# Sedimentology, Resource Conservation Methods and Environmental Policy of Irrigated Row Crop Agriculture in the Salinas Valley

A Capstone Project

Presented to the Faculty of Earth Systems Science and Policy

in the

Center for Science, Technology, and Information Resources

at

California State University, Monterey Bay

in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science

by

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**May, 2001**

Preface

This is an under-graduate student report. The opinions and conclusions presented do not necessarily reflect the final material to be presented as the outcome of the Salinas Sediment Study (2000-1 contract). Nor do they necessarily reflect the opinions or conclusions of the Central Coast Regional Water Quality Control Board, who funded the work, or any of its staff.

Having said that, I hope you enjoy the report. It is the product of an extra-ordinary level student dedication to the science of bettering the environment of the Central Coast while recognizing the social and economic importance of its agriculture and industry.

Dr. Fred Watson
Project leader.
Student Capstone Advisor

**Sedimentology, Resource Conservation Methods and Environmental Policy of Irrigated Row Crop Agriculture in the Salinas Valley, CA**

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**Abstract**

The primary goal of this study is to *determine typical sediment yields from irrigated agricultural fields in the Salinas Valley, California.* The study presented here quantified erosion amounts from vegetable row croplands by measuring water application, runoff and sediment loads coming from row crops in the Salinas Valley during irrigation and rainfall events. It estimated that for the period April 2000 through March 2001, 234 kilo-tonnes (2.9 tonnes/ha) of soil eroded from approximately 60% of agricultural row-croplands. These lands had slopes less than 2.3%. It was estimated that 70% of this eroded material was of silt & clay composition. Finally, it was determined that a properly functioning and maintained detention basin could remove over 99% of sediment from water leaving the basin. The ultimate goal is to use these data in the larger scope of the Salinas River sediment budget to help establish the total maximum daily load (TMDL) for sediment in the river. This is related to two larger issues. First, it is in partial compliance with the Clean Water Act to address non-point source pollution. Second, it addresses concerns over habitat degradation of the steelhead trout (*Onchorhynchus mykiss*), protected under the Endangered Species Act.

## 1. Background

The study presented is within the context of a broader project that seeks to evaluate sediment loads of the Salinas River on a watershed scale. The general background of this broader project is presented here. Details of the study of focus follow.

### 1.1. Sediment

Sediment transport in rivers is a natural process. In coastal streams and rivers, sediment is often necessary to replenish sands that are transported from beaches by wave action (MBNMS, 1997). However, when land uses such agriculture modify large tracts of land, and dams modify the hydrologic regime of rivers, severe changes can occur to sediment transport (Mount, 1995). When large rain events happen, large amounts of erosion occur and sediment can accumulate in stream channels. This can affect not only river, but wetland and ocean processes as well. Excess sediment in the form of sand in stream channels can amount to aggradation of the stream channel, broadening the floodplain and leaving land adjacent to the water body more vulnerable to flooding. Sediment in the form of silt and clay can carry nutrients and chemicals from agricultural land into the surface water systems, causing problems with biotic systems. Finally, the loss of the soil from agricultural land may reduce productivity, causing significant economic loss (MBNMS, 1999). The implications of sediment transport problems to economic, engineering, environmental and land management concerns makes it important to study.

### 1.2. The Salinas Sediment Study

The Watershed Institute at the California State University, Monterey Bay (CSUMB) in February 2000 received a grant from the State Water Resources Control Board (SWRCB) for the primary purpose of providing technical assistance toward the development of a total maximum daily load (TMDL) for sediment in the Salinas River. This project has been named the Salinas Sediment Study (SSS). The Salinas River flows through the heart of the Salinas Valley and is surrounded by agricultural land, especially in the northern section of the valley (see Fig. 1). In addition, this river is regulated by two large dams, which are located in the southern section of the valley. Data from the study will be used to help determine the TMDL of sediment that will be a benchmark to determine whether excessive amounts of sediment (considered a pollutant) are present. Part of the study is to determine if some correlation between particular land uses and associated sediment loads in rivers exist. Another is to develop a monitoring strategy to determine pollutant levels.

### 1.3. The SS Study Area

The Salinas Valley is located along the central coast region of the state of California in the United States (Fig. 2). Its watershed covers some 11,000 $km^2$ ranging from its southern extent near the city of Paso Robles to its northern extent at the mouth of the Salinas River near the city of Salinas. The valley has a mediterranean climate, which is influenced by coastal processes giving much of the northern section a partly maritime climate, also. At the city of Salinas, the temperature ranges from a maximum average of 19.9 C to a minimum average of 8.2 C. The average annual rainfall is 338.3 mm, with 95% falling from October to April (Western Regional Climate Center, 2001).

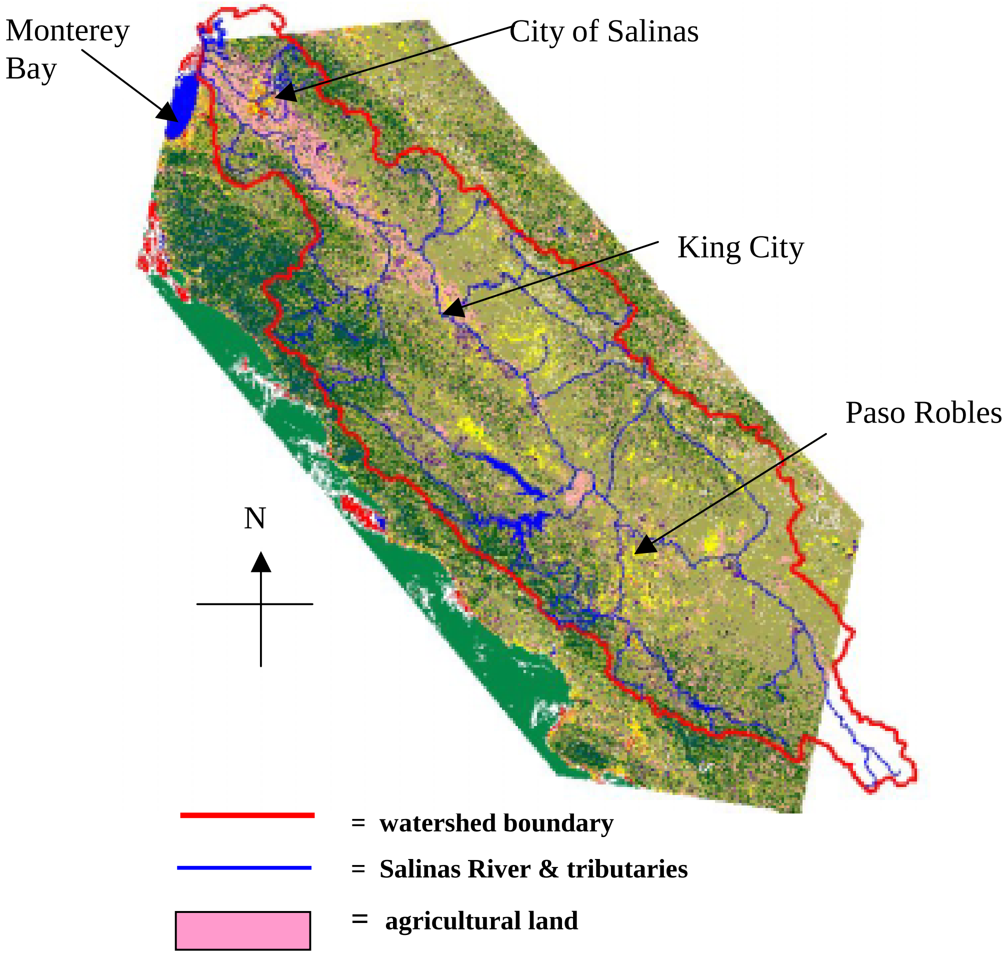



**Figure 1. Salinas Valley Watershed, 2000**

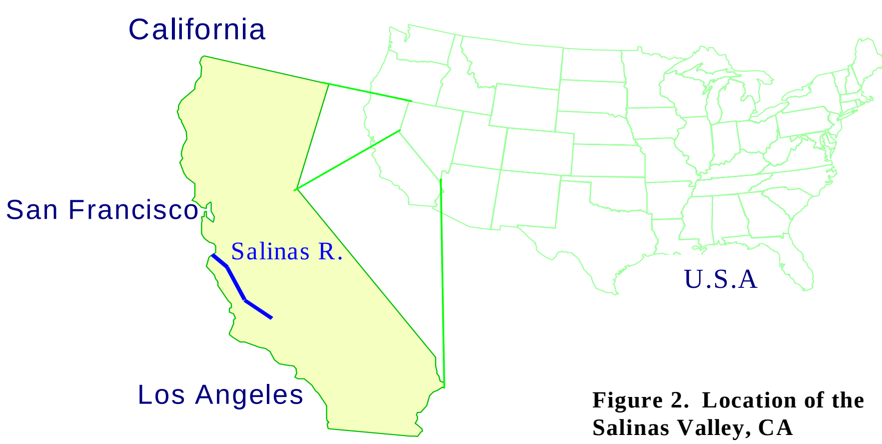



**Figure 2. Location of the Salinas Valley, CA**

## 1.4. Need for the Study

### 1.4.1. The Clean Water Act

The need for the present study of sediment in the Salinas River comes from a mandate by the federal government (Clean Water Act, 1972). The Clean Water Act (CWA) requires states to list water bodies that do not meet quality standards. The Salinas River has been listed for several different pollutants, one of them being sediment (MBNMS, 1999).

Sediment levels allowed by law are determined through a concept of total maximum daily load (TMDL). The definition of a "TMDL" varies from situation to situation. It has not been completely defined for the Salinas River. The federal government requires that the state reduce sediment levels via the TMDL "process". This process evaluates pollutant levels through monitoring, assessing whether those levels need to be modified, and then enacting appropriate management strategies to modify them, if necessary.

Although it has been nearly 30 years since the CWA was enacted, there currently is no established TMDL for sediment on the Salinas River. It is the responsibility of the Central Coast Regional Water Quality Control Board (CCRWQCB) to define and implement TMDLs of various pollutants within the Salinas River (MBNMS, 1999). Initial establishment of a sediment limit is scheduled to occur in May 2001.

### 1.4.2. The Endangered Species Act & Steelhead

Another need for the study concerns the steelhead trout (*Onchorhynchus mykiss)*. In most years, the Salinas River flows enough to breach through a small tidal sand barrier at its mouth. Just offshore, adult steelhead trout may linger for months to gain access to their upstream spawning grounds (Dettman and Kelley, 1986). When the Salinas does breach and connects with the ocean, the steelhead swim up to the river's tributaries to spawn. Use by the steelhead has been recognized as a beneficial use of the Salinas River (SWRCB, 1994).

In 1997, the steelhead was listed as a threatened species and placed under protection by the Endangered Species Act (ESA) (50 CFR Part 17). The ESA was established in 1973 with the intention to "provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species"(16 USCS § 1531). Of most recent development is the July 2000 final rule governing take (killing) of 14 threatened salmon and steelhead Evolutionarily Significant Units (species)(50 CFR Part 226). This outlines in general the need for control of erosion and sediment in rivers of known steelhead use (50 CFR Part 223, 65 FR 42422).

With the listing of the steelhead trout as threatened, there is more urgent need to evaluate and mitigate stream pollutant sources. One potential source of sediment is erosion due to agriculture. It has been estimated that 40% of the suspended sediment load of U.S. streams comes from the erosion of cultivated land (Woodward and Foster, 1997).

## 2. Presented Study

Agricultural land use in California has contributed to water pollution (Mount, 1995). This is an issue of particular relevance in the Salinas Valley, where the dominant industry is agriculture, a 3 billion-dollar per year business (MBNMS, 1999). Erosion coming from surrounding agricultural lands may be degrading water quality and threatening steelhead habitat.

Investigation into the quantity and nature of erosion due to agriculture is an important step toward understanding the sediment processes of the Salinas River and developing a TMDL based in part on them. This study investigates the quantity of erosion to agricultural land caused by irrigation and rainfall events. It then seeks to determine how much of that erosion is sand or silt and clay in composition. Finally, it investigates how effective a particular management practice, a detention basin, can be at mitigating this erosion.

### 2.1. Irrigation and Rainfall Erosion

There may be two ways that significant sediment can leave an agricultural field. The first is through irrigation of the crops. There are several ways in which crops are irrigated, and each has a different erosive effect. The second is through rainfall events. It is not known how much of each of these components could contribute to a sediment problem in the Salinas River. Therefore, it is necessary to examine these potential sources.

#### 2.1.1. Types of Irrigation

As stated before, there are two ways that significant sediment might leave an agricultural field. One may be through irrigation of the crops during the summer months. There are three major classes of irrigation: furrow, sprinkler, and drip. Furrow irrigation is not common in the Salinas Valley, and in fact has become less common in California in general (Snyder, 1996). Most common is sprinkler irrigation, where water is delivered under pressure through pipes to be sprayed upward via sprinklers along a lateral arm that lies on the ground. Typically, a system will have several lateral arms attached to a main line. Other systems are "linear" types that deliver water sprayed downward from an overhead lateral on wheels that move along the field.

Drip irrigation on vegetable crops is not yet widely used, but is used on certain fruits, particularly strawberries. In a study of Koluvek, et al. (1993), it was observed that the only study to date to measure erosion under sprinkler irrigation was carried out under center-pivot systems. These data were not published, and are of little relevance since the Salinas Valley has no known systems of this type currently in use.

### 2.1.2. Irrigation Erosion

Although few if any published studies have addressed sprinkler irrigation erosion and sediment transport in the Salinas Valley specifically, there is some information that gives an idea of what the relative amount might be.

First, most irrigated areas in California have small slopes and contain fairly stable soils, resulting in low erosion rates. Slopes above 2% often exhibit excessive erosion rates (Koluvek, et al. 1993). Agricultural land is defined here as land used in the cultivation of crops (i.e. vegetables, grains), but not for pastoral or viticulture use. The SSS has determined through GIS analysis that approximately 60% of tilled agricultural land south of the city of Salinas is at 2% slope or less. Second, a 1985/86 survey by the USDA Soil Conservation Service concluded that no agricultural land was affected by irrigation-induced erosion in the Salinas Valley (Koluvek, et al. 1993). Finally, erosion of land using the sprinkler system is dependent upon water application in excess of the soil infiltration rate (Trout and Neibling, 1993). With the use of best management practices and careful application of water, excess flow can be reduced.

It is likely that an erosion problem due to irrigation is low. In any case, there is not likely to be water applications large enough to move this eroded soil to the Salinas River. However, what usually happens is that eroded soil is stored nearby in ditches or basins. If this eroded soil is not managed in some way, it is likely that it will be mobilized toward the river during winter storm events.

### 2.1.3. Rainfall Erosion

During the winter, anywhere from October through March, the Salinas Valley is subject to winter storms. These storms can produce large amounts of rain, sometimes intensely, and can last for long periods of time. It is during these storms that erosion is likely to be great, especially on fallow fields. Just how much erosion occurs due to a storm event is difficult to ascertain, especially over large areas. The process of erosion is complex enough given the consistent water application of irrigation. It is all the more so with the additional complexity of rainfall dynamics.

The prediction of erosion due to rainfall is of great interest, especially for this study. Many inferences about erosion in general are drawn from the studies of rainfall erosion on agricultural land (Trout and Neibling, 1993). Wischmeier and Smith (1978) developed the Universal Soil Loss Equation (USLE) for predicting rainfall erosion. Their study pertains to the erosivity factors of the rainfall and runoff combined with the erodibility factors relating to soil properties, vegetation, topography and particular land use practices.

Although the USLE is useful for determining erosion on agricultural fields, it was designed for the management of erosion of individual land parcels in the eastern United States, and not on watershed-scale applications. It involves determining parameters that would not be practical to measure on such large scales. Furthermore, a regional specific analysis of agricultural erosion must be applied here. Therefore, the USLE is of little use to this study.

## 2.2. Agriculture and Best Management Practices

Farmers understand the value of the soil and the merit in keeping it where it belongs, on the land. Doing so can be difficult during times of severe weather, especially on fallow ground. Management techniques that help minimize or mitigate erosion have been developed. These strategies have been called best management practices (BMPs). A few examples are:

- vegetated buffer strips
- contour plowing
- cover cropping
- sediment recovery from ditches
- detention basins

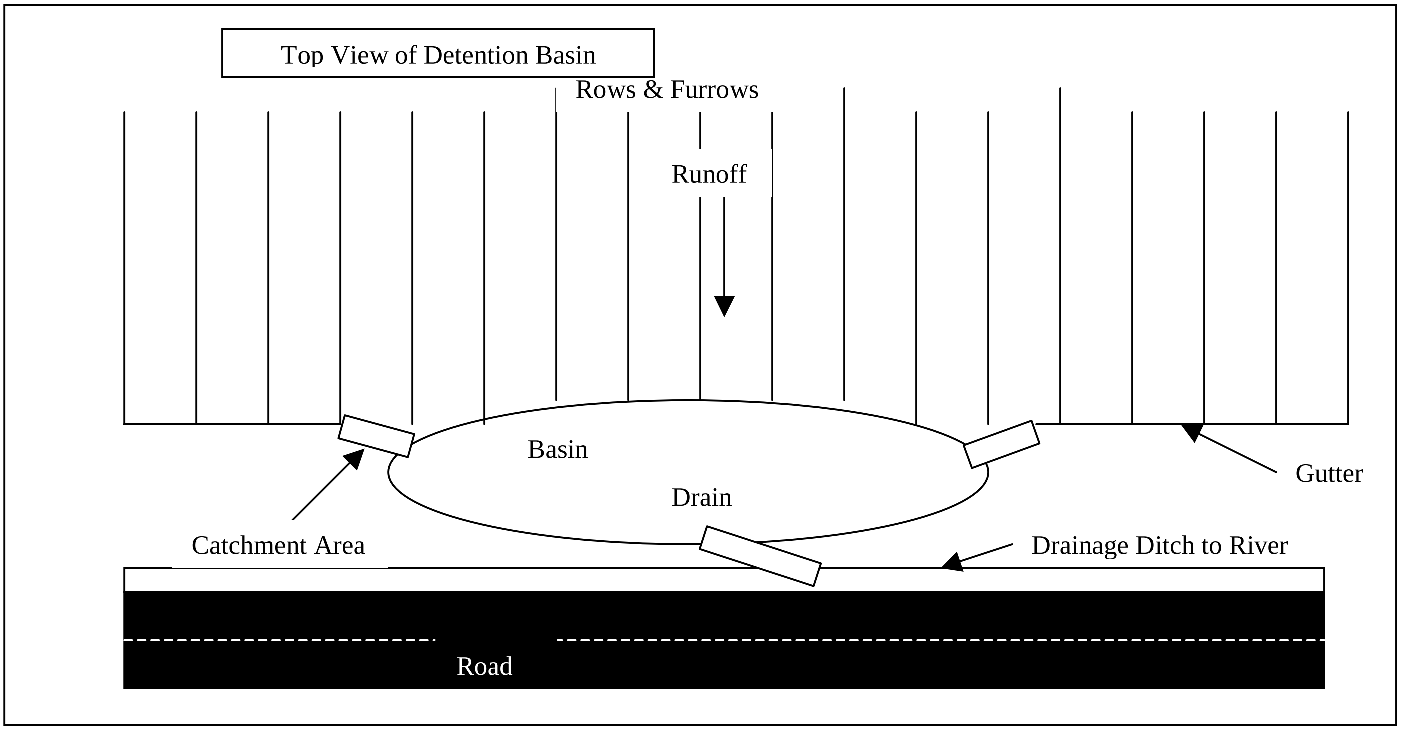
A certain amount of erosion might be considered acceptable to farmers under sustainable conditions. Erosion that is considered acceptable for sustainable farming may not be acceptable as sediment loads in rivers. Where a farmer may not have had a need to establish a BMP from the point of view of productive soil loss, there may be a need to establish one from a water quality point of view. This viewpoint may not be immediately obvious to farmers or the general public. The Monterey Bay National Marine Sanctuary is currently working with area Farm Bureaus in an effort to communicate this viewpoint (MBNMS, 1999). Farmers have responded positively (personal communication, Farm Bureau).

### 2.2.1. Current BMP Policy of the Salinas Valley

Although there are BMPs that help to mitigate sediment travel from a farmer's land, these practices are not required by regulatory agencies in most areas of Monterey County where the majority of the Salinas Valley lies. Use of BMPS has been a voluntary action initiated by landowners. A farmer may have concerns about the amount of sediment leaving his/her property for one reason or another. They may then seek the advice of the local Farm Bureau or Resource Conservation District, which will supply assistance in selecting the BMP that best suits the needs of the farmer. When this occurs, the farmer gains knowledge of water quality issues and can incorporate this knowledge into his/her BMP decisions. Every indication from the various agencies involved in regulating resources suggests a strong support of educational efforts to assist those in a voluntary position to help solve environmental problems (MBNMS, 1999).

### 2.2.2. Detention Basins as a BMP

One management practice that may be particularly useful for mitigating sediment-laden runoff is the detention basin (Fig. 3). The basin works by capturing runoff into a holding pond, slowing its velocity. This basin is typically located close (or even within) the field. The reduced velocity allows the sediment to settle out of the water. As the basin fills with runoff, the “cleaner” water near the top is slowly released out of the basin, usually by raised drains. If runoff amounts are small, such as with irrigation or light rains, water does not reach a level high enough to leave the basin. In these cases, all eroded soil that left the field can be trapped in the basin.



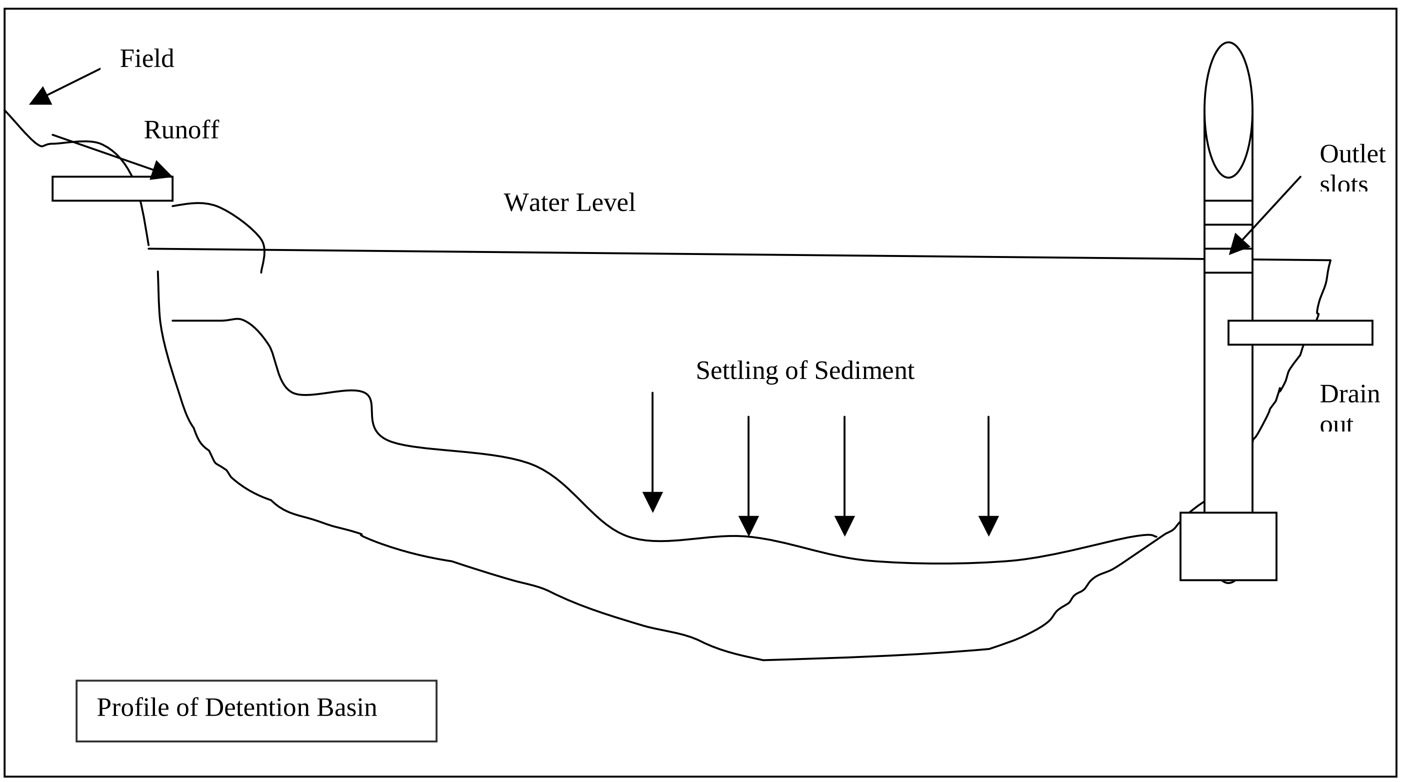




**Figure 3. Sketches of Detention Basin**

Sediment basins are not maintenance-free. The sediment that accumulates at the bottom of the basin must be removed. Otherwise, the sediment would simply fill the basin, leaving it ineffective. This sediment can be removed from the basin using earthmoving equipment and returned to the field.

How often a retention basin needs to be maintained is a matter of:

- basin size compared to the field
- erosion characteristics of the field
- size of the storm/irrigation events
- time and equipment availability to the farmer

In general, a larger basin would need maintenance less often, but might take valuable land out of production. If the field is on steeper slopes and/or has easily eroded soil, a larger basin might be needed. A basin designed to accommodate irrigation events will not be as effective (if effective at all) during heavy storm years. Resource Conservation Districts usually employ engineers that can assist farmers with determining the correct size basin for their needs.

### 2.3. Project Goals and Approach

The primary goal of this study is to *determine typical sediment yields from irrigated agricultural fields in the Salinas Valley during irrigation and rainfall events.*

The project has the following sub goals:

- Measure erosion from a number of irrigated fields under differing irrigation and rainfall regimes
- Use this information to establish a relationship/model that can be used to predict erosion given simple water application and landscape parameters
- Use this model to upscale erosion data to the entire Salinas Valley
- Determine what percentage of erosion is sand vs. silt and clay
- Determine the effectiveness of detention basins in trapping eroded soil

Erosion from irrigation is expected to be relatively small compared to that resulting from winter storms if those storms are sufficiently intense and/or long. However, it is likely that there are strong relationships between the causal processes in each case. Thus, by measuring summer erosion due to irrigation (which is in many ways easier than rainfall erosion) insight is gained that may apply to all erosion. Since the sand and silt/clay components produce different problems environmentally and may be mitigated in different ways, it would be useful to understand how much of each component is leaving the field. Finally, knowledge of the efficiency of best management practices currently employed (detention basins) is important for managerial/policy purposes.

## 3. Agricultural Study Area

Because of the climate, the northern section of the Salinas Valley is an area of intense agriculture, especially along the flat alluvial deposits bordering the Salinas River (Fig. 1). The SSS has estimated that approximately 15% of the Salinas Valley watershed is row crop agriculture (165,000 ha). The study area for the presented project is agricultural land south of the town of Spreckels, very near the city of Salinas. Agricultural area of this region is estimated to be 135,280 ha. This area (a little smaller than the agricultural area of the total watershed) was chosen for two reasons. First, data was readily available for GIS analysis. Second, the remaining drainage of the northern section of the watershed (surrounding the area of the city of Salinas) has been so channeled that little runoff makes it to the Salinas River.

Although this region is fertile, it is dry. Tilled agriculture relies almost entirely on irrigation during the summer growing season. In the winter, storms are often frequent or intense enough to make it impossible to work the land, and temperatures can cool to less than optimum for the vegetable crops. Therefore, much of the agricultural lands stay fallow during the winter (November thru February).

This study examines erosion on these agricultural fields on four farms distributed over the length of greatest agricultural activity from Greenfield north to the city of Salinas. The farmland studied during the winter storm period was a fallow field. Specific locations and farmer's names are held confidential as per agreement with the SSS.

# 4. Methods

## 4.1. Site Selection and Overview

Fields in the valley were selected such that field size and boundaries were unambiguous and application and runoff rates of water were easy to measure. Measurements were made of the sediment carried by the water past some point, usually the tail end of a furrow, field, or the drain from an irrigation system. Monitoring started at the beginning of water application (either irrigation or rainfall) to the field and proceeded until all runoff had ceased. Measurements and samples included:

- Water applied or that fell as rainfall
- Runoff water from the field
- Runoff water samples.
- Field size
- Field slope

This study covered the period from April 2000 through March 2001. A total of nine irrigation events from three different farms and six rain events from one other farm were monitored. These sites ranged the span of the Salinas Valley from the town of Greenfield (southern extent) to the city of Salinas (northern extent).

An event is classified as a single watering occurrence either by irrigation (usually a few hours in length) or rainfall (of approximately the same duration). One field measured at two distinct and separate locations during one rain or irrigation occurrence is considered two “events”. These farms ranged in slope from 0.15% to 2.1%. GIS analysis by the SSS has determined that this slope gradient represents approximately 60% of agricultural land south of the town of Spreckels (very near the city of Salinas). This land predominantly borders the Salinas River and would likely have the most immediate impact on sediment levels during storm events. However, there is land about tributaries of the Salinas that have slopes above this level. These could be significant contributors to sediment levels during rainfall events.

There are three distinct types of water applications that were observed: two types of irrigation (sprinkler and linear) and rainfall.

Samples were taken back to the SSS lab at the Watershed Institute and analyzed for sediment concentration. Total loads were calculated as the product of discharge and sediment concentration (see details below). Various sized filters enabled the analysis of sand vs. silt/clay percentage of sediment composition. Finally, data analysis allowed for the development of the model used to predict valley-wide erosion on agricultural land. The following are general procedures. Detailed instructions are provided in Appendix 1.

## 4.2. Measurement of On-Field Erosion

Data were collected in the field and samples taken back to the lab for processing in all cases. Analyses utilized rainfall/application rates (mm/hr) and runoff rates (L/sec) combined with total sediment (TS) concentrations (g/L) to obtain erosion (tonnes). Runoff rates multiplied by TS concentrations gave the load (g/sec) of sediment coming off the field. At times during sampling the runoff and TS samples were not taken simultaneously, and/or a TS sample may have been taken every other runoff measurement during consistent flows. In these cases, the average TS value for the representative time period was used in calculations. The summation of these calculated load values over the representative time periods gives the total amount of soil (tonnes) off the field. This divided by the area of the field (ha) gives the erosion value.

### 4.2.1. Field Data Collection

1) The selected fields were measured before the events to ascertain the size of the area irrigated ($m^2$), its drainage points, slope, stage of crop, type and condition (last tillage) of the soil. Slope was determined either through direct measurement (survey with digital theodolite and laser distance meter) or was supplied by the farm manager.
2) At the drainage point, a capture system was constructed in such a way as to allow for the normal flow of water to exit the field in one continuous flow from which samples can be taken. Typically, a detention basin or runoff ditch that drains the field served well as a site for the construction of the catchment system. In some cases the field had a pre-existing drainpipe, so construction was unnecessary.
3) Once the sprinkler system was in operation (or rain started), starting time was recorded. Application rates were determined by one of the following methods:
    - measuring the flow at the irrigation nozzles with buckets & stopwatches

- placing buckets in the field and measuring depth of water over time
- pump flow meters
- rain gauges combined with the time the gauge was observed.

If the irrigation system was a linear one, the rate of travel of the system and the width of instantaneous irrigation (that part of the field being watered at any particular moment) was also recorded.

4) Once runoff reached the catchment system, the time of initiation was recorded
5) At regular intervals a bucket was placed under the drainage flow and filled. The time to fill the bucket and the exact volume collected was recorded. This was done throughout the runoff duration at approximately 5 – 20 minute intervals, depending upon how quickly runoff rates were changing.
6) A sample of the runoff water was taken from the runoff flow at the same time that discharge was measured. This sample was analyzed for total sediment (TS, procedures to follow). During times of consistent flow, a TS sample was sometimes only taken every other discharge measurement.
7) The time that the sprinklers shut off or rain stopped was recorded, as well as the ending time of the runoff.

#### 4.2.2. Total Solids (TS) Laboratory Procedure

The TS procedure was employed to determine the concentration of sediment in a water sample. A filtration process was employed, based on Woodward and Foster (1997). The procedure is summarized here and reproduced in detail in the Appendix.

1) Sample bottles were pre-weighed (to the nearest 0.01g) and numbered.
2) After the sample was obtained, the outside of the sample bottle was rinsed and dried, then weighed to the to the nearest 0.01g.
3) A small amount (literally a pinch) of sodium hexametaphosphate was added to the sample and shaken thoroughly. This helped suspend particles and keep them from flocculating.
4) Pre-dried and pre-weighed (to the nearest .001g) disposable glass filters (filter size, 1.5 micron) were used to vacuum filter the water sample.
5) The filters containing the sediment portion of the water sample were then dried for 2 hours at 100°C to evaporate any remaining water.

6) The filters were reweighed to determine the amount of soil in the sample (to the mg).
7) The volume of the sample was determined from its weight and the density of water.
8) Concentrations of samples were recorded in mg/L.

Estimated error of the results is dependent upon mass and volume of the sample. The error associated with a large sample (approximately one liter) with highly concentrated sediment will be approximately 2%. Small samples (approximately 1/4 liter) with small sediment concentrations can have errors near 100%. This large error in “clean” samples is not viewed as a problem, because a 100% error in small sediment concentrations has little affect on estimated loads. Furthermore, most samples taken are large enough and “dirty” enough to keep errors low.

#### 4.2.3. Data Analysis

Sediment concentration data along with water application and discharge rates can be combined to give the following information:

- Irrigation water (or rainfall) application rate over time, giving the amount of water applied
- Runoff rate over time, giving the total amount of water discharged
- The load, or amount of sediment movement per time (mass/unit time)
- Total load, or load over time (mass)

### 4.3. Modeling

Models were developed to predict or describe:

- Erosion from a field
- Delivery off the field
- Upscaling from field to watershed scale, modeling:
    - area and slope of agricultural land
    - rainfall/irrigation amounts and intensities
        - erosion due to irrigation
        - erosion due to rainfall
        - total erosion

### 4.3.1. Erosion Model

Development of the erosion model was done by multiple regression analysis using SPSS statistical analysis software. By looking at the various parameters measured about the event and finding the strongest correlating relationships between them and the erosion amounts, a model was constructed that used easily measured parameters to estimate erosion. That is:

E = f (V1, V2, V3…) where,

E = Erosion, and

V1, V2, V3, are possible controlling variables.

These controlling variables were determined to be:

- Maximum intensity of water application
- Total amount of water applied
- Slope of the field

These results are addressed again later, but it is important to mention them here. The development of methods for the upscaling model relies upon the results of erosion analysis and parameter correlations.

Knowing that many factors would contribute to variation of the data from the model, it was expected that variance would be large. However, it was felt that this estimate was more than adequate and the range of error acceptable for the purposes of the project. It is expected that as future data is collected, the model will become more robust.

### 4.3.2. Delivery Model

The delivery model predicts how much of the eroded material could make it to the Salinas River to become sediment. A simplistic view of the erosion transport process is taken. This view assumes that all eroded soil will be "flushed" to the river if not somehow managed. This relationship is expressed as:

$D = SDR \times E$, where

D is sediment (tonnes) delivered to the river (sediment not managed in some way) and

SDR is the sediment delivery ratio, somewhere between 0 – 100%, and

E is the amount of erosion from the fields (tonnes).

### 4.3.3. Upscaling

Upscaling is the process of taking information from field scale erosion and delivery models and applying it to give an estimate of erosion for the entire Salinas Valley. An important part of this process is to determine how much area has a given slope. With this information and rainfall/irrigation application, erosion due to irrigation and erosion due to storm events can be predicted. The two are added to give total erosion.

#### 4.3.3.1. Finding Area and Slope

Upscaling was performed by first determining the amount of agricultural area within the Salinas Valley that would have to potential to contribute to the Salinas River sediment budget. This was done through GIS analysis using the Tarsier modeling framework (Watson et al., 2000) based on information from the Association of Monterey Bay Area Governments (AMBAG). Since erosion-modeling results demonstrated a good relationship between slope of the field and erosion, it had to be determined what portion of that area had what slope. This was also done using Tarsier. Slope categorization started at 0.0 degrees and increased by increments of 0.1 degrees. These categories were developed throughout all agricultural fields. Tarsier was used to determine how much acreage fell into each of the slope categories and to calculate the average slope of the area. This average was used in calculations after conversion from degrees to percent slope.

#### 4.3.3.2. Rainfall/Irrigation Model

The rainfall model is used to determine the amount of rain and the maximum ten-minute intensity of winter storm events within the Salinas Valley. The maximum ten-minute application rate of a storm event is based upon the one-hour maximum rate reported by the California Irrigation Management Information System (CIMIS, 2001). There are four CIMIS stations recording precipitation along the Salinas Valley within the agricultural study area. Their data are available from the web, but only as intensities based on one-hour averages. It is felt that there are intensity averaging periods that play a more significant role in erosion that must be determined from shorter timescales. A timescale based on a ten-minute recording interval is felt to represent appropriate intensities and is approximately the same as the recording intervals established in the field during storm event monitoring.

It was necessary to determine the relationship between 10-min. intensities and 1-hour intensities. A tipping-bucket rain gage that records each 0.025 mm of rain received is located on the roof of the Watershed Institute. This data was recorded throughout the winter season. Near instantaneous rainfall intensities can be derived from these data. Through data regression analysis based on the winter's rain record, a relationship was established between ten-minute intensity and hourly intensity. This relationship is strongest for high intensities because the gauge records more bucket-tips in a ten-minute period. Maximum hourly intensities for winter storm events reported by CIMIS were converted to estimated ten-minute intensities and used for the model.

Total rain amounts (as opposed to intensities) were determined directly from the reported CIMIS amounts. Both rain amounts and maximum intensities were determined for each rainfall event. A rainfall event was characterized as a period of precipitation activity on the order of several hours to a couple of days, with intensities greater than 0.2mm/hr (based upon hourly averaging). Within these events there occur smaller time frames, perhaps a few hours, of greater precipitation activity separated by lesser activity. It might also be appropriate to separate out these storm "cells" and treat them as separate storm events. However, it is felt that these cells occurred close enough in time to each other that treating them individually would probably not make much difference on the scale examined.

Finally, data from the four CIMIS stations were averaged arithmetically per rain event and used in the upscaling calculations.

Irrigation intensities remain constant, so there is no need to scale them. Irrigation intensity and amount were determined from data collected during the monitoring of irrigation events.

Given acreage, slope and rainfall/irrigation information, upscaling is broken into 2 parts: 1) determining erosion due to irrigation, and 2) erosion due to rainfall events.

#### 4.3.3.3. Erosion Due to Irrigation

The results of erosion, rainfall and upscale modeling are brought together to create a valley-wide estimate of erosion due to irrigation. Since irrigation water application intensity is consistent throughout the irrigation event, the maximum intensity is the application intensity. For scaling purposes, the average irrigation intensity for sprinkler irrigation events was used as the maximum intensity for the model. The total amount of water applied was the average amount applied per irrigation. With slope class average, maximum intensity and total amount of water applied input to the erosion model, an erosion estimate (tonnes/ha) is given for each event (irrigation) and slope class. Total erosion (tonnes) due to irrigation is then determined by:

$$\mathrm{E}_a = (N \times C)\sum_{i=1}^{n}(E_i \times A_i) \quad \text{where,}$$

$\mathrm{E}_a$ = Erosion due to *a*pplied irrigation water,

$N$ = *N*umber of irrigations per crop,

$C$ = *C*rops per growing season,

$E_i$ = Modeled erosion of the i$^{th}$ slope class,

$A_i$ = Modeled area of the i$^{th}$ slope class, and

$n$ = *n*umber of slope classes.

#### 4.3.3.4. Erosion Due to Rainfall Events

The results of erosion, rainfall, and upscale modeling are brought together to create a valley-wide estimate of erosion due to rainfall events. Maximum rain intensity, total amount of rain and each of the slope class averages are input to the erosion model giving erosion (tonnes/ha) for each rain event and slope class. Total erosion (tonnes) due to rainfall events is then determined by:

$$\mathrm{E}_r = \sum_{j=1}^{J}\left(\sum_{i=1}^{I}(\mathrm{E}_i \times \mathrm{A}_i)\right)_j \quad \text{where,}$$

$\mathrm{E}_r$ = Erosion (tonnes) due to *r*ainfall,

$\mathrm{E}_i$ =Modeled erosion of the i$^{th}$ slope class,

$\mathrm{A}_i$ =Modeled area of the i$^{th}$ slope class,

I = the number of slope classes, and

J = the number of rain events.

#### 4.3.3.5. Total Erosion

Finally, total erosion is found by:

$$E_t = E_a + E_r$$

### 4.4. Sand vs. Silt/Clay Components of Erosion.

Sediment samples measured from the rain events were filtered specially to determine the percentage composition of sand and silt/clay. Before the samples were filtered using the 1.5-micron filters, the samples were vacuum filtered through a 63-micron sieve. This is the accepted size delineation that defines sand from smaller sediment components (Dunne and Leopold, 1978). The fraction coarser than 63 microns was then transferred onto a 2.4 – 6 micron glass filter and dried. The total sediment concentration was thus derived as the sum of the concentration for fractions coarser and finer than 63 microns.

### 4.5. Detention Basin Efficiency

A pre-existing detention basin measuring 184 m by 13 m was selected for the study (Fig. 2). It was integrated into the field that was measured during a rainfall event analysis (2/19/01 event). Due to how the basin is designed, it was impossible to determine runoff or sediment contribution to the basin from the field's middle section. To determine how well the detention basin worked, first an estimate was made of the total amount of runoff and erosion entering the basin. Estimates were made of the middle section's contribution using erosion data from the lesser-contributing adjacent section. This estimated contribution was combined with the measured contribution of the two adjacent sides to give total runoff and sediment to the basin. Using the lesser contributing data will decrease the calculated efficiency.

Sediment samples were taken of the water leaving the basin; however, runoff measurements were not. There is a dampening of variation in sediment concentrations leaving the basin due to the nature of its design. Therefore, fewer samples need be taken. The greatest concentration of sediment flowing out of the basin is expected to be from the beginning of outflow to peak discharge. Total discharge of water out of the basin can take a considerable amount of time. Since the interest in basin efficiency is one of a worst-case scenario (or how much sediment could escape), samples were taken during the time of greatest sediment concentration only.

In order to determine basin efficiency two assumptions had to be made. First, all the runoff volume that enters the basin will leave the basin. Second, the total volume of water leaving the basin will have a sediment concentration equal to the greatest concentration sampled leaving. The results of these assumptions will bias the calculated efficiency toward lower levels.

# 5. Results

## 5.1. Measurement of On-Field Erosion

Approximately 310 sediment samples and 410 runoff measurements were taken and analyzed during the course of this study. This information for all events was graphically analyzed and is presented in Appendix 2.

### 5.1.1. Sprinkler Irrigation Erosion

Figure 4 represents a "typical signature" of a sprinkler event. Water application rates range from 6 – 10 mm/hr. Total water applied ranged from 8 – 50 mm. Runoff rates are typically low (1 – 4.6 L/sec peaks) and tend to lag considerably in time compared to application rates. It is generally seen that the peak in runoff corresponds with the ending of the application of water. Peak TS levels (1.1 – 54.8 g/L) may also coincide with this runoff peak, but not necessarily. Peak TS values can also appear at the beginning or even near the end of runoff. However, the effect of the load being a product of runoff and TS concentration is seen graphically as peak loads (2.5 – 71.3 g/sec) generally corresponding with peak runoffs. Erosion rates from sprinkler irrigation range from .0039 - .0777 tonnes/ha.

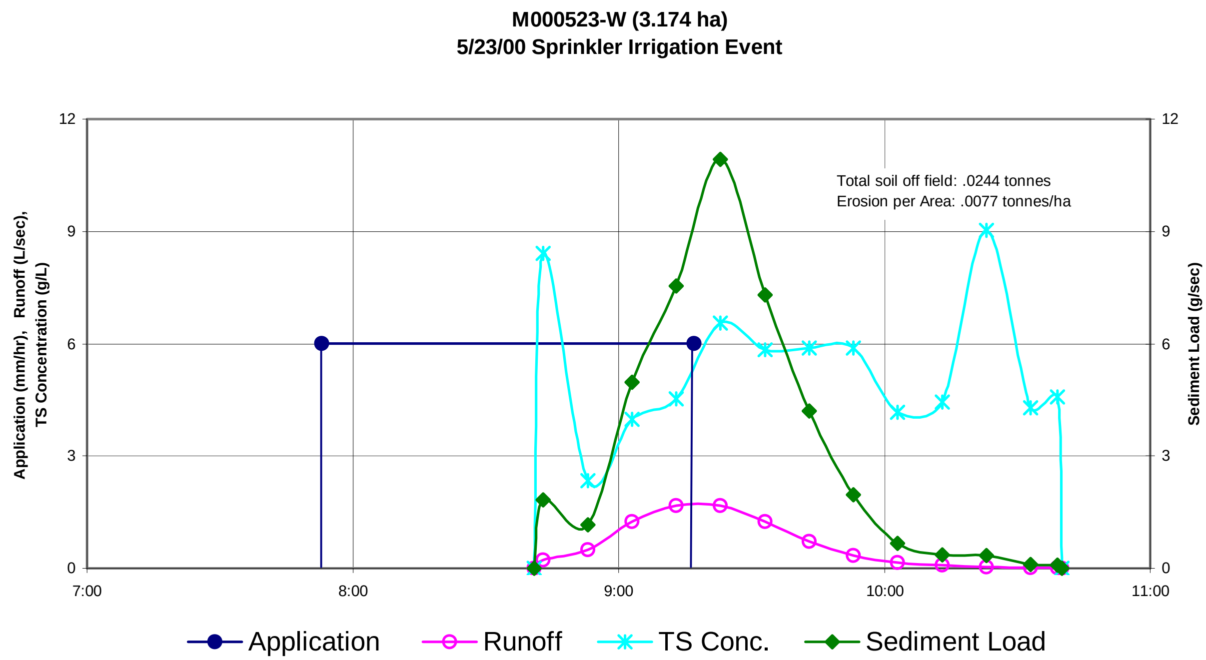



**Figure 4. Typical sprinkler irrigation "signature" showing application rate, runoff rate, TS concentration and sediment load.**

### 5.1.2. Linear Irrigation Erosion

Figure 5 represents a "typical signature" of a linear event. Water application rates range from 34.4 – 46.6 mm/hr. Total water applied ranged from 13 – 26 mm. Runoff rates are again typically low (3 – 3.6 L/sec peaks), but do not tend to lag considerably in time compared to application rates as sprinkler irrigation does. It is generally seen that there is not a well-defined peak in runoff, but rather a more consistent runoff rate over time with much smaller "mini" peaks. This is likely due to the nature of the water application. As the linear apparatus travels along the field, it progressively saturates the rows running parallel to the overhead sprinklers and runoff occurs. The peaks may develop as new sections of land saturate enough to release a pulse of runoff. Peak TS levels (9.1 – 43.0 g/L) tend to be found near the middle of runoff, but typically they are more like higher values within a series of spikes that occur throughout the event, much like the runoff. Peak sediment loads (22.2 – 51.5 g/sec) correspond with the peak runoff and TS levels. Erosion rates from linear irrigation range from .0586 - .1785 tonnes/ha, which is greater than sprinkler irrigation (see Discussion section for interpretation of this).

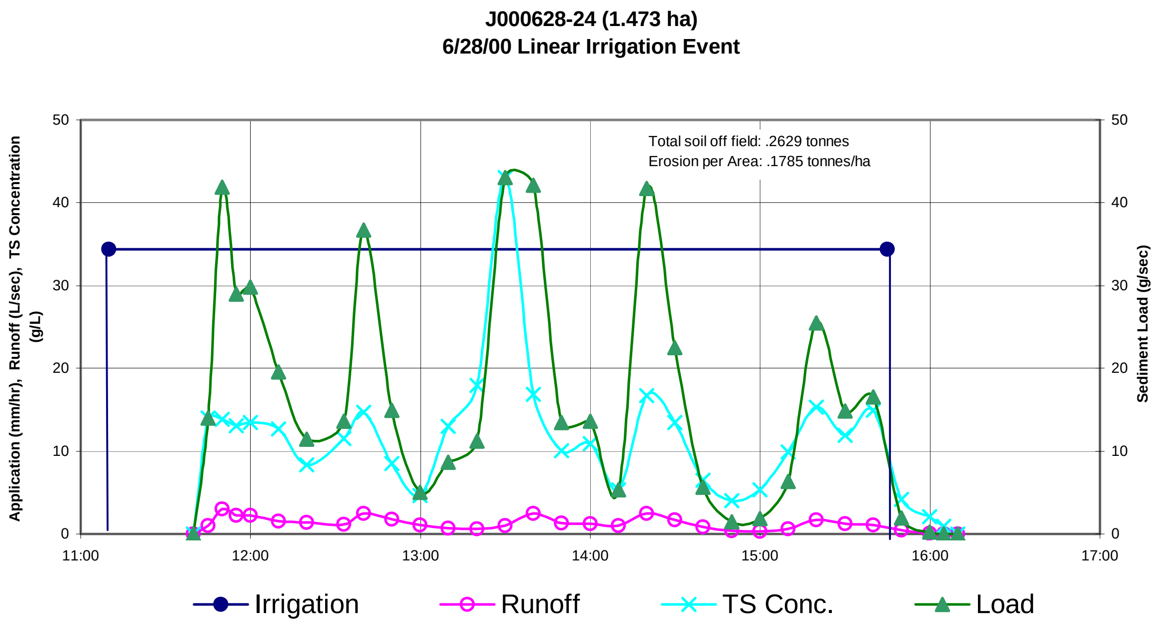



**Figure 5. Typical linear irrigation "signature" showing application rate, runoff rate, TS concentration and sediment load.**

### 5.1.3. Rainfall Erosion

Figure 6 represents a "typical signature" of a rain event. Average rainfall rate ranged from 1.6 – 3.8 mm/hr. In addition, the maximum rate of rainfall (or rainfall intensity) was measured to range from 1.9 to 13.2 mm/hr, based upon an approximate 10-minute sampling interval. Total rain amounts ranged from 4-14 mm. Runoff rates are generally higher compared to irrigation events (1.5 – 17.2 L/sec peaks). Peak runoff rates tend to lag in time compared to peak application rates, but runoff duration in general is not very different temporally than application duration. Peak TS levels (3.1 – 46.4 g/L), as in sprinkler irrigation, can be found either in the beginning or near the middle of runoff duration. Peak sediment loads (4.7 – 800.0 g/sec) correspond with peak runoff and peak TS levels. Erosion rates from rainfall events ranged from .0028 - .5466 tonnes/ha. These figures indicate the wide range of rates that rain can cause, from below to far above anything measured in any irrigation event

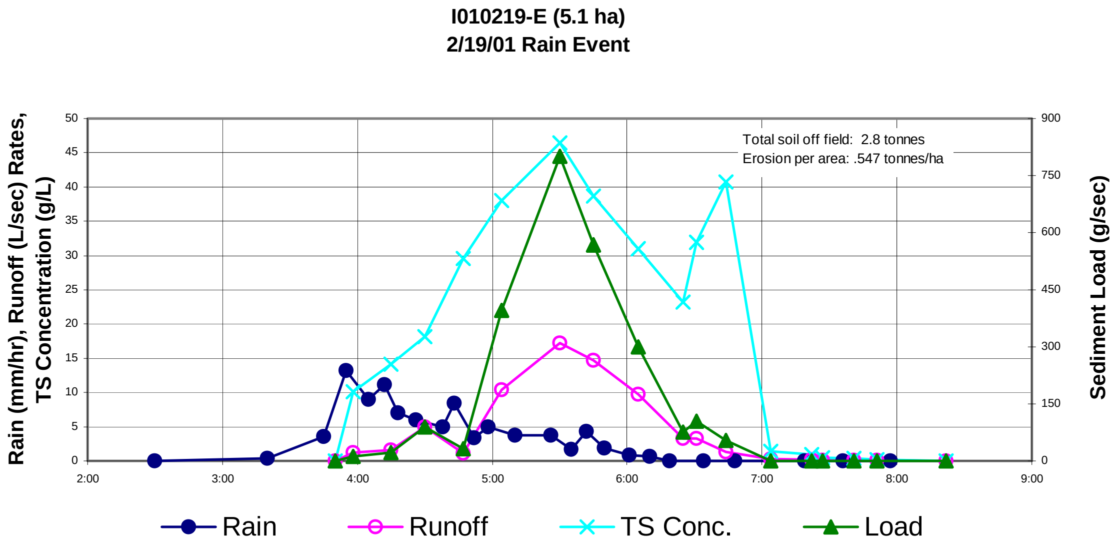



**Figure 6. Typical rainfall "signature" showing application rate, runoff rate, TS concentration and sediment load.**

Note that the stated ranges for runoff, TS concentration and sediment load are not scaled to field size, and therefore are not directly comparable; however, application rates, total amount of water applied and total erosion are.

The information from this analysis, combined with measured field parameters, is summarized in Table 1. Data is missing from the table represents data that was either unavailable, unknown, or was simply not measured

**Table 1. Summary of Irrigation and Rainfall Event Parameters.**

| SSS ID# | M000523-E | M000523-W | M000630-E | M000630-W | J000622-4 | J000628-24 | J000628-4 |
|---|---|---|---|---|---|---|---|
| Farm | A | A | A | A | B | B | B |
| Soil type | | | | | DG | DG | DG |
| Slope | 0.3 | 0.3 | 0.3 | 0.3 | 0.9 | 0.52 | 0.9 |
| Crop stage | ? | ? | ? | ? | ? | ? | ? |
| Soil state | ? | ? | ? | ? | Cultivated | Sealed? | Sealed? |
| Irrigation type | Sprinkler | Sprinkler | Sprinkler | Sprinkler | Linear | Linear | Linear |
| Ave Application Rate (mm/hr) | 6 | 6 | 8.7 | 8.7 | 31.4 | 34.4 | 46.6 |
| Maximum Application Rate (mm/hr) | 6 | 6 | 8.7 | 8.7 | 31.4 | 34.4 | 46.6 |
| Application Duration (min) | 84 | 84 | 188 | 188 | 25 | 45 | 24 |
| Amount of Water Applied (mm) | 8.4 | 8.4 | 27.2 | 27.2 | 13.0 | 26.0 | 18.8 |
| Runoff Coefficient | 0.01 | 0.04 | 0.09 | 0.09 | 0.07 | 0.05 | 0.09 |
| Runoff Duration (min) | 171 | 117 | 235 | 276 | 176 | 260 | 320 |
| Erosion (tonnes/ha) | 0.0039 | 0.0077 | 0.0088 | 0.0777 | 0.0586 | 0.1785 | 0.1397 |

| SSS ID# | B000722-6 | B000808-6 | I010211-E | I010211-W | I010212-E | I010212-W | I010219-E | I010219-W |
|---|---|---|---|---|---|---|---|---|
| Farm | C | C | D | D | D | D | D | D |
| Soil type | Heavy | Heavy | | | | | | |
| Slope | 0.15 | 0.15 | 2.12 | 1.8 | 2.12 | 1.8 | 2.12 | 1.8 |
| Crop stage | Mid | Mid | fallow | fallow | fallow | fallow | fallow | fallow |
| Soil state | Cultivated | Cultivated? | cultivated | cultivated | cultivated | cultivated | cultivated | cultivated |
| Irrigation type | Sprinkler | Sprinkler | Rainfall | Rainfall | Rainfall | Rainfall | Rainfall | Rainfall |
| Ave Application Rate (mm/hr) | 10 | 8.4 | 1.6 | 1.6 | 2.4 | 2.4 | 3.8 | 3.8 |
| Maximum Application Rate (mm/hr) | 10 | 8.4 | 1.9 | 1.9 | 7.5 | 7.5 | 13.2 | 13.2 |
| Application Duration (min) | 301 | 345 | 137 | 137 | 24 | 24 | 220 | 220 |
| Amount of Water Applied (mm) | 50 | 48 | 3.8 | 3.8 | 2 | 2 | 14 | 14 |
| Runoff Coefficient | 0.02 | 0.03 | 0.09 | 0.04 | 0.23 | 0.10 | 0.11 | 0.06 |
| Runoff Duration (min) | 170 | 242 | 151 | 140 | 175 | 143 | 241 | 208 |
| Erosion (tonnes/ha) | 0.0701 | 0.0471 | 0.0202 | 0.0028 | 0.0553 | 0.0116 | 0.5466 | 0.0542 |

## 5.2. Modeling

### 5.2.1. Erosion Model

Statistical analysis using SPSS was used to determine a multiple regression model based upon parameters found in Table 1, with erosion the independent variable. Parameters of most importance were determined to be:

- Maximum intensity of rainfall/irrigation
- Total amount of water fallen/applied
- Slope of the field

Log transformations were necessary for all variables except the slope. Analysis demonstrated a good relationship between the log of erosion and the log of maximum intensity of water application ($R^2$ = .46). Weaker relationships occur between log of erosion and both log of total amount applied and slope. The best fit model overall ($R^2$ = .76, see Fig. 7) was determined to be:

**$\log E = 0.89 \times \log M + \log A + 0.64 \times S - 4.1$, where**

**E** = Erosion (tonnes/ha)

**M** = Maximum intensity of rainfall/applied water (mm/hr, 10-min average)

**A** = total Amount of water fallen/applied (mm)

**S** = Slope of the field (%)

This model will allow for the prediction of erosion within the following parameters:

- Maximum intensities up to approximately 47 mm/hr
- Total rainfall amounts up to approximately 50mm
- Slopes to approximately 2.2%

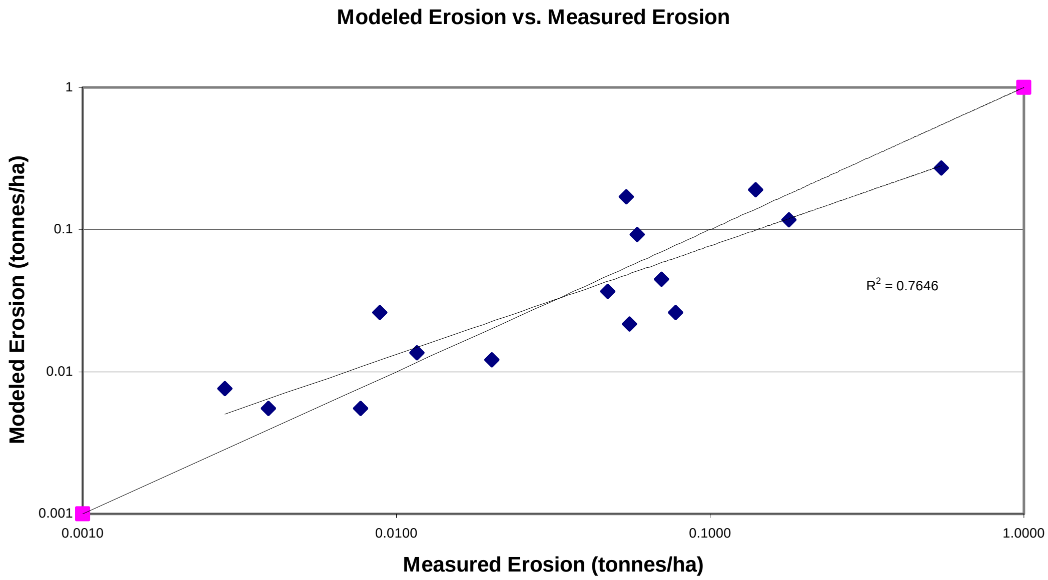



**Figure 7. Modeled erosion vs. measured erosion**

### 5.2.2. Delivery Model

Recall that a simplistic view of the erosion transport process is taken to describe the delivery of eroded soil to the Salinas River. The delivery model is partially based upon the results obtained from the detention basin study. It was found that the detention basin could detain 99% of erosion entering it. Therefore, 1 % of all eroded material will be transported to the Salinas River, assuming 100% adoption of a detention basin BMP and no other BMPs are in place. If no BMPs are in place to manage this soil erosion, it is assumed that 100% of that soil will be transported to the river. Therefore:

$$1\% \times E \leq D \leq 100\% \times E\ .$$

Values for the range of estimated delivered amounts are given along with the erosion estimates.

### 5.2.3. Upscaling

#### 5.2.3.1. Area and Slope

GIS analysis by the SSS determined area and slope for agricultural uses within the Salinas Valley south of the town of Spreckels. This analysis was performed using the Tarsier modeling framework at 360 meter pixel resolution, considered appropriate for this study (Watson, 2001). There is approximately 1353 $km^2$ (135,300 ha) of agricultural land use, as defined by a map produced by the Association of Monterey Bay Area Governments (AMBAG), in this area. This is primarily row crop agriculture. Of this land, approximately 60% (805 $km^2$, 80500 ha) has a slope of 2.2% or less. Figure 8 displays agricultural land area and slope relationships.

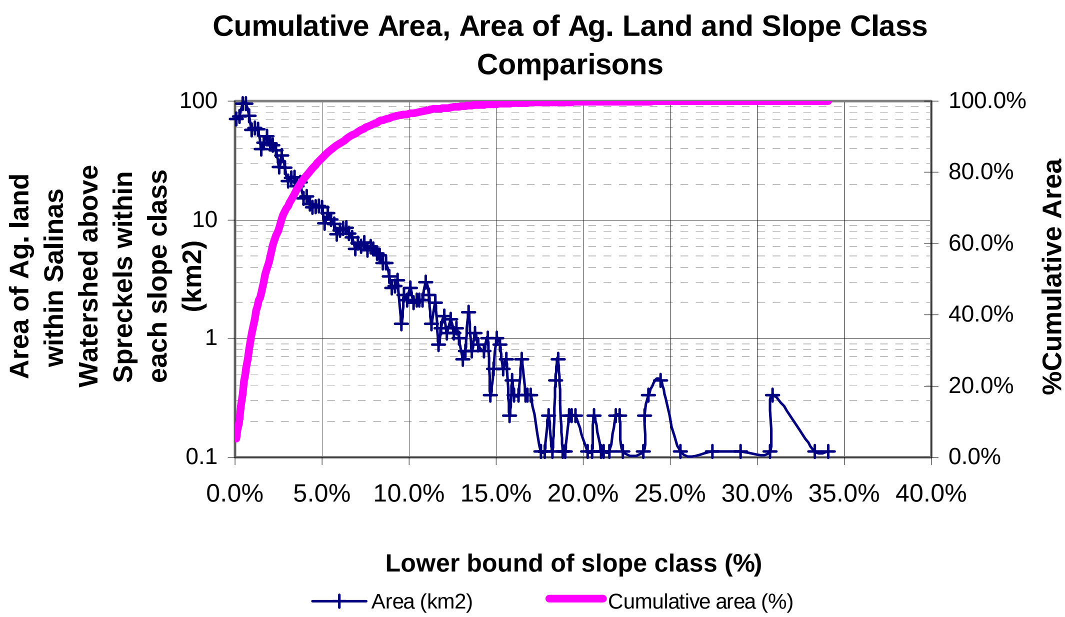



**Figure 8. Area, %cumulative area and slope class of agricultural land south of Spreckels.**

Table 2 lists the area associated with each slope class of 2.2% or less and the average slope within that class. These data were used in the upscaling of the erosion model.

**Table 2. Area and Average Slope**

| Area (km2) | Area (ha) | Average slope (%) |
|---|---|---|
| 71.0 | 7095 | 0.09 |
| 74.0 | 7396 | 0.27 |
| 95.3 | 9535 | 0.44 |
| 95.5 | 9546 | 0.61 |
| 74.7 | 7474 | 0.79 |
| 57.1 | 5714 | 0.96 |
| 59.3 | 5926 | 1.13 |
| 57.6 | 5759 | 1.32 |
| 39.2 | 3921 | 1.49 |
| 44.4 | 4444 | 1.65 |
| 50.5 | 5046 | 1.83 |
| 44.1 | 4411 | 2.01 |
| 42.6 | 4255 | 2.17 |

#### 5.2.3.2. Rainfall Model

Based on the criteria for defining a rainfall event (section 5.3.3.2), six storm events occurred in the Salinas Valley between the start of April 2000 and the end of March 2001: one in October, two in January, two in February and one in March.

Through regression analysis, it was determined that the relationship between the dependant variable "ten-minute intensity" ($I_{10min}$) and the independent variable "one-hour intensity" ($I_{60min}$) was:

$$\mathbf{I_{10min} = 3.0 \times (I_{60min})^{0.76}}, \quad (R^2 = .45).$$

The most intense (amount of rain and maximum intensity) storms were in the beginning of January and March. Unfortunately, rain event measurements were not obtained during these times. Storm monitoring was performed during the two February events: two in the first and one in the second. Monitoring of these events was not performed throughout the entire duration of the event, but rather during storm cells within the event period. The maximum 10-min. intensities ranged from approximately 10 – 12 mm/hr. Total amounts ranged from 17.7 – 53.8 mm. The total precipitation recorded from October through March, averaged from the four CIMIS stations, was 218.6 mm. Table 3 shows the summary of precipitation analysis based upon CIMIS data.

**Table 3. Summary of hourly and ten-minute averaged Maximum Storm Intensity and Total Amount of Rainfall per Storm Event. Highlighted data were used for upscaling.**

| **Oct Event (25-31)** | 116-Salinas N. | 89-Salinas S. | 114-Arroyo | 113-King City | Mean |
|---|---|---|---|---|---|
| Max Intensity (hourly averaged, CIMIS data, mm/hr) | 4.4 | 11.7 | 3.9 | 4.3 | 6.1 |
| Max Intensity (ten-min averaging by rainfall model, mm/hr) | 9.1 | 19.1 | 8.3 | 9.0 | 11.7 |
| Amount Total Rain (CIMIS data, mm) | 38.2 | 52 | 31 | 29.1 | 37.6 |
| **1-Jan Event (7-15)** | | | | | |
| Max Intensity (hourly averaged, CIMIS data, mm/hr) | 3.6 | 6.1 | 7.9 | 7.3 | 6.225 |
| Max Intensity (ten-min averaging by rainfall model, mm/hr) | 7.8 | 11.7 | 14.2 | 13.4 | 11.9 |
| Amount Total Rain (CIMIS data, mm) | 31 | 67.5 | 55 | 61.8 | 53.8 |
| **2-Jan Event (23-29)** | | | | | |
| Max Intensity (hourly averaged, CIMIS data, mm/hr) | 6.8 | 8.2 | 6.2 | 4.8 | 6.5 |
| Max Intensity (ten-min averaging by rainfall model, mm/hr) | 12.7 | 14.6 | 11.8 | 9.8 | 12.3 |
| Amount Total Rain (CIMIS data, mm) | 28 | 28.5 | 20.8 | 19.5 | 24.2 |
| **1-Feb Event (9-13)** | | | | | |
| Max Intensity (hourly averaged, CIMIS data, mm/hr) | 5.9 | 5 | 4.9 | 4 | 4.95 |
| Max Intensity (ten-min averaging by rainfall model, mm/hr) | 11.4 | 10.1 | 9.9 | 8.5 | 10.0 |
| Amount Total Rain (CIMIS data, mm) | 37.6 | 43.2 | 27.4 | 31.4 | 34.9 |
| **2-Feb Event (18-20)** | | | | | |
| Max Intensity (hourly averaged, CIMIS data, mm/hr) | 5.3 | 4.8 | 8.1 | 5.8 | 6 |
| Max Intensity (ten-min averaging by rainfall, mm/hr) | 10.5 | 9.7 | 14.5 | 11.3 | 11.5 |
| Amount Total Rain (CIMIS data, mm) | 14.2 | 13.7 | 21.4 | 21.4 | 17.7 |
| **March Event (2-6)** | | | | | |
| Max Intensity (hourly averaged, CIMIS data, mm/hr) | 3.6 | 7.7 | 5.4 | 8.9 | 6.4 |
| Max Intensity (ten-min averaging by rainfall model, mm/hr) | 7.8 | 13.9 | 10.7 | 15.6 | 12.1 |
| Amount Total Rain (CIMIS data, mm) | 36.2 | 41.7 | 63.4 | 60.4 | 50.4 |

#### 5.2.3.3. Erosion and Delivery due to Irrigation in One Season

The "typical" irrigation season was characterized as follows. The growing season was favorable during the time of this study. It is expected that most of the row crop farmers were able to get in two to three harvests during this time. This is not yet verified, but it is a likely assumption. For each crop grown, approximately .05 - 1 inch (12.7 - 25.4 mm, average $\approx$ 19.0 mm) of water is applied during each irrigation event, with about 10 events per crop. This is quite variable depending upon conditions, but is an amount commonly related by farm managers. Most irrigation is of the sprinkler variety, so for this scaling exercise linear irrigation is ignored. The average irrigation rate (therefore the maximum intensity) was determined to be 8 mm/hr, based upon 6 sprinkler events.

Using the erosion, area/slope, and upscaling models (sec. 6.3.1, 6.3.3.1 & 6.3.3.3) in conjunction with the above figures, an estimate of erosion due to irrigation was obtained. Erosion due to irrigation during the study period is estimated to be approximately:

**141 kilo-tonnes, 1.7 tonnes/ha** (see Table 4).

This would be considered a typical amount of erosion due to irrigation from year to year, as long as irrigation strategies and agricultural area do no vary much. Recall that this is only for agricultural land below 2.2% slope, representing some 60% of agricultural land use.

Delivery of this eroded material to the Salinas River was determined to be:

- Best case scenario (full adoption of detention basin BMP, no other BMPs):
    - $D \geq 1\% \times E_a \approx 1.4$ kilo-tonnes
- Worst-case scenario (adoption of no BMPs):
    - $D \leq 100\% \times E_a \approx 141$ kilo-tonnes

**Table 4. Summation of Erosion due to Irrigation**

| Average slope per slope class (%) | Erosion Model (tonnes/ha): M = 8, A = 19, S = column 1 | Area per slope class (ha) | Erosion (tonnes) per slope class per event | Erosion (tonnes) X 25 events (10 irrigations, 2.5 crops) |
|---|---|---|---|---|
| 0.09 | 0.0122 | 7095 | 87 | 2171 |
| 0.27 | 0.0160 | 7396 | 118 | 2960 |
| 0.44 | 0.0205 | 9535 | 195 | 4880 |
| 0.61 | 0.0263 | 9546 | 251 | 6284 |
| 0.79 | 0.0343 | 7474 | 257 | 6414 |
| 0.96 | 0.0442 | 5714 | 252 | 6307 |
| 1.13 | 0.0566 | 5926 | 335 | 8378 |
| 1.32 | 0.0739 | 5759 | 426 | 10639 |
| 1.49 | 0.0953 | 3921 | 374 | 9342 |
| 1.65 | 0.1208 | 4444 | 537 | 13425 |
| 1.83 | 0.1573 | 5046 | 794 | 19845 |
| 2.01 | 0.2037 | 4411 | 898 | 22462 |
| 2.17 | 0.2592 | 4255 | 1103 | 27574 |
| | | | Total Erosion (tonnes)= | 140682 |

### 5.2.3.4. Erosion due to Rainfall Events during the 2000 – 01 Winter Season

Recall that six rainfall events occurred in the Salinas Valley between the start of April 2000 and the end of March 2001: one in October, two in January, two in February and one in March.

Using the erosion, area/slope, rainfall, and upscaling models (sects. 6.3.1, 6.3.3.1, 6.3.3.2, 6.3.3.4), an estimate of erosion due to storm events was calculated. Table 5 shows a summary of erosion per slope class per event. The table shows summations of these figures. The total erosion due to rainfall for the 2000 – 01 winter storm season is:

**93 kilo-tonnes, 1.2 tonnes/ha**.

**Table 5. Summary of Erosion due to Storm Events**

| Area (ha) | Average slope (%) | Oct tonnes | 1-Jan tonnes | 2-Jan tonnes | 1-Feb tonnes | 2-Feb tonnes | March tonnes |
|---|---|---|---|---|---|---|---|
| 7095 | 0.09 | 247 | 365 | 163 | 199 | 112 | 347 |
| 7396 | 0.27 | 337 | 498 | 223 | 272 | 152 | 474 |
| 9535 | 0.44 | 555 | 820 | 367 | 448 | 251 | 781 |
| 9546 | 0.61 | 715 | 1056 | 473 | 577 | 323 | 1005 |
| 7474 | 0.79 | 730 | 1078 | 483 | 589 | 330 | 1026 |
| 5714 | 0.96 | 717 | 1060 | 475 | 579 | 324 | 1009 |
| 5926 | 1.13 | 953 | 1408 | 631 | 769 | 431 | 1340 |
| 5759 | 1.32 | 1210 | 1788 | 801 | 976 | 547 | 1702 |
| 3921 | 1.49 | 1063 | 1570 | 703 | 857 | 481 | 1495 |
| 4444 | 1.65 | 1527 | 2256 | 1011 | 1232 | 691 | 2148 |
| 5046 | 1.83 | 2257 | 3335 | 1494 | 1821 | 1021 | 3175 |
| 4411 | 2.01 | 2555 | 3775 | 1691 | 2061 | 1155 | 3594 |
| 4255 | 2.17 | 3136 | 4634 | 2076 | 2530 | 1418 | 4412 |
| | subtotal: | 16000 | 23645 | 10592 | 12908 | 7236 | 22509 |
| | Total erosion (tonnes): | 92890 | | | | | |

Delivery of this eroded material to the Salinas River was determined to be:

- .93 kilo-tonnes (930 tonnes) ≤ D ≤ 93 kilo-tonnes

### 5.2.3.5. Total Erosion, April 2000 – March 2001

Adding erosion due to irrigation and erosion due to rainfall events gives total erosion of agricultural land on 2.2% slopes or less (60% of agricultural land) in the Salinas Valley south of Spreckels:

**234 kilo-tonnes, 2.9 tonnes/ha**.

Delivery of this eroded material to the Salinas River was determined to be:

- 2.34 kilo-tonnes ≤ D ≤ 234 kilo-tonnes

## 5.3. Sand vs. Silt/Clay Components of Erosion.

Consistent sand breaks, or the filtering of the 63-micron and greater component, are not always performed in the TSS lab methods. Originally, the intension of doing sand breaks was to facilitate faster filtering of the sample, as sand would quickly clog the filters leading to the use of numerous coarse filters. However, this filtering technique is also useful for determining the amount of TS that is sand and that which is silt/clay. This technique of filtering using the sand break was not used consistently for the irrigation events, but was used for the rain events. Therefore, the results that follow are only from the six analyses that occurred during the February 2001 rain events. Recall that these were all from the same farm.

In general, of all the erosion leaving the fields, sand tends to make up the lesser of the two divisions by weight (Table 6). Typically the sand component rarely exceeds the amount of silt/clay throughout the runoff duration of the field; however, there are exceptions. The average percentage of sand by weight for all samples taken is 30%, SD = 21%. Sand percentages range from 0% – 80%. The east field produced an average of 34% sand through the events while the west averaged 27%. Figure 9 illustrates an example of the general pattern of these relationships. Graphs of all the measured events can be found in Appendix 3. Figure 10 shows the relationship between runoff and % sand component. It shows no discernable relationship between the percentage of sand in a sample compared to how much water is coming off a field.

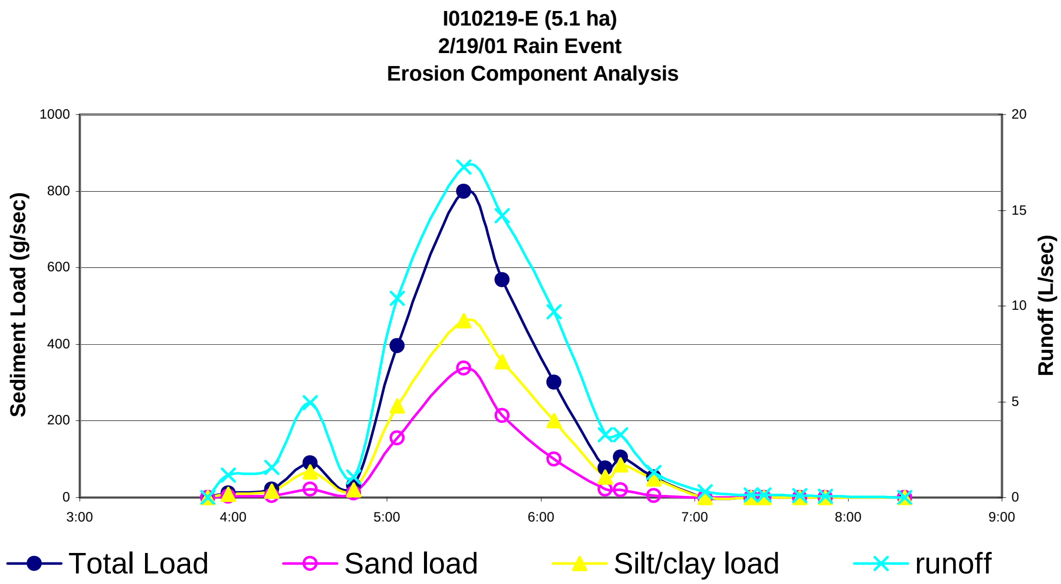



**Figure 9. Runoff and Load Relationships during a Rain Event.**

**Table 6. Average %Sand of Sediment samples**

**Average % Sand (> 63 µm) of TS Samples**

| | 11-Feb | 12-Feb | 19-Feb | TTL Ave |
|---|---|---|---|---|
| East Field | 43% | 38% | 22% | 34% |
| West Field | 22% | 23% | 35% | 27% |

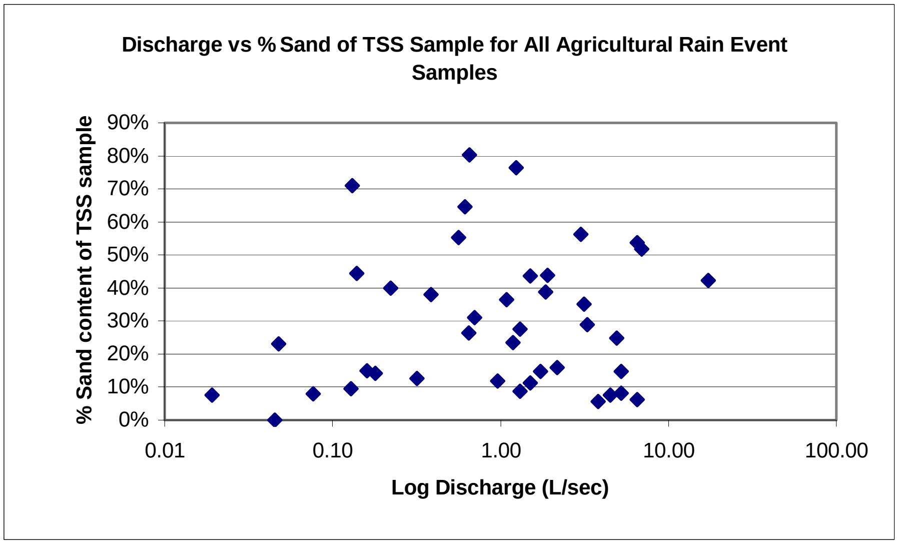



**Figure 10. Log of Discharge vs. %Sand Component of Sediment Samples**

### 5.4. Detention Basin Efficiency

The efficiency of the detention basin was determined by comparing the sediment leaving the basin to the sediment entering the basin. This was based on the February 19th event, which was the most intense of the events, mobilizing more sediment.

Approximately 3.3 tonnes of material was estimated to have entered the detention basin from the entire field. The measurements of the mid-section of the field were not possible, but estimates were made based upon erosion activity of the west field (see Table 7). The west field was used in order to err on the side of decreasing an estimate of efficiency.

An upper-bound estimate of 0.032 tonnes of sediment left the basin. This was based on the assumption that the volume of water leaving the basin equaled the volume entering (153 $m^3$).

Although percolation and evaporation of water would be expected, these parameters were not readily measurable. The assumption that all runoff entering the basin left the basin errs on the side of decreasing efficiency. The maximum TS level that was measured from the basin outflow (211.3mg/L) was used to determine an estimate of load. Therefore, it is found that this basin was at least 99% efficient at retaining all sediment that entered it (Table 7).

$$\% \text{ Efficiency} = \frac{3.302in - 0.032out}{3.302in} \times 100$$

**Table 7. Figures used to estimate mid-field erosion and basin efficiency**

| | Erosion (tonnes/ha) | Area (ha) | Sed. In (tonnes) | TS Conc out (mg/L) | Discharged off (L/ha) | Liters in/out | Sed. out (tonnes) | |
|---|---|---|---|---|---|---|---|---|
| East | 0.547 | 5.123 | 2.800 | 211.3 | 14912.5 | 76396.5 | 0.016 | |
| West | 0.054 | 3.849 | 0.208 | 211.3 | 8254.3 | 31770.8 | 0.007 | |
| Mid | 0.054 | 5.428 | 0.294 | 211.3 | 8254.3 | 44804.4 | 0.009 | Efficiency |
| Total | | | 3.302 | | | | 0.032 | 99.02% |

Estimates based on erosion activity of west field

Samples indicate that all TS levels leaving the basin were low. Table 8 shows the TS values for the samples collected, the %sand component, and the daily average TS for the events measured. It shows TS values ranging from 72 – 211 mg/L. The %sand composition is somewhat smaller than what was generally experienced to come into the basin. This is addressed in the Discussion section.

**Table 8. Average %Sand of TS sample leaving the basin per storm event**

| Date | TS (mg/L) | % sand | TS Ave for day |
|---|---|---|---|
| 11-Feb | 100.5 | 9% | 100.5 |
| 12-Feb | 142.0 | 5% | |
| 12-Feb | 105.0 | 17% | |
| 12-Feb | 72.3 | 3% | 106.4 |
| 19-Feb | 112.9 | 27% | |
| 19-Feb | 211.3 | 33% | |
| 19-Feb | 184.7 | 0% | |
| 19-Feb | 195.4 | 16% | |
| 19-Feb | 188.4 | 6% | 178.5 |
| Total average: | 145.8 | 13% | |
| SD = | 50.4 | | |

## 6. Discussion

Perhaps the first thing that should be stated and kept in mind when interpreting this erosion data is that no where near all of this erosion is making it to the Salinas River. Best management practices were employed on all farms that were in this study. The potential for contribution of sediment to the river by agriculture is great if no BMPs are applied. However, from the general field observations made by this study it is evident that most farmers are doing a good job of managing erosion.

From the examination of the results presented in Table 1 (Summary of Irrigation and Storm Event Parameters), some interesting points arise. The storms seen this year had average application rates far below any irrigation rates measured. Maximum intensities, however, are comparable to sprinkler irrigation maximum intensities. This illustrates the importance of scaling the maximum intensities reported by the CIMIS data down to 10-minute scale when using the erosion model. The amount of water applied during two storm measurements was much lower than from irrigation; however, these events were only partial measurements based on the tail end of the storm cells. It is recognized that the model should incorporate more storm events to be more robust. Erosion amounts from storm event # I010219-E (547 kg/ha) demonstrate that storm events can be quite erosive.

Average linear irrigation application rates are some 4.7 times what sprinkler irrigation rates are. Average erosion rates reflect this by being 3.5 times higher as well. Part of this may be due to the greater slopes that linear irrigation was measured on. At any rate, the data indicate that if a management goal is to reduce erosion, using linear irrigation may not be the watering strategy of choice, especially on sloped fields. Runoff coefficients (runoff/applied) are comparable to those of sprinkler irrigation, indicating the problem is not an increase in runoff, but rather an increase in sediment levels associated with the runoff. Since the amount of water applied is comparable to sprinkler irrigation, the conclusion is that the application rate is too high for the slope of the field. However, the farmer may well have a management strategy that justifies this. Linear systems offer more control of water application, may lead to less evaporation of applied water, and cost less in labor to operate.

Events B000722-6 and B000808-6 (sprinkler events) had large amounts of water applied to the field, but runoff coefficients are low. This is likely due to the small slope of the field. Erosion was a little higher compared to other sprinkler events, but not much. It is speculated that the soil type and perhaps the crop stage dictated the large application of water.

Construction of the presented erosion model began with some considerations in mind. It is recognized that erosion is a complex process with many different variables of consequence. Therefore, it was important to examine many different variations/locations of row croplands for this study. For a watershed the size of the Salinas Valley, what is needed is an estimate based on readily observed or obtained precipitation/irrigation data and slope field parameters. The erosion model presented here, based on these readily available data and inclusive of all the other variations, gives an order of magnitude/accuracy appropriate for the purposes of the Salinas Sediment Study. Again, the model is expected to become more robust with additional data.

The development of the erosion model, based on the presented 15 events, is limited by the variables measured. In order to determine the erosion contribution by the 40% of agricultural land above a 2.2% slope, more measurements involving higher slopes will be needed. As indicated earlier, slopes greater than 2% often exhibit excessive erosion rates. This will be important data to ascertain, as erosion rates are expected to be quite high in these areas and are likely to contribute significantly to sediment levels of the Salinas River.

Although 6 rainfall events were measured, these were all on the same farm ranging over 2 partial and one full event, so the erosion model lacks much variation in parameters concerning rainfall events. It will help to obtain a wider variety of rainfall parameters on various farms in the future.

Some storm events of this year had parameters that just exceeded the expected limits of the model. Future model improvements should focus on obtaining more storm event data. The estimate for storm erosion presented here is likely low. One important variable concerning erosion is antecedent soil moisture. Irrigation timing is to a large degree determined by the level of soil moisture. When moisture levels are lower, irrigation is required. Therefore, much of the water applied is expected to infiltrate and not cause erosion. During storm events, however, the soil can quickly become saturated and much more erosion can occur. This variation is not likely to present itself in the measurement of irrigated soils.

Further statistical analysis of the erosion model could be done to determine whether it is the most appropriate one to use. There may be other parameters not considered that could make it a better predictor. Overall, this model is felt to provide a good estimate of erosion based upon the observed data.

The rainfall model could likely be improved in a few ways. First, it would be useful to obtain the raw rain data collected by CIMIS to calculate actual ten-minute averaged maximum intensities rather than calculating them through regression analysis against 1-hour intensities. Second, it might also be appropriate to calculate storm “cells” as events rather than using the storm events presented here. Finally, GIS analysis could be used to construct Thiessen polygons surrounding the CIMIS stations to get a more accurate measure of rainfall amounts and intensities over agricultural areas.

A lower estimate was obtained of erosion for rainfall events (93 kilo-tonnes) than for irrigation events (141 kilo-tonnes). It is likely that the storm estimate is low due to the limited parameters observed for the erosion model mentioned previously. However, if we except the estimate obtained, one interpretation is to consider each irrigation event as a mini rainfall event. It is not coincidental that the sprinkler irrigation graphs bear somewhat of a resemblance to the storm graphs. Both ways of water delivery are similar, except that irrigation has a constant delivery rate. In this case, there are some 25 - 30 of these events that occur on a field during the year. They may not deliver as much water as a rainfall event, or with quite the intensity (linear applications excepted), but in this particular year there were five times as many of them. Viewed in this light, the results are less surprising. In addition, the average precipitation amount for the Salinas Valley is 338 mm, whereas the total rainfall for these data obtained October thru March was 219 mm. This is somewhat less than the estimated 475 mm applied by irrigation over the course of a season.

The figure for the potential erosion contribution of row croplands in the Salinas Valley watershed was developed for the use by Salinas Sediment Study to help determine what the possible contribution of this land use is to the sediment budget of the Salinas River. The issue of whether this eroded material actually makes it to the river is not addressed in this study. Although we have an estimate of how much erosion during the year April ’00 – March ’01, this does not mean that this much soil made it to the Salinas River to become sediment. This erosion estimate represents the potential contribution to the sediment budget if that soil was not detained, but allowed to flow off the fields, channeled to eventually find the river.

An estimate was made as to how much eroded material was sand compared to silt/clay. As stated earlier, the two have different implications toward environmental degradation and management policies. The sand break was only performed on six rain events, all from the same farm/field. The only conclusions that can be drawn from the data will relate to soils of about the same composition as the soil on this field. It was found that, on average, the soil eroded from the field was about 30% sand, 70% silt/clay. This would indicate that more management effort might need to be focused on controlling the silt/clay component. However, both have a healthy percentage represented and management focus would really depend upon the issues of concern. These figures indicate that there might be a need for a TMDL that addresses each of these components separately rather than addressing only “sediment”.

One might expect that as runoff flows in the field increase, more sand would be mobilized than silt/clay. Figure 10 indicates that this isn’t so. There does not appear to be a relationship between the percentage of sand and discharge. Spikes or drops in the percentage of sand at any time at a specific place during runoff appear to be random. Perhaps the erosion that is occurring in the field is behaving much as it would on a larger scale in rivers, where the sand behaves as bed load that moves in pulses.

The estimate was made that, in the particular field studied here, the detention basin designed to hold these sand and silt/clay components was 99% effective in doing so. This figure was derived from an estimate of what the middle section of the field was contributing to the basin. The estimate is probably lower than it truly was. The reasoning is that the data from the west side of the field, which had the lower soil loss of the two field sides, was used to estimate the larger middle portion. One might expect that the middle section be the average of the east and west fields. It is desirable for the error to fall on the side of dropping the basin's efficiency. Therefore the lower of the soil erosion figures was used. In addition, the maximum TS value (211 mg/L) leaving the detention basin was used to estimate overall soil loss. Again, one might expect that the average of the TSS figures would be appropriate to use, but the highest gives the lesser efficiency. Given these considerations, 99% efficiency is considered conservative.

Qualitatively, samples of water leaving the basin appeared clear. Water entering the basin looked like dark chocolate milk. One would hardly need to do the kind of quantitative measurements done here to appreciate that this basin was doing a very good job at what it was designed to do.

The associated percentage sand components and TS concentrations leaving the basin were presented (sect. 6.5). The TSS figures of 100 – 200 mg/L are very low. Only a few grains of sand need be in the sample to make up 10-30% of this. Much, perhaps all, of what was filtered out was organic material. No effort was made to differentiate between organics and sand in the lab so the amount was not quantified. Nevertheless, the condition was noticed. Given these considerations, it is concluded that this particular retention basin removes 100% of the sand component and is at least 99% effective at removing all silt/clay components. However, the basin is expected to lose this efficiency if allowed to fill with sediment. Filling could occur due to a lack of maintenance or because of a particularly large storm event.

## 7. Summary

Recall the goal of this project: *determine typical sediment yields from irrigated agricultural fields in the Salinas Valley during irrigation and rainfall events.*

With the following sub goals:

- Measure erosion from a number of irrigated fields under differing irrigation and rainfall regimes

- Use this information to establish a relationship/model that can be used predict erosion given simple water application parameters
- Use this model to upscale erosion data to the entire Salinas Valley
- Determine what percentage of erosion is sand vs. silt/clay
- Determine the effectiveness of detention basins in trapping eroded soil

To determine this, a total of 15 events (6 storm and 9 irrigation) covering four different farms were measured. The results for each event were an estimate of the total erosion and values for a number of variables suspected of influencing erosion. Data were analyzed and a simple erosion model was constructed based on the following:

- Maximum water application rates
- Total water applied
- Field slopes
- Resulting erosion

The erosion model was then used to upscale the data to reflect easily measured Salinas Valley agricultural field parameters, namely area and slope characteristics. This was done using a rainfall model and GIS analysis. Finally, an estimated range of how much erosion could become sediment in the Salinas River was given using a delivery model.

The study was performed via the examination of lettuce crops and fallow fields. It is not intended to estimate nor is it based on erosion of fruit crops, vineyards or orchards.

Erosion dynamics of sprinkler irrigation and storm events are more similar to each other than to linear irrigation. Linear irrigation tends to be more erosive to soils and its use is not recommended on land with significant slopes if control of erosion is of primary concern.

It was estimated that erosion from fields in the Salinas Valley (Spreckels south) from April ’00 to March ’01 was about **234 kilo-tonnes, (2.9 tonnes/ha)**. Delivery of this eroded material to the Salinas River could range from 2.3 kilo-tonnes to 234 kilo-tonnes, depending upon BMPs currently in place. This came from approximately 60% of the agricultural land in this area, all of which was 2.2% in slope or less. The other 40% of agricultural land above these slope sizes was not estimated, but is expected to contribute much more than what is reported here. Approximately 1.7 tonnes/ha came from irrigation events, while 1.2 tonnes/ha came from storm events. This soil had at least the potential to find its way into the Salinas River to contribute to the sediment budget. No assumptions were made as to how much actually made it to the river.

It was estimated that 30% of this amount of erosion was made up of a sand component or coarser, leaving a 70% silt/clay component.

Examination of a detention basin's efficiency indicates that a basin can be nearly 100% effective in removing sediment from runoff of agricultural fields, even when sediment concentrations entering the basin are as high as 46.4 g/L.

## 8. Conclusions

Human activities upon the Earth that affect the environment and its ecologies are only expected to increase. The view that growth is necessary for our economic survival is a paradigm that assures this relationship, especially when it comes to feeding our increasing population. If we are to satisfy both our need for food production while looking out for the quality of water in our rivers and the species that live in them, careful management of our land and water resources will be paramount. With the knowledge that row crop agriculture here in the Salinas Valley has the potential to mobilize 234 kilo-tonnes of soil, management of this land use is vital to assuring that this soil does not enter the Salinas River to become sediment. Some thirty percent of this pollutant could otherwise reach the waterway to contribute to channel aggradation, thereby leading to potential flooding along the river. Perhaps as much as seventy percent that would otherwise be a productive nutrient rich component of soil could make it to the Salinas, carrying with it pollutants such as various pesticides. Both components could be potentially harmful to the steelhead using the river as a migratory corridor.

There are many best management practices that can be used to help reduce this potential sediment contribution. Many BMPs are currently in place and working successfully in the Salinas Valley. Every indication is that many farmers are doing a good job of keeping the soil where it belongs. Evidence presented here indicates that when a properly engineered detention basin is used, nearly all of the soil eroded from the field can be captured for productive return to the field, rather than polluting the waterways. When detention basins are used in conjunction with other BMP strategies, such as vegetated buffer strips, it should be possible to fully retain all eroded soil from agricultural lands even during very large storm events. The key is appropriate engineering.

Detention basins need not be expensive or take a lot of room. The basin in this study took up 2% of the total field area, designed and situated on the typically marginally productive border of cropland. Agencies like the Resource Conservation District are available to assist the farmer with implementing such BMP strategies. If expense is truly an issue, the fact that such strategies can help keep water resources clean might entice subsidies from state and federal agencies to assist in their structure and maintenance.

BMP strategies, particularly detention basins that are properly engineered and maintained, can and do work.  If the true goal of policy is to keep the waterways clean, then the means are available to mitigate possibly the most visible culprit, agricultural runoff.

## 9. Acknowledgements

I would like to thank the following for their support of this study: the State Water Resources Control Board and the Regional Water Quality Control Board for funding the Salinas Sediment Study, Mark Angelo of the RWQCB for his supportive guidance, the NASA/EPA project and Dr. Lars Pierce, Bryan Largay with the Monterey County Resource Conservation District, the farmers that graciously allowed the SSS to study on their land, and last but not least the SSS team: Wendi Newman, Thor Anderson, Joel Casagrande, Adrian Rocha, Julie Hager, Alana Oakins, and Bronwyn Fierkert. Very special thanks go to our fearless leader, Dr. Fred Watson, who was instrumental in directing me with this report and I dare say is an inspiration to all of us on the SSS.

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# 11. Appendices

## 11.1. Appendix 1: Field and Laboratory Procedures for the Salinas Sediment Study

**Field collection procedure:**

*Materials:*
- 10L bucket with graduated scale
- Stop watch
- 25-50 1L Nalgene bottles (perhaps more, depending on event length), pre-weighed & cataloged
- Meter tape measure
- Various digging tools (shovels, hoes, etc)
- Various plastic/metal pipes & pieces for re-routing flow into sample bottles
- Waterproof field recording book, with pencils

*Procedure:*
1) Scout the field of interest well before the event to ascertain the size of the plot irrigated ($m^2$), its drainage points, slope, stage of crop, type and condition (last tillage) of the soil. The farm manager is a good source of information for much of this data.
2) The procedure for collecting samples in the agricultural field is less regimented than the laboratory procedures and requires a bit of ingenuity and flexibility. At the drainage point, a capture system must be constructed in such a way as to allow for the normal flow of sediment-laden water to exit the field in one continuous flow from which samples can be taken. It is essential that, whatever way this construction is made, it allow for all the sediment that would naturally have left the field to do so. However, it must be kept in mind that the system cannot add sediment that would not have normally been present, either. Experience proves invaluable here. Typically, a retention basin or runoff ditch that drains the field serves well for the construction of the catchment system.
3) Once the sprinkler system is in operation (or rain starts), record the starting time. It will take some time before runoff occurs. This is a good time to determine application rates. Randomly select about 10 irrigation sprinkler nozzles and for each, deflect flow into the bucket until 10L has been obtained, timing how long it took to get the 10L. The average is used for calculations. If the irrigation system is a linear one, also record the rate of travel of the system and the width of instantaneous irrigation. Rate of travel can be obtained by marking a starting and ending point, measuring the distance between the two, and then timing how long it takes the system to travel that distance. Instantaneous irrigation width is simply the width of the area that is being wetted at any point in time. Be aware that changes in the wind can affect this width. For determining rainfall rates, place a rain gage in the field prior to the event and record throughout time the amount of rainfall.
4) Once runoff reaches the catchment system, record the time. There is likely to be an initial burst of sediment flow at the beginning of the event that will be important to record, so samples should be taken every 5 minutes for about the first 20 minutes, then at 10 minute intervals thereafter. This is flexible and experience will dictate when to take more than fewer samples, but generally if there is reason to believe that there will be great changes in load, more samples should be taken. Furthermore, due to the sheer number of sediment samples that can be generated in this way, once flow is consistent one can assume that the load is not likely to change much and thus one can take perhaps one sediment sample for each two discharge samples. For those discharges that have no corresponding sediment samples, an averaging of sediment concentrations from those taken around it is used. The idea should be to take sediment samples relatively close in time to the discharge samples. Sampling consists of:
    a) Taking a discharge measurement: Place the bucket under the flow and fill it. Record the time to fill the bucket and the exact volume collected.
    b) Taking a sediment sample: Place a Nalgene bottle under the flow and move it throughout the flow continuously until ample sample is obtained. This will ensure an accurate concentration

when the sample is filtered in the lab. If the discharge is dirty, about half the bottle is sufficient. If it is clean, fill the whole bottle.

5) Record the time every sample was taken.
6) Record the time that the sprinklers shut off or rain stops.
7) Continue sampling until there is no more tailwater coming off the field; record the time when this happens.
8) If monitoring a linear system, be aware to note if the system ever changes speed.

## Total Suspended Solids (TSS) Laboratory Procedure:

*Materials:*

- 250mL Beaker
- Total Dissolved Solid (TDS) meter
- Transparency Tube
- Filter Funnels with Vacuum Flask, Vacuum Pump and coarse and fine filter papers
- Aluminum Drying Tins
- Sand Break (63 micron) Filter Funnel
- Scales, (1) decigram sensitivity, (1) milligram sensitivity
- Oven
- Calgon (Sodium Hexametaphosphate)
- Forceps

*Procedure:*

1) Record all values to a master data sheet
2) Before each procedure is performed, **SHAKE THE SAMPLE VIGOROUSLY!!!**
3) Read manufacturers instructions (or be taught by lab personnel) on how to use a TDS meter, a turbidity tube, vacuum apparatus, scales and oven.
4) Determine TDS by pouring a small amount of sample into a beaker, then using the TDS probe (be sure of current calibration) record the value in microSeimons (µS). Allow time for sample to equilibrate with the ambient temperature. Return amount sampled to the original sample.
5) Determine transparency (recorded in cm) by use of transparency tube. Return the sample to its bottle. If transparency is < 5cm, do the following:

   Pour small amount (~2-3cm) of sample into turbidity tube, then fill the rest of the tube to ~50cm with clear water. The exact amounts are not important; what is important is to record the actual amount of sample (cm) used and the total final (sample + clear water (cm)) amount of sample. Then determine the transparency of that mixture. True transparency of the sample is then determined by (sample* transparency)/ total. Due to the dilution, this portion of sample is now contaminated and should NOT be returned to the original sample. For this reason, it is important to use as little of the original sample as possible that will still give a good turbidity reading. Experience will help here, but the dirtier the sample, the less one needs.

6) Rinse and dry the outside of the sample bottle, then weigh the bottle with sample (g, to the nearest dg).
7) Add a small amount (quite literally a pinch) of Calgon to the sample and shake thoroughly. This will help suspend particles and keep them from clumping.
8) Pre-dry (bake) all disposable filters in the oven for 15 minutes at 100°C. Allow drying 15 minutes. Place into labeled tins, weigh (g, to the nearest mg) and record tin #, tin and filter weight and filter category (coarse or fine). **Note:** it is important not to touch the filter paper as oils from your hand will affect the paper's ability to filter. Always use forceps to handle unused filter paper.
9) Vacuum filter the sand component (> 63 microns) using sand break filter. Then transfer this sand component onto a coarse filter by vacuum filtration.
10) Place filter w/sample back to baking tin; place tin and sample in batch for drying.
11) Vacuum filter the sample again, this time using a coarse filter. Repeat step 10.
12) Vacuum filter the sample again, this time using a fine filter. Repeat step 10.

13) Once there are enough samples for drying, dry the batch for 2 hours at 100°C. Allow to cool for 15 minutes and reweigh the samples (g, to the mg).
14) Discard the weighed filter w/sample to the trash when finished.

Notes on steps 6-9: This is a general procedure for filtering samples. Experience with samples will help dictate exact protocols to be taken. For example, if a sample looks extremely clean and was taken in mid-water, a sand break and coarse filtration may not be necessary. If the sample is dirty, perhaps two or more coarse filtrations will have to be performed before the final fine one. The intention of using different sized filters is not to determine TSS size; the intention is to allow the less expensive coarse filters to do as much of the work as possible so that only 1 fine filter is needed to remove the final amount of TSS remaining in the sample. In all cases where there is a suspected sand component, that information is important because sand particles are often anomalous components of a sample and a sand break should be performed. Raw data from this procedure is entered into a spreadsheet that uses the information to calculate the final TSS. For the SSS, this spreadsheet is a Microsoft Excel program.

**Data Analysis:**

TSS data along with water application and discharge rates can be combined to give the following information:

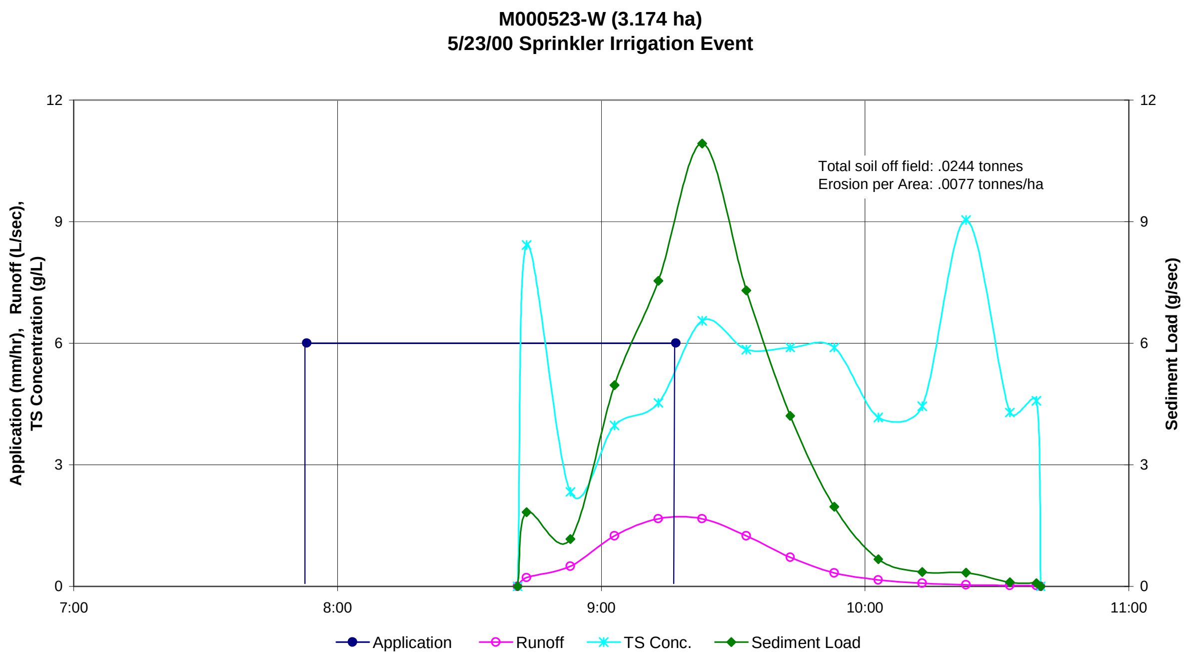
- Runoff rate over time giving the total amount of water discharged
- Irrigation water application rate over time giving the amount of water applied
- Area of irrigation
- Sediment concentration (processed in lab as Total Suspended Solids).

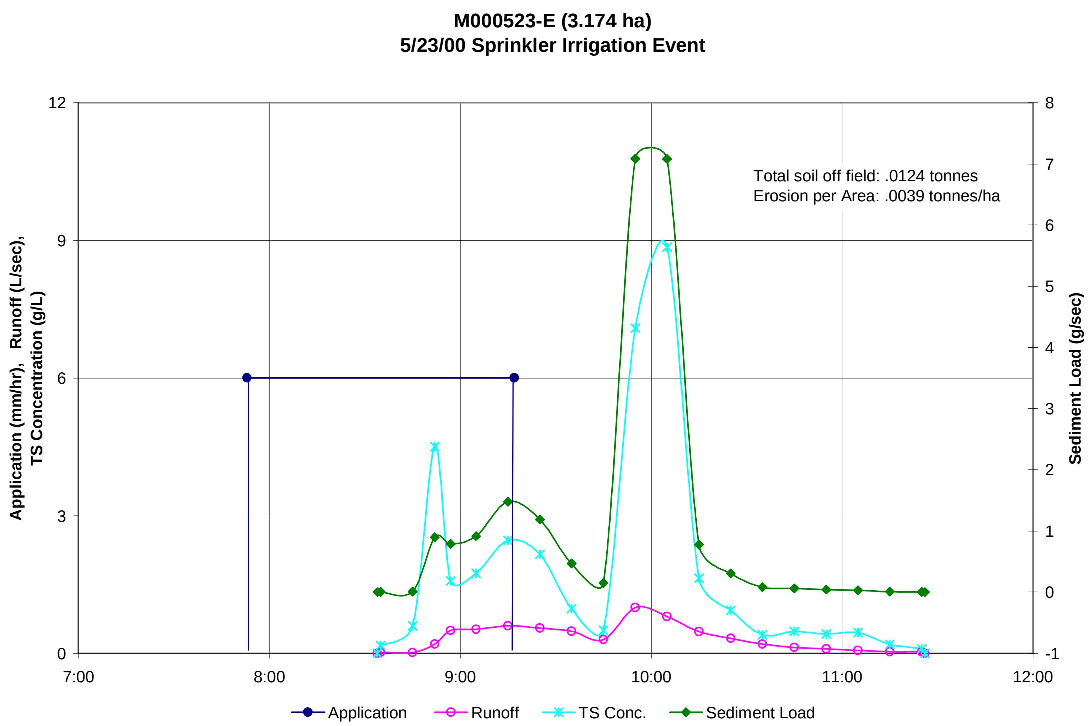
The load rate (mass/unit time) is calculated from these data as the product of sediment concentration and water flow rate. A load rate per area (mass/area/unit time), and a total load (mass) based on load rate over time are also calculated. Certain field parameters are recorded that have large effects on erosion and sediment movement. These are:

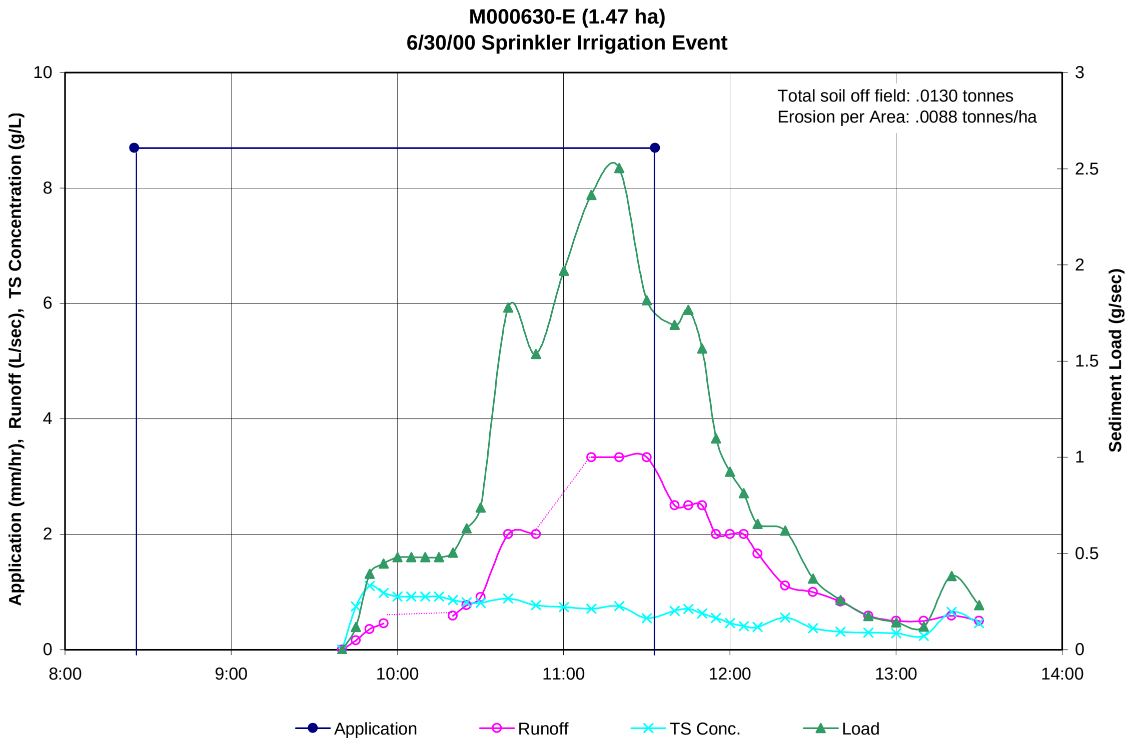
- The slope of the field
- Stage of the crop
- Type of soil
- Last tillage of the soil.

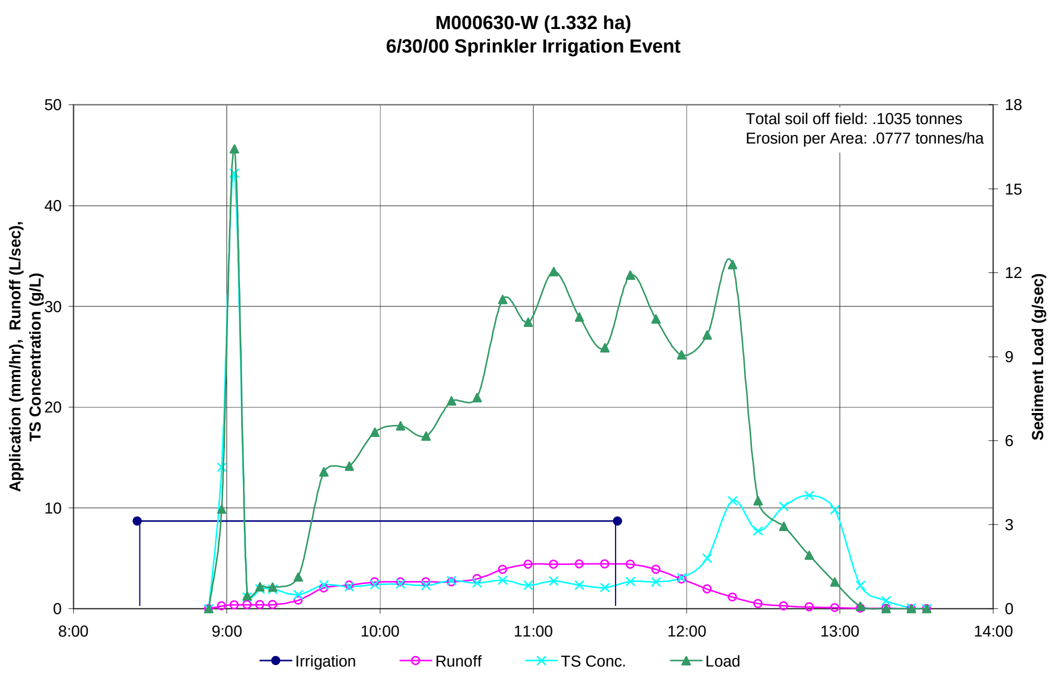
Finally, irrigation and storm runoff data is upscaled to reflect total appropriate area of agricultural row cropland use in the Salinas Valley.

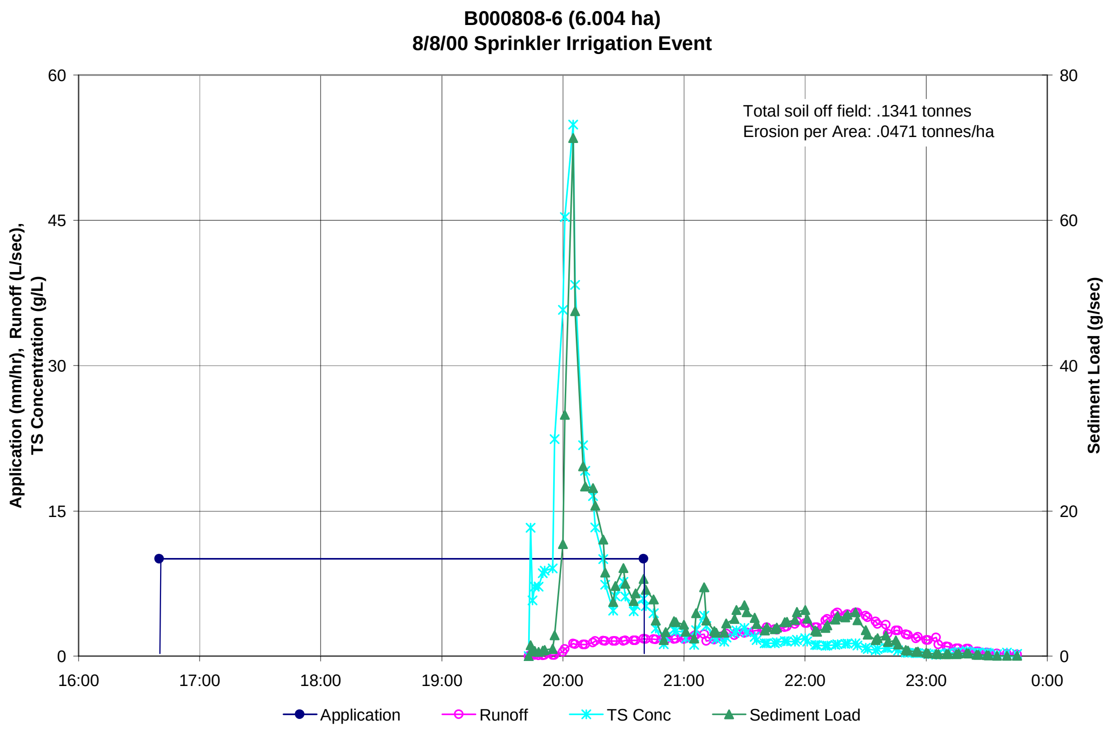
## Appendix 2: Graphs of Irrigation and Storm Event Dynamics

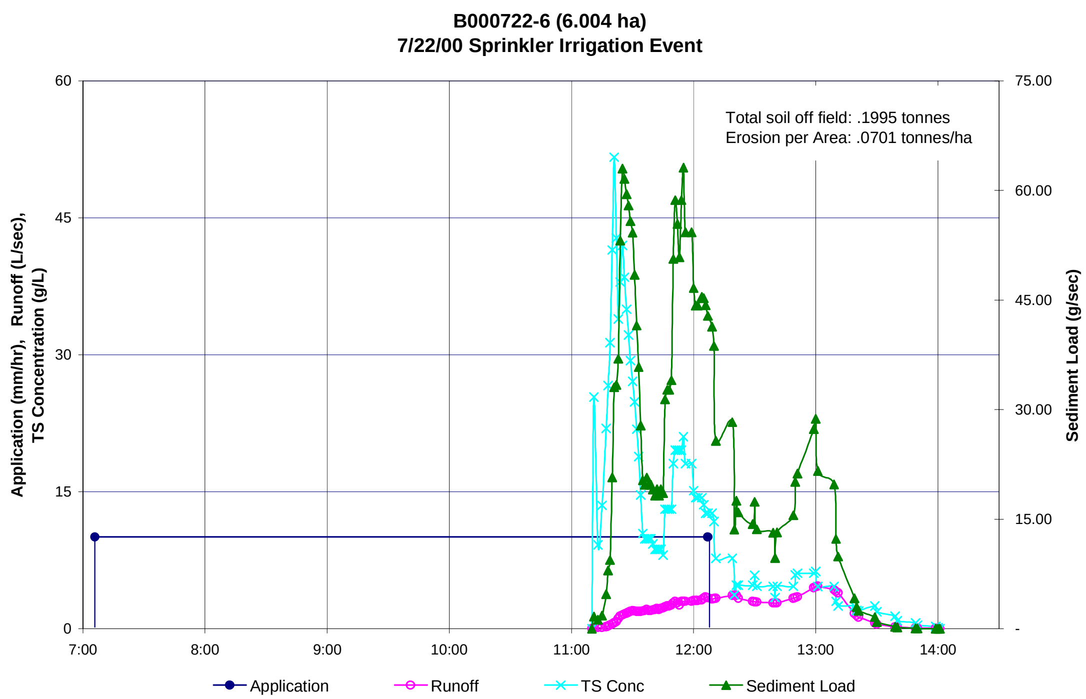


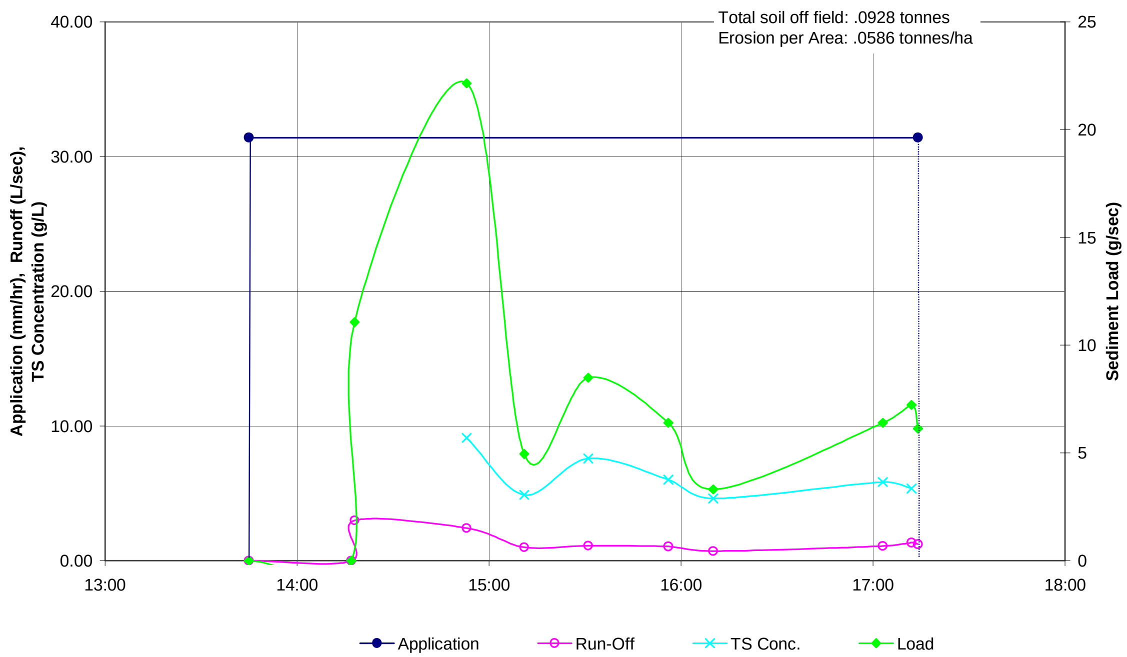

M000630-E (1.47 ha)
6/30/00 Sprinkler Irrigation Event
Total soil off field: .0130 tonnes
Erosion per Area: .0088 tonnes/ha
Application (mm/hr), Runoff (L/sec), TS Concentration (g/L)
Sediment Load (g/sec)
10
8
6
4
2
0
3
2.5
2
1.5
1
0.5
0
8:00
9:00
10:00
11:00
12:00
13:00
14:00
Application
Runoff
TS Conc.
Load


M000630-W (1.332 ha)
6/30/00 Sprinkler Irrigation Event
Total soil off field: .1035 tonnes
Erosion per Area: .0777 tonnes/ha
Application (mm/hr), Runoff (L/sec), TS Concentration (g/L)
Sediment Load (g/sec)
50
40
30
20
10
0
18
15
12
9
6
3
0
8:00
9:00
10:00
11:00
12:00
13:00
14:00
Irrigation
Runoff
TS Conc.
Load

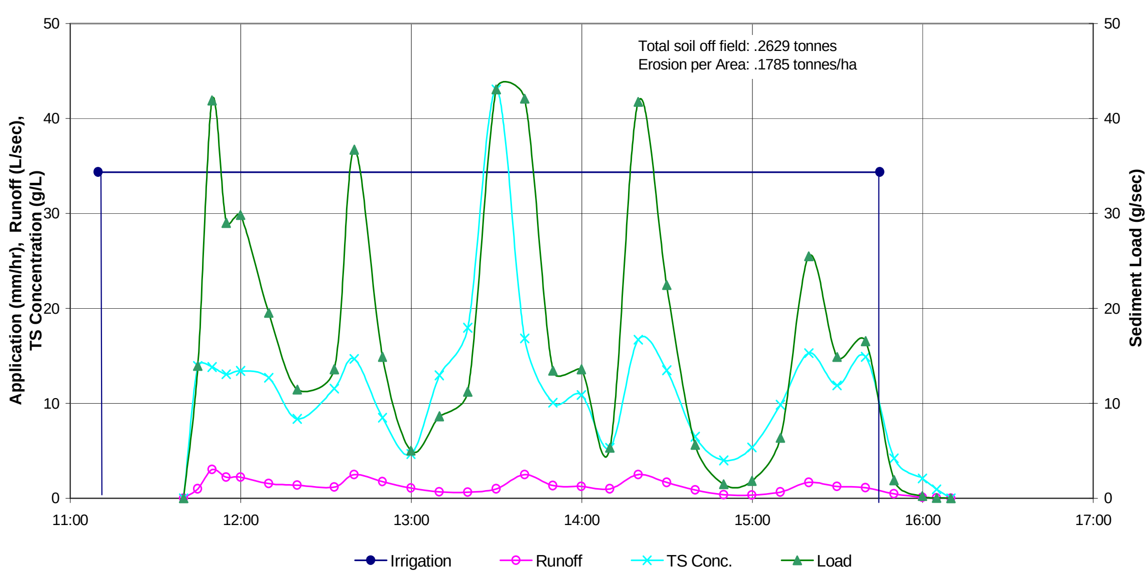

B000808-6 (6.004 ha)
8/8/00 Sprinkler Irrigation Event
Total soil off field: .1341 tonnes
Erosion per Area: .0471 tonnes/ha
Application (mm/hr), Runoff (L/sec), TS Concentration (g/L)
Sediment Load (g/sec)
60
45
30
15
0
80
60
40
20
0
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Application
Runoff
TS Conc
Sediment Load

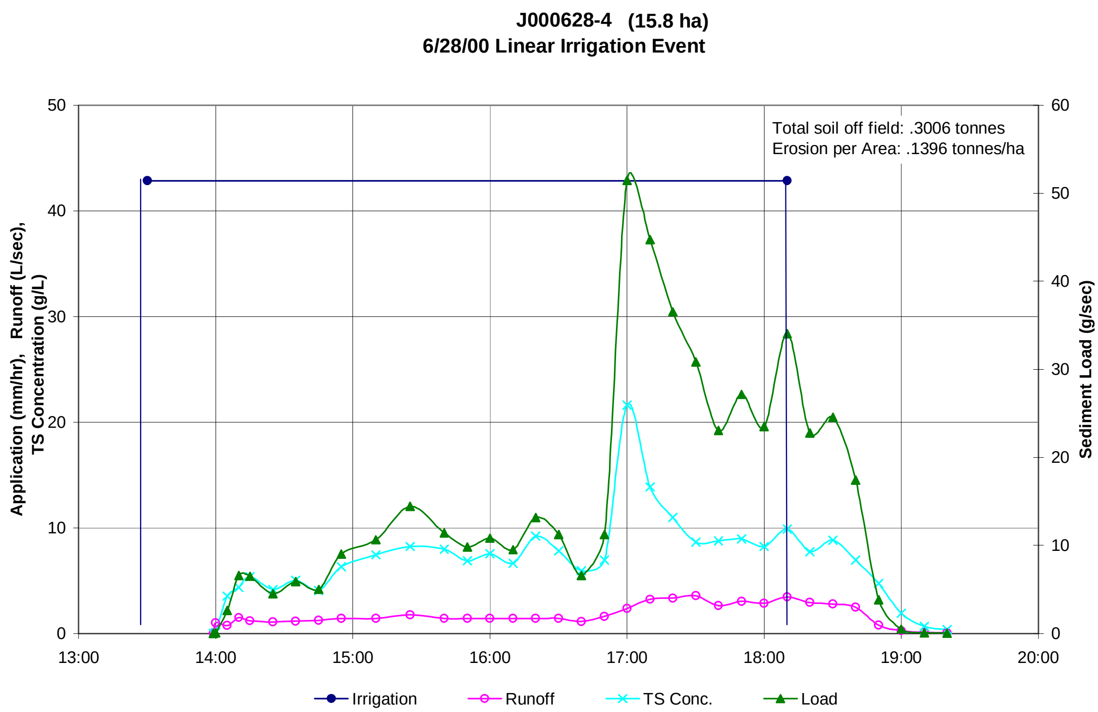

B000722-6 (6.004 ha)
7/22/00 Sprinkler Irrigation Event
Total soil off field: .1995 tonnes
Erosion per Area: .0701 tonnes/ha
Application (mm/hr), Runoff (L/sec), TS Concentration (g/L)
Sediment Load (g/sec)
60
45
30
15
0
75.00
60.00
45.00
30.00
15.00
-
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
Application
Runoff
TS Conc
Sediment Load

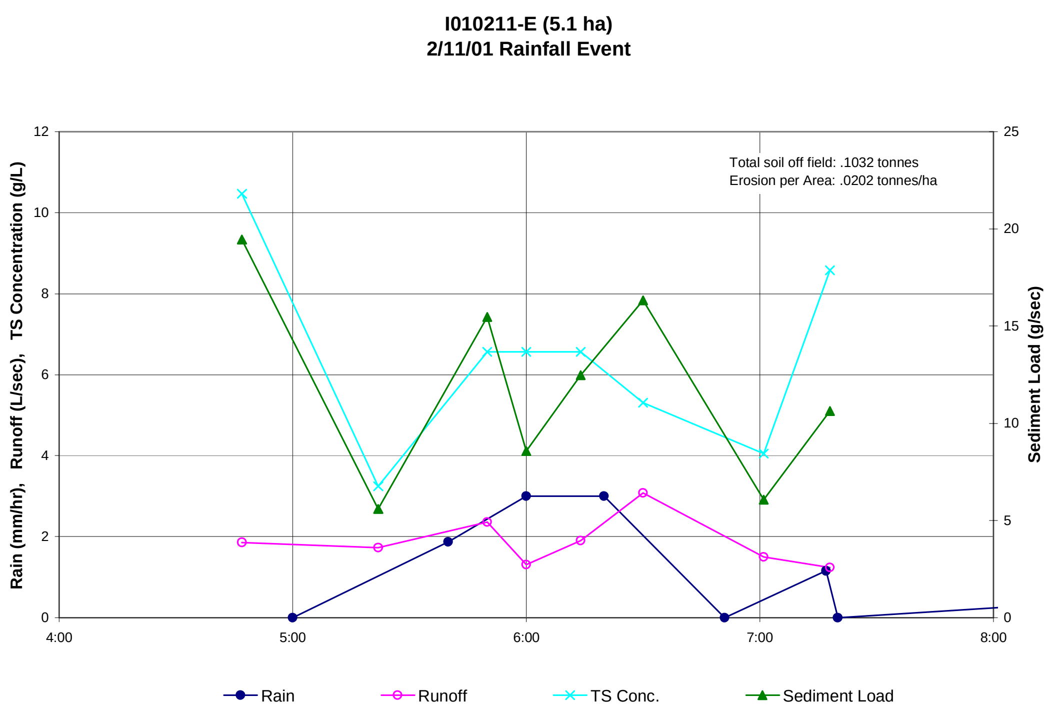
**J000622-4 (15.8 ha)**
**6/22/00 Linear Irrigation Event**



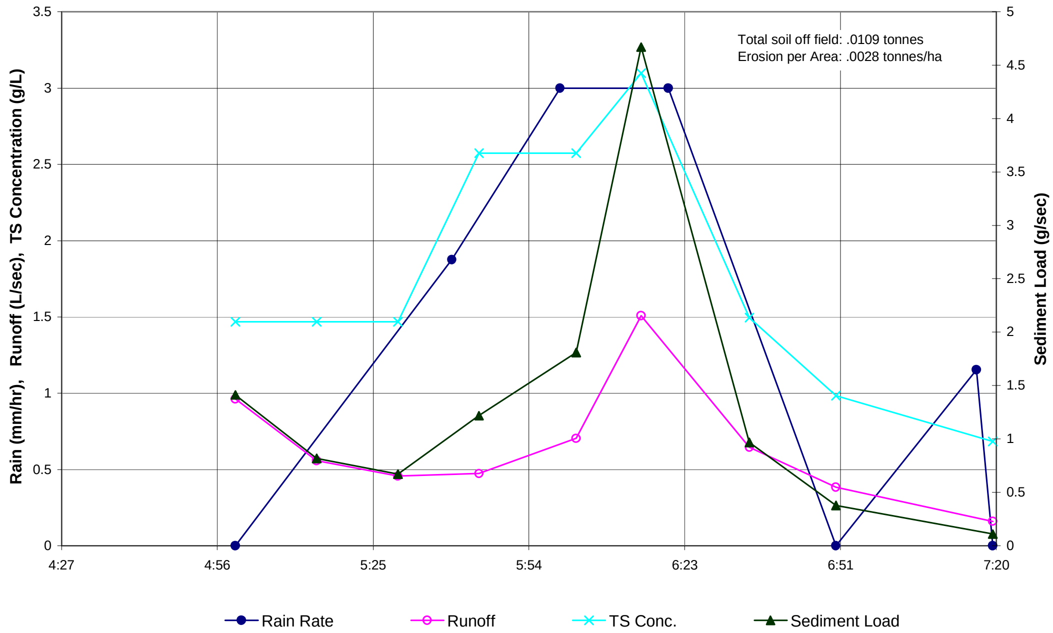

**J000628-24 (1.473 ha)**
**6/28/00 Linear Irrigation Event**



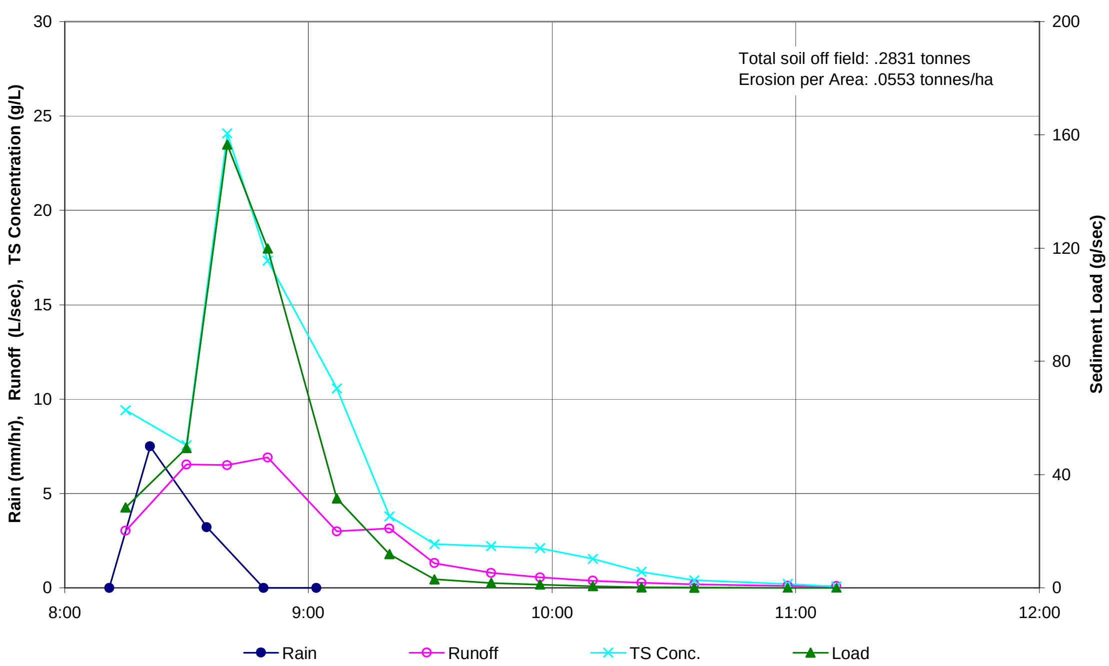

J000628-4 (15.8 ha)
6/28/00 Linear Irrigation Event
Total soil off field: .3006 tonnes
Erosion per Area: .1396 tonnes/ha
Application (mm/hr), Runoff (L/sec), TS Concentration (g/L)
Sediment Load (g/sec)
0
10
20
30
40
50
60
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
Irrigation
Runoff
TS Conc.
Load


I010211-E (5.1 ha)
2/11/01 Rainfall Event
Total soil off field: .1032 tonnes
Erosion per Area: .0202 tonnes/ha
Rain (mm/hr), Runoff (L/sec), TS Concentration (g/L)
Sediment Load (g/sec)
0
2
4
6
8
10
12
5
15
20
25
4:00
5:00
6:00
7:00
8:00
Rain
Runoff
TS Conc.
Sediment Load

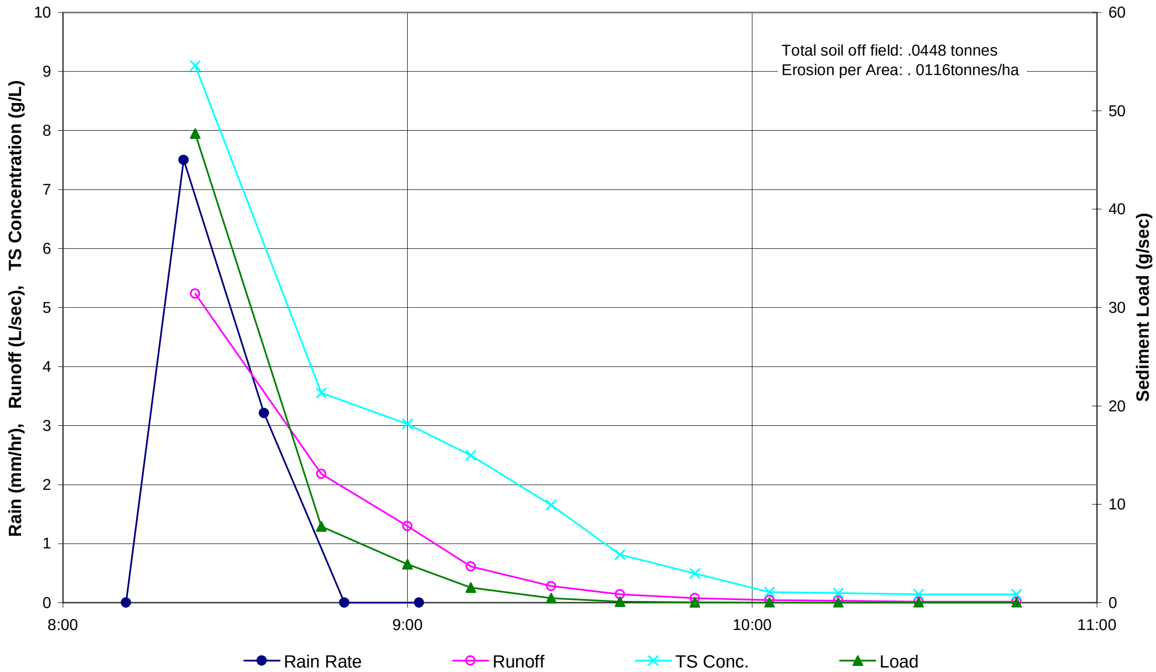
**I010211-W (3.8 ha)**
**2/11/01 Rainfall Event**



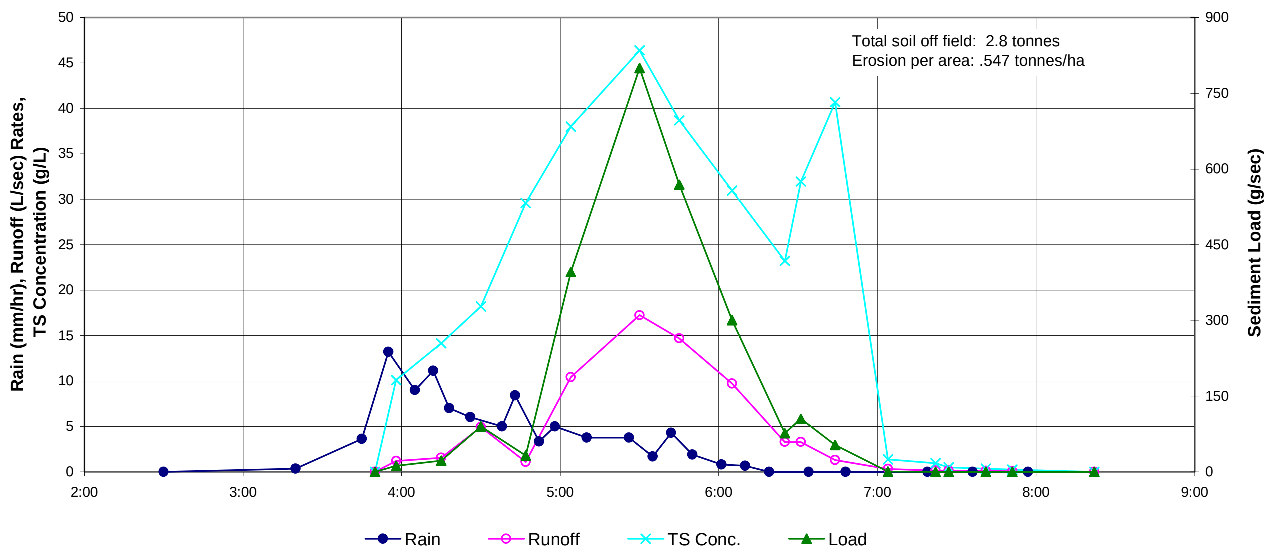

**I010212-E (5.1 ha)**
**2/12/01 Rain Event**

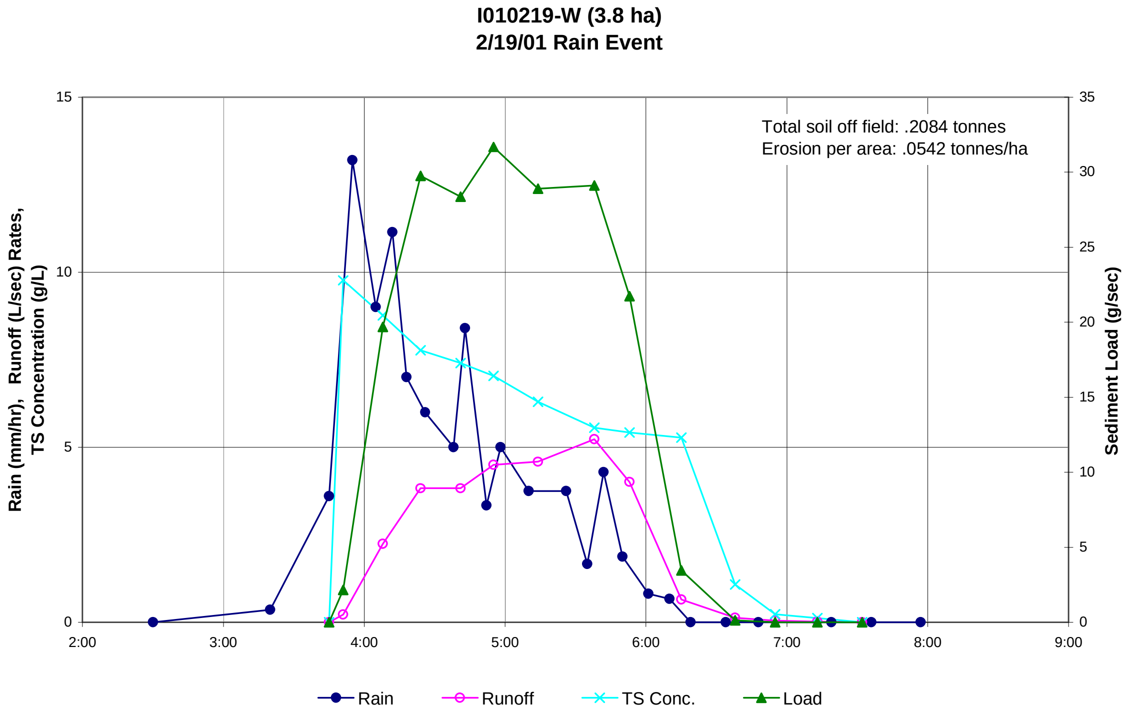


**I010212-W (3.8 ha)**
**2/12/01 Rain Event**

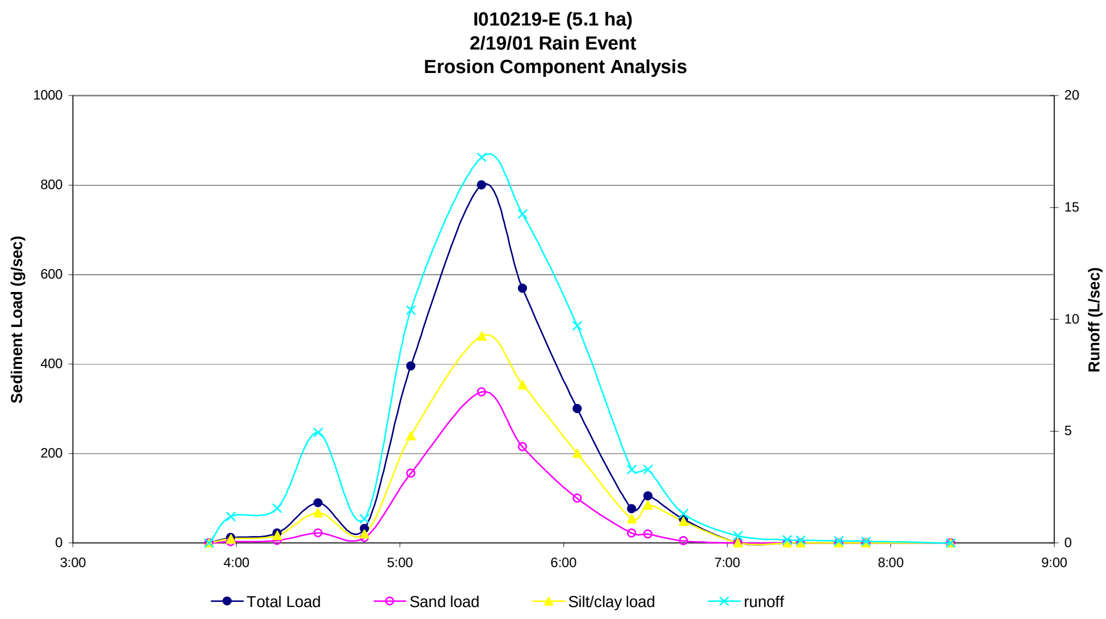


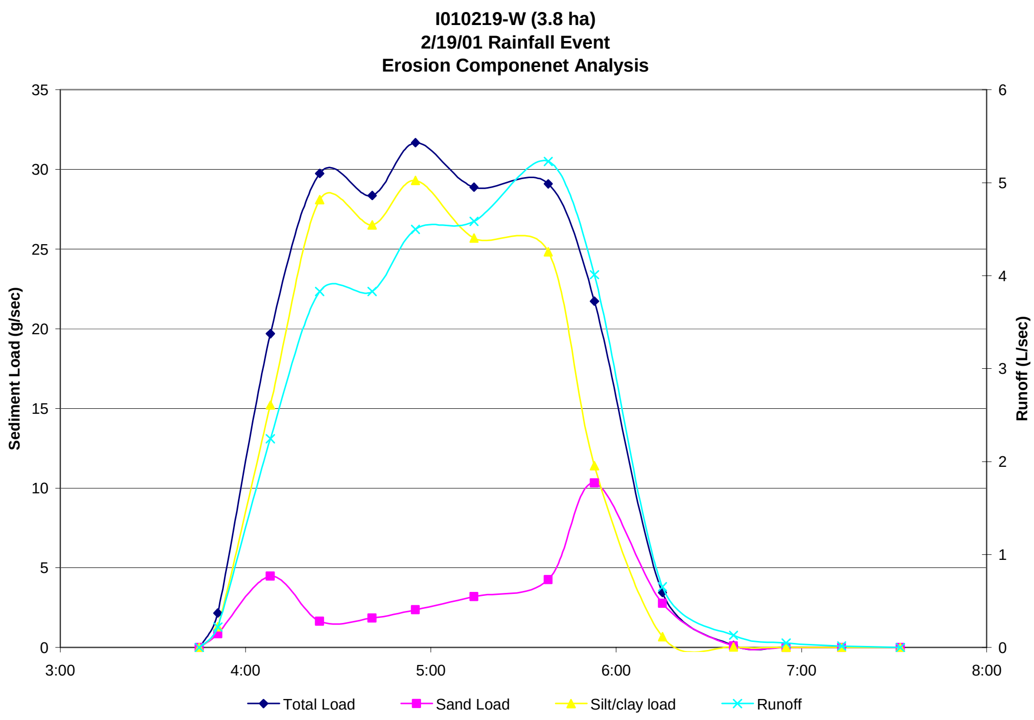

**I010219-E (5.1 ha)**
**2/19/01 Rain Event**

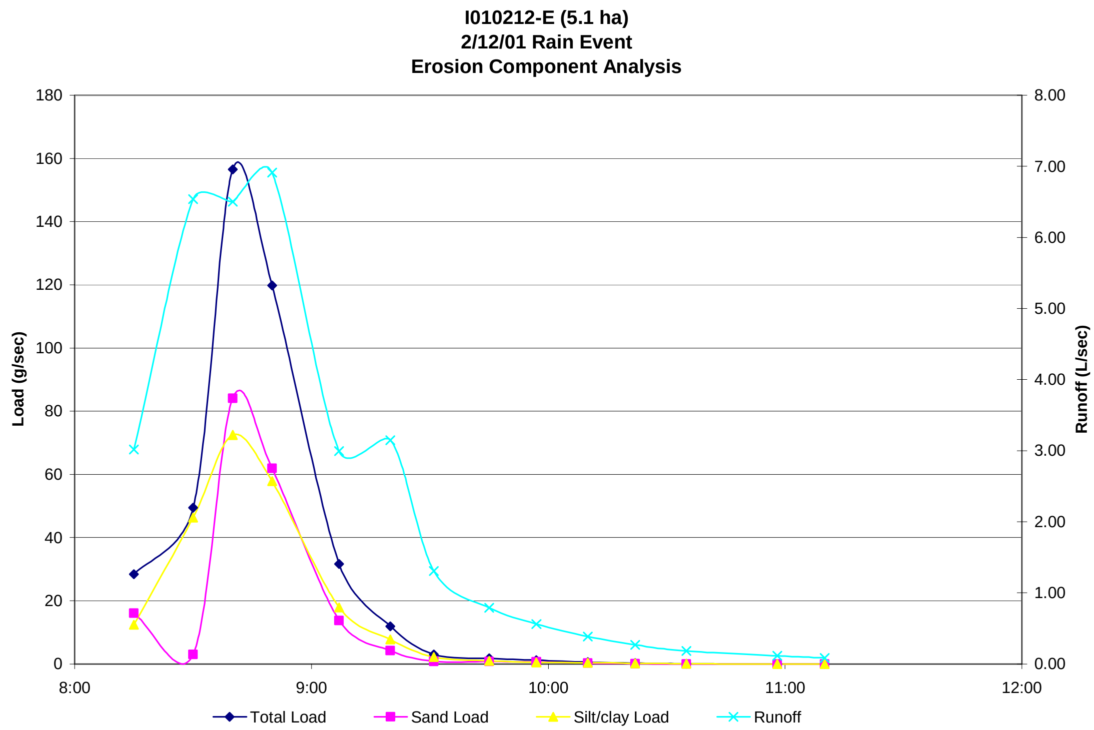


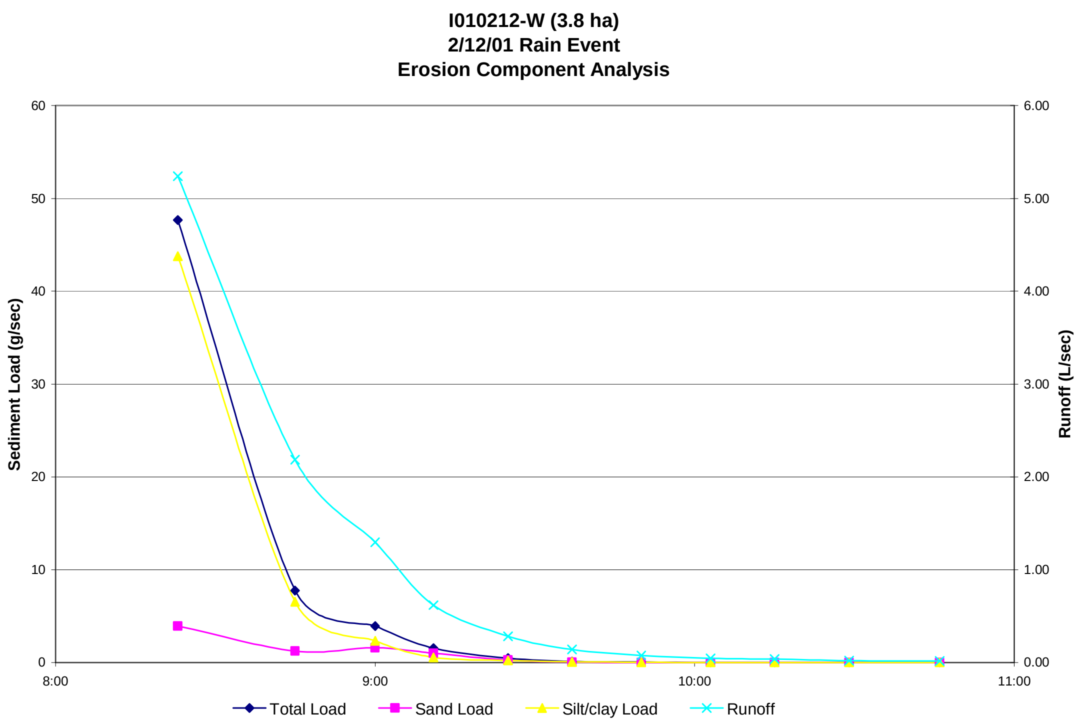

I010219-W (3.8 ha)
2/19/01 Rain Event
Total soil off field: .2084 tonnes
Erosion per area: .0542 tonnes/ha
Rain (mm/hr), Runoff (L/sec) Rates, TS Concentration (g/L)
Sediment Load (g/sec)
15
10
5
0
35
30
25
20
15
10
5
0
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
Rain
Runoff
TS Conc.
Load

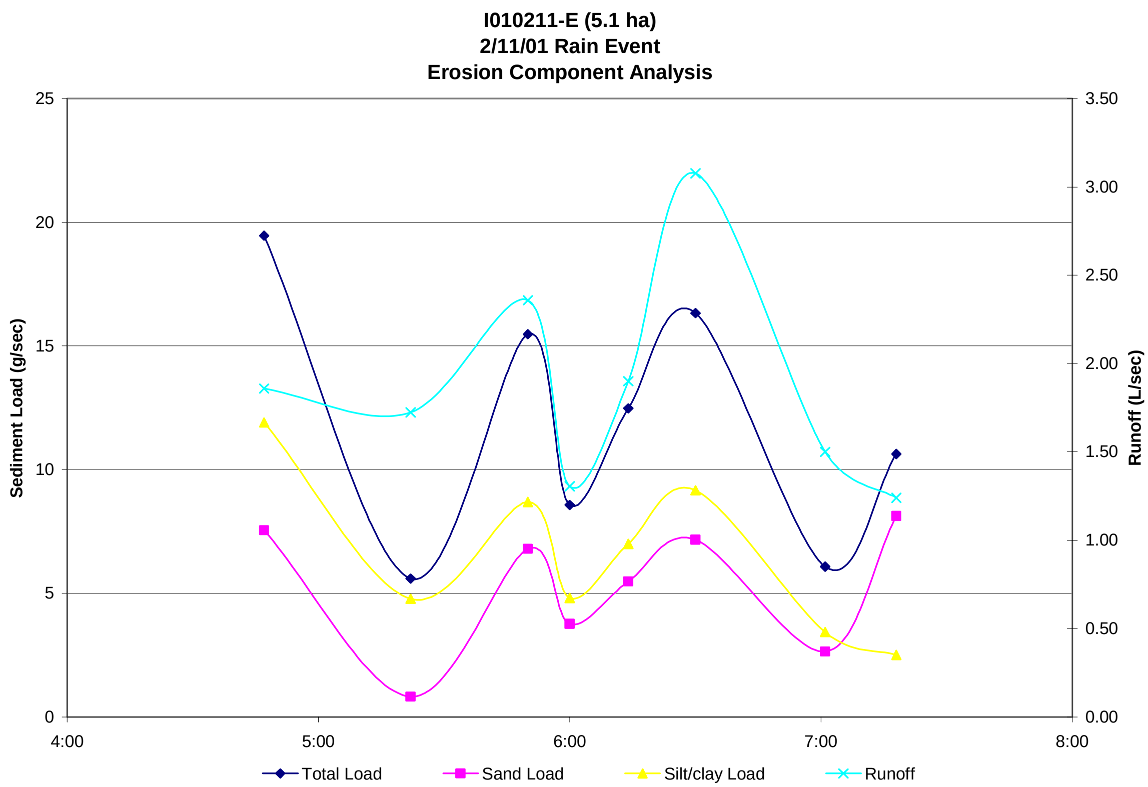
# Appendix 3: Graphs of Load Erosion Component Analysis for Storm Events

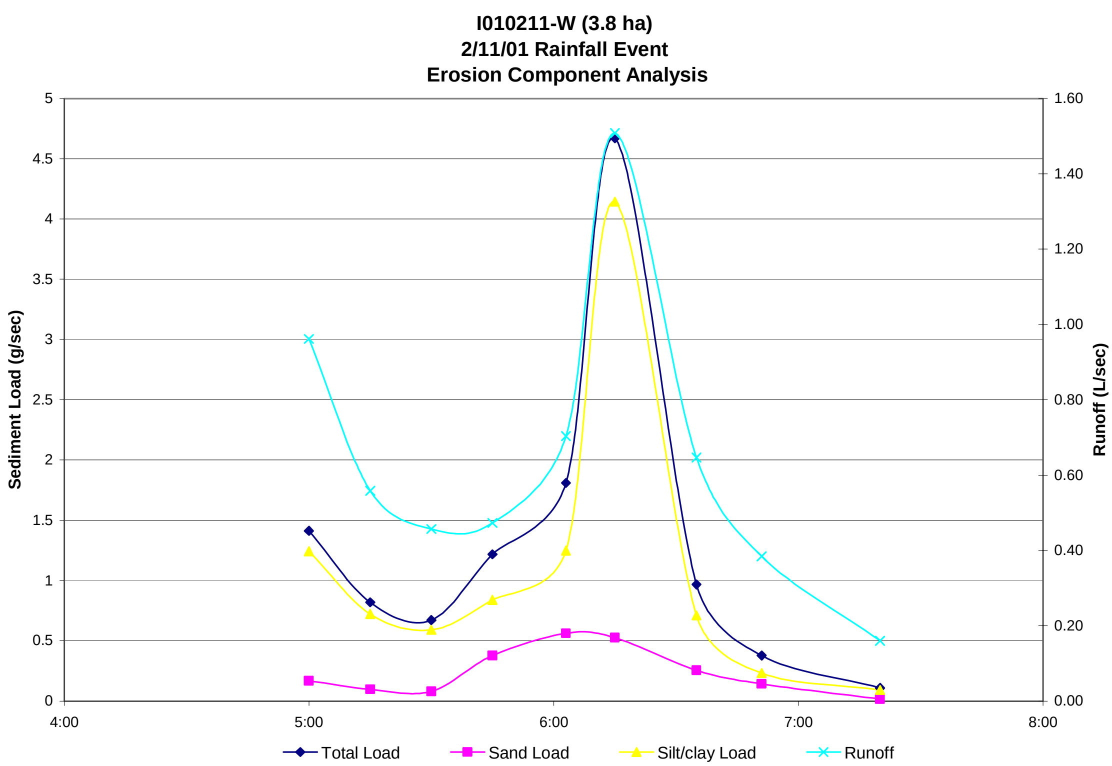



I010212-E (5.1 ha)
2/12/01 Rain Event
Erosion Component Analysis
Load (g/sec)
Runoff (L/sec)
180
160
140
120
100
80
60
40
20
0
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
8:00
9:00
10:00
11:00
12:00
Total Load
Sand Load
Silt/clay Load
Runoff


I010212-W (3.8 ha)
2/12/01 Rain Event
Erosion Component Analysis
Sediment Load (g/sec)
Runoff (L/sec)
60
50
40
30
20
10
0
6.00
5.00
4.00
3.00
2.00
1.00
0.00
8:00
9:00
10:00
11:00
Total Load
Sand Load
Silt/clay Load
Runoff


I010211-E (5.1 ha)
2/11/01 Rain Event
Erosion Component Analysis
Sediment Load (g/sec)
Runoff (L/sec)
25
20
15
10
5
0
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
4:00
5:00
6:00
7:00
8:00
Total Load
Sand Load
Silt/clay Load
Runoff


I010211-W (3.8 ha)
2/11/01 Rainfall Event
Erosion Component Analysis
Sediment Load (g/sec)
Runoff (L/sec)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
4:00
5:00
6:00
7:00
8:00
Total Load
Sand Load
Silt/clay Load
Runoff