainfall and Stormwater N Loads

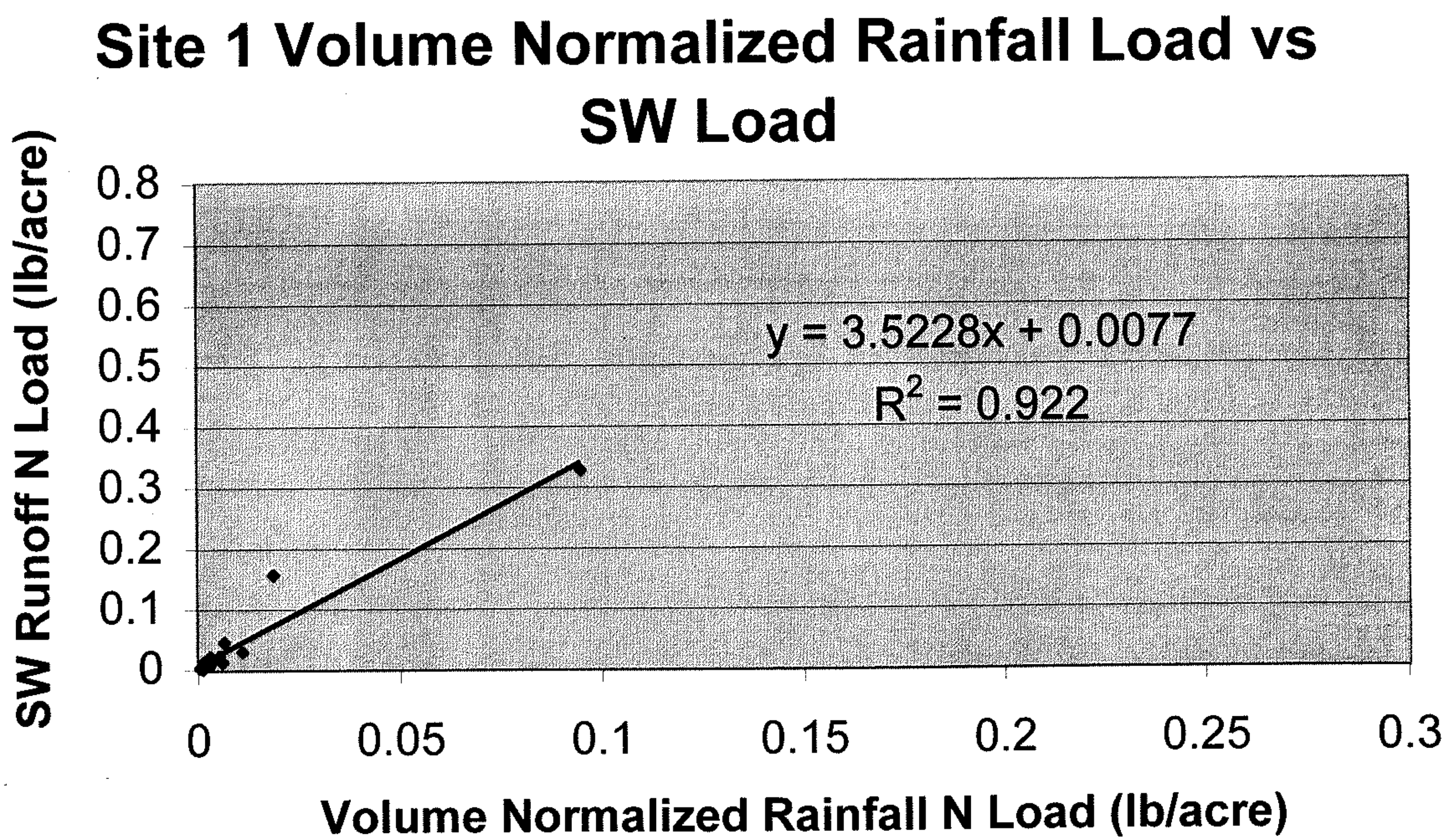

Figure 7-4A Site 1 Normalized Rainfall vs Stormwater N Loads

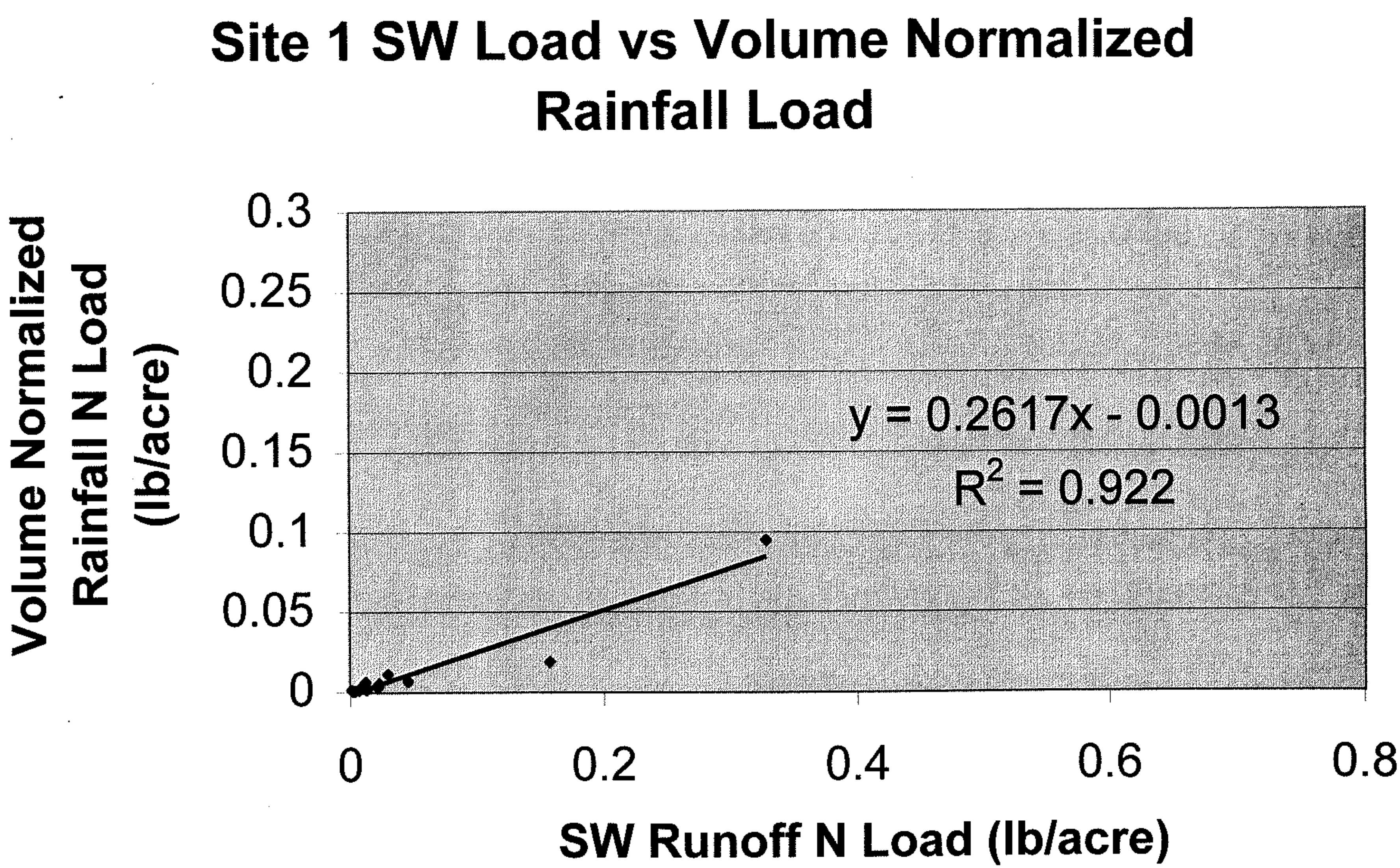

Figure 7-4B Site 1 Normalized Rainfall vs Stormwater N Loads

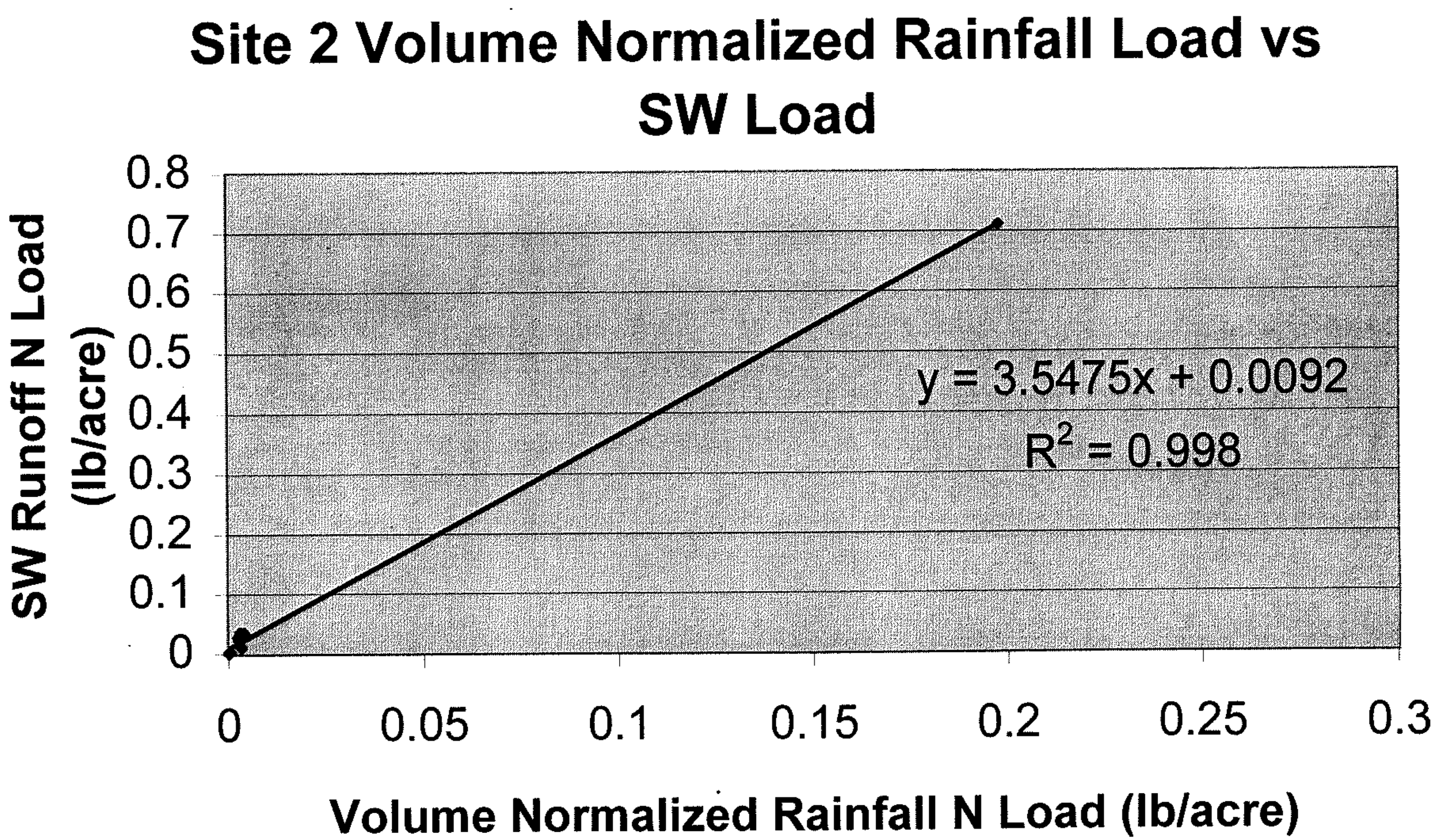

Figure 7-5A Site 2 Normalized Rainfall vs Stormwater N Loads

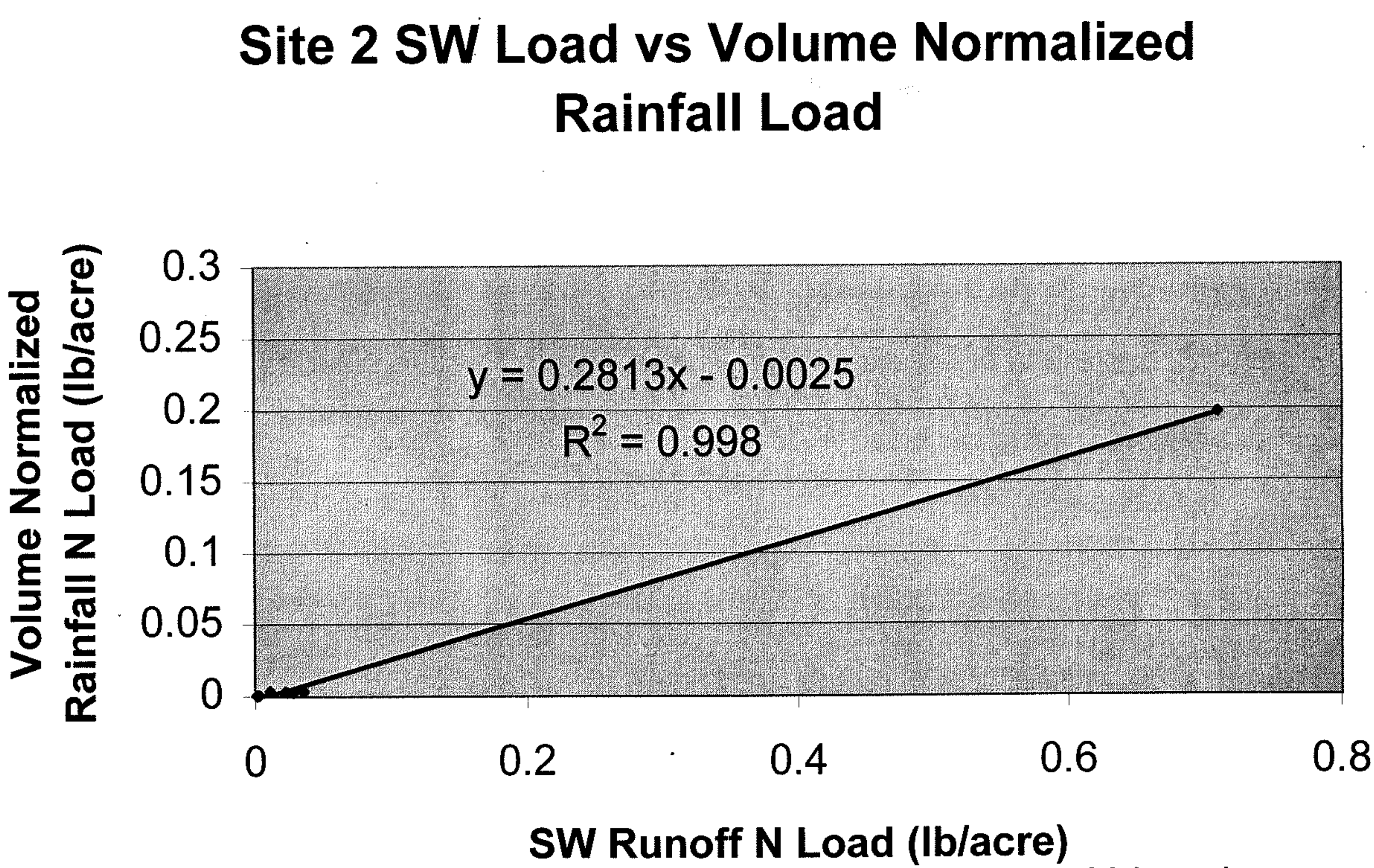

Figure 7-5B Site 2 Normalized Rainfall vs Stormwater N Loads

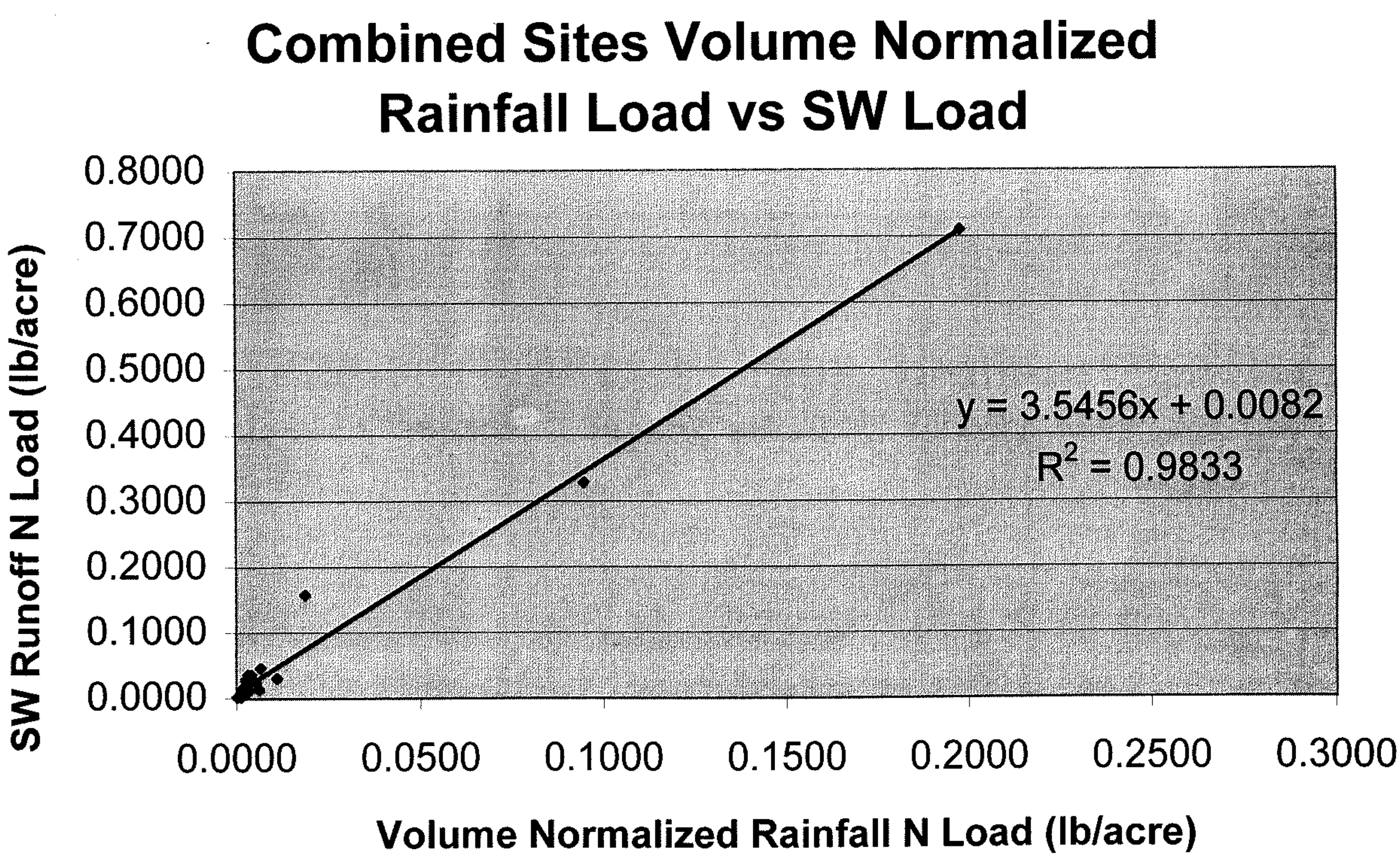

Figure 7-6A Comb. Site Normalized Rainfall vs Stormwater N Loads

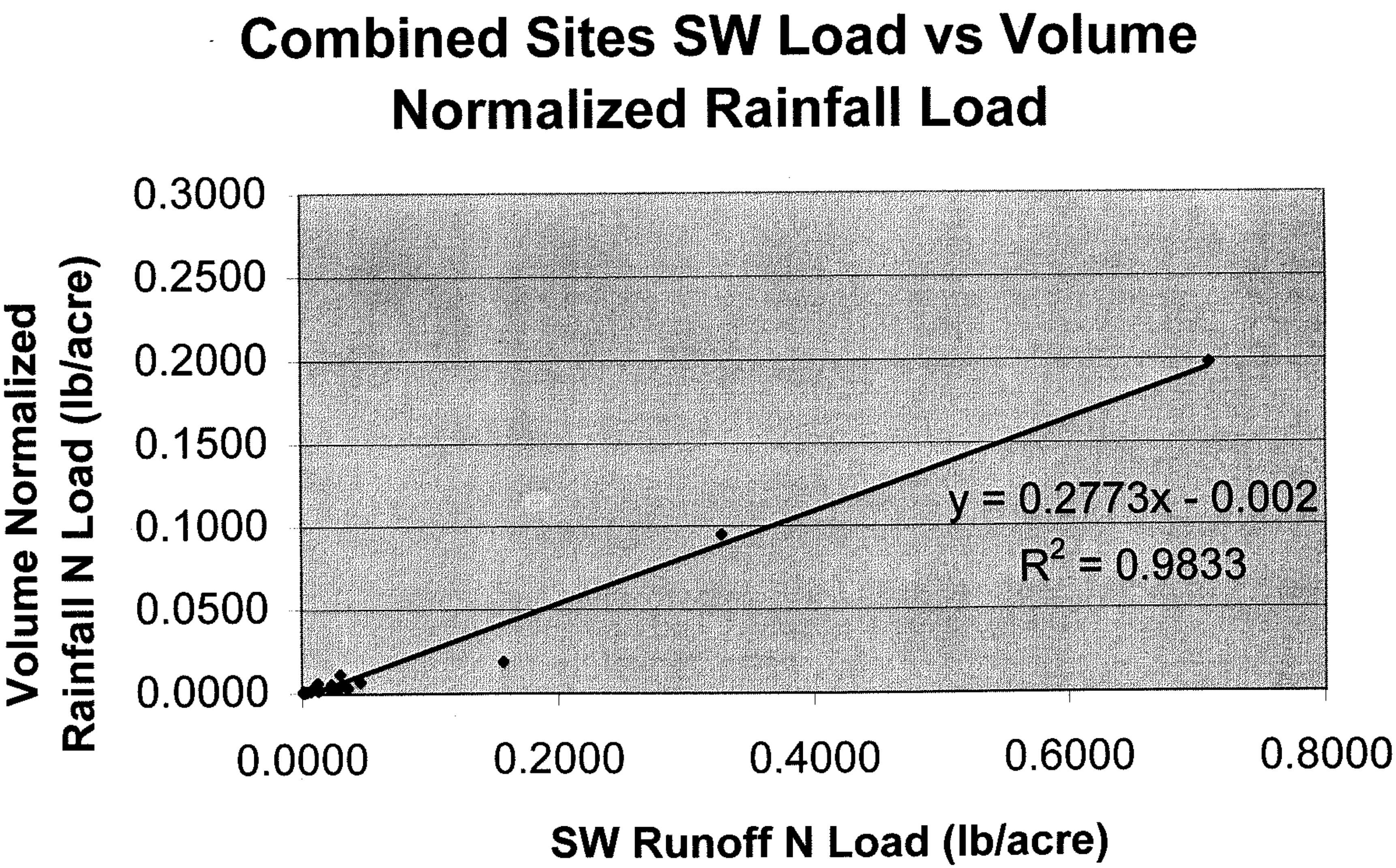

Figure 7-6B Comb. Site Normalized Rainfall vs Stormwater N Loads

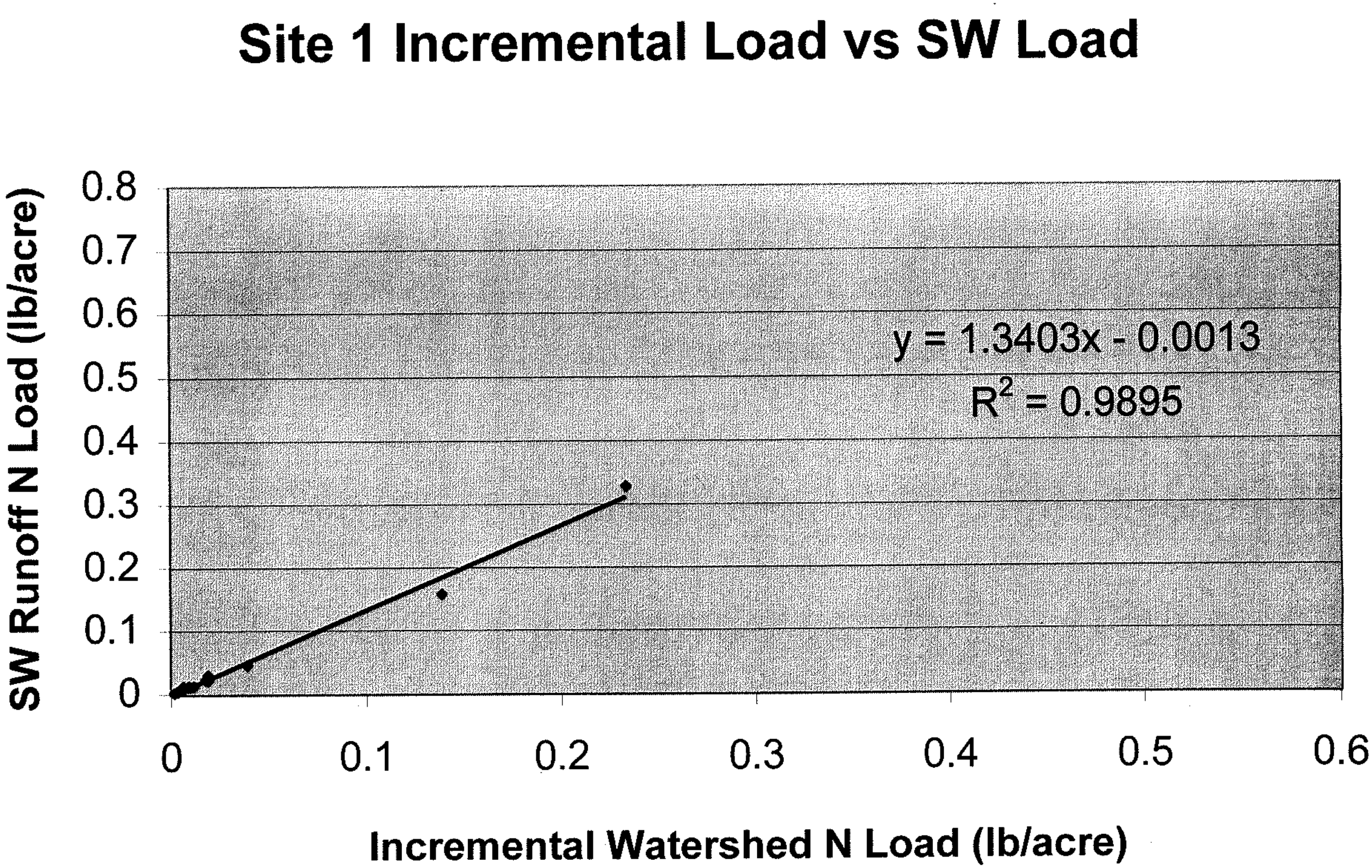

Figure 7-7A Site 1 Incremental Watershed vs Stormwater N Loads

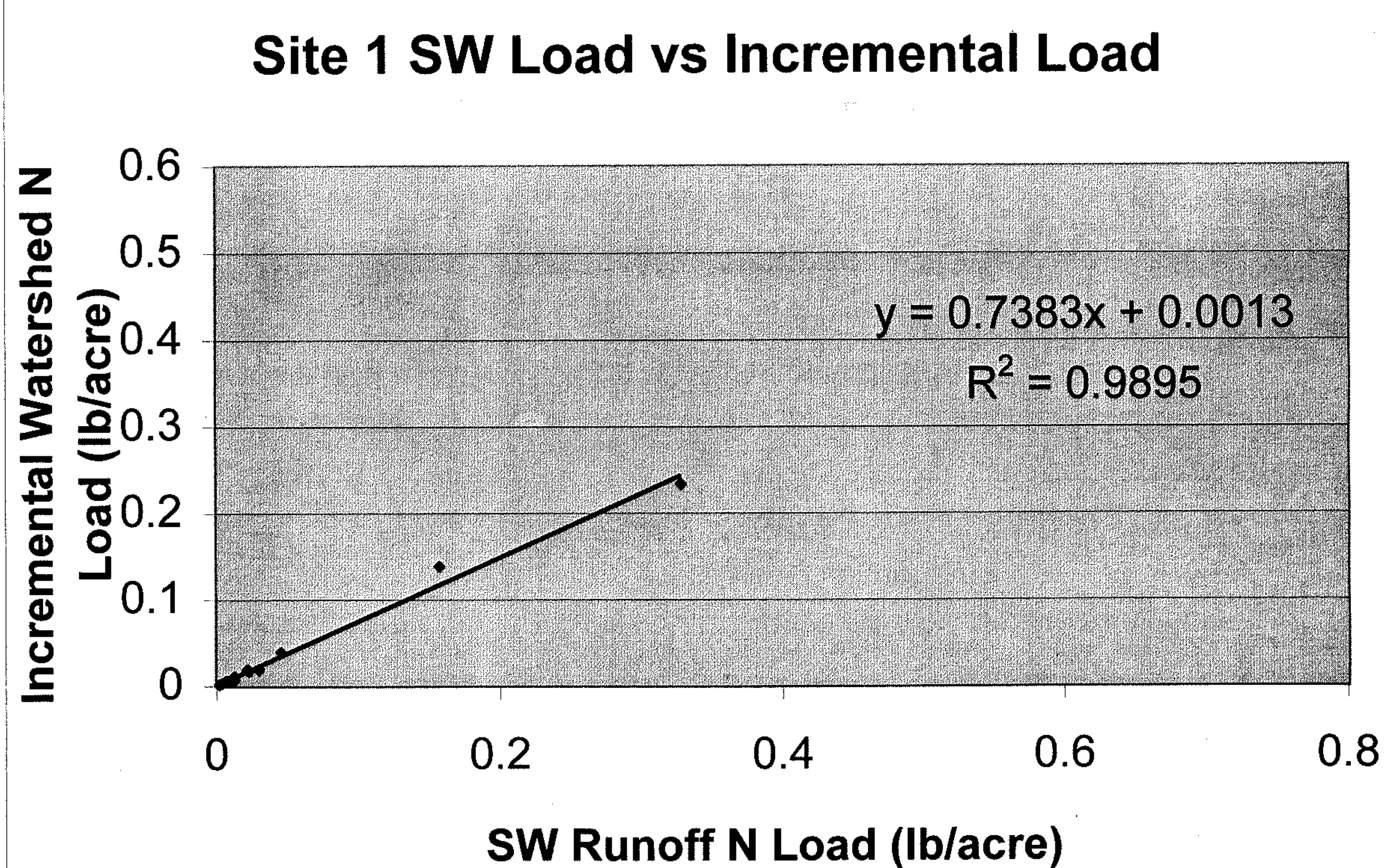

Figure 7-7B Site 1 Incremental Watershed vs Stormwater N Load

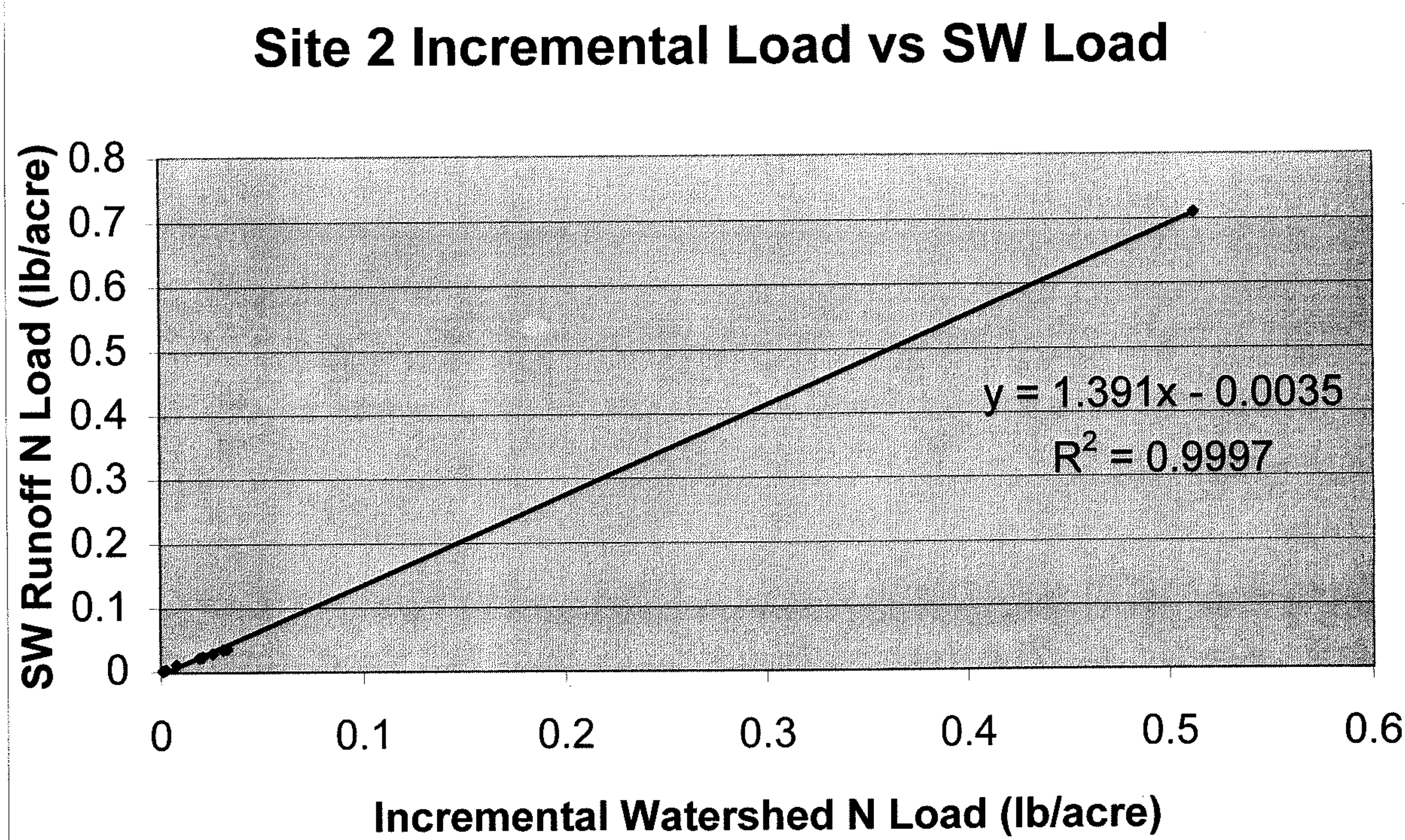

Figure 7-8A Site 2 Incremental Watershed vs Stormwater N Loads

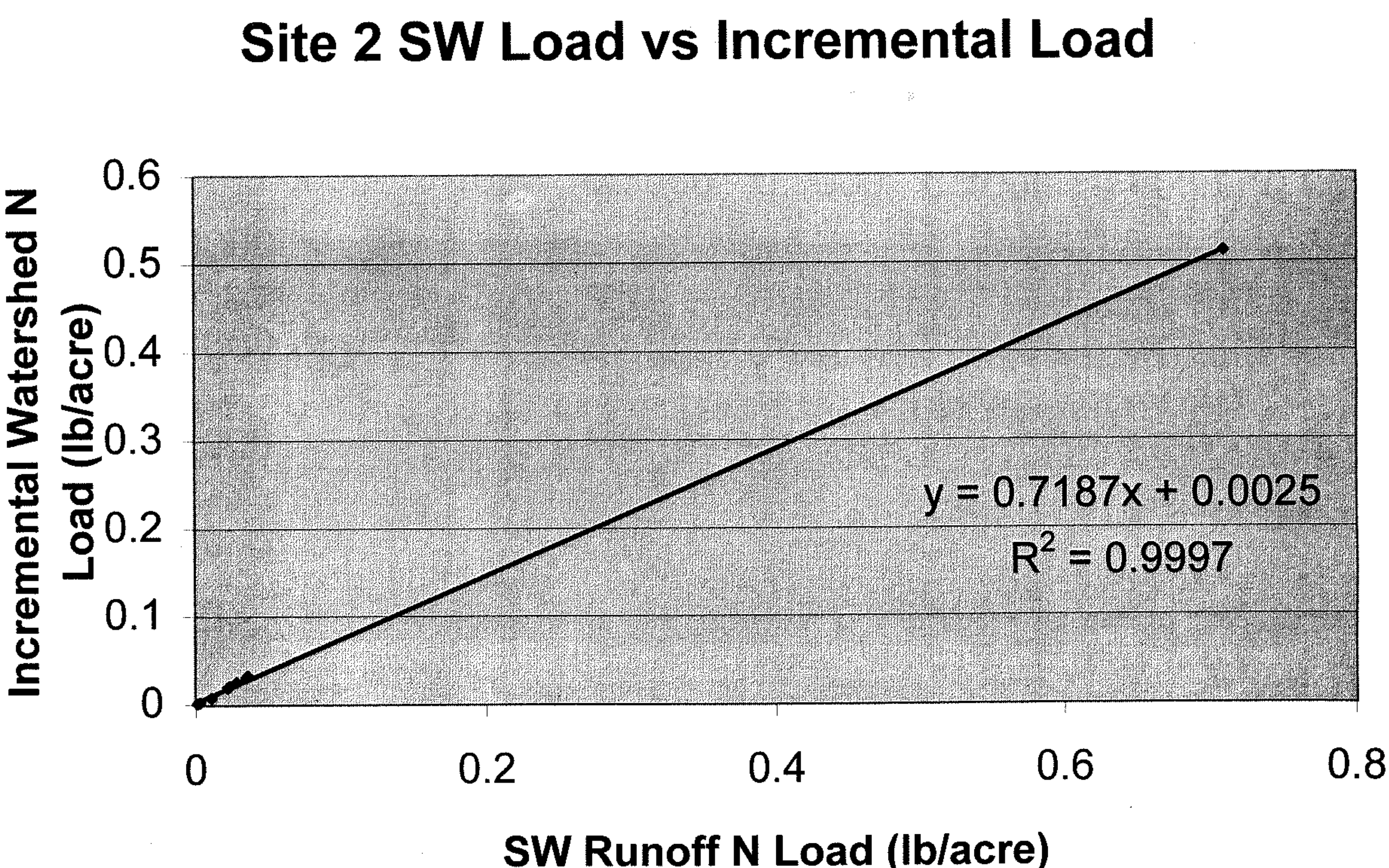

Figure 7-8B Site 2 Incremental Watershed vs Stormwater N Load

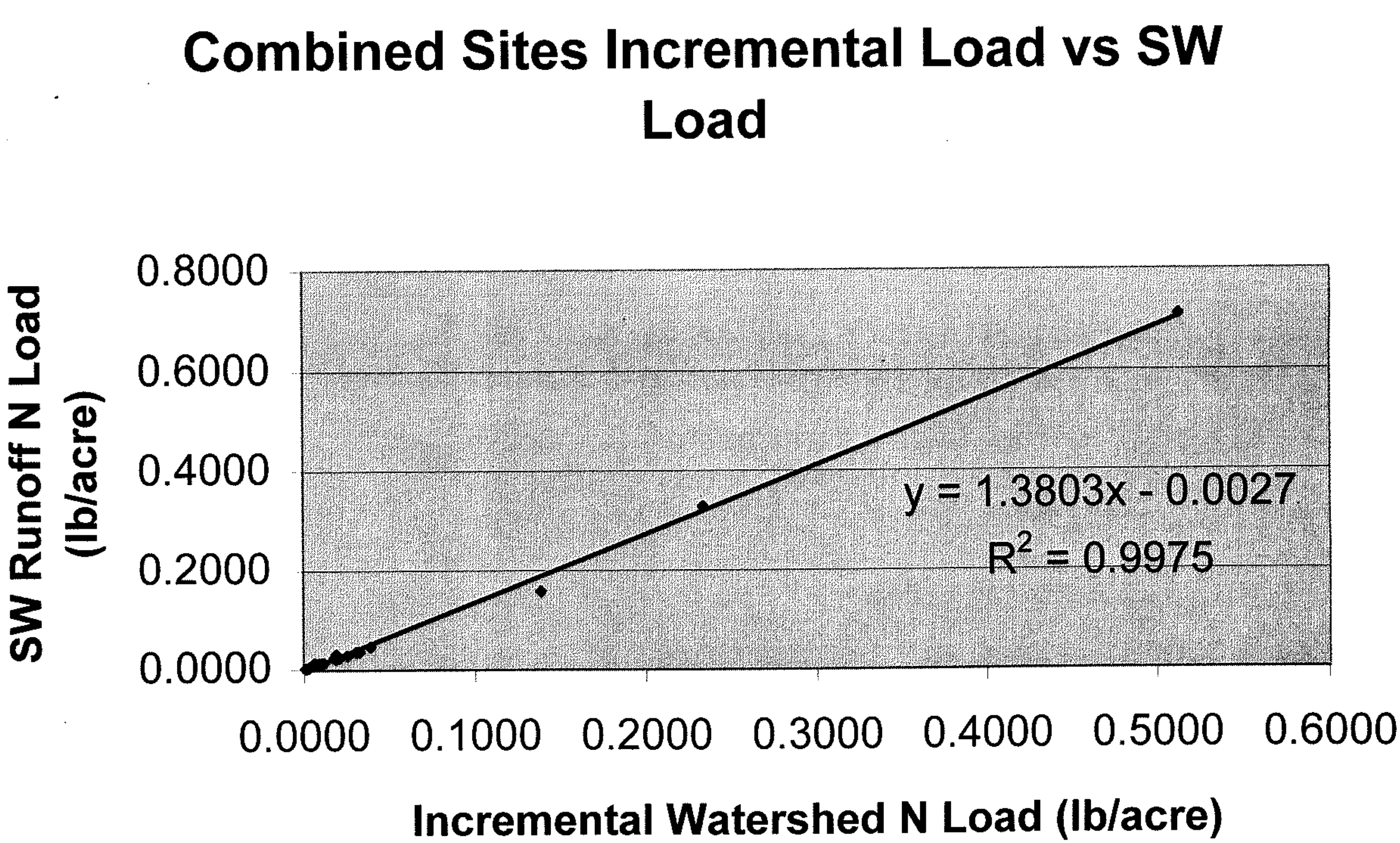

Figure 7-9A Comb. Sites Incr. Watershed vs Stormwater N Loads

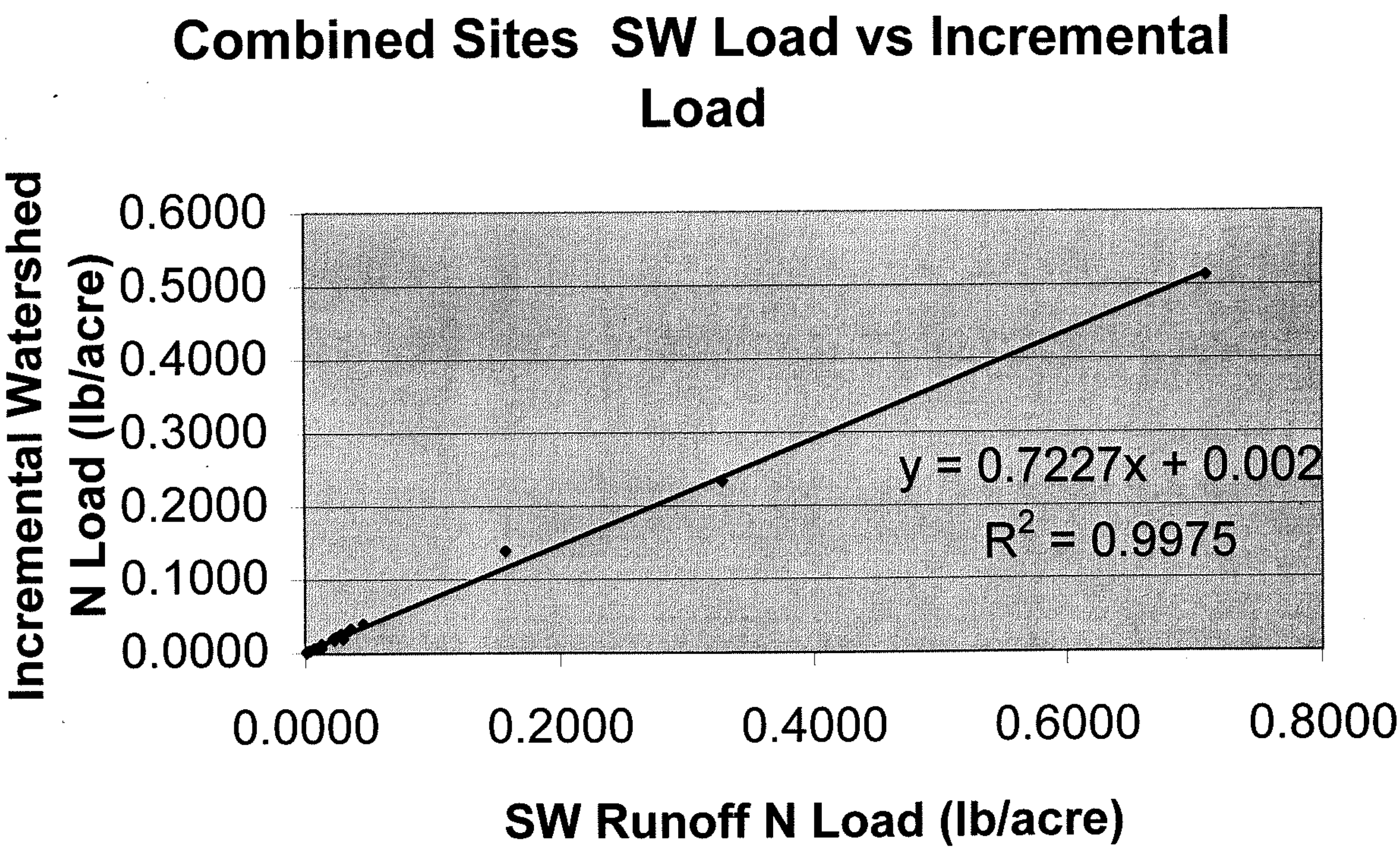

Figure 7-9B Comb. Sites Incr. Watershed vs Stormwater N Load

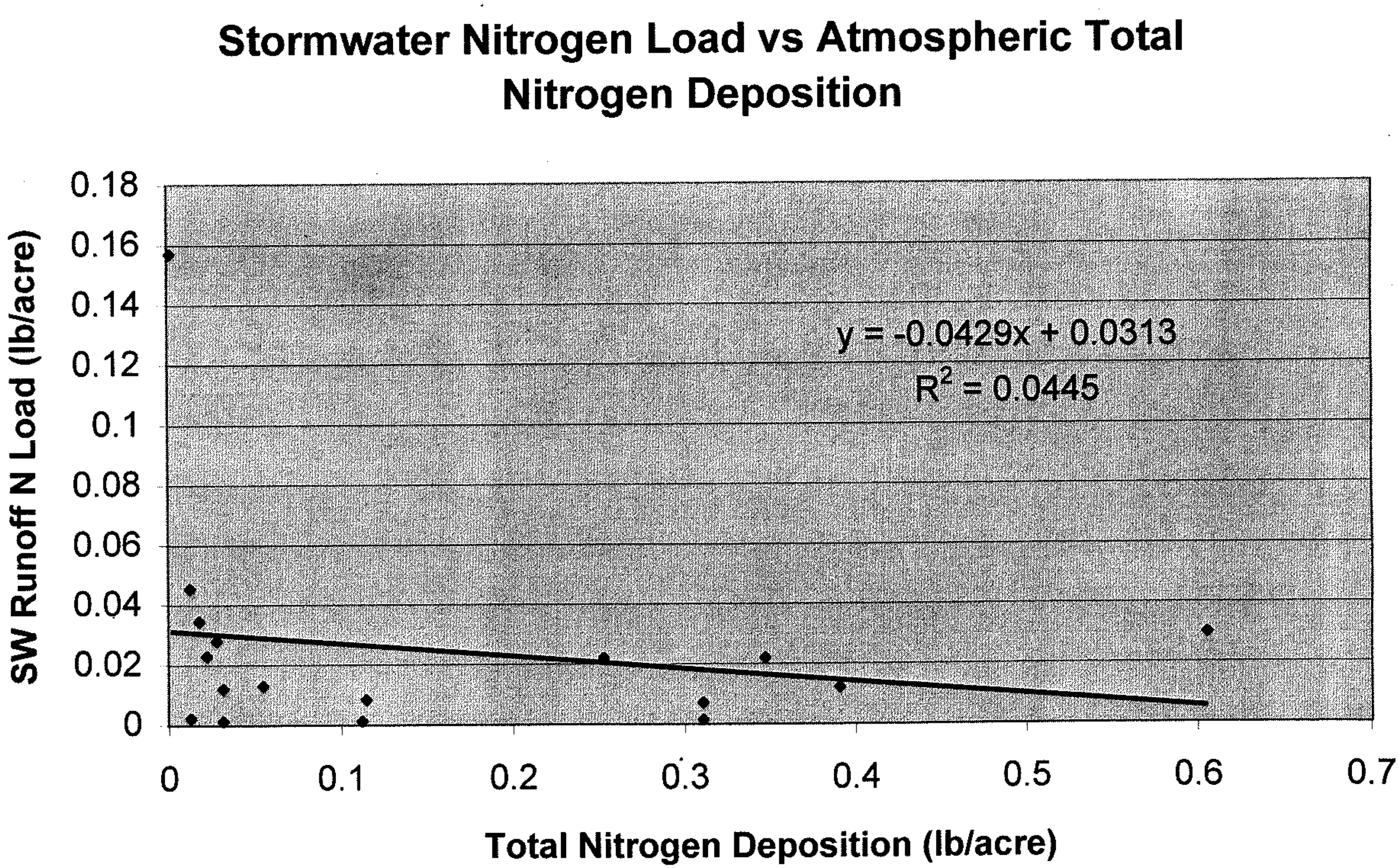

Figure 7-10 Stormwater Nitrogen Load vs Atmospheric Total (Wet + Dry) Nitrogen Load

REFERENCES

Pribble, J.R., and A.J. Janicki. 1998. Atmospheric deposition contributions to nitrogen and phosphorus loadings in Tampa Bay: Intensive wet and dry deposition data collection and analysis. (Draft). Prepared by: PBS&J, 1998. Prepared for: Tampa Bay National Estuary Program.

USEPA, 1981. Process Design Manual for Land Treatment of Municipal Wastewater. U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA 625/1-81-013

USEPA, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia. EPA/600/6-85/002

Valigura, R.A. 1995. Iterative bulk exchange model for estimating air-water transfer of HNO_3. Journal of Geophysical Research, Vol. 100, No. D12, pp. 26,045-26,050.

Zarbock, H., A. Janicki, D. Wade, D. Heimbuch, and H. Wilson. 1994. Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida. Tampa Bay National Estuary Program Technical Publication #04-94. Prepared by: Coastal Environmental, Inc. Prepared for: Tampa Bay National Estuary Program.

REFERENCES

Pribble, J.R., and A.J. Janicki. 1998. Atmospheric deposition contributions to nitrogen and phosphorus loadings in Tampa Bay: Intensive wet and dry deposition data collection and analysis. (Draft). Prepared by: PBS&J, 1998. Prepared for: Tampa Bay National Estuary Program.

USEPA, 1981. Process Design Manual for Land Treatment of Municipal Wastewater. U.S. Environmental Protection Agency, Cincinnati, Ohio. EPA 625/1-81-013

USEPA, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia. EPA/600/6-85/002

Valigura, R.A. 1995. Iterative bulk exchange model for estimating air-water transfer of HNO_3. Journal of Geophysical Research, Vol. 100, No. D12, pp. 26,045-26,050.

Zarbock, H., A. Janicki, D. Wade, D. Heimbuch, and H. Wilson. 1994. Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida. Tampa Bay National Estuary Program Technical Publication #04-94. Prepared by: Coastal Environmental, Inc. Prepared for: Tampa Bay National Estuary Program.

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Mike Timpe	**BCI Engineers & Scientists**
Paul Yosler	**Coastal/ PBSJ**
Hans Zarbock	**Coastal/ PBSJ**

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