How Land-Use Affects Sediment Yields and Surface Runoff in a Small Semi-arid Watersheds

A Case Study of the El Toro Watershed

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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.

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Project leader.
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Abstract

El Toro Creek Watershed is a small semi-arid watershed known to exhibit high transmission loss and produce flash floods. In order to compare land-use types and slope to sediment yields, El Toro Creek Watershed was monitored for suspended sediment and surface runoff in February 2001. Slope, soil type, and land-use sub-basin characteristics were delineated using Geographical Information Systems and used to explain suspended sediment transportation and surface runoff in the watershed. Steep slopes associated with non-vegetated banks exhibited high loads of sediment and surface runoff. Lack of sediment to the lower watershed from upstream depositional areas has produced stream bank failure in El Toro Creek. Revegetation of theses downstream banks would help decrease erosion from creek bed and alleviate flooding in the lower portion of this small semi- arid watershed.

Introduction

Small semi-arid watersheds containing multiple land-use practices exhibit diverse levels of surface runoff and sediment yield. Land-use alterations such as urban development, agriculture, grazing, golf courses, and open space affect interactions in the watershed. One example of land-use alteration is the extension of urban development into a small semi arid watershed's floodplain, causing changes in stream morphology and hydrological processes. Lowland areas in a watershed will flood more frequently when impervious surfaces from urban development cause surface absorption to decrease. For example, Ralson Creek Watershed in Iowa exhibited an increased frequency and magnitude of flooding when urban development grew 25% over a thirty-eight year period (Barnard 1978). At the watershed scale soil and water conservation practices may significantly decrease surface runoff impacts in small semi-arid watersheds. Geologic and hydrologic process interactions can provide valuable information for evaluating land-use affects. It is necessary to build a deeper understanding of these processes in a watershed in order to suggest watershed polices. This study will focus on stream monitoring, historical watershed background, and land-use practices in a small semi-arid watershed for the purpose of understanding land-use affects on surface runoff and sediment yields.

El Toro Creek Watershed

El Toro Creek Watershed case study focused on subjects relating land-use, geology/hydrology, land modification, and policy implications. The goal was to relate collected monitoring data to land-use in the El Toro Creek Watershed. El Toro Creek Watershed is located off of Highway 68 just west of Salinas, California (Figure 1). El Toro area is an example of a small semi-arid watershed containing several land-use practices. Few studies in the El Toro Creek Watershed area have provided information that helps to explain system interaction. This study will supply improved facts on semi-arid watersheds. A flash flood system such as El Toro Creek Watershed provides a difficult environment for understanding these system interactions. Knowledge shared with interested community participates can be beneficial for future watershed planning.

Community participation in El Toro Creek Watershed has aided in the development of this study and progress of watershed restoration projects. Community participation in making watershed management decisions can help improve planning.
" The perceived effects of participatory watershed planning include increasing awareness of watershed conditions, heightening interagency coordination, reaching consensus on resource management plans, and lending legitimacy to final plans"(Duram 1999). A Watershed Council in El Toro Creek Watershed was established to discuss community concerns.

On January 19, 2000 the first El Toro Creek Watershed meeting provided educational background on invasive weeds and an open forum discussion about community concerns. The concerns that were discussed by community attendants on January 19th for El Toro Creek Watershed were flooding and erosion The direct watershed concerns made by community members at this first meeting were: creek bank erosion, sandbar erosion, landslides, surface runoff from development, impervious surfaces causing flooding, and downstream impacts of flooding.

Currently local landowners and governmental agencies (Bureau of Land Management, Watershed Institute at California State University Monterey Bay, and County Parks) are collaboratively working to increase biodiversity in the local ecosystems and decrease flooding. Sediment concentrations and surface runoff monitoring will provide the El Toro Watershed community with educational material on geologic and hydrologic process interactions associated with land-use.

Figure 1. Location of El Toro Creek Watershed
in relation to Salinas, California (Newman 1999)

I Policy:

Watershed policy planning is effective if three steps are taken:(1) first recognizing the watershed issues, (2) discussing potential solutions to the issues, and (3) having active participation from community members. El Toro Creek Watershed Council is designed to determine these watershed issues and the potential solutions that could be implemented. The El Toro Creek Watershed community has stressed concerns about erosion and flooding, but no policy implications have currently been addressed. Possible policy issues that could decrease surface runoff and sediment yields in El Toro Creek Watershed include: an urban growth boundary, stream buffers, and rotation grazing near stream banks.

Urban development increases surface runoff with increasing impervious surfaces. Urban containment would (1) promote compact, contiguous, and accessible development provided with efficient public services and (2) preserve open spaces, agricultural land and environmentally sensitive areas that are not currently suitable for development (Nelson 2000). Under an urban containment policy, rangeland areas in El Toro Watershed could be categorized as agricultural lands and therefore considered non-developable areas.

Stream buffers in El Toro Creek Watershed would provide stabilization of stream banks and establish a non-destructive flooding zone. In Vermont, legislation "Act 250" was passed thirty years ago to protect streams… "rapid and unplanned development on their fragile mountainous slopes and unstable slopes caused substantial environmental harm (Sanford, 2000)." Lowland areas that are frequently flooded could be turned into riparian buffer strips and protect local areas. This option would require government subsides of current housing property in the El Toro Creek area.

Grazing stream banks and riparian zones causes stream bank destabilization increasing runoff and erosion (Lyons 2000). Rotational grazing within riparian zones as a management practice reduces the environmental affects of increased runoff and erosion (Lyons 2000). The largest land-use in El Toro Creek Watershed is grazing of cattle. This is a valuable resource to the community. With sustainable management of rangelands grazing could reduce erosion and surface runoff to streams.

II Objectives:

The goal of this study was to use stream monitoring to understand the dynamics of the El Toro Creek Watershed and the influences from land use. Three questions formed the basis of this goal:

1. How has land use changed in El Toro Creek over the past 30 years?

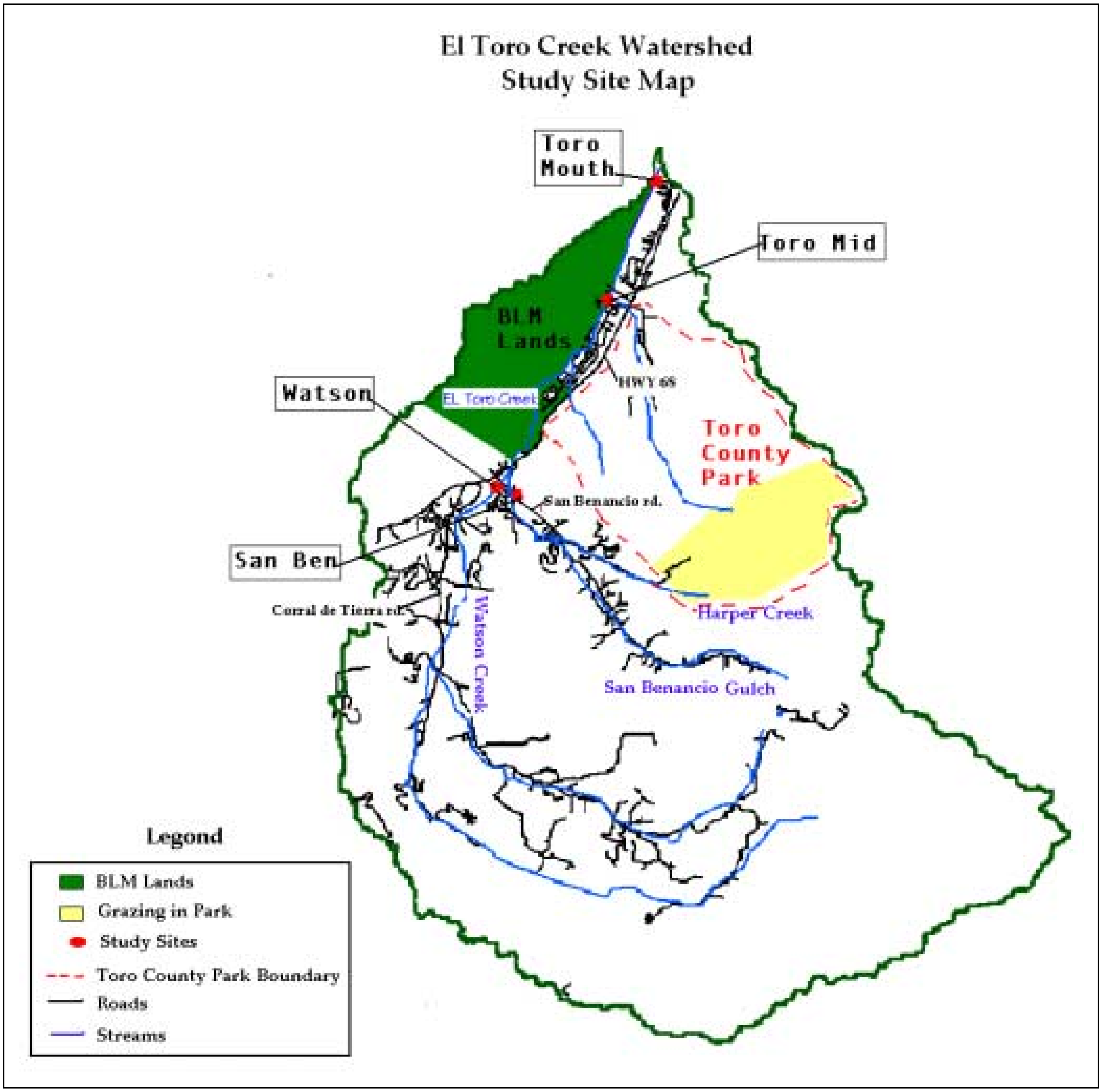
2. Does land use influence sediment yield and surface runoff?

3. Can El Toro Watershed be monitored effectively to predict sediment yield and surface runoff?

III Land use in El Toro Creek Watershed:

El Toro Watershed has a basin area of 36.6mi^2 containing several land-use practices: rangeland, urban, golf course, agricultural, and open space (Fig. 2). Land-use practice is a key element when considering how to monitor and analyze surface runoff and sediment yields in the watershed. Toro is one of the planning areas in Monterey County that has experienced rapid land use growth in the past twenty years. Simultaneously this area faces significant resource and infrastructure constraints in terms of water and traffic (Monterey County General Plan 1999). This section provides information on El Toro Creek Watershed land-use practices and will be used to evaluate stream monitoring of surface runoff and sediment yield.

Figure 2: El Toro Creek Watershed Study Site Map



Urban development is located in the upper and lower portions of El Toro Creek Watershed. Residential development is the second largest land-use area in the watershed. Urban development of the lower El Toro Creek watershed has increased after 1966.

Aerial photos taken in 1966 show evidence of grated dirt roads in the low land areas adjacent to El Toro Creek, suggesting this area was soon to be developed. Houses in the upper watershed are mostly scattered with a small, condensed community located at the San Benancio road and Highway 68 convergence. Monterey County General Plan indicated that the Toro area increased residential land use by almost 384 percent compared to existing residential use in 1983. Future housing is planned for the El Toro Creek Watershed area.

Rangelands, consisting of cattle and sheep grazing, are scattered throughout El Toro Creek Watershed. The grassland ecosystem encompasses a majority of the watershed. This provides a suitable environment for the grazing of cattle and sheep. Cattle are grazed year round, where as, sheep grazing occurs only a few months out of the year. A majority of the grazing area is located on privately owned land with the exception of Toro County Park and BLM.

Toro County Park incorporates a $2mi^2$ cattle grazing area that is rented out to local ranchers in the area. Toro County Park is operational year round and management requires only fifty cows grazed in the $2mi^2$ area. The geographic area of grazing in Toro County Park extends from Harper Canyon to Marks Canyon (Figure 2). Sheep grazing occurs for a few months on BLM lands and is used to eradicate weeds in the grassland habitat located adjacent to El Toro Creek (Figure 2). The locations of rangelands in El Toro Creek Watershed are important for analyzing surface runoff and sediment yields.

El Toro Creek Watershed contains one golf course, the Corral de Tierra club, located on Corral de Tierra road. The $0.168mi^2$ area the private golf course has established is about 0.005% of the El Toro Creek Watershed area. A portion of Watson Creek meanders through the golf course and is not known to contain flow after the grounds are watered. The golf course is not categorized as an open space for this study in order to differentiate between natural land and golf coarse land-use affects.

Toro County Park, BLM, and privately owned land characterize open spaces in El Toro Creek Watershed. Toro County Park is a natural, generally undisturbed, area containing grassland, chaparral, and oak woodland ecosystems. The recreational activities the park provides are hiking, biking, horseback riding, and picnicking in designated areas. Baseball fields, trails and fire roads are the only development the County has implemented in the park boundary. The fire roads surrounding the park contain trenches built diagonally to steep slopes to prevent gully formation. In most places trench management is effective. In some places large gullies have formed parallel to the dirt roads.

Another open space in El Toro Creek Watershed is BLM land that was acquired in 1994 from the closure of Fort Ord Military Base. Few paved roads still exist, and both paved and dirt roads are used as recreational trails for biking, hiking, and horseback riding.

Agricultural lands in El Toro Creek Watershed represent less than one percent of the total surface area. Located in the watershed are one lettuce field and a few vineyards. The one-acre lettuce plot is located near the outlet of the watershed, but no monitoring locations were established below the field. For this reason the land-use is noted, but not considered when analyzing stream-monitoring results. The vineyards are located in San Benancio Gulch and Corral de Tierra Valley. The few plots are about one- two acres in area and newly developed. Vineyard irrigation management is not known and precipitation will be considered only the influence to surface runoff and sediment yields.

IV Geology and Hydrology of El Toro Creek Watershed:

El Toro Creek Watershed is a complex system of geologic and hydrologic processes involving multiple soil types, steep slopes, is associated with low annual precipitation. Understanding these process interactions help to define quantitative measurements of sediment yields from El Toro Creek Watershed.

Formation morphology and associated soil type is important information when assessing hydrologic processes in a watershed. There are three formations located in the El Toro Creek Watershed: Pleistocene Aromas Sandstone, Pleistocene Paso Robles-fluvial deposits, and Miocene Santa Margarita Sand (West 1999, Smith 2001). The Paso Robles formation is a highly erodible formation located in the upper watershed. The Aromas Sandstone, less erodible and derived from Quaternary sand dunes is located in the lower watershed. The Miocene Santa Margarita Sand is located in the fluvial deposits of El Toro Creek. Diverse types of soils are located throughout the watershed. A majority of these soils contain high percentages of sand and low levels of clay. Clay levels increase with soil depth and increase near watershed outlet. This study focuses on soil types located in the streambeds of each sub-basin.

El Toro Creek Watershed's diverse terrain, low land valleys, high mountainous ridges, and sandy slopes generate high levels of erosion. The highest peak is Mt. Toro (3800 ft) located near the rear of San Benancio Gulch. The lowest elevation is located near the outlet of the watershed in the El Toro Creek floodplain, which ranges from zero to two degrees of slope. Slopes influence surface flow, channel morphology, and sediment transportation. Gradient is only one contributing factor of the watersheds geologic and hydrologic processes. Precipitation coupled with slope gradients determines erosion thresholds within the watershed.

The semi-arid flash flood system of El Toro Creek Watershed has characteristics of low annual precipitation, sandy soils, and steep slopes. An average annual precipitation of 14inches (356mm) and a high sandy soil substrate, contribute to high infiltration rates. The hydraulic conductivity in the alluvial deposits has been known to be as high as 11 inches/hour (West 1999). The high hydraulic conductivity levels in the watershed, transmission loss, require high intensity storms to saturate soils and produce overland flow. High infiltration levels and low precipitation levels create an environment with very little surface runoff. The streams in El Toro Creek Watershed for this reason are categorized as ephemeral, which means the streams contain flow less than 25 percent of the year.

Land surface morphology produces a network of streams that combine to form El Toro Creek, the outlet that empties into the Salinas River. Four tributaries form to create El Toro Creek: Harper Canyon, Watson Creek, San Benancio Creek, and Corral de Tierra (Figure 2). Harper Creek drains from El Toro County Park, converges with San Benancio Gulch. Corral de Tierra Creek converges with Watson Creek in Corral de Tierra Valley. Watson Creek and San Benancio Gulch converge directly below Highway 68 and San Benancio road to form El Toro Creek. All streams contain no flow majority of the year with the exception of observed year round flow in Watson Creek at the San Benancio Road and Highway 68 convergence. This year round flow is a perennial stream entering Watson creek below Corral De Tierra golf course. The El Toro Creek Watershed stream network helps to characterize the fluvial process occurring in the upper and lower watershed.

The single thread, high sandy soil streambed of El Toro Creek Watershed produces high levels of deposition and aggredation. A 1998 study of El Toro Creek classified the stream as exhibiting an arroyo cycle (West 1999). The arroyo stream transports large amounts of sediment and deposits in areas adjust the slope gradient in order to continue to move more of the sediment supply. West, 1978 said “ The heaviest sand loadings are found in steep ephemeral streams in semi-arid regions, where large quantities of sand can be transported during brief and infrequent flash flows… if the general attitude of the landscape permits it, of steep valley slopes adjusted to provide large competences needed to maintain grade.” A stream will always work towards equilibrium, in order to reduce energy use for transporting sediment. High sediment laden streams, such as El Toro Creek, are continually adjusting their streambeds through deposition and agredation.

V Alterations to Alleviate Flooding in El Toro Creek Watershed

Intense flooding of the lower El Toro Creek Watershed has caused governmental agencies to provide services for improving residential quality of life. BLM, the Watershed Institute at CSUMB, and the Monterey County Public Works have produced solutions to lessen flooding conditions in the lower El Toro Creek that have caused problems for several years. Streambed revegetation, riprap construction, and streambed dredging are projects used in the past to reduce flooding.

To alleviate or decrease flooding, Cal Trans (Monterey County Public Works) implemented a few construction and restoration projects in the El Toro Creek Watershed. Dredging El Toro Creek, installation of riprap, and willow planting were several of the short-term solutions that Cal Trans implemented. Dredging decreased sediment supplied to the lower El Toro creek and as a result decreased flooding. However, the lack of sediment to the creek increased downstream bank erosion. Cal Trans attempted to stabilize banks near Highway 68 with willow planting, but the vegetation never rooted. Rip- rap installments by Cal Trans at several bridges have created little check damns that prevent sediment transportation downstream and reduce downstream flooding.

BLM and Return of the Natives (affiliated with Watershed Institute at CSUMB) are currently working together to reduce erosion, flooding and increase biodiversity. In 1998 Steve West and Danielle Lowry from CSUMB were the first to study and implement a stream bank restoration project (West 1999). Unfortunately, El Niño conditions were not favorable for the survival of willows planted in the lower reaches of El Toro Creek (West 1999). Other restoration projects involving willows plugging along the banks of El Toro Creek have been very successful. Qualitatively, stream bank erosion in planted areas has decreased and for this reason future willow planting projects are in progress.

Methodology

Stream monitoring and geographic information systems were tools used to create a land-use map, slope map, and predict sediment loads for the El Toro Creek Watershed. Monitoring of El Toro Watershed was conducted based on standards from the Salinas Sediment Study (SSS) affiliated with California State University, Monterey Bay Watershed Institute. Field measurements located at seven sites were collected during the month of February 2001. Site locations were based on access and sub-basin boundaries. Boundaries were delineated based on land-use, slope, and soil type using topographic maps, Landsat 7 Thematic Mapper (1999), a digital elevation map, and Monterey County Soil maps (1978). The land-use map and slope maps were created using the geographic information system program, TNT-mips. This information was then used to determine land-use change and sediment yields in the El Toro Creek Watershed.

Land-use and Slope Maps

Advanced technology of Geographic Information Systems (GIS) was used to create a land-use map and slope map for analysis of past and present conditions of the El Toro Creek Watershed. GIS program TNT-mips was used in this study to delineate land-use and slope classifications. Past land-use classification was determined from 1966 aerial photos of the El Toro Creek Watershed area. Present classification was determined with spectral analysis of a 1999 Lansat 7 Thematic Mapper image with 30m resolution.

Slope classification of El Toro Creek Watershed was determined using a Digital Elevation Map (DEM) image with 30m resolution.

Land-use classification was conducted using reflectance values from the Landsat 7 1999 image using TNTmips. An area slightly larger than El Toro Creek Watershed was extracted from the Landsat 7 image for spectral analysis. Bare soil required for determining reflectance values was not present within the El Toro Creek Watershed so a portion of Salinas's agricultural bare fields was included.

An object will give off a multispectral signature that can be used to identify it throughout the raster providing a tool to determine land use (Paris 1999). Each band within a Landsat 7 image can be used to determine an object's reflectance value. This value is the amount of light reflecting off an object when the time when the satellite photo was taken. A bare soil will have a low reflectance in band 1 and increase in spectral signature until band 7 (having the largest percentage of reflectance). Bands 3 and 4 represent longer wavelengths and are most used in determining reflectance signatures from an object. The reflectance factor (RF) is only created as a vague spectral analysis and is not used in creating a land-use map. It is used to assist in separating objects within the watershed. The RF is to assure that herbaceous vegetation, seen as having the brightest reflectance values, is associated with band 4. Supervised and unsupervised classifications are then generated using the multispectural signatures of different objects to separate land-uses within the watershed.

A supervised and unsupervised classification is necessary in creating a detailed land-use map of an area. An unsupervised classification, also known as a 30-class auto-classification, was used to separate RF values previously assigned. From that step four classes were created: Green Woody Vegetation, Green Herbaceous Vegetation, Grassland, and Urban Development. A supervised classification was then used to extract known features from the unsupervised land-use map. The golf course was extracted from the herbaceous green vegetation classification and the agriculture field was extracted from the grassland classification. The area of interest, agricultural fields and golf course, was selected apart from the other reflectance values and new values were assigned. This was used for the golf course and agriculture field. The feature map created has six classes: (1) golf course (2) agriculture (3) grassland (4) green woody vegetation (5) green herbaceous vegetation (6) urban development (Fig. 4). The six-class classification map represents land-use for the El Toro Creek Watershed and was then compared to a slope classification map.

The slope map was created for the El Toro Creek Watershed using a DEM in order to determine sub-basin slope averages related to land use. A DEM with the extents of the El Toro Creek Watershed area was processed to determine slope, aspect, and shading. The DEM slope raster assigned 53 classes to the El Toro Creek Watershed, each class representing one degree of freedom. A color table was inserted assigning a color for degree of slope in the watershed. Dark colors were assigned to low elevations (dark blue) and high elevations (black and purple). Lighter colors (green, yellow and pink) were assigned to the medium elevations. Color enhancement was used to show dramatic changes of elevation in the watershed. The color enhanced slope map and previously created land-use map were then directly compared to determine slope class percent values for each watershed land-use.

Landsat 7 TM image and 1966 aerial photos were used to determine land-use change in El Toro Creek Watershed in the past 30 years. Aerial photos were digitized using a 400 dpi resolution setting. Georeferencing of the 1966 scanned aerial photos was necessary in order to compare land-use in 1966 to 1999 photos. The resolution of the 1966 aerial photos (1.3m) was accurate enough to determine urban development within the watershed. The lower El Toro Watershed area where urban development increased after 1966 was delineated from the aerial photos. Other land-use practices, such as rangelands, were too difficult to distinguish in the 1966 aerial photos and 30-year changes could not be made.

Field Data Collection

Field data measurements of suspended sediment, velocity, and stage, were collected during February 2001 storm events. The objective was to collect data before, during, and after peak flows of each event. Small semi-arid watersheds, such as El Toro Creek, provide a difficult stream-monitoring environment. Multiple peaks can occur during one storm event and make monitoring strategies challenging. This study used eight study sites to monitor suspended sediment and surface runoff. Some sites were considered more important than others, based on water availability and borders of land-use change. Higher priority sites required more frequent visitation during a storm event leaving less time for lower priority sites. Data collection methods were adequate enough to measure suspended sediment, velocity, and stage for a flash flood environment.

I Study Sites:

Installations of eight study sites in El Toro Creek Watershed were monitored during February 2001 storm events. Prior to collection, prospective sites were located and assessed to determine access to the site, available staff plate installation, and safety. Eight sites were chosen and named based on stream and geographic location (Fig.3): Tor-mou, Tor-mid, Tor Park-mid, San Ben, Watson, Watson-upper, Olison Creek, and Marks Canyon. Staff plates in meters were installed at each study site prior to stream monitoring. Wooden staff plates at Toro Park- mid and Olison Creek were installed in the stream bank because no structure was present to mount a metal staff plate. Metal staff plates were installed onto bridge structures at the other six sites. The staff plate at Toro-mou was installed below the current streambed level because of prior knowledge of aggredation. Before and during stream data collection, trenches were excavated when stream flow could not reach the staff plate. Staff plate readings were extremely important at all eight sites during data collection of suspended sediment and discharge.

II Suspended Sediment

Total suspended sediment (TSS) was collected at each site during a storm event when stream flow was present. A DH-48 instrument was used to collect suspended sediment sand particles in stream flow. Three-fourths of a 1L collection bottle was filled and the bottle number, site code, date, and time were recorded. Samples were taken to the lab and weighed (bottle included), filtered, dried, and weighed again (without bottle) to determine concentration of sediment per sample. Total suspended sediment was calculated in milligrams per liter from the sample weight before (water and sediment) and after the drying process (sediment weight).

Figure 3: TSS sampling using a DH-48 instrument

III Discharge

To calculate discharge it was necessary to collect velocity measurements per unit area using three methods: surface velocity, bucket velocity, and flow probe velocity. The volume per unit of time is the discharge measurement (Leopold 1994). No discharge measurements for the same stage were recorded. Three methods of velocity were collected to calculate discharge: Surface velocity, Bucket, and Flow Probe. The discharge measurements were then plotted over time to produce a hydrograph and compared to hyetograph showing rate of rainfall. A rating curve with stage vs. measurement discharge was used to calculate discharge from a linear regression equation. A given basin will characteristically produce nearly the same hydrograph from different storms of equal magnitude and distribution (Leopold 1994). Taking this into consideration, no two discharge measurements were taken for a single stage at each study site.

Surface velocity of fast-flowing water was taken based on stream length, width, and depth of the timed area. Generally a length of 2 meters was used to time passing dry leaf debris floating on the surface of the stream. Width was determined based on the area of fast flowing water and the average depth (meters). Surface velocity measurements allowed rapid data collection during a storm event. The surface velocity was not considered representative of the water column and a logarithmic function (equation 1) was used to calculate average velocity (Gordan 1992).

$$\mathbf{v_{(avg.)} = 5.75\ V * \log (12.3R/k)} \qquad \textbf{Equation 1}$$

In some cases a bucket was used to collect velocity measurements when conditions made it difficult to use a flow probe or surface velocity. For instance site San Ben had a drop off below the bridge where water could be collected into a 10L bucket during a time interval. The amount of liters and time were recorded to represent velocity in liters over seconds. This measurement was converted to match the surface velocity and flow probe velocity measurements in order to calculate discharge.

The flow probe was used to collect velocity measurements when time was not a restraint. El Toro Creek Watershed is a flash flood system that required collection of data to be a rapid routine and using the flow probe became a timely process. A flow probe instrument was used once to calculate velocity for a cross section at site Toro Park-mid.

Discharge, calculated by taking the velocity and multiplying the cross-sectional area (width, length, and depth). Discharge rating curve was determined by plotting the measured discharge vs. stage. A linear regression of at least two or more measurements produced a discharge rating curve equation. Three measurements are preferred, but in some cases only two were able to be collected. For this reason tow measurements of discharge were considered sufficient enough information to obtain a rating curve equation. Sites San Ben, Tor-mid, and Tor-mouth had two or more discharge measurements and had three measurements. Rating curves were produced for these four sites and the regression equation was used to calculate discharge for known stages without collected measurements.

Results

Land-Use Change Analysis

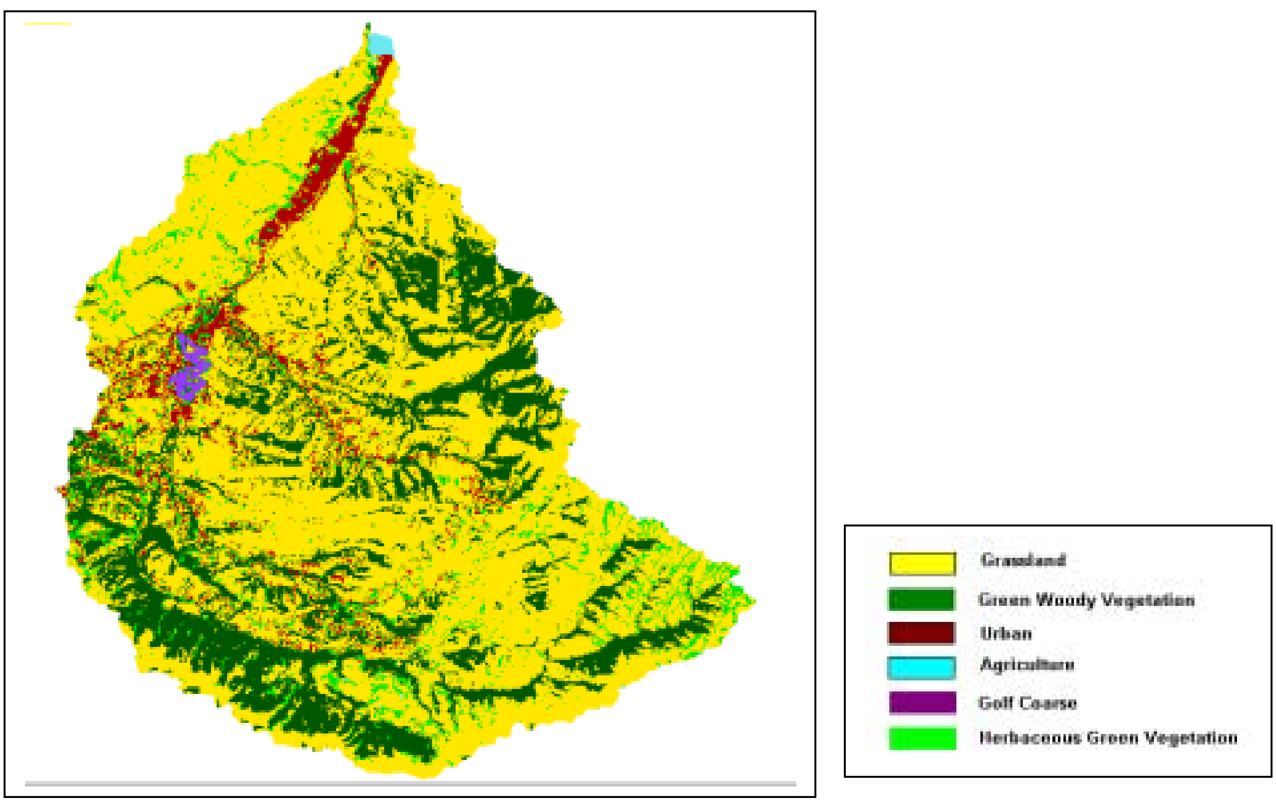
Total sub-basin area, average slope, and land-use were measured for each sub-basin study site (Table 1). Total sub-basin areas were calculated and distributed as the area above each study site. The land-use characteristics per sub-basin, shown below, were delineated as anything above each study site. The golf course located above the Watson site was not considered a land-use value for sub-basins Toro-mid and Toro –mou below the site. Average slopes decreased from the upper to lower watershed sub-basins. San Ben sub-basin had the largest average slope of 22.25º with the smallest area of 5.91mi^2.

Table 1. Shows Sub-basin land-use and total basin area mi^2

Sub-Basin	Total Sub-Basin Area (mi^2)	Average Slope Degrees	Land-use
Watson	21.29	17.4°	Urban Golf Course Grazing Open Space
San Ben	5.91	22.25°	Urban Grazing Open Space
Tor-mid	29.3	11.7°	Urban Grazing Open Space
Tor-mou	36.8	11.7°	Urban Grazing Open Space

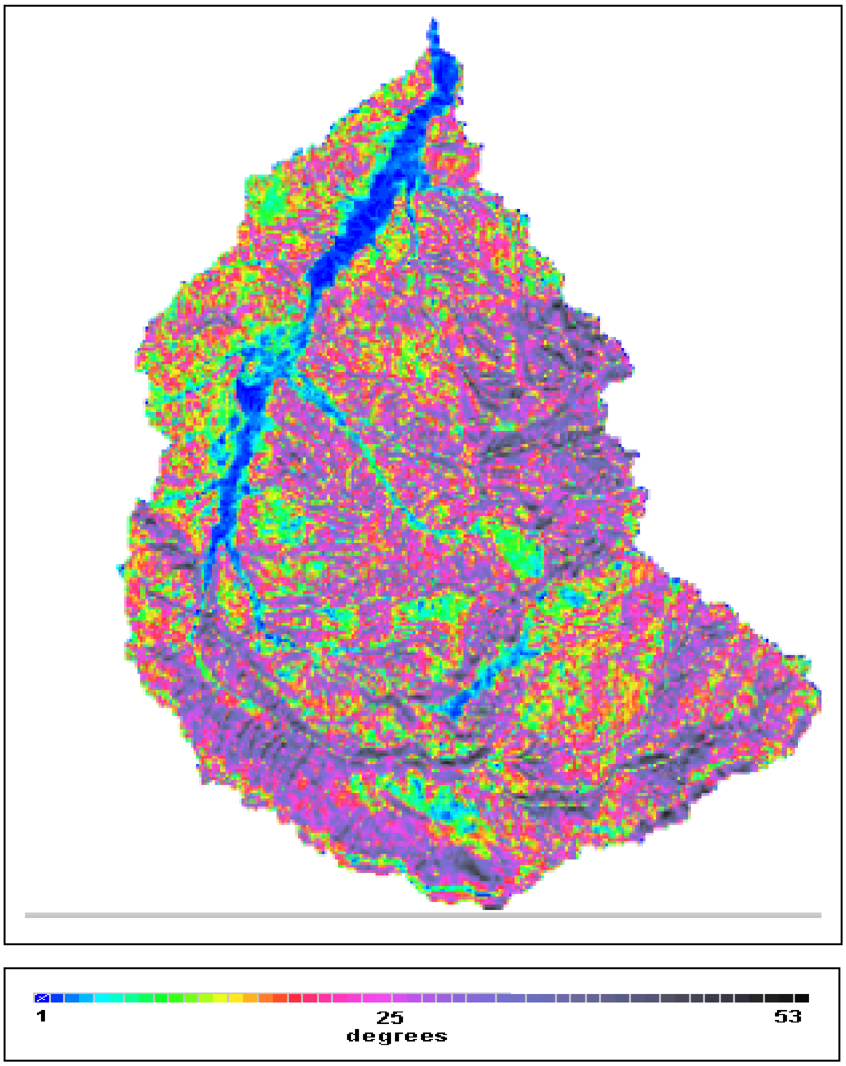
A land-use map was created using GIS supervised auto-classification and unsupervised classification based on reflectance values. Six groups of land use were separated: grassland, green woody vegetation, urban, agriculture, golf course, and herbaceous green vegetation (Fig 4). Rangelands are difficult to delineate, but considered to be associated with the grassland ecosystem. Toro Park grazing contains areas of grassland and green woody vegetation. Other areas of grazing are classified in the grassland group, but not considered the full grassland area. Golf course has an area of 0.168mi^2 and has not changed according to the 1966 Aerial photos (based on sand traps seen in the current golf course area). The slope classification (Fig 5) showed the highest degree to be located in Toro County Park and the range separating Corral de Tierra Valley and Calera Canyon. All streams appear to have between 1-5 degrees of slope decreasing from upper to lower watershed. Toro Park sub- basin shows the largest area of small slopes averaging 1-2 degrees.

Figure 4. Land-Use Map Classification based on Reflectance Values.



The largest elevation changes take place in the upper El Toro Creek Watershed. The largest degree of slope change is seen in the Toro County Park and Corral de Tierra areas. The lowland areas are located in the El Toro Creek sub-basin and Watson sub-basin. There also is a small lowland area located between San Benancio Gulch and Corral de Tierra Valley.

Figure 5. Slope Classification of El Toro Creek Watershed



Stream Monitoring

Three storm events in February 2001 were monitored for suspended sediment, discharge, and stage measurements. Storm events were separated based on precipitation intensities during the month. Three storm events were monitored during this time: February 9th, February 11th, and February 19th. Watson, San Ben, Tor-mid, and Tor -mou were the only sites with enough data for accurate analysis because of low precipitation during the month of February 2001. Antecedent conditions, average discharge, average TSS concentrations, and average TSS loads were analyzed for each storm event.

I **February 9th**

Prior to the February 9th storm event, conditions were fairly dry. No precipitation occurred in the year 2001 before February 9th. This storm event received 15.3 mm during the twenty-four hour period. Storm intensity ranged from 0 to 5 mm/hr according to the South Salinas weather station.

The average discharge measurements for February 9th were calculated for sites Tor mid, Watson and San Ben (Graph 1). The average discharge measurement for San Ben (0.001m^{3}s) was extremely low and not visible on Graph 1. Watson had the largest average discharge measurement (0.12m^{3}s) for the February 9th event. Average discharge measurements had Tor mid (0.027m^{3}s) comparatively lower than the Watson site located upstream. Site Tor- mou never reached stream flow during the February 9th storm event and therefore a discharge could not be calculated.

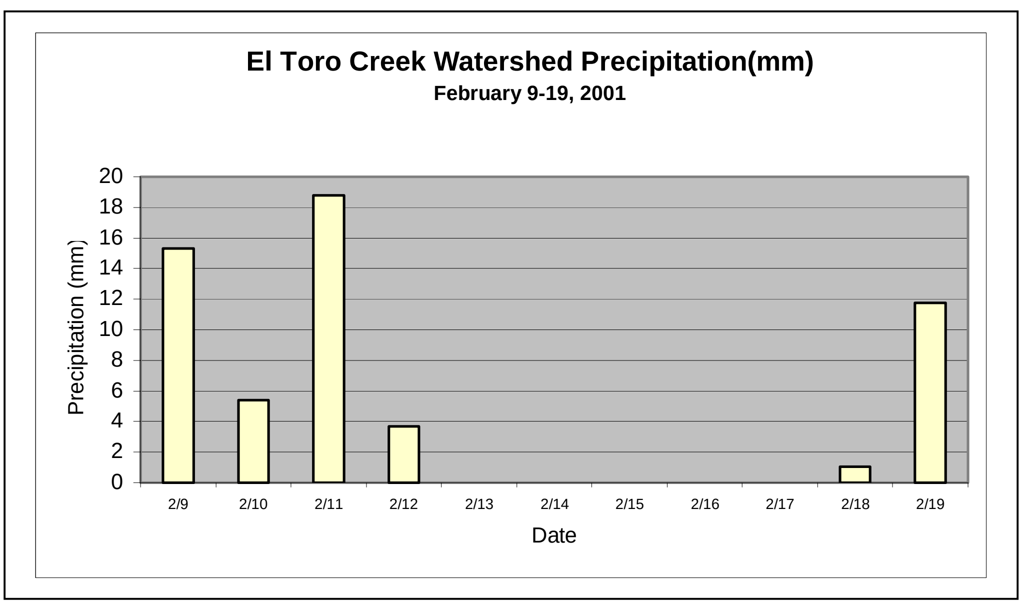
The average TSS concentrations for February 9th were calculated for Tor-mid, Watson, and San Ben (Graph 2). The highest average discharge, Watson, did not have the highest average TSS concentration for the February 9th storm event. Tor-mid had the highest average TSS concentrations (1308.87 mg/L) for the February 9th storm event. Watson, on the other hand, had a average TSS concentration of 628.17 mg/L. Average TSS concentrations at San Ben for February 9th were 20.14 mg/L and comparatively low to the other sites.

The average TSS loads for February 9th were calculated for Tor-mid, Watson, and San Ben (Graph 3). Watson had the highest average TSS concentrations per unit area (3.58m$^{3/}$s/mi^2) for the first storm event. The next highest average TSS load for a sub-basin was San Ben (1.25$m^{3/}$s/mi^2) and comparatively higher than Tor-mid (0.004$m^{3/}$s/mi^2). During this storm event stream flow from the San Ben/Watson convergence never reached the Tor-mid site. This TSS loads are calculated on the sub-basin area, but in this case miss represents true TSS concentrations per unit area. Accurate sub-basin area for Tor-mid during the February 9th storm event could not be estimated but noted as a data collection error.

II February 11th

Prior to the February 11th storm event soil conditions were moderately saturated. The El Toro Creek Watershed received 20.7mm of precipitation from February 9th to 10th. Stream flow from the February 9th event had infiltrated to the ground water by the end of the day. Low intensity storms on the 10th kept the ground moist, but considerable overland flow did not occur. February 11th produced 18.8mm of precipitation over a course of twenty-four hours. Storm intensity ranged from 0 to 4.1 mm/hr during a 5 hour time frame. Saturated soils and high intensity precipitation on February 11th produced high surface runoff in the El Toro Creek Watershed. Average discharge, average TSS concentrations, and average TSS loads were measurements for Tor-mid, Tor-mou, San Ben, and Watson.

Graph 1. Precipitation (mm) of El Toro Creek Watershed: February 9th-19th, 2001.

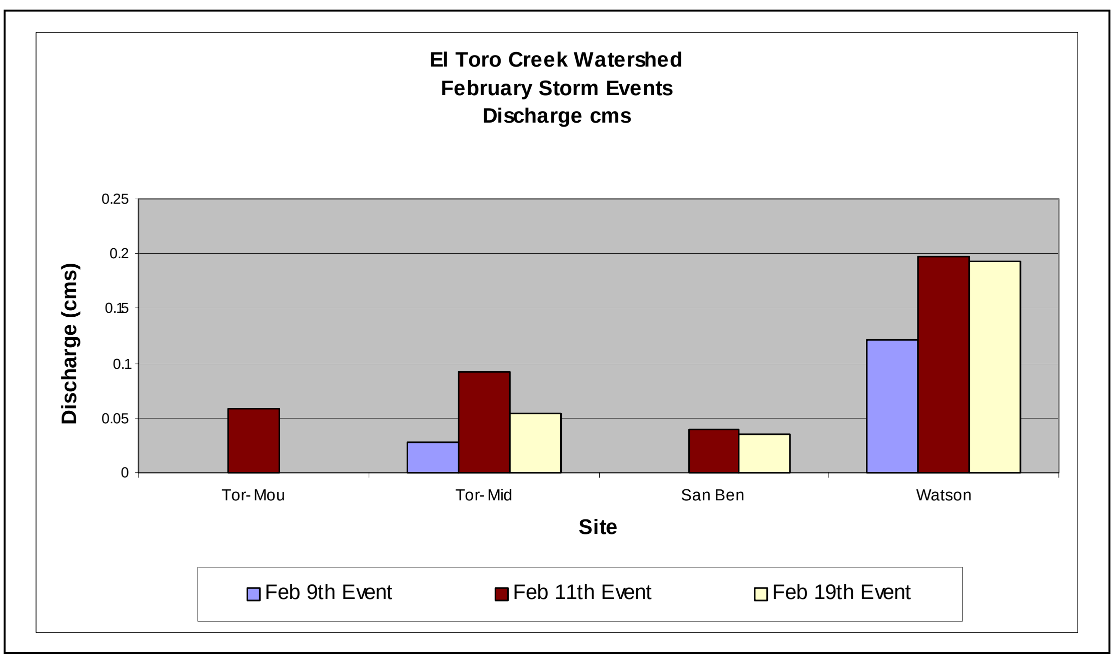


The average discharge measurements for February 11th were calculated for sites Tor mid, Tor-mou, Watson and San Ben (Graph 2). The highest average discharge measurement was for the Watson sub-basin (0.197m^{3}s). The three sites had relatively low discharge measurements compared to Watson. Tor-mid had an average calculated discharge of 0.092m^{3}s and compared to Tor-mou (0.059m^{3}s) and San Ben (0.039m^{3}s) was not considerably higher.

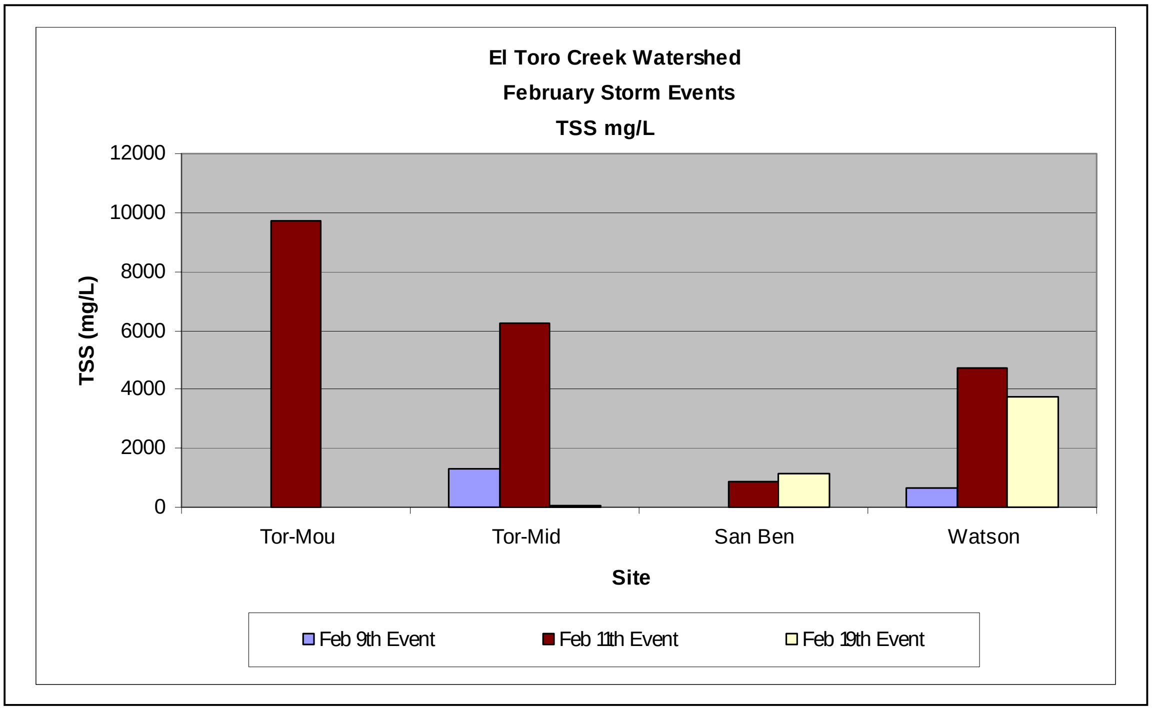
The average TSS concentrations for February 11th were calculated for Tor-mid, Tor-mou, Watson, and San Ben (Graph 3). TSS concentrations increased from upper to lower watershed. The highest average TSS concentration was measured at the watershed mouth (Tor-mou: 9728.96 mg/L). The Tor- mou site measurement was relatively higher than the other three sites. Tor-mid (6224.2mg/L) and Watson (4713.8mg/L) TSS concentrations were comparatively similar, but the lower watershed site (Tor-mid) had higher levels of TSS than the upper watershed site (Watson). San Ben had the lowest levels of TSS concentration (872.2mg/L) for the February 11th storm event.

The average TSS loads for February 11th were calculated for Tor-mid, Tor-mou, Watson, and San Ben (Graph 4). Watson had the highest TSS concentrations per unit area (51.83m$^{3/}$s/mi^2). Tor-mid average TSS load (18.3m$^{3/}$s/mi^2) was slightly larger than the load at Tor-mou (17.01m$^{3/}$s/mi^2) located downstream. San Ben produced the lowest level of TSS load (10.65m$^{3/}$s/mi^2) for the February 11th Storm event.

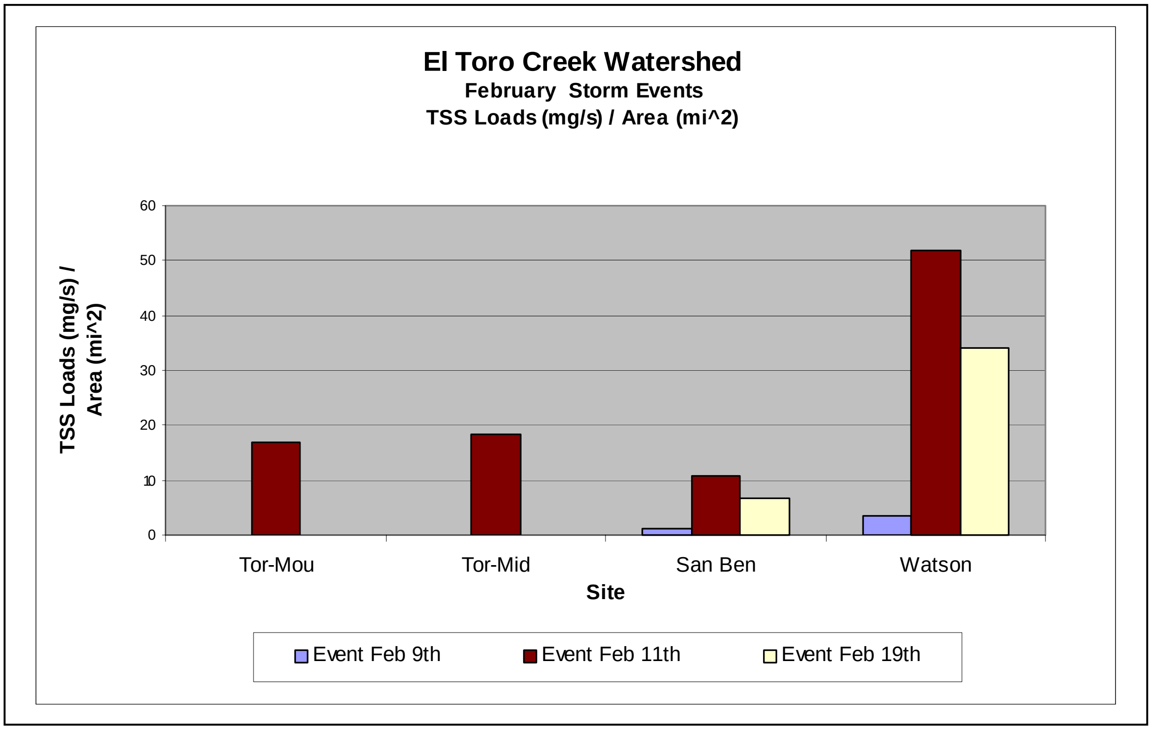
Graph 2: El Toro Creek Watershed – Average discharge (cms) for February Storm Events



Graph 3: El Toro Creek Watershed – Average TSS (mg/L) for February Storm Events



Graph 4: El Toro Creek Watershed- Average TSS loads (mg/s/mi^2) for February Storm Events.



III February 19th

The event on February 19th following the February 11th storm event was similar to prior conditions of February 9th. No precipitation occurred from February 13th –17th in the El Toro Creek Watershed. The streambed became semi-dry and required high precipitation levels for soil saturation. On February 18th a very low amount, 1.04mm, of rain fell in the watershed area. This was not enough precipitation to saturate the soil substrate in the streambeds. A total of 11.75mm of precipitation occurred during the 19th storm event and little surface runoff was observed. Average discharge, average TSS concentrations, and average TSS loads were measurements for Tor-mid, San Ben, and Watson.

The average discharge measurements for February 19th were calculated for sites Tor mid, Watson and San Ben (Graph 1). Highest average discharge measurements came from Watson (0.133m^{3}s) in the upper watershed. Tor-mid (0.054m^{3}s) had higher average discharge measurements than San Ben (0.035m^{3}s). Stream flow did not reach site Tor-mou and therefore no average discharge measurements could be taken for Feburary19th Storm event.

The average TSS concentrations for February 19th were calculated for Tor-mid, Watson, and San Ben (Graph 2). Highest average TSS concentrations were calculated from Watson creek (3763.1mg/L). Tor-mid (70.7mg/L) had the lowest average TSS concentrations measured for the February 19th storm event. San Ben was measured as having 1118.2mg/L of average TSS concentrations for the storm event.

The average TSS loads for February 19th were calculated for Tor-mid, Watson, and San Ben (Graph 3). Highest average TSS load was calculated from the Watson site (34.18m$^{3/}$s/mi^2). The TSS load at Watson was extremely higher than levels calculated from Tor-mid (0.12m$^{3/}$s/mi^2) and San Ben (6.60m$^{3/}$s/mi^2). These storm event average TSS loads were similar in trend, but not magnitude to the February 9th storm event.

Discussion

The objective of this study was to see how land use affected sediment yields and surface runoff in a small semi-arid watershed. Three specific questions addressed were: How has land use changed in El Toro Creek over the past 30yrs? Does land use influence sediment yield and surface runoff? Can El Toro Watershed be monitored affectivity to predict surface yield and surface runoff?

Stream monitoring of a small semi-arid watershed proved to be extremely difficult for predicting sediment yields and surface runoff. Stream flow must be present in order to collect total suspended sediment samples and determine surface runoff. The 2001 rainy season for El Toro Creek Watershed produced low precipitation events and as a result not much surface runoff was present during collection times. Despite collection and weather difficulties, valuable information was obtained to better understand system interactions with land-use.

Intense urban development in the El Toro Creek Watershed over the past 30 years has created increased surface runoff. Impervious surfaces associated with urban development (roads) has increases surface runoff lag time to streams in the El Toro Creek and San Benancio Gulch areas. Over the past 30 years the area adjacent to El Toro Creek has drastically decreased pervious sandy soil surfaces and these areas were replaced with concrete roads and houses. This increased surface runoff to El Toro Creek and subsequently flooded the area on a more frequent interval. The lower El Toro Creek Watershed shows the most dramatic affects of land use interaction, but the field measurements showed the upper watershed having higher quantities of sediment yield.

The upper El Toro Creek Watershed produced the higher levels of sediment loads compared to the lower watershed study sites. Levels from Watson sub-basin in the upper watershed had the highest sediment yields. One good explanation for the TSS decrease from Watson to Toro- mid is because large amounts of sediment are being deposited between these two study sites. The sediment deposition site directly below Highway 68 on El Toro Creek because there is slight change in channel slope. Slope change at this point is widening the creek and depositing sediment carried in stream flow. Directly above Watson study site is a golf course and is not known to be affecting high sediment levels from this sub watershed. It is suggested that more field surveys of the upper watershed land-uses need to be assessed to further determine reasons for the high sediment loads.

Despite low precipitation levels for the month of February 2001 in the El Toro Creek Watershed, sediment yields and surface could be monitored more affectivity with more assistance. Generally sediment levels and surface runoff were predicted for the upper and lower watershed. During higher precipitation years more study sites could help to improve knowledge of where high sediment levels are concentrated in the upper El Toro Creek Watershed. A site above the golf course was installed, but did not receive enough stream flow to collect data. This site during higher precipitation intensity could provide improved sediment load levels in Watson sub-basin.

Stream monitoring of small semi-arid watersheds, like El Toro Creek Watershed, should be conducted over an extended period of time. Stream monitoring for three years collecting during at least 10 storm events would provide extensive information of surface runoff and sediment yield related to land use in a small semi- arid watershed. Monitoring in this study was done to the best of the team's ability and provided a great framework for future study sites that would improve upper watershed analysis. I suggest that an investigation of stream bank stabilization in the upper and lower El Toro Creek Watershed would provide a better understanding of surface runoff and sediment yields with land use.

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