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The contribution of small anthropogenic particulates (SAP) to the sediment load of a major ephemeral fluvial system, Santa Ana River (SAR), Southern California

Junjie Shen

THE CONTRIBUTION OF SMALL ANTHROPOGENIC PARTICULATES (SAP)
TO THE SEDIMENT LOAD OF A MAJOR EPHEMERAL FLUVIAL SYSTEM,
SANTA ANA RIVER (SAR), SOUTHERN CALIFORNIA

A Project

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Environmental Sciences

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by

Junjie Shen

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March 2013

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ABSTRACT

Small Anthropogenic Particulates (SAP) in the fluvial system have not received significant scientific attention, especially in urbanized Southern California. The purpose of this project is to establish a baseline for future changes in SAP for environmental monitoring. SAP refer to pieces of materials that are made by human activity and may or may not contain harmful chemical substances. They are essentially produced as a byproduct of human activity. In this project, sand samples had been collected approximately at five mile intervals along the Santa Ana River (SAR). Then, samples were dried in the oven, and statistically homogenized by a sediment splitter. All the identifiable or questionable SAP were picked out and mounted to microscope slides. After all the particles were identified, the results showed: Site 6 and Site 13 had relatively higher numbers of SAP. This shows that the debris in the SAR has not been significantly transported far away from its potential source by the fluvial system, while certain events have major influences on the distribution of SAP in the SAR. Three recommendations to improve this project are offered: first

is to keep the samples uncontaminated; second is to improve the efficiency of the methodology; third is to find a more suitable binding adhesive to stick the particles to the microscope slides, instead of Elmer's Glue.

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I would like to gratefully acknowledge and personally thank several people who made enormous contributions to my project:

Dr. Britt Leatham, my major advisor for this project, supervised this entire research from the beginning to the end. He helped me establish the basic idea of conducting scientific research. He gave me some valuable suggestions when it was needed; and encouraged me to search for the information by myself when it was not.

Dr. Robert Phalen, one of my committee members, gave me instructions about sampling, and helped me conduct statistical analyses of the data.

Dr. Bo Xu, one of my committee members, offered me helpful advices to make the project better, and helped me correct the thesis.

Finally, Yebo Wang, my best friend at Cal State San Bernardino, helped me collect the samples and with other field work.

DEDICATION

To make my parents proud.

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CHAPTER ONE

INTRODUCTION

Background

Small Anthropogenic Particulates (SAP) in the fluvial system have not received significant scientific attention. SAP are generally those particles that are smaller than geological pebbles (minimum diameter 4 mm), but bigger than fine sands (minimum diameter 0.25 mm) (*1*). For example, pieces of plastic, rusted metal, and discarded toys found on the riverbed are considered to be typical sources of SAP. SAP may accumulate in any sedimentary basin or environment as a byproduct of human activity. As with all particulates, once SAP get into an area, they are especially obedient to the "natural rules" governing that particular sedimentary system. However, SAP differ significantly from natural sediment by the manner of inclusion, the origin, and the predominantly different composition or shape. Natural sediment is a product of weathering, erosion, and other physical and chemical processes. SAP should have an effective influence on the natural dynamics of the ecological system and may affect the living organisms in fluvial systems and their associated flood plains and deltas.

Project Objectives

This research was undertaken to explore the distribution of SAP in the Santa Ana River (SAR), and to determine the contribution of SAP to the sediment load of the SAR. SAP have never been documented before in fluvial systems, especially in urbanized Southern California. This project will effectively establish a baseline for future changes in SAP for environmental monitoring and regulations.

The Santa Ana River

The Santa Ana River is the largest river in southern California. It originates from the San Bernardino Mountains, flows past the cities of San Bernardino and Riverside, cuts through the northern tip of the Santa Ana Mountains, runs southwest through Orange County, and finally merges into the Pacific Ocean between Huntington Beach and Newport Beach. The Santa Ana River is 96 miles long, and its drainage basin spans four counties: San Bernardino, Riverside, Los Angeles and Orange (*2*). The average discharge at the mouth of the Santa Ana River at Huntington Beach is 445 cu ft/s, and the maximum discharge is 317,000 cu ft/s (*3*).

Cities along the Santa Ana River

Several major cities are located in the SAR drainage basin. The SAR originates in Highland. Highland is a city in San Bernardino County, California, with a population of 53,104 in 2010, up from 44,605 in 2000(*4*). Redlands is the next one down the stream. Redlands had a population of 68,747 in 2010, up from 63,591 in 2000 (*4*). Citrus used to be the major industry of Redlands for almost 75 years (*5*). At present, the major organizations and businesses are: University of Redlands---a private liberal arts and sciences university; Esri---a major Geographic Information System (GIS) software company; Gill Batteries---manufacturer of Aviation Batteries, used in everything from General Aviation aircraft to Airliners (*6*); and Hydro Tek Systems---a manufacturer of high pressure washers and industrial cleaning equipment (*7*). Loma Linda is the third city along the SAR, with a population of 23,261 in 2010, up from 18,681 at the time of the 2000 census (*4*). Loma Linda University and its Medical Center are the primary infrastructure in Loma Linda.

San Bernardino is another major city. San Bernardino serves as the county seat of San Bernardino County, with a population of 209,924 in 2010(*4*). California State University San Bernardino and the Inland Center Mall are the major organization and business in San Bernardino. Colton is the city next to San Bernardino along the SAR. Colton had a population of 52,154 in 2010, up from 47,662 in 2000(*4*). The Arrowhead Regional Medical Center is a hospital located in Colton. Agua Mansa was once the largest settlement in San Bernardino County. It was established in 1845 on the SAR (*8*). Grand Terrace is a small city between the cities of San Bernardino and Riverside, with a population of 12,040 in 2010, up from 11,626 in 2000(*4*).

The next region is Riverside County. Rubidoux is the first city along the SAR in Riverside County. It had a population of 34,280 in 2010, up from 29,180 in 2000(*4*). A small public airport, the Flabob Airport, is located in that area beside the SAR. Riverside is the county city of the eponymous county, named for its location beside the SAR. As of the 2010 census, Riverside had a population of 303,871(*4*). The Mission Inn is a historic landmark hotel in downtown Riverside. University of California, Riverside, La Sierra University, and California Baptist University are three major universities in Riverside. Riverside Municipal Airport is a private and business airport. Mira Loma is a small city in Riverside County, with a population of 21,930 in 2010, up from 17,617 in 2000(*4*). Eastvale is a city located in northwestern Riverside County, with a population of 53,668 in 2010 (*4*). Corona is another major city in Riverside County. In 2010, the city had a population of 152,374, up from 124,966 at the 2000 census (*4*). Kaiser Permanente, Fender Musical Instruments Corporation, All American Asphalt, and TWR Framing are the major businesses in Corona.

The above is the basic information of the cities along the SAR. Based on the US Census data, the population in the SAR drainage basin has been growing since the beginning of the 21st century. More and more human activity is occurring along the SAR, which might increase the number of SAP in the SAR.

Characteristic of Small Anthropogenic Particulates

According to the Atlas of Anthropogenic Particles, published by International Committee for Coal and Organic Petrology (ICCP) in 2006, anthropogenic particulates can be classified by source or site of occurrence (*9*). By source, anthropogenic particulates can be combustion-derived, carbonization-derived, manufacture-derived, or other. By site of occurrence, anthropogenic particulates contain atmospheric particles, soil (peat) particles, and water sediment particles (*9*). Anthropogenically sourced sediments include both sediment grains that come from materials that are anthropogenic in origin and sedimentary materials that have been heavily impacted by anthropogenic activity (*10*).

Since the types of SAP vary, the chemical and physical properties are significantly different. Some of them are crystallized, some are metals, some are plastic, and others are made of various types of materials. Once they are released to the environment, SAP will affect the ecosystem differentially. When it comes to the fluvial system, SAP have a tremendous contribution to the sediment load of the river system.

Although sediment dynamics and accumulation rates are mainly determined by seasonal and natural changes in energy levels, there is a clear link between anthropogenic activities and sedimentary system response (*10*). Anthropogenic activities can modify rates of sediment input, sediment transport pathways and the composition of the accumulating sedimentary materials. At a global scale, sediment is mainly transported through river systems from upland "source" to marine "sink". However, this process is extremely sensitive to human activities, such as construction, manufacturing, transportation, water conservation, and land-use change. Some of these activities may increase sediment load, but others, will reduce sediment transport. In some area, reduced sediment supply has resulted in incredible changes in the pathway and geomorphology of fluvial systems.

Hypothesis

Along the SAR, human activities, buildings and industry seem to increase further from its headwaters. The SAR passes through three of the most populated counties: San Bernardino, Riverside and Orange (*2*). Hypothetically, SAP should become a greater statistical contributor to sand substrates farther from the beginning of the river. Besides, due to their differential density, shape and composition, SAP contributions should be affected more by the variations in fluvial discharge and velocity, than natural fluvial sediments.

Related Literature

In 2006, the International Committee for Coal and Organic Petrology (ICCP) published the *Atlas of Anthropogenic Particles* (*9*). In this atlas, images were compiled from 2002 to 2005. Most of the images were taken under a reflected light microscope (both with dry objective and in oil), although some images from a scanning electron microscope (SEM) and a transmission electron microscope were included. Images were grouped into two sections: 1) anthropogenic particles classified by source, including particles from well- defined sources (for example power plants, or coke plants); and 2) anthropogenic particles classified by the site of their occurrence (for example soil, air, and water). This atlas would be used as a reference when the samples were examined under a microscope.

CHAPTER TWO

METHODOLOGY

Overview

In this project, sand samples had been collected approximately at five mile intervals along the SAR from its headwaters below the Seven Oaks Dam through the urbanized area of Redlands to the western edge of the Puente Hills of eastern Orange County, Southern California. At each site, three samples were collected generally perpendicular to the axis of the river. The samples were dried in the oven. The sand was then statistically homogenized using a sediment splitter. After the proper amount of sample was prepared, an US Standard Testing Sieve NO.60 was utilized to sieve out the fines. Since Sieve 60 had an opening of 0.250 mm, the size of the SAP caught by the sieve would be sand-size, but greater than 0.250 mm (*1*). Using a dissecting microscope, about one thousand grains were point counted from each sample, and all potential SAP from those point counted grains were retained for later inspection. Then, all the SAP from each sample were classified and statistically analyzed. After that, the distribution of SAP was plotted and contoured to determine its contribution to the sedimentary load of the SAR.

Pre-field Preparation

At the beginning of the research, some background information was collected on the internet; then a list of potential sources of SAP was formed. Dr. Leatham helped establish the potential source categories. The potential categories of anthropogenic sources are as follows:

A. Plastics

B. Wood

C. Paper

D. Rubber

E. Construction materials

F. Automotive materials

G. Beverage and food container

H. Industrial and manufacturing materials

I. Mass transit

J. Road and paving materials

K. Residential materials

L. Glass

M. Metals

N. Rusted metals

O. Utilities and infrastructure

P. Food

Another important component of pre-field work was to find the potential sites where samples were supposed to be collected. On Google Earth, 12 potential sites for sampling were found, according to the hypothesis that, if two stream flows merge, the total number of SAP from these two branches is supposed to equal the number of SAP of the main stream flow. In addition, the residential communities along the SAR dramatically affect the contribution of SAP, which is also taken into account. Based on these assumptions, the map of 12 potential sites is shown in Figure 2-1:

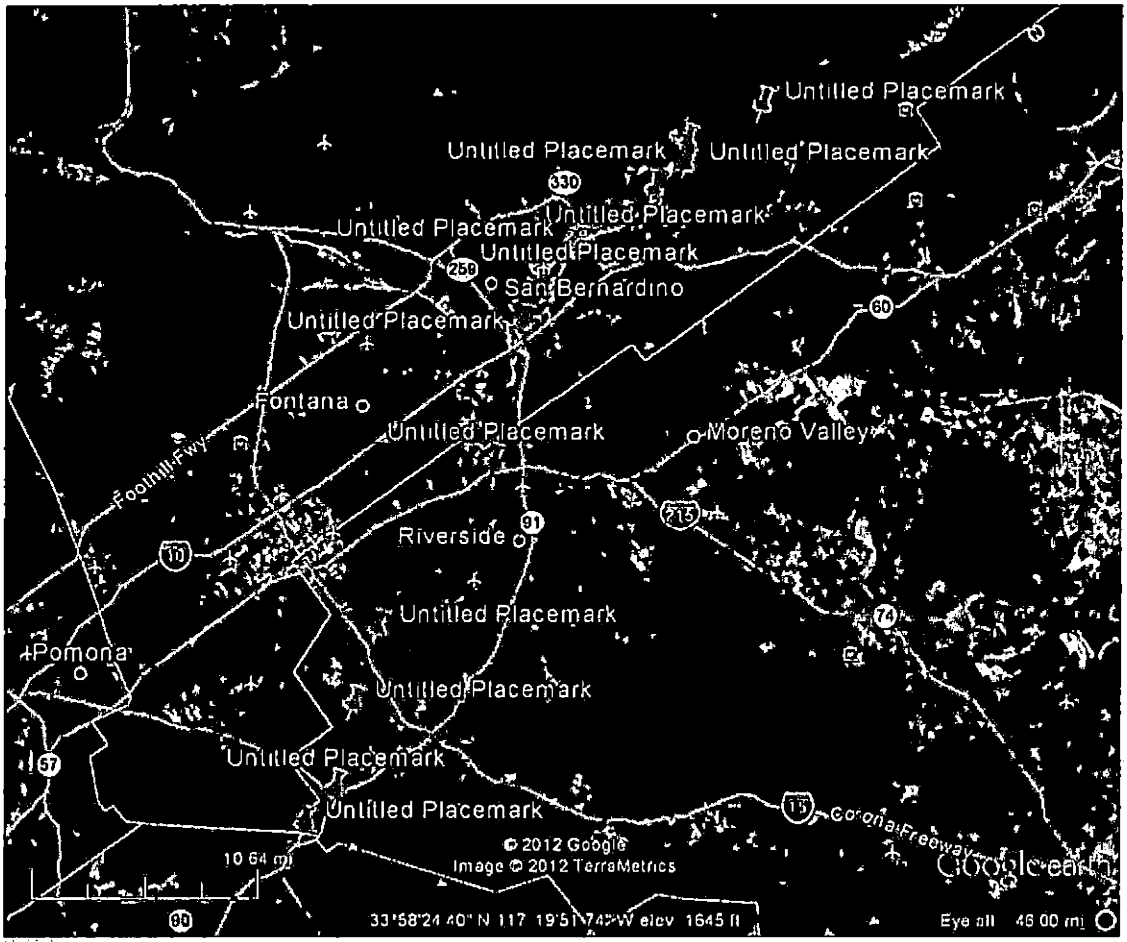

Figure 2-1. A Satellite Map of 12 Potential Sites for Sample Collection

The next step was to prepare the tools for sampling, including a shovel, a field camera, a labeling pen, label paper, and 26.8cm×27.3cm Ziploc bags.

Field Sampling

On April 17th, 2012, I drove to the headwaters of the SAR below the Seven Oaks Dam. I stopped by the bridge right below the dam, randomly picked three sites near the river bed, took several awesome field pictures, then shoveled three half-bags of sample sand. This was Site 1, labeled as JS-1.1; JS-1.2; and JS-1.3. Later on, I drove to Site 2, which was a bridge on Greenspot Road, and Site 3 on Highway 38. 3 samples were collected at each site.

On April 19th, 2012, I drove to the intersection of I-215 and I-10, which was named Site 9, and collected 3 samples. Then, I drove to San Bernardino downtown, collecting 3 samples at Site 8 where California Street meets the river, and another 3 samples at Site 7 where Alabama Street crosses the river. After that, I drove east along San Bernardino Ave; then turned left on Orange Street. Before reaching the river, I found parking at the Redlands Shooting Club. I walked to the riverbed, took some photos, and collected 3 samples. Subsequently, I drove to Redlands and collected 3 samples at Site 5 where Greenspot Road and Florida Street connect. The last site on that day was Site 4 where Garnet Avenue crosses the river..

On April 20th, 2012, I drove on Freeway 60 and collected

3 samples by Market Street, which was Site 10. Then, I drove to Hamner Avenue and collected 3 samples, which was marked as Site 11. After that, I drove to River Road, which was Site 12, and took 3 samples. Site 13 was in Orange County. I took Highway 91 West, and exited Yorba Linda Boulevard. I walked along the Santa Ana River Trail to find a good path to get into the riverbed. Finally, I collected 3 samples.

On May 5th, 2012, I went to Prado Dam, which was the last site, Site 14, to take 3 samples. All the samples were labeled with the site number and tray number, such as JS-5.1, JS-6.2, and JS-7.3. All the field pictures are included in the Appendix Photo Gallery.

Distribution of Sites

After I collected all the samples, I took them back to the lab. Immediately, I plotted each site from which the samples were collected onto Google Earth, and wrote down the coordinates, which is shown in Table 2-1:

Table 2-1. Coordinates of Each Site

Site NO.	Latitude	Longitude	Elevation (meters)
JS-1.1	34° 06′ 02.60″ N	117° 06′ 19.31″ W	571
JS-1.2	34° 06′ 02.87″ N	117° 06′ 19.45″ W	571
JS-1.3	34° 06′ 03.20″ N	117° 06′ 19.10″ W	571
JS-2.1	34° 06′ 36.92″ N	117° 08′ 57.87″ W	448
JS-2.2	34° 06′ 36.81″ N	117° 08′ 58.29″ W	448
JS-2.3	34° 06′ 36.64″ N	117° 08′ 58.56″ W	448
JS-3.1	34° 04′ 31.73″ N	117° 04′ 07.21″ W	731
JS-3.2	34° 04′ 31.82″ N	117° 04′ 07.41″ W	731
JS-3.3	34° 04′ 31.86″ N	117° 04′ 07.65″ W	730
JS-4.1	34° 04′ 39.30″ N	117° 05′ 58.88″ W	611
JS-4.2	34° 04′ 39.46″ N	117° 05′ 59.13″ W	611
JS-4.3	34° 04′ 39.38″ N	117° 05′ 59.57″ W	610
JS-5.1	34° 05′ 10.10″ N	117° 06′ 46.94″ W	549
JS-5.2	34° 05′ 09.73″ N	117° 06′ 47.17″ W	549
JS-5.3	34° 05′ 09.08″ N	117° 06′ 46.99″ W	548
JS-6.1	34° 05′ 24.11″ N	117° 11′ 09.98″ W	390
JS-6.2	34° 05′ 23.35″ N	117° 11′ 11.06″ W	389
JS-6.3	34° 05′ 22.44″ N	117° 11′ 09.15″ W	390
JS-7.1	34° 05′ 38.42″ N	117° 12′ 26.92″ W	364
JS-7.2	34° 05′ 38.94″ N	117° 12′ 28.02″ W	363
JS-7.3	34° 05′ 39.41″ N	117° 12′ 29.24″ W	363
JS-8.1	34° 05′ 29.17″ N	117° 13′ 36.31″ W	344
JS-8.2	34° 05′ 29.89″ N	117° 13′ 37.87″ W	345
JS-8.3	34° 05′ 31.25″ N	117° 13′ 38.74″ W	343
JS-9.1	34° 04′ 00.95″ N	117° 17′ 53.28″ W	294
JS-9.2	34° 04′ 00.75″ N	117° 17′ 52.67″ W	293
JS-9.3	34° 04′ 00.41″ N	117° 17′ 52.93″ W	293
JS-10.1	34° 00′ 21.63″ N	117° 22′ 51.14″ W	244
JS-10.2	34° 00′ 20.66″ N	117° 22′ 52.08″ W	244
JS-10.3	34° 00′ 19.66″ N	117° 22′ 53.37″ W	245
JS-11.1	33° 56′ 47.60″ N	117° 33′ 25.22″ W	174
JS-11.2	33° 56′ 47.06″ N	117° 33′ 26.12″ W	174
JS-11.3	33° 56′ 46.51″ N	117° 33′ 26.06″ W	175

Continued on next page

Table 2-1. Coordinates of Each Site (continued)

JS-12.1	33° 55′ 20.10″ N	117° 35′ 52.20″ W	159
JS-12.2	33° 55′ 20.72″ N	117° 35′ 52.15″ W	159
JS-12.3	33° 55′ 20.75″ N	117° 35′ 53.27″ W	159
JS-13.1	33° 52′ 37.20″ N	117° 44′ 48.05″ W	102
JS-13.2	33° 52′ 37.90″ N	117° 44′ 47.23″ W	102
JS-13.3	33° 52′ 38.34″ N	117° 44′ 46.48″ W	102
JS-14.1	33° 53′ 01.58″ N	117° 39′ 03.18″ W	137
JS-14.2	33° 53′ 00.44″ N	117° 38′ 58.87″ W	137
JS-14.3	33° 52′ 58.46″ N	117° 38′ 50.66″ W	137

From the coordinates, the distances between each site were measured by the path of the SAR on Google Earth. These distances are listed in Table 2-2:

Table 2-2. Distances between Each Site by Path (units: miles)

Site 3 to site 4	1.82
Site 4 to site 5	0.98
Site 5 to site 6	4.66
Site 1 to site 6	5.10
Site 6 to site 7	1.29
Site 7 to site 8	1.13
Site 2 to site 8	5.17
Site 8 to site 9	4.62
Site 9 to site 10	7.19
Site 10 to site 11	12.01
Site 11 to site 12	3.84
Site 12 to site 14	4.21
Site 14 to site 13	6.68

Based on the information from Table 2-2, I was able to figure out how long those sample particles travelled. Meanwhile, the actual sites are shown in Figure 2-2:

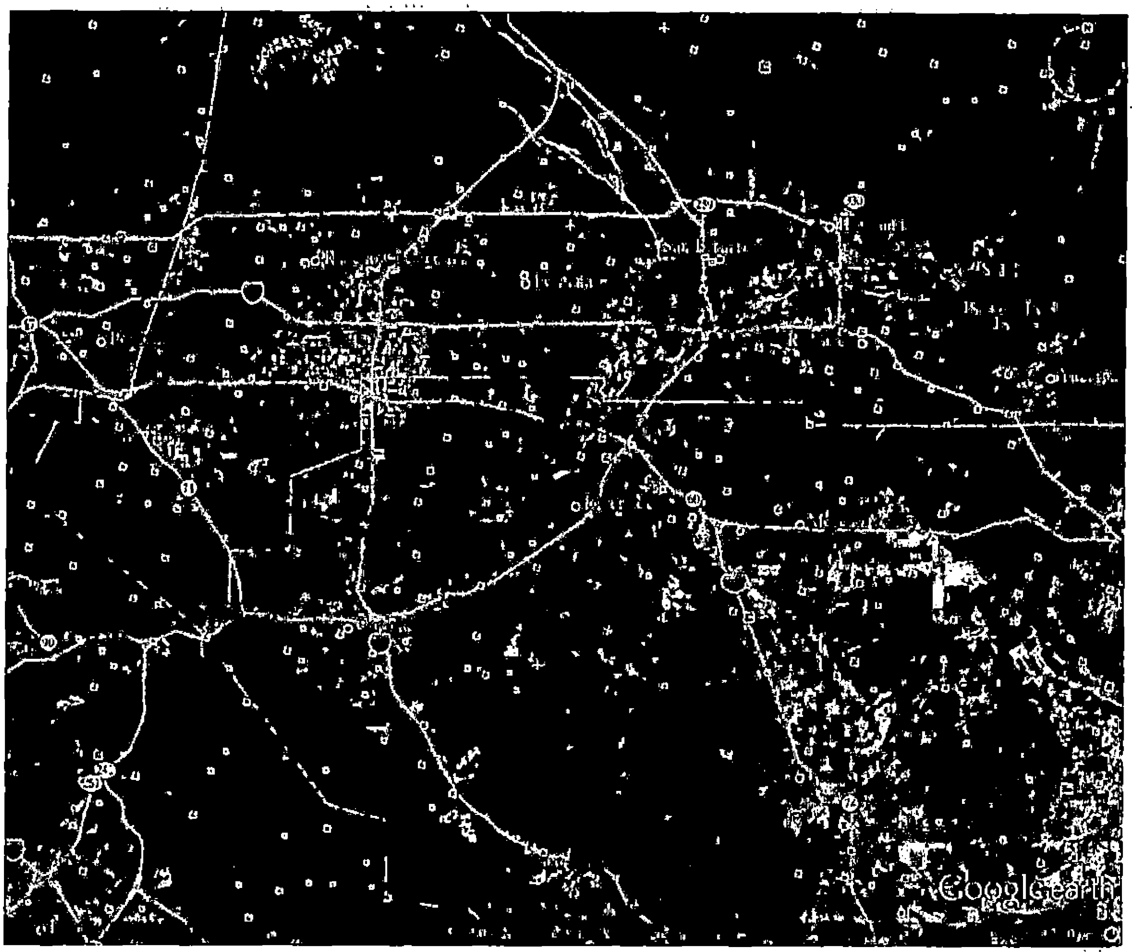

Figure 2-2. A Satellite Map of 14 Actual Sites Where Samples were Collected

Sample Drying

Later on, each sample was weighed. Then, the samples were dried in the oven, with the temperature set between 70℃ and 85℃ After drying, each sample was weighed again, and the weight of water evaporated was calculated. The weight of each sample before and after drying, and the weight of water evaporated are shown in the following tables:

Table 2-3. Weight of Each Sample before Dry (units: g)

Site NO.	X-1	X-2	X-3
Site 1	2014.0	2093.4	1937.8
Site 2	2063.9	2064.8	1896.5
Site 3	2321.1	2307.9	2265.7
Site 4	2563.7	2284.3	2644.5
Site 5	2400.9	2336.5	2267.1
Site 6	2218.6	2456.7	2445.4
Site 7	2344.2	2546.5	2258.9
Site 8	2368.7	2314.7	2287.1
Site 9	2385.9	2463.0	2467.1
Site 10	2640.9	2919.8	2743.4
Site 11	2835.0	3016.9	2871.7
Site 12	3145.7	2790.1	2876.3
Site 13	2746.1	2617.3	2533.4
Site 14	3325.8	3226.5	3070.9

Table 2-4. Weight of Each Sample after Dry (units: g)

Site NO.	X-1	X-2	X-3
Site 1	1994.9	2086.1	1897.0
Site 2	1957.3	2018.5	1846.2
Site 3	2318.8	2304.7	2175.0
Site 4	2549.2	2227.2	2317.9
Site 5	2398.6	2312.9	2242.1
Site 6	2195.4	2436.3	2444.0
Site 7	2331.1	2540.6	2242.1
Site 8	2340.6	2264.4	2256.7
Site 9	2372.8	2459.9	2458.5
Site 10	2599.1	2889.4	2278.0
Site 11	2467.6	2698.9	2785.1
Site 12	2490.3	2642.7	2758.8
Site 13	2670.3	2555.1	2491.6
Site 14	2771.5	3225.1	3043.7

Table 2-5. Weight of Water Lost during Drying (units: g)

Site NO.	X-1	X-2	X-3
Site 1	19.1	7.3	40.8
Site 2	106.6	46.3	50.3
Site 3	2.3	3.2	90.7
Site 4	14.5	57.1	326.6
Site 5	2.3	23.6	25
Site 6	23.2	20.4	1.4
Site 7	13.3	5.9	17.8
Site 8	28.1	50.3	30.4
Site 9	13.1	3.1	8.6
Site 10	41.8	30.4	465.4
Site 11	367.4	318	86.6
Site 12	655.4	147.4	117.5
Site 13	75.8	62.2	41.8
Site 14	554.3	1.4	27.2

Sample Splitting

Dry samples were ready to be split. A sample splitter was used to statistically split the first sample 5 times, to reduce it to 1/32 of the original sample, which resulted in a sub-sample of 57.0 g; then, a U.S.A. Standard NO. 60 Sieve, with an opening of 0.250 mm, was chosen to sieve out the finer sand: the 57.0 g sub-sample was put into the sieve, and sieved for 45 seconds. As a result, 51.5 g of sands was retrieved, which was statistically homogenized and sieved. However, some of the samples were split 6 times, depending on the original weight of the dry sample, to obtain approximately 50g of statistically homogenized and sieved sand for microscope inspection. Therefore, the weight of each sample after being split 5 or 6 times is shown in Table 2-6:

Table 2-6. Weight of Each Sample after Being Split 5 or 6 Times (Units: g)

Site NO.	X-1	X-2
Site 1	51.5	58.7
Site 3	48.5	46.2
Site 5	49.1	50.3
Site 6	50.6	37.4
Site 7	33.9	37.9
Site 8	42.2	28.3
Site 9	50.0	33.6
Site 10	72.4	41.7
Site 11	57.8	42.8
Site 12	47.2	33.4
Site 13	38.0	43.2
Site 14	50.9	39.3

Because of limited time, the samples taken from Site 2 and Site 4 were skipped. The third tray of all the samples was also excluded from the research. Even though some data were not considered, this process of picking out identifiable or questionable particulates from samples took about 250 hours. Some of the laboratory images are shown in the Appendix Photo Gallery.

Microscope Inspection

A 12 cm by 7 cm cardboard container was made. One layer of sand One grain deep was put on the cardboard to be inspected under a microscope. If something identifiable or questionable were found, they would be picked out, and mounted on the microscopic slides. Here, distilled water mixed with some Elmer's glue was used to stick the particles onto the slides.

Standard Small Anthropogenic Particulates Categories

Once the process of examining samples under a microscope was done, and all the identifiable or questionable particles were picked out, the identifying process started. During this process, most particles picked out were investigated under a polarizing microscope, because quartz, glass and plastic otherwise look very similar when they break into fine grains. The garnet was also a common component in the samples, which made it more difficult to differentiate them. The method to distinguish these similar-looking particulates was to make a reference of each kind of potential SAP, then compare the questionable particles with the reference under a polarizing microscope to identify them. Here, the reference was called Standard SAP Categories, which included several common types of human-made particles.

Standard SAP Category NO.1 is Glass, see Figure 2-3:

Figure 2-3. Glass
This is a piece of glass under a polarizing microscope. The parameter for this picture is Nikon 4*/0.10 Pol. ∞/- WD 30. Length = 1.364 mm, width = 1.061 mm.

Standard SAP Category NO.2 is Epoxy, see Figure 2-4:

Figure 2-4. Epoxy
This is a piece of epoxy under a polarizing microscope. The parameter for this picture is Nikon 4*/0.10 Pol. ∞/- WD 30. Length = 1.000 mm, width = 0.7576 mm.

Standard SAP Category NO.3 is Plastic, see Figure 2-5:

Figure 2-5. Plastic

This is a piece of transparent plastic from a Nestle water bottle under a polarizing microscope. The parameter for this picture is Nikon 4*/0.10 Pol. ∞/- WD 30. This picture shows the edge of the piece of plastic. Plastic appears colorful under a polarizing microscope, because the index of refraction of plastic is much greater than that of air. As a result, the light will bend in towards normal.

Common Minerals

A slide of quartz was made as a reference, see Figure 2-6:

Figure 2-6. Quartz

The parameter for this picture is Nikon 4*/0.10 Pol. ∞ /- WD 30. The average length of these particles is 0.5152 mm. Quartz shows some different colors: green, blue, red, purple, pink, and yellow. When the slide is spun, the particles will change their color. Because the refractive index of quartz is greater than that of air, when the light travels from air to quartz, the direction of light will be changed. That's why quartz appears to be colorful and changing its color when it's spun.

As mentioned previously, the garnet was a very common particle found in the samples. Here is a picture of garnet under a polarizing microscope, see Figure 2-7:

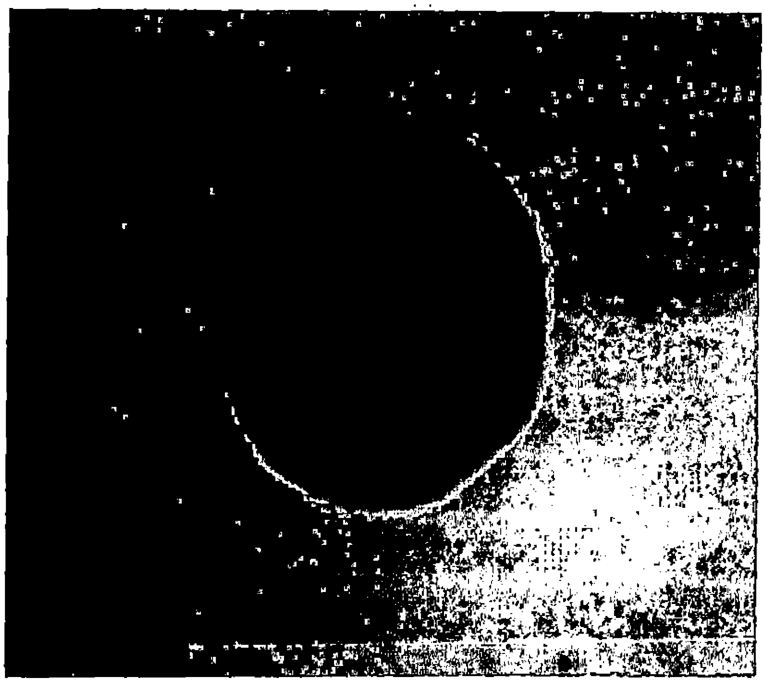

Figure 2-7. Garnet
The parameter for this picture is Nikon 4*/0.10 Pol. ∞/- WD 30. The diameter of this particle is 0.6364 mm. Garnets are found in many different colors, such as red, orange, yellow, green, blue, purple, brown, black, pink and colorless.

Glass Bottle Simulation

Before the identifying process started, some glass bottles were ground as a simulation of the river flow system. The information of the tumbler used here is:

LORTONE INC. Compact Lapidary Tumbler Model: QT-N.R. 115V/AC 60 cycle 60 watts-.92 amps. Seattle, WA 98107.

First, I weighed the bottle; then I put the bottle into a metal container and broke it with a hammer. Next, I put the crushed glass into the tumbler with some ingredients to help grind the glass. The ingredients included 200 g of sand, 450 ml of water, and 481 g of rock. I turned on the tumbler, let it grind for 24 hours. Since the diameter of the tumbler (D) was 19.3 cm and the rotation speed of the tumbler was 30 r/min, the circumference of the tumbler was $\pi D = 3.14*19.3$ cm = 60.6 cm. Therefore, within 24 hours, the distance the glass travelled was 60.6 cm * 30 r/min * 24 hours * 60 min/hour = 2618006.4 cm = 26.18 km = 16.27 miles. This was a very simple simulation of how the river flow system affected pieces of glass bottle that had fallen into the river.

Bottle 1: 12 FL.OZ. Blue Moon Beer Bottle, brown, 195.3 g, see Figure 2-8 & Figure 2-9:

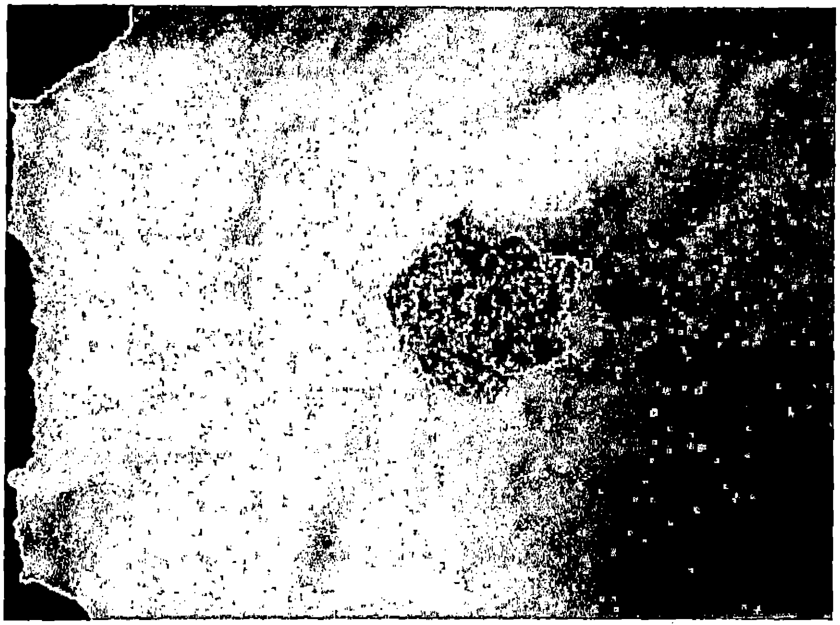

Figure 2-8. Sand-size Particles from Blue Moon Beer Bottle These are the particles caught between US. Standard Sieve 18 and Sieve 60. The opening for Sieve 18 is 1.00 mm; and Sieve 60 has a 0.250 mm opening. This means the diameters of all the particles are between 1.00 mm and 0.250 mm. Total weight is 7.0 g, and the paper weighs 2.3 g. So, the weight of the particles is 4.7 g.

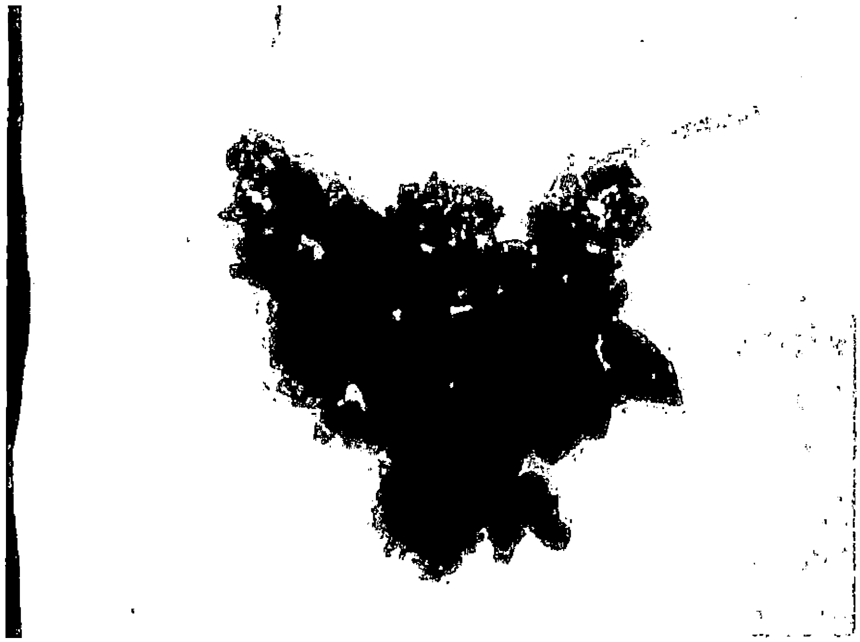

Figure 2-9. Crushed Pieces of Glass from Blue Moon Beer Bottle
These are the crushed pieces of glass caught in the Sieve 18, which means the average diameters of all the pieces are greater than 1.00 mm. Total weight is 297.3 g. Weight of the paper is 10.3 g. So, weight of all the pieces is 287.0 g.

Here, the ratio of the bottle being broken down into SAP size (R) can be calculated:

R = 4.7 g / 195.3 g * 100% = 2.41%

Bottle 2: 12 FL.OZ. New Castle Brown Ale, transparent, 196.9 g, see Figure 2-10 & Figure 2-11:

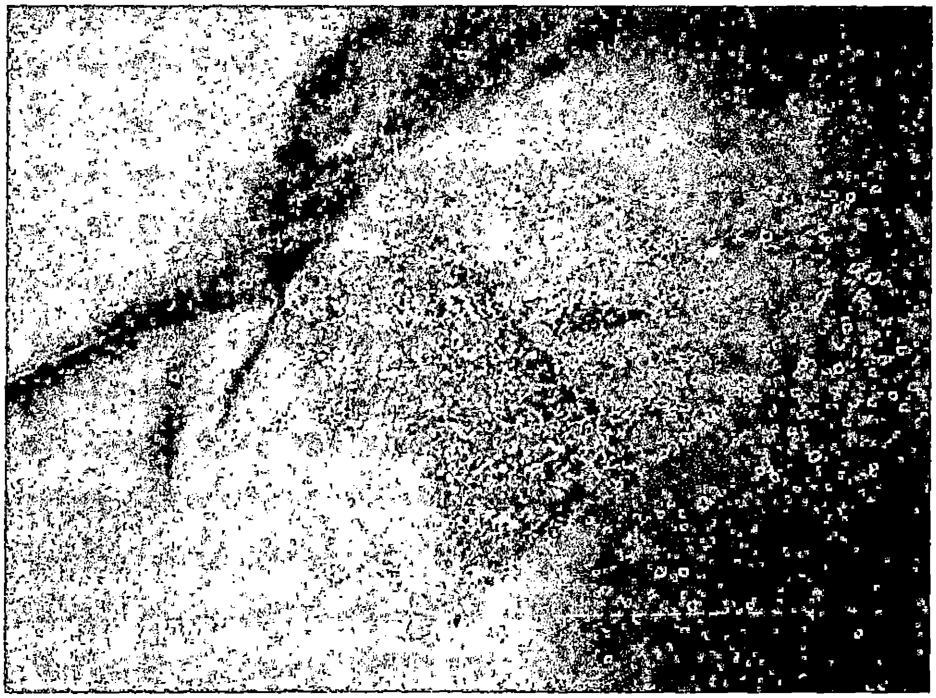

Figure 2-10. Sand-size Particles from New Castle Beer Bottle

The size of the particles is between 1.00 mm and 0.250 mm. Total weight is 15.0 g, and the paper weighs 2.7 g. So, the weight of the particles is 12.3 g.

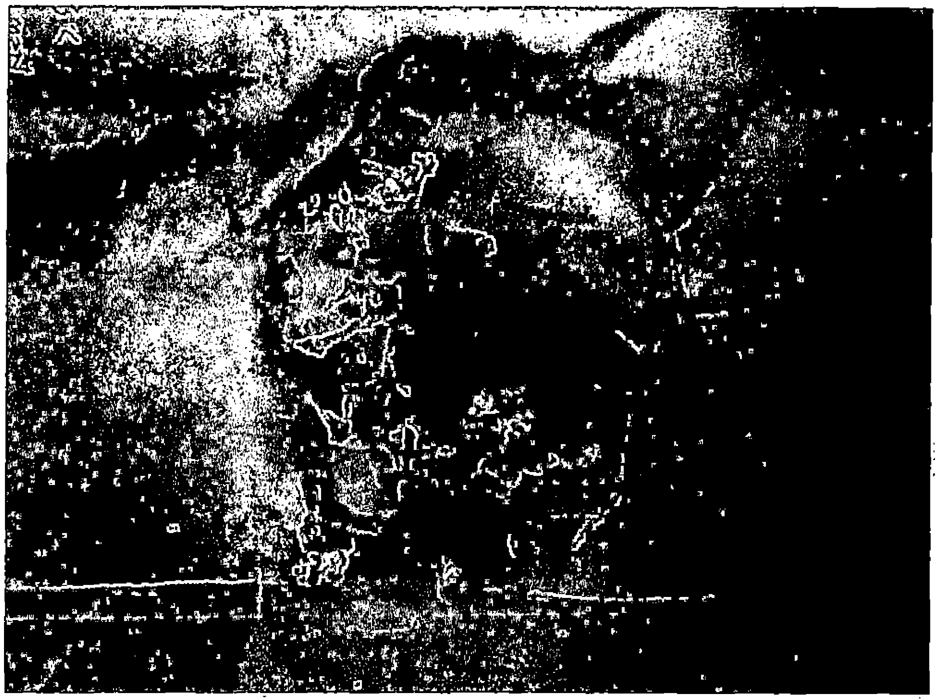

Figure 2-11. Crushed Pieces of Glass from New Castle Beer Bottle
The sizes of all the pieces are greater than 1.00 mm. Total weight is 212.5 g, and the paper weighs 9.3 g. So, the weight of the pieces is 203.2 g.

Here, the ratio of the bottle being broken down into SAP size (R) can be calculated:

R = 12.3 g / 196.9 g * 100% = 6.25%

Bottle 3: Perrier Lemon Sparkling Water, 25 oz, Green, 453.6 g, see Figure 2-12 & Figure 2-13:

Figure 2-12. Sand-size Particles from Perrier Lemon Sparkling Water Bottle
The size of these particles is between 1.00 mm and 0.250 mm. Total weight is 12.5 g, and the paper weighs 2.4 g. So, the weight of the particles is 10.1 g.

Figure 2-13. Crushed Pieces of Glass from Perrier Lemon Sparkling Water Bottle
The size of these pieces is greater than 1.00 mm. Total weight is 488.6 g, and the paper weighs 10.5 g. So, the weight of the pieces is 478.1 g.

Here, the ratio of the bottle being broken down into SAP size (R) can be calculated:

R = 10.1 g / 453.6 g * 100% = 2.23%

Therefore, the average ratio of a glass bottle being broken down into SAP size will be (2.41%+6.25%+2.23%) / 3 = 3.63%. This ratio means at the flow rate of 30 r/min * D/2 = 30 r/min * 9.65 cm = 2.895 m/min, after travelling 16.27 miles, glass bottles will be broken down 3.63% by average.

CHAPTER THREE

RESULTS AND DISCUSSION

Data

After the identifying process was done, every type of SAP for each sample was counted; then the data were obtained, and some tables and graphs were produced subsequently as seen in the following tables and figures:

Table 3-1. Tray 1 Original Count

Site N.O.	Category	Number of Each Kind	Notes	Total Number of SAP at Each Site
JS-1.1	Glass	6		8
	Sea shell	1	Not belong there, transported by humans	
	Plastic	1		
JS-3.1	Charcoal	1		4
	Processed Garnet (PG)	3		
JS-5.1	None	0		0
JS-6.1	Shotgun Bullet	5		5
	Ant Head Shell	1		
JS-7.1	Brick	1		1
JS-8.1	Glass	1		1
JS-9.1	PG	1		1
JS-10.1	PG	6		6
JS-11.1	PG	2		3
	Wax	1		
JS-12.1	Charcoal	1		4
	Coal	1		
	Glass	1		
	Epoxy Paint Plastic	1		
JS-13.1	Ant Head Shell	1		11
	PG	8		
	Glass	3		
	Lizard Skin	1		
	Coating for a Seed	1		
JS-14.1	Glass	1		1

Table 3-2. Tray 2 Original Count

Site N.O.	Category	Number of Each Kind	Notes	Total Number of SAP at Each Site
JS-1.2	PG	2		2
JS-3.2	PG	2		2
JS-5.2	Glass	1		1
JS-6.2	PG	2		35
	Shotgun Bullet	32		
	Plastic	1		
JS-7.2	PG	3		3
JS-8.2	PG	2		2
JS-9.2	Brick	1		1
JS-10.2	PG	1		2
	Plywood	1		
JS-11.1	Mini Snail	1		3
	Big Piece of Concrete	1		
	Asphalt	1		
	PG	1		
JS-12.2	Glass	1		4
	Fly Ash	2	Little magnetic balls, may come from cement factory at Riverside near SAR	
	Slag	1		
JS-13.2	NO.20 looks sparkly(shiny)	1	Turns out to be stem from a plant	0
JS-14.2	Glass	1		1

Table 3-3. Tray 1 Convert to Count of 100 g Sample

Site N.O.	Category	Number of Each Kind	Notes	Total Number of SAP at Each Site
JS-1.1	Glass	12		16
	Sea shell	2	Not belong there, transported by humans	
	Plastic	2		
JS-3.1	Charcoal	2		8
	Processed Garnet(PG)	6		
JS-5.1	None	0		0
JS-6.1	Shotgun Bullet	10		10
	Ant Head Shell	2		
JS-7.1	Brick	3		3
JS-8.1	Glass	2		2
JS-9.1	PG	2		2
JS-10.1	PG	8		8
JS-11.1	PG	3		5
	Wax	2		
JS-12.1	Charcoal	2		8
	Coal	2		
	Glass	2		
	Epoxy Paint Plastic	2		
JS-13.1	Ant Head Shell	3		29
	PG	21		
	Glass	8		
	Lizard Skin	3		
	Coating for a Seed	3		
JS-14.1	Glass	2		2

To calculate the standard deviation of Total Number of SAP at Each Site:
Total numbers: 12

Mean (Average): 7.75
Standard Deviation: 8.05803
Variance (Standard Deviation): 64.93182

Table 3-4. Tray 2 Convert to Count of 100 g Sample

Site N.O.	Category	Number of Each Kind	Notes	Total Number of SAP at Each Site
JS-1.2	PG	3		3
JS-3.2	PG	4		4
JS-5.2	Glass	2		2
JS-6.2	PG	5		94
	Shotgun Bullet	86		
	Plastic	3		
JS-7.2	PG	8		8
JS-8.2	PG	7		7
JS-9.2	Brick	3		3
JS-10.2	PG	2		4
	Plywood	2		
JS-11.1	Mini Snail	2		6
	Big Piece of Concrete	2		
	Asphalt	2		
	PG	2		
JS-12.2	Glass	3		12
	Fly Ash	6	Little magnetic balls, may come from cement factory at Riverside near SAR	
	Slag	3		
JS-13.2	NO.20 looks sparkly(shiny)	2	Turns out to be stem from a plant	0
JS-14.2	Glass	3		3

To calculate the standard deviation of Total Number.of SAP at Each Site:
Total numbers: 12
Mean (Average): 12.16667
Standard Deviation: 25.96443
Variance (Standard Deviation): 674.15152

Formula:

Mean: Mean = Sum of X values / N(Number of values)

Standard Deviation :

$$s=\sqrt{\frac{\sum(X-M)^2}{n-1}}$$

Variance: Variance = s^2

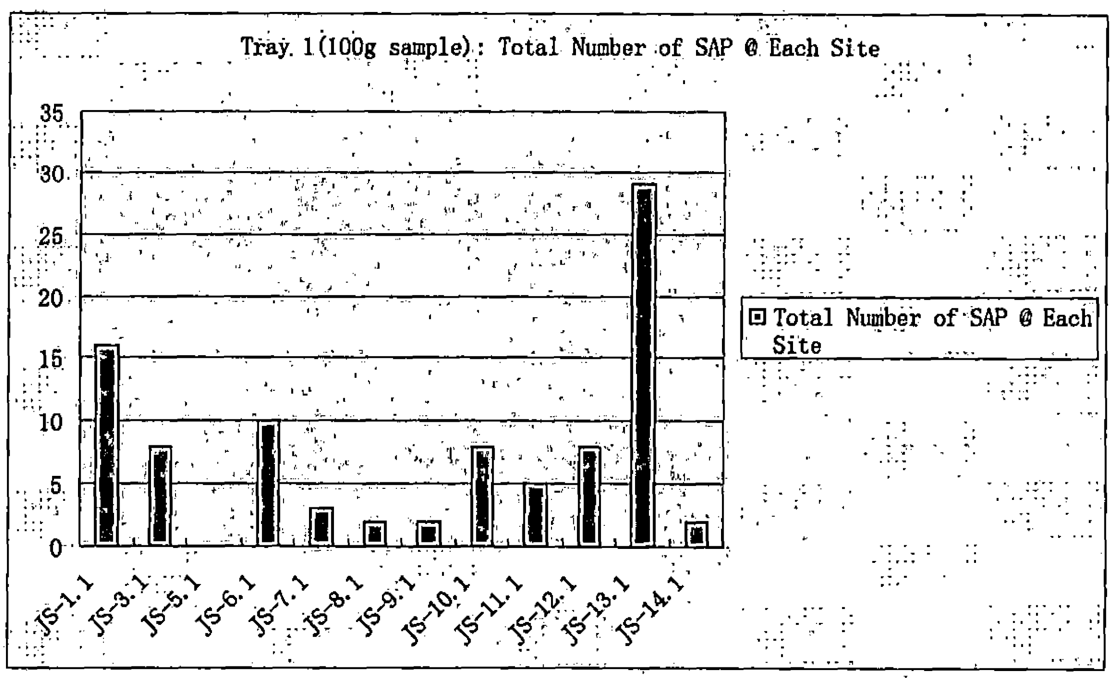

Figure 3-1. Total Number of Small Anthropogenic Particulates per 100 g Sample at Each Site for Tray 1

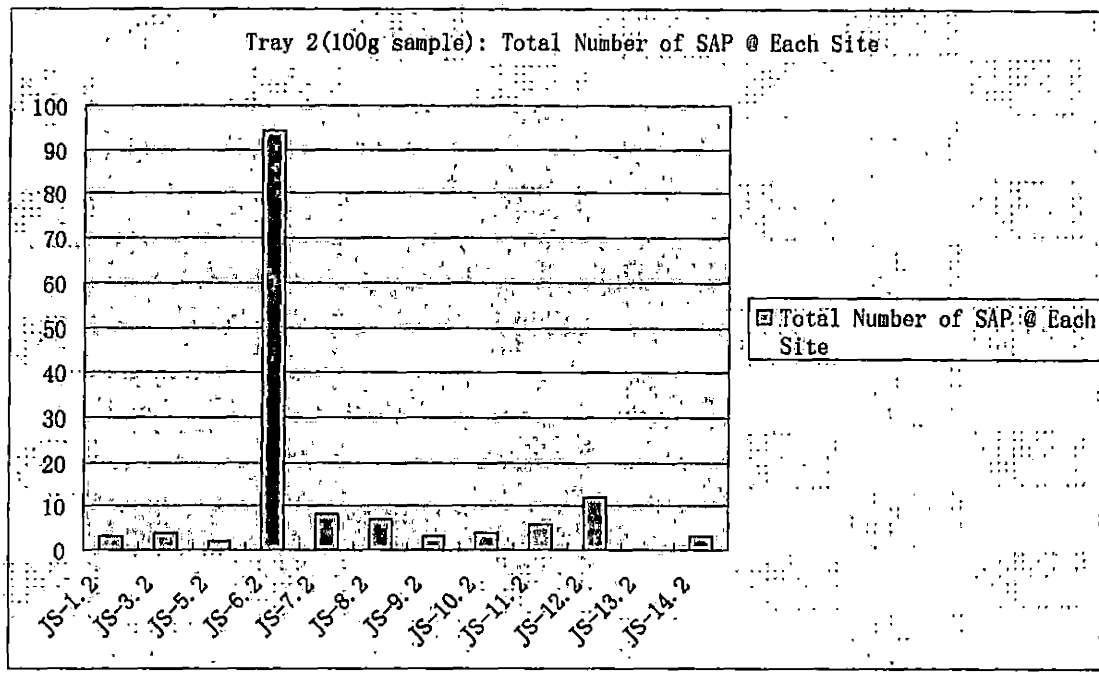

Figure 3-2. Total Number of Small Anthropogenic Particulates per 100 g Sample at Each Site for Tray 2

From the data, two high values are observed: one is Site 13 Tray 1, which has 29 pieces of SAP/100 g sample; the other is Site 6 Tray 2, which has 94 pieces of SAP/100 g sample.

Wilcoxon Rank Sum Test

In order to make the data towards more normal distribution, one type of non-parametric test called Wilcoxon Rank Sum Test was performed, see Figure 3-3:

Wilcoxon Rank Sum Test

Upper River	Rank	Middle River	Rank	Lower River	Rank
16	22	3	8.5	5	13
8	17.5	2	4.5	8	17.5
0	1.5	2	4.5	29	23
10	20	8	17.5	2	4.5
3	8.5	8	17.5	6	14
4	11.5	7	15	12	21
2	4.5	3	8.5	0	1.5
94	24	4	11.5	3	8.5
Mean	13.6875		10.9375		12.875
Stdv	8.404664946		5.314653		7.652031

T test: Upper VS. Middle 0.449478 — No significant difference between Upper River and Middle River ($p>0.05$)

T test: Upper VS. Lower 0.842705 — No significant difference between Upper River and Lower River ($p>0.05$)

T test: Middle VS. Lower 0.566888 — No significant difference between Middle River and Lower River ($p>0.05$)

Figure 3-3. Wilcoxon Rank Sum Test of the Data

Microscope Images

In this project, lots of interesting particulates were found from the samples, and some of them were anthropogenic, while others were not. Manufacture-derived particles were the major part of the SAP found from the sample, which also belonged to water sediment particles. A good example in point was sand-size glass particulates. Of course, various types of SAP were found from the SAR, including garnets from sand paper, coal, shotgun bullets from a shooting range at Redlands, which was located at Site 6, and paint. The interesting point was that even some ant head shells after molting were hidden in the samples. However, they were excluded from SAP.

All the identifiable particulates were photographed under a microscope through Lumenera camera: LU-200C. For example, NO.1 in JS-1.1 Part 1, see Figure 3-4:

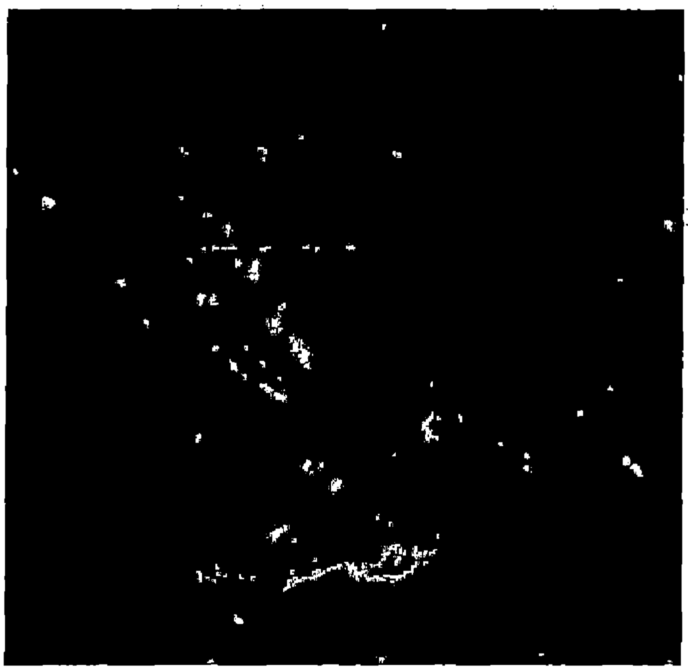

Figure 3-4. Sea Shell
The magnification of the picture is ×1. It looks like a mini tooth, made of ceramic. Hydrochloric acid was used to test it, and it started bubbling after one drop of 5% Hydrochloric was put on the particle. Then, it was identified as sea shell. However, it should not belong to the SAR. Most likely, it was transported by human activity. That is why it was considered to be SAP.

Next one is NO.26 in JS-1.1 Part 2, see Figure 3-5:

Figure 3-5. Natural Pink Garnet
The magnification of this picture is 2.6. This is a piece of natural pink garnet, non-anthropogenic.

The third one is NO.20 in JS-1.1 Part 1, see Figure 3-6:

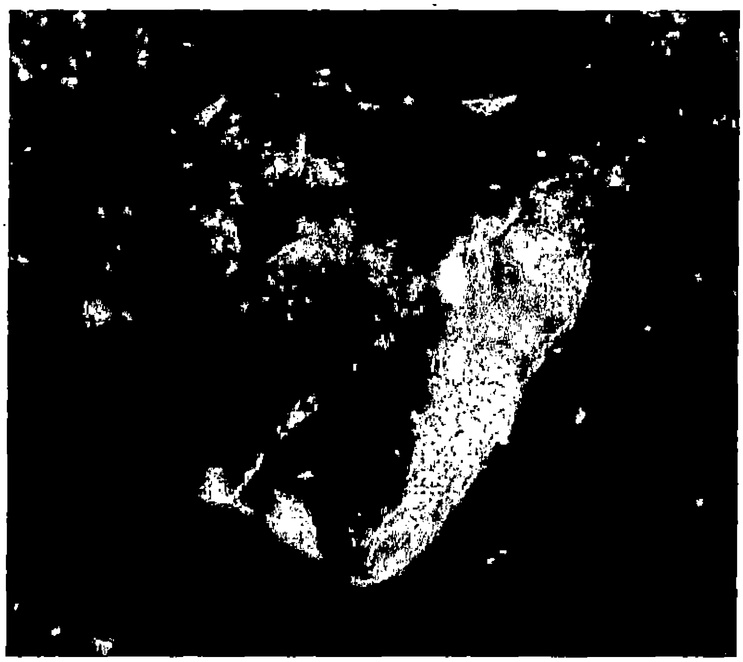

Figure 3-6. Glass
The magnification of the picture is 1.7. This is a piece of glass. It does not change color under a polarizing microscope. And glass is anthropogenic.

The fourth one is NO.1 in JS-3.1, see Figure 3-7:

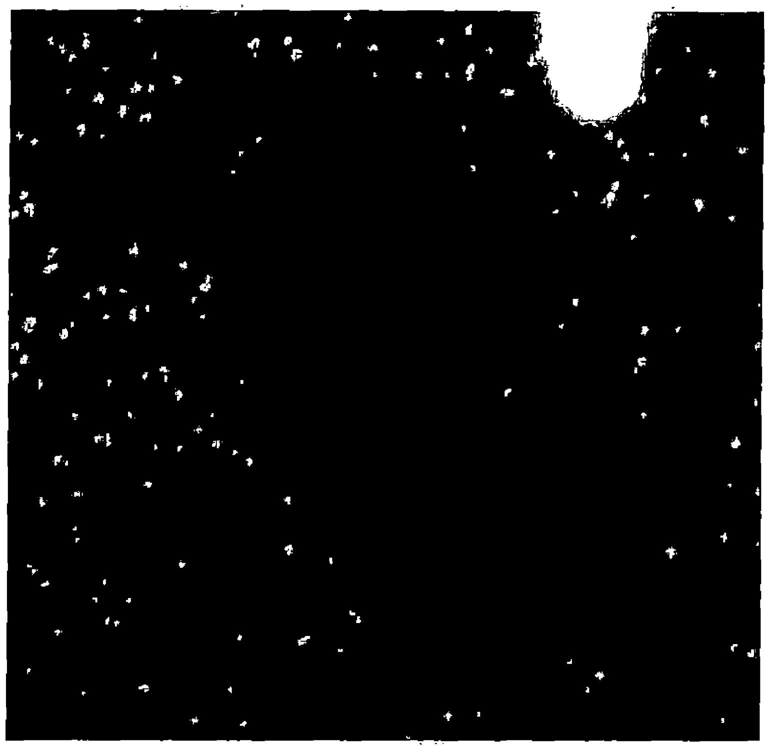

Figure 3-7. Charcoal
The magnification of the picture is 1.2. This is a piece of charcoal, belonging to SAP.

The fifth particle is NO.15 in JS-3.1, see Figure 3-8:

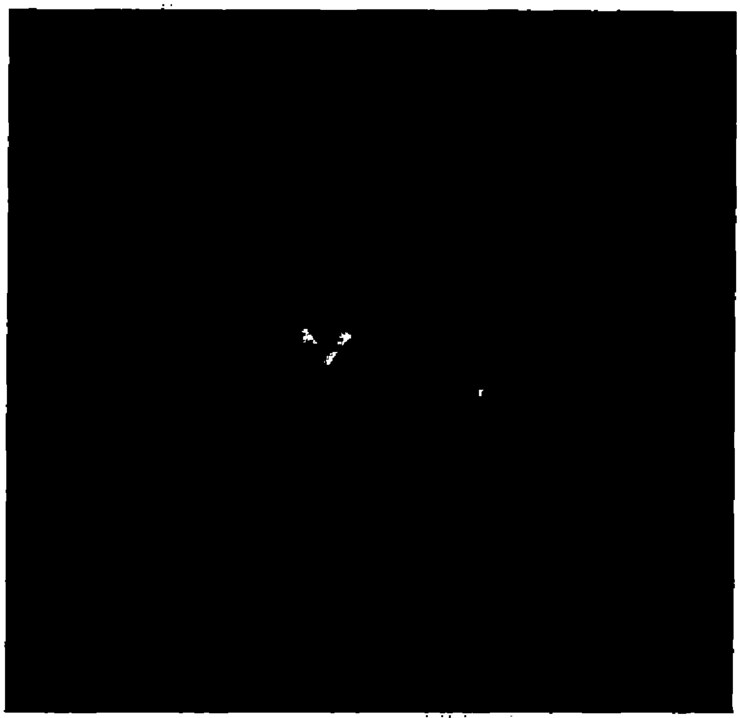

Figure 3-8. Processed Garnet
The magnification of the picture is 2.8. This is a piece of processed garnet, mostly comes from jewelry or sand paper, which is identified as anthropogenic.

The sixth one is NO.15 in JS-6.1, see Figure 3-9:

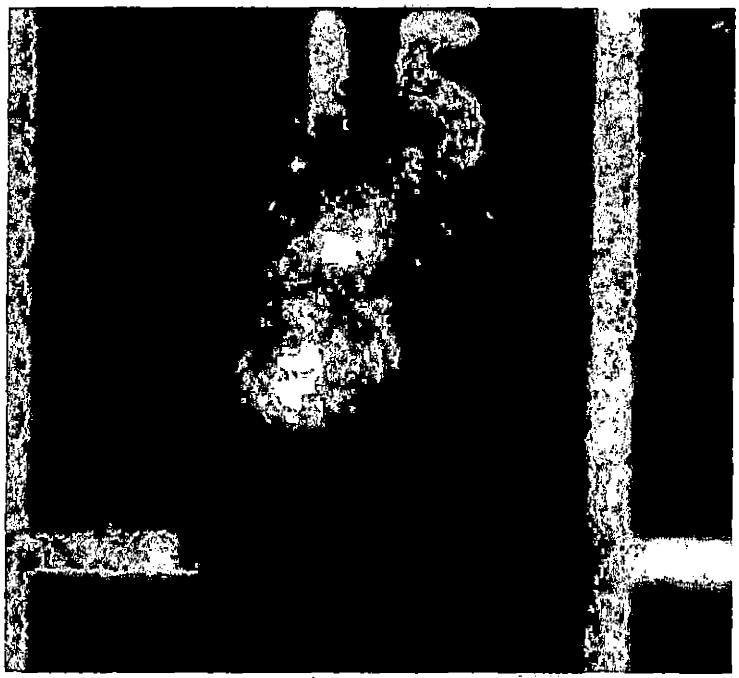
Figure 3-9. Shotgun Bullet
The magnification of the picture is 0.5. This is a shotgun bullet, made of lead. It is found from Sample 6.1, which is located near Redlands Shooting Park at 2125 Orange St, Redlands, CA 92374.

These data show that shotgun bullets were found at Site 6: Sample 6.1 contains 10 pieces/100 g, while Sample 6.2 has a higher concentration: 86 pieces/100 g. Although the data may vary depending on the location, this means certain events, such as shooting practice at Redlands Shooting Park, have a major contribution to the sediment load of the SAR. The second sample contained much more shotgun bullets than the first one. There is a high probability that the lead balls in the second sample came from one shell, which means one certain event, such as one shot, could exert considerable influence on certain area of the river. Compared with a glass bottle thrown into the river, shotgun bullets are much smaller particles, and affect the river system faster and more easily, because it takes longer time to break the glass bottle into sand-size grains than the shotgun bullets. In other words, smaller particles have a more direct influence on the sediment load of the fluvial system.

The Seventh one is NO.7 in JS-7.1, see Figure 3-10:

Figure 3-10. Quartz
The magnification of the picture is 2.0. This is a piece of quartz. It shows different colors under a polarizing microscope, when it is spun. Therefore, it is not anthropogenic.

The eighth one is NO.8 in JS-8.1, see Figure 3-11:

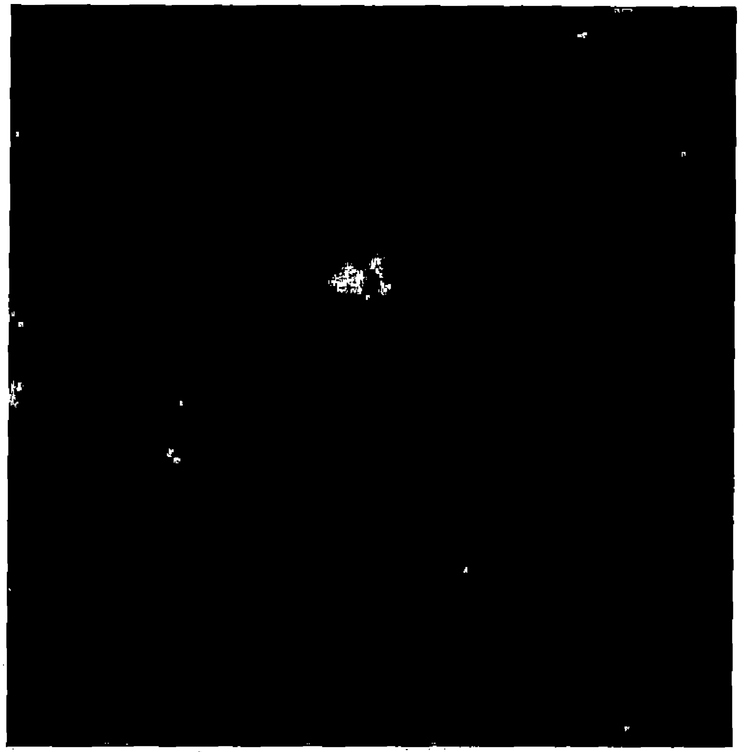

Figure 3-11. Glass Ball
The magnification of the picture is 2.2. This is a tiny glass ball. It does not change color under a polarizing microscope, when it is spun. As a result, it is anthropogenic.

The ninth one is NO.14 in JS-12.1, see Figure 3-12:

Figure 3-12. Stem
The magnification of the picture is 2.2. It looks like a little piece of wood stick. However, the surface turns sparkly, which is from plant cells. This means it is a piece of stem from a certain plant.

The tenth one is NO.5 in JS-13.1, see Figure 3-13:

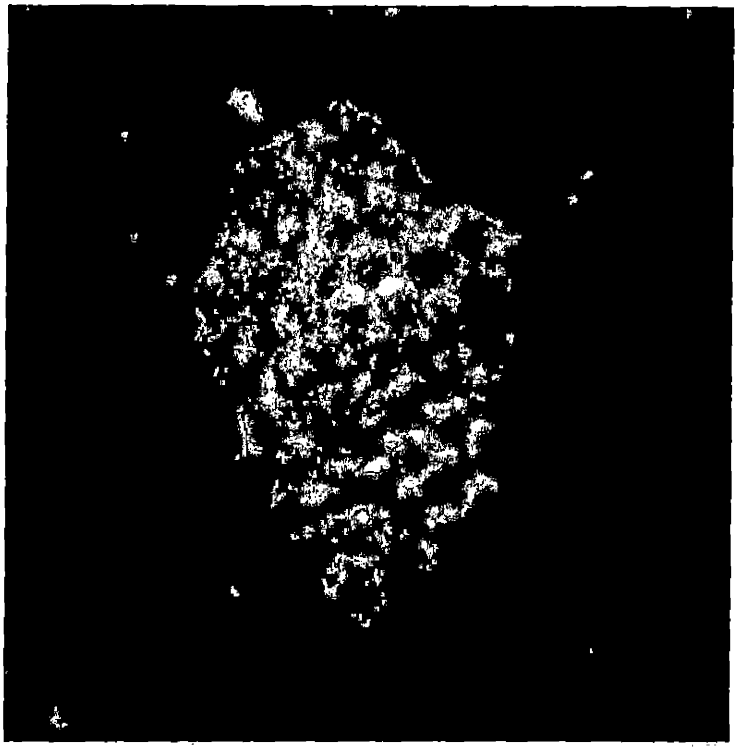

Figure 3-13. Lizard Skin

The magnification of the picture is 3.1. It looks like some bug eggs. However, it turned out to be a piece of lizard skin. Therefore, it is non-anthropogenic.

The eleventh one is NO.3 in JS-13.1, see Figure 3-14:

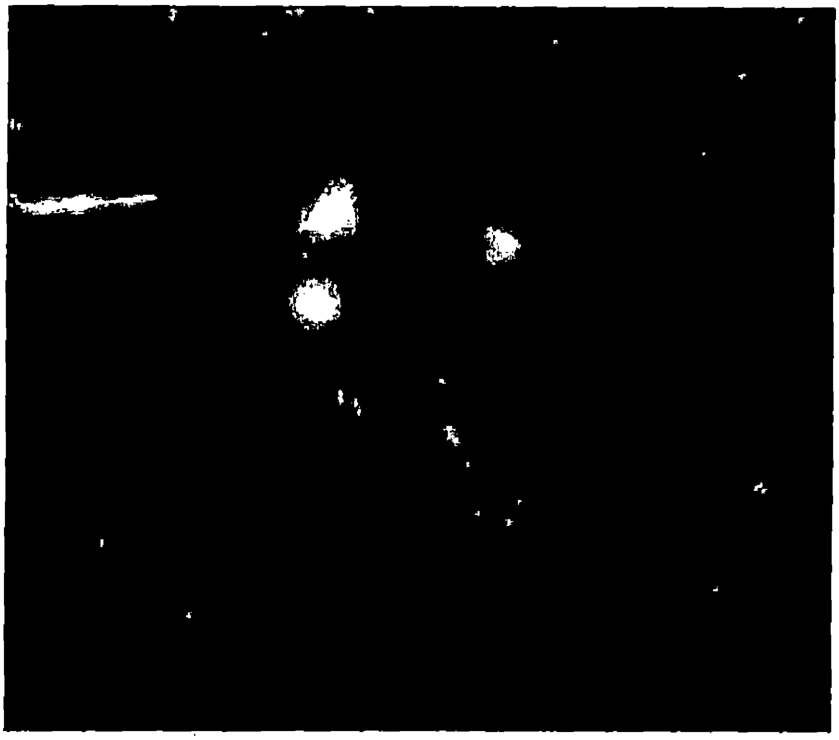

Figure 3-14. Ant Head Shell
The magnification of the picture is 1.8. This is an interesting finding: a piece of ant head shell. It is non-anthropogenic.

The Twelfth one is NO.6 in JS-9.2, see Figure 3-15:

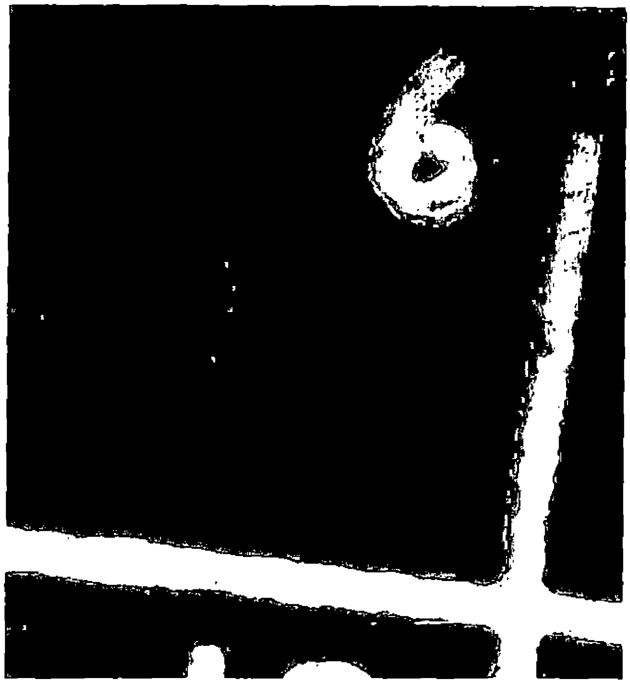

Figure 3-15. Brick
The magnification of the picture is 1.0. This is a piece of brick, identified under a microscope. It is anthropogenic.

The thirteenth one is NO.10 in JS-12.2, see Figure 3-16:

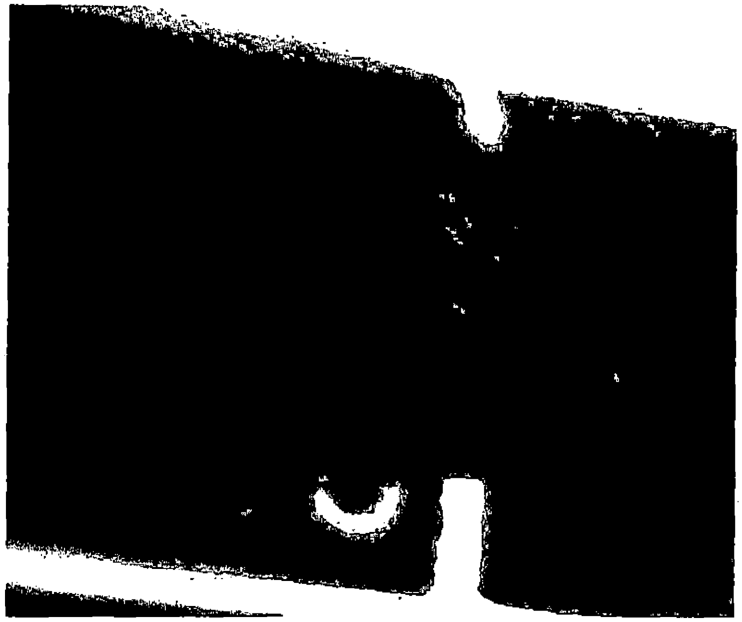

Figure 3-16. Slag
The magnification of the picture is 1.6, and the size of the particle is 3.80 mm. This is a piece of slag. It is anthropogenic.

There is a cement plant at Colton near the SAR, see Figure 3-17:

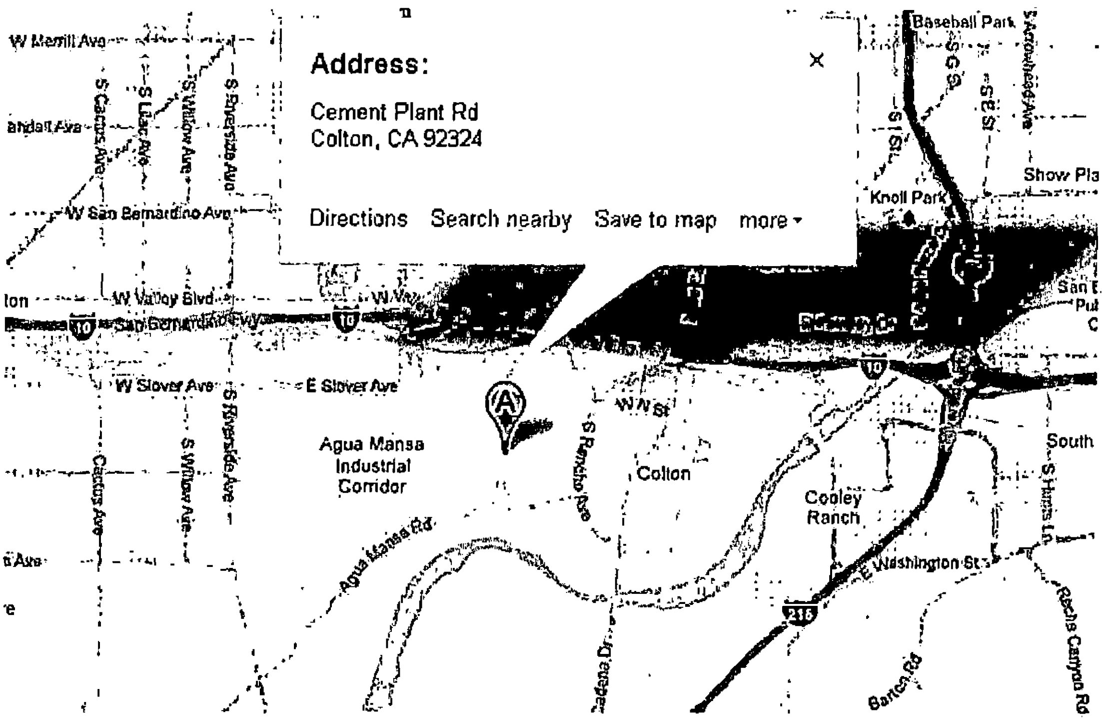

Figure 3-17. A Cement Plant by the Santa Ana River
The map provides some clue about the source of the slag. It is produced in the cement plant, and transported by some natural forces, such wind, water flow, or human activity, like dumping. Therefore, slag is considered to SAP by origin.

The fourteenth one is a big piece of concrete in JS-11.2, see Figure 3-18:

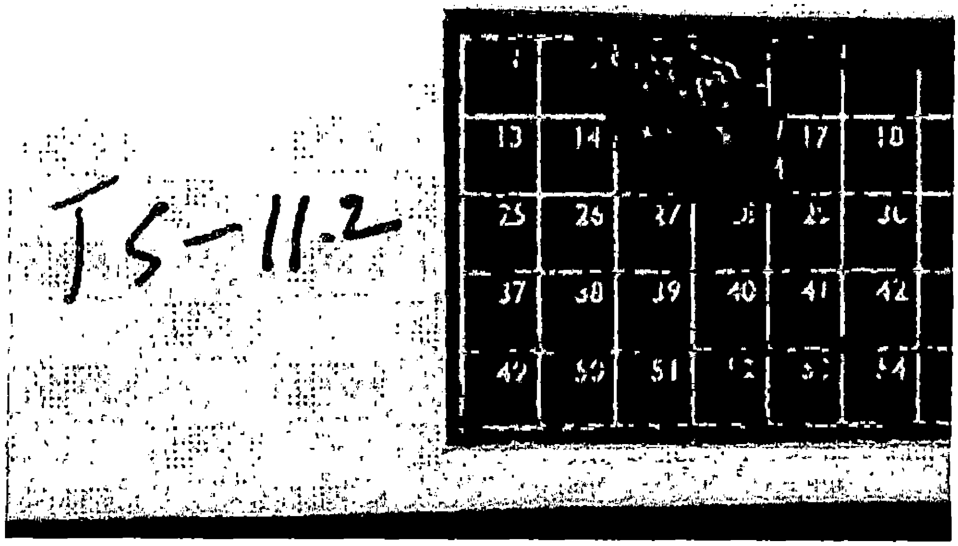

Figure 3-18. Concrete
The size of the piece is 8.75 mm long. It comes from construction material. It is anthropogenic.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATIONS

Conclusion

Along the SAR path from its headwaters to the ocean, human activities, buildings, industry, and residential communities increase. Hypothetically, SAP should become a greater statistical contributor to sand substrates farther from the beginning of the river. However, Wilcoxon Rank Sum Test demonstrates that the debris in the SAR has not been transported far away from the potential source. Further down the river, the number of SAP found in the sample does not accumulate. In other words, the distribution of SAP has not been significantly ($p > 0.05$) affected by the fluvial system. Certain events or human activities exert more significant influence on the sediment load of the SAR instead. For example, at Site 6, the shooting practice at Redlands Shooting Park adds a considerable number of shotgun bullets into the sand on the riverbed, which makes the samples from Sits 6 contain a large number of shotgun bullets. Another good example is the cement plant at Colton releasing slag into the SAR. As a result, for certain parts of the river, the anthropogenic activities are the major contributive factor to the sediment load of the SAR. Of course, the distribution of SAP should be affected by the variations in fluvial discharge, and velocity, because of their differential density, shape, and composition from natural fluvial sediments. In addition, storm or flood could exert tremendous influence on the distribution of SAP.

Recommendations

Improvement of Methodology

During the process of the project, several problems were encountered. First, the samples are easily contaminated by lab tools or mixed. For example, when the first sample was split, aluminum foil was used to wrap the pan. Unexpectedly, a little piece of aluminum foil was found in the sample sand. Therefore, it is critical to try to keep the samples uncontaminated. Second, the methodology of the project needs to be improved, because looking through about 50 g of sand under microscope takes approximately 12 hours. A total of 42 samples were collected, so there would be about 500 hours of microscope inspection work, which is not very time-efficient. If a new method of splitting SAP from sand could be found, that will be a big step in improving the methodology of the project. Third, Elmer's glue used on the slides caused a problem in the subsequent process. After the glue around the particles become dry, it makes the particles look like coated with an anthropogenic cover around it. As a result, the particles become more difficult to be identified.

Further Research

Another promising aspect for further research is how to distinguish SAP in origin and minerals that have been affected by human activities. From the geological records, the type of rocks for certain parts of the SAR can be determined. Sample minerals are supposed to match these criteria. If not, they have probably been moved by humans, which makes them anthropogenic; or by the river flow, even floods, which stays natural. In this project, lots of garnets were found. Garnets are a group of common, widespread aluminum or calcium silicate minerals. They are generally crystallized, and mostly used as gemstones or abrasives, like those on the sand paper. Here comes the question:

how to determine the garnets found from the samples are anthropogenic or not. This will be interesting. By checking the geological records and analyzing the human activities along the SAR, some clue might emerge to help figure out the source of those garnets.

APPENDIX

PHOTO GALLERY

All Photos by Junjie Shen
Field Pictures

Photo #1: This is the steel arch bridge at Site 1.

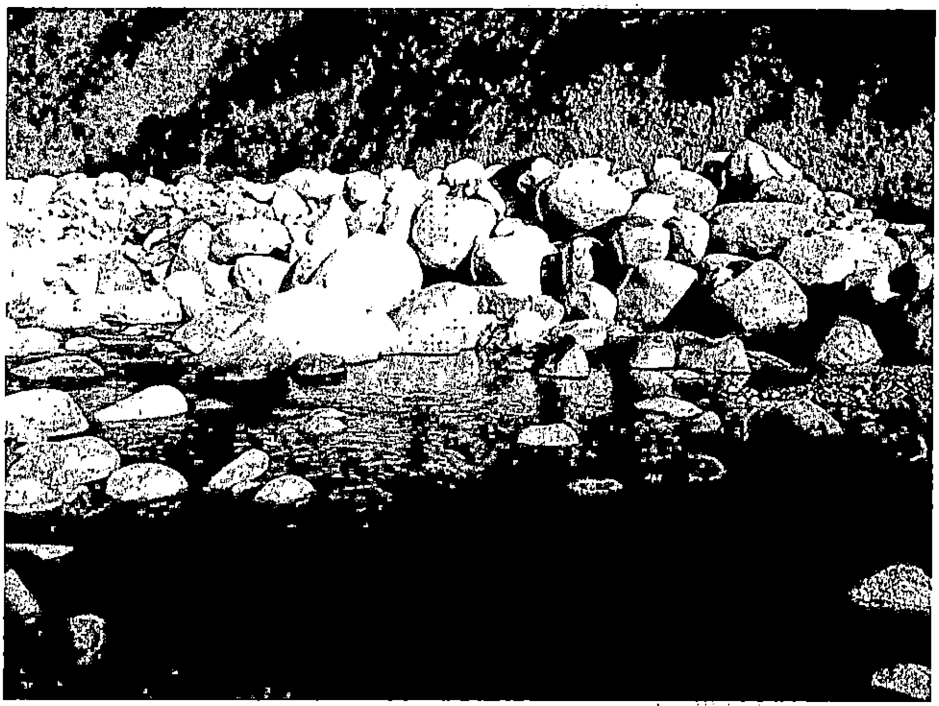

Photo #2: This is the stream flow at Site 1, just below Seven Oaks Dam.

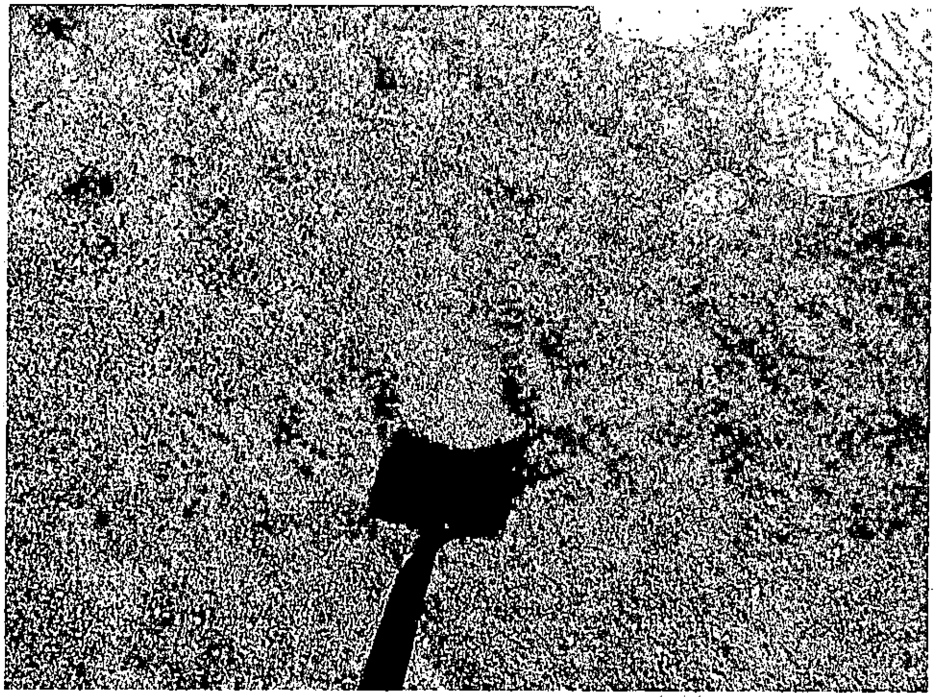

Photo #3: This is the spot where sample JS-1.1 was collected.

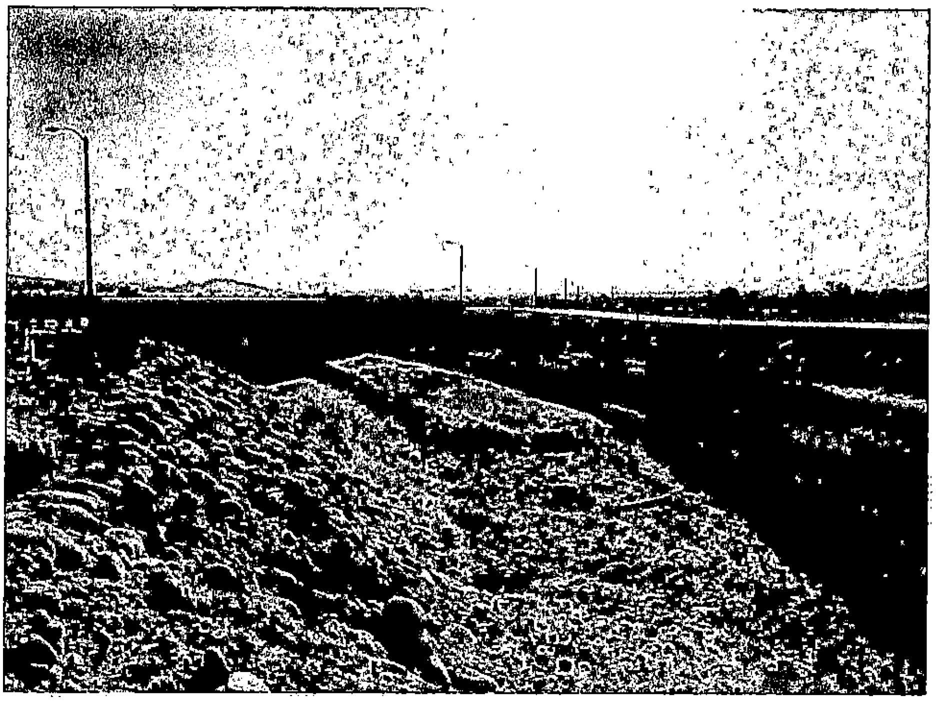

Photo #4: This is the riverbed at Site 2.

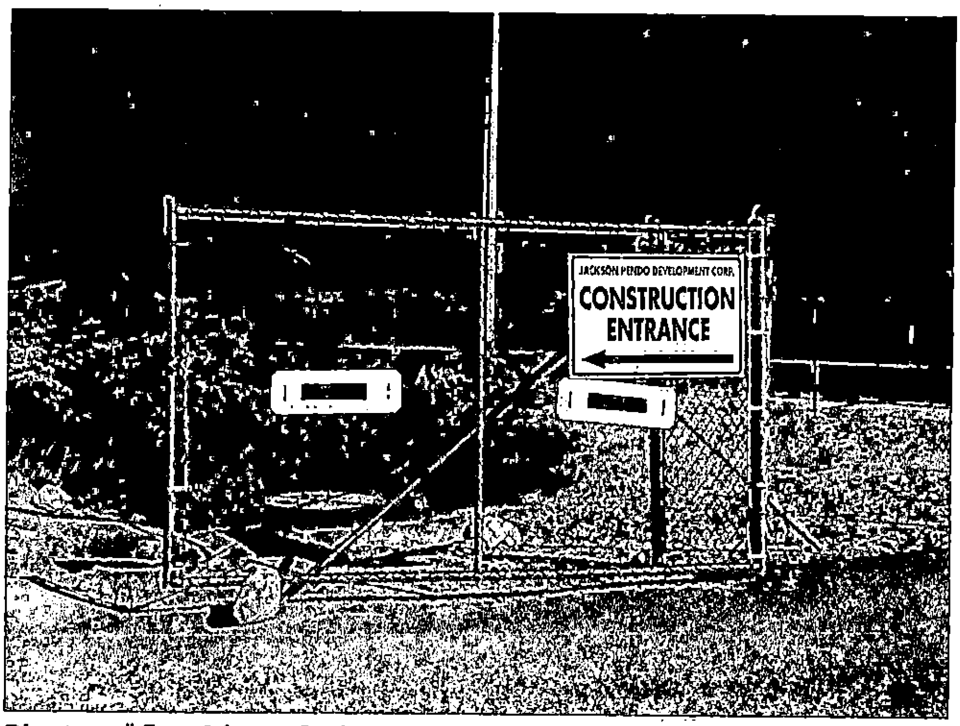

Photo #5: Site 2 is located in a construction field.

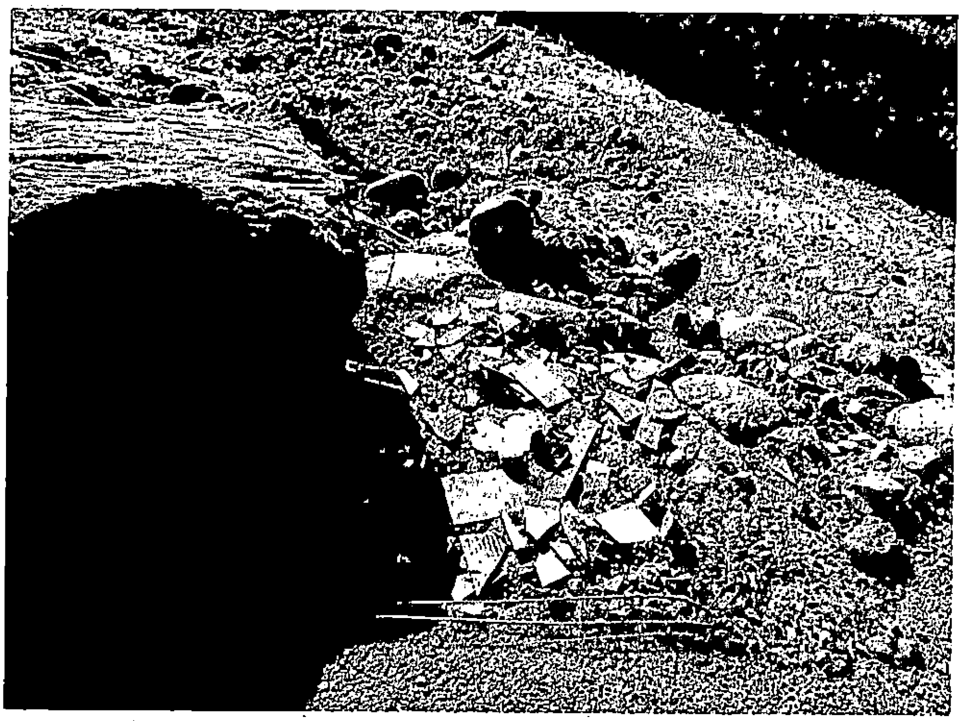
Photo #6: Some construction materials were found at Site 2. They are anthropogenic sources.

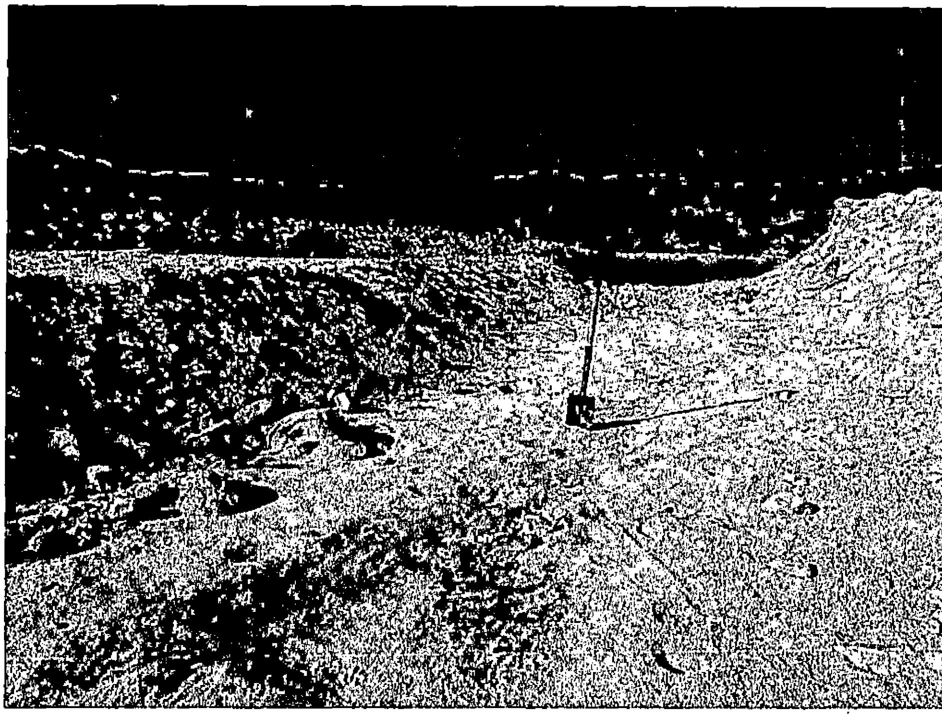
Photo #7: This is the shovel used for sampling.

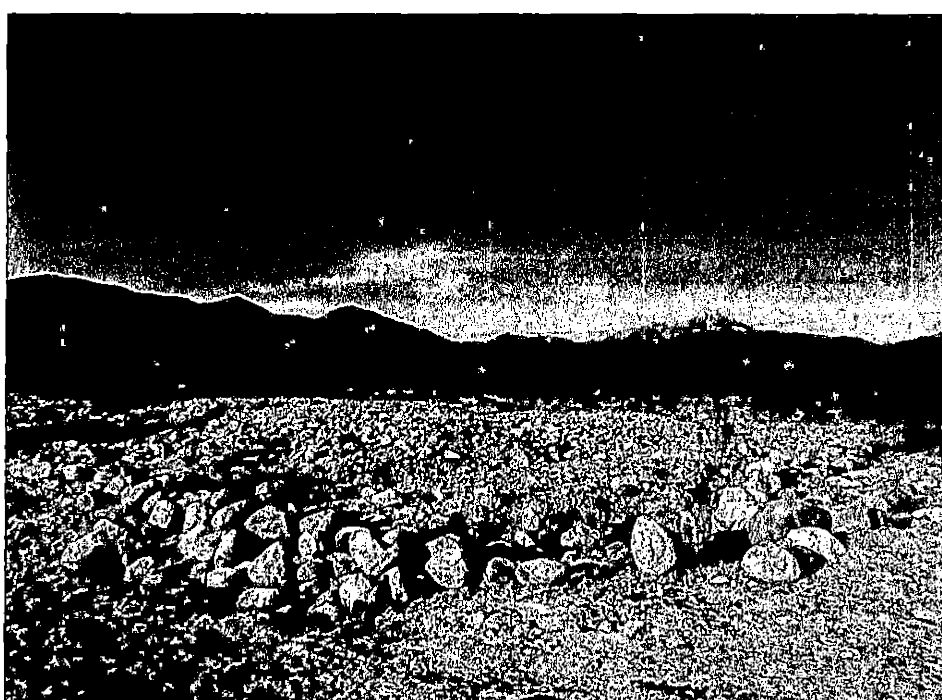
Photo #8: This is the riverbed at Site 3.

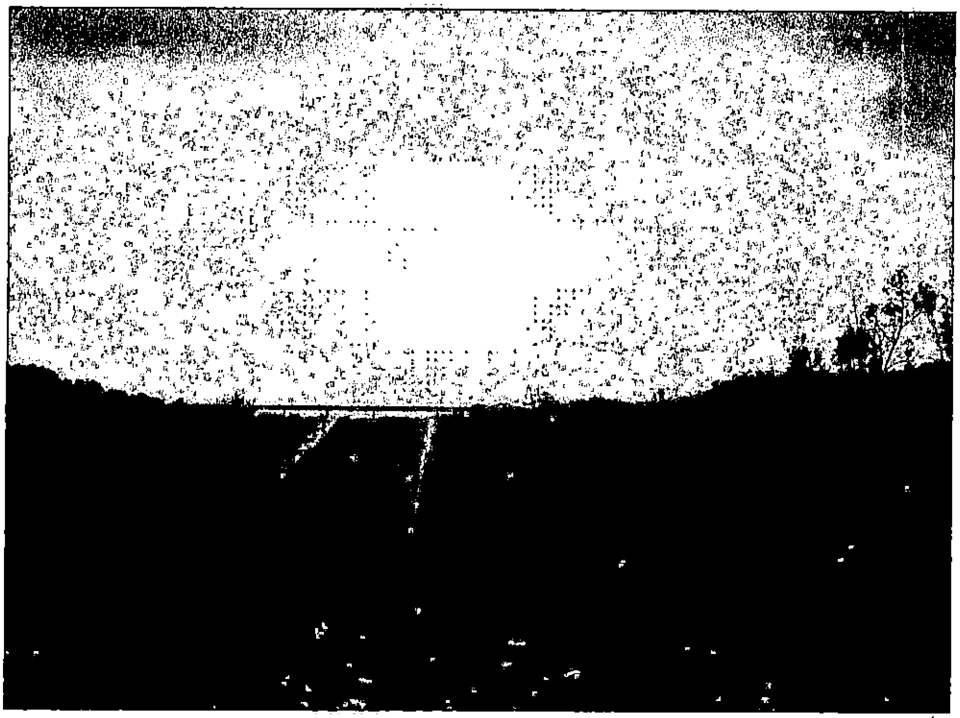

Photo #9: This is another photograph of riverbed at Site 3.

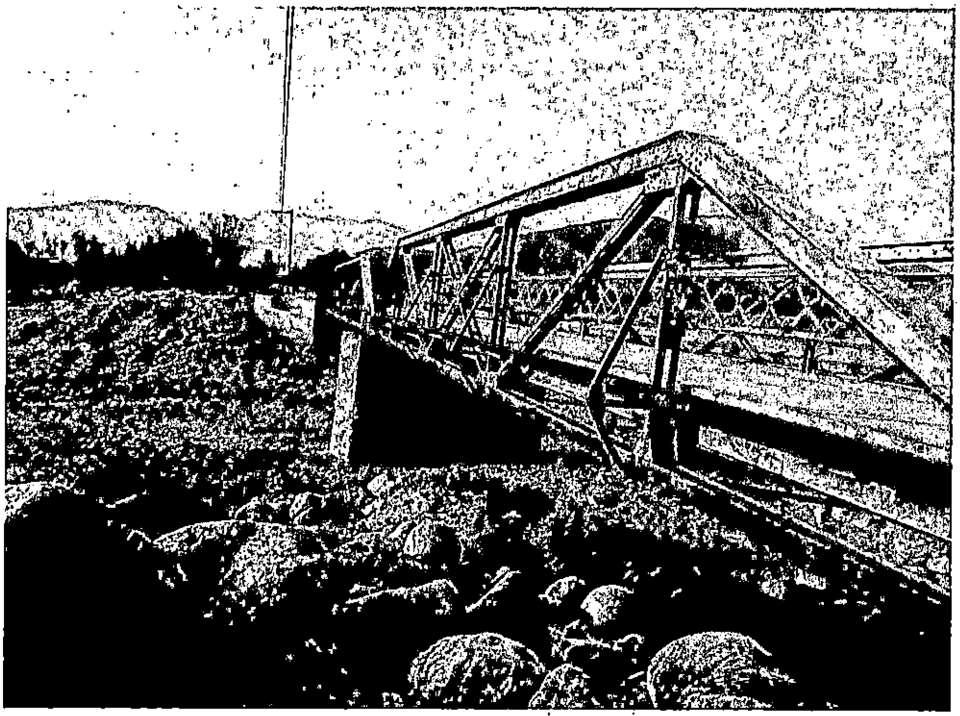

Photo #10: This is the bridge at Site 4.

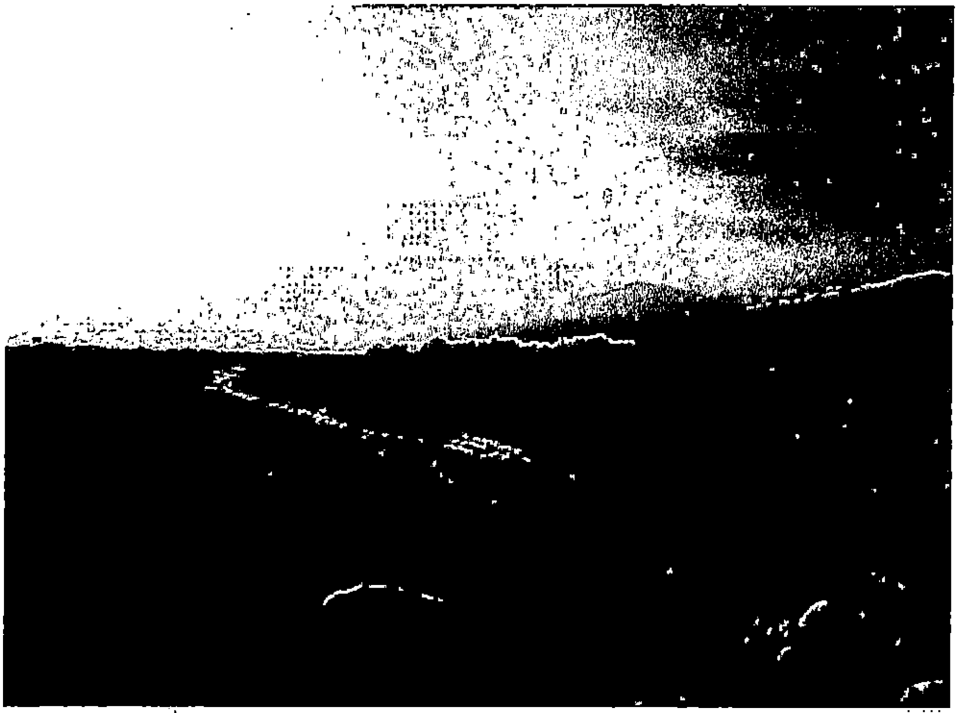

Photo #11: This is the riverbed at Site 4.

Photo #12: This is a piece of glasses found on the riverbed at Site 4. It is an anthropogenic source.

Photo #13: This is an Aquafina water bottle (16.9 FL OZ) found on the riverbed at Site 4. It is a source of SAP.

Photo #14: This is a Budweiser beer can (12 oz) found on the riverbed at Site 4. It is an anthropogenic source.

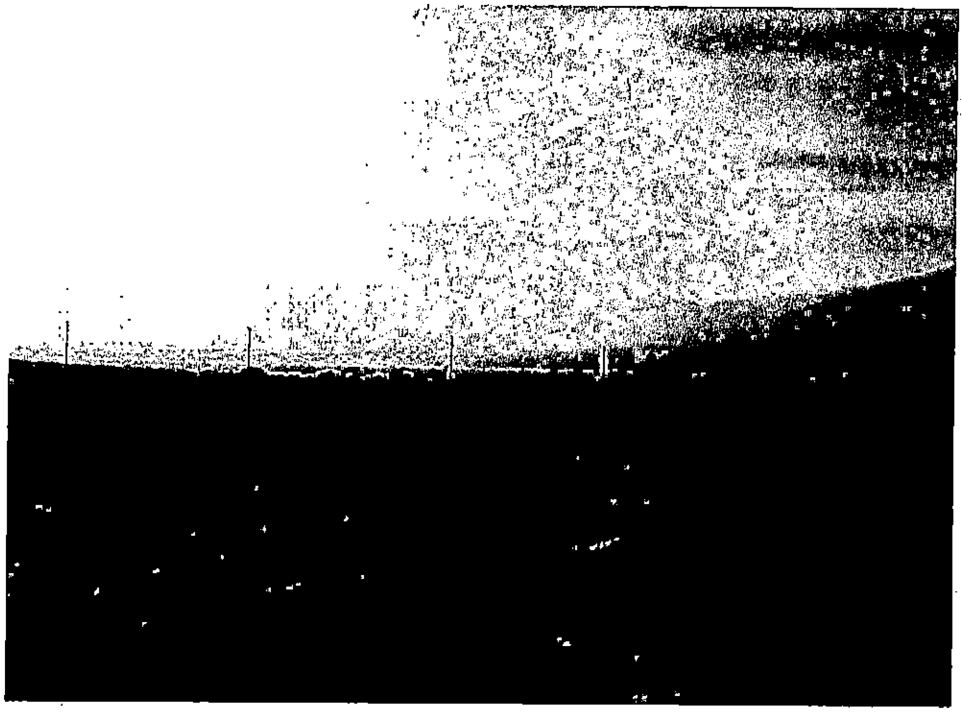

Photo #15: This is the riverbed at Site 5.

Photo #16: This is the orange grove at Site 5 by Florida Street in Redlands.

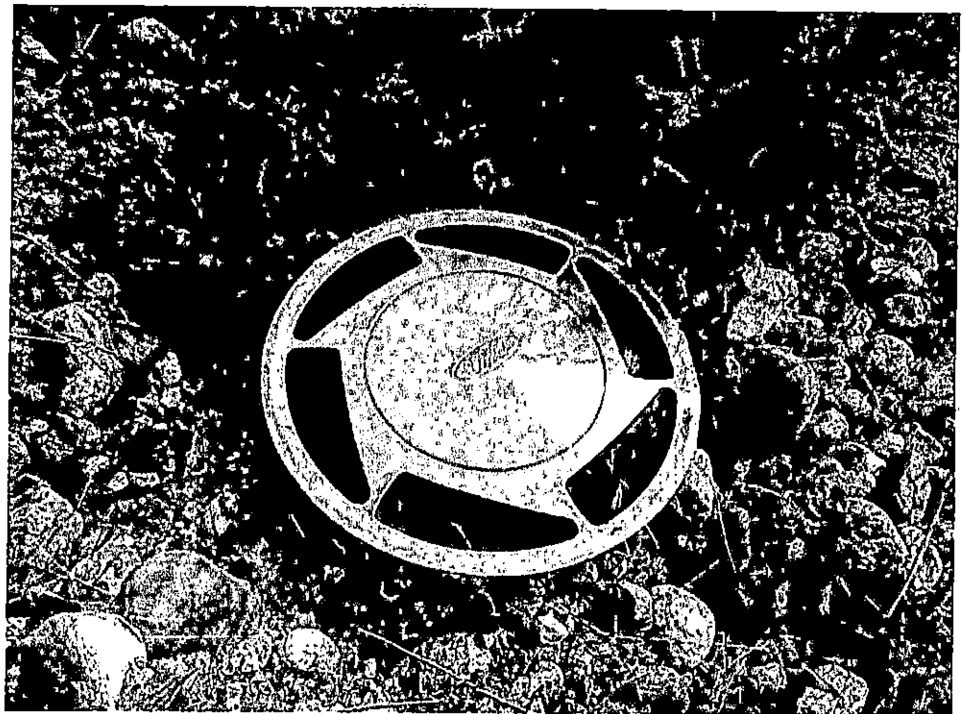

Photo # 17: This is an automobile wheel cover (Ford brand) found on the riverbed at Site 5. It is also an anthropogenic source.

Photo #18: This is the riverbed at Site 6.

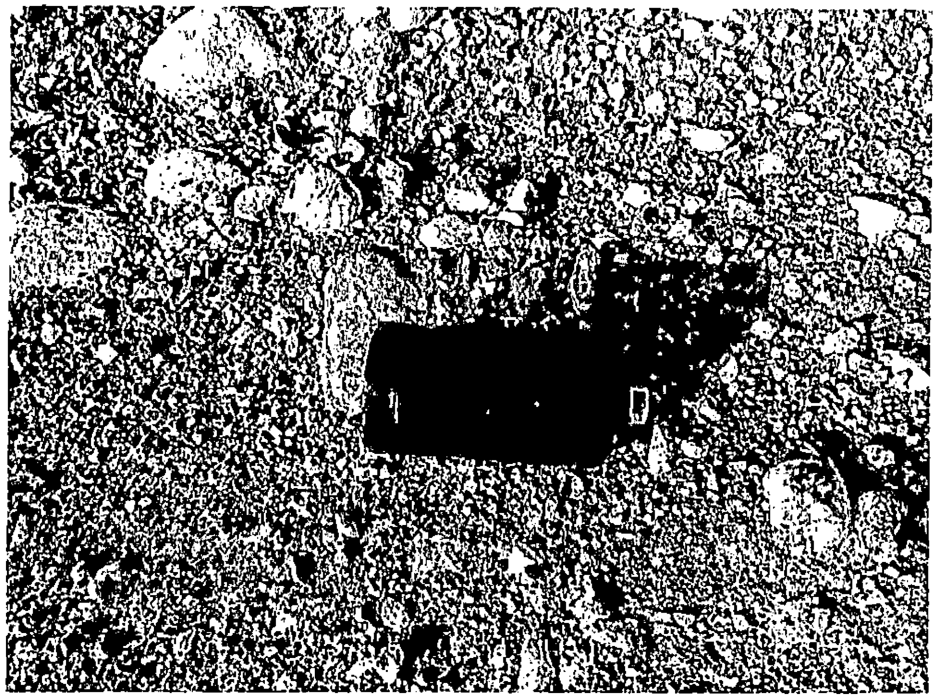

Photo #19: This is a propylene gas tank found on the riverbed at Site 6. It is also an anthropogenic source.

Photo #20: This is two tires found on the riverbed at Site 7. They are anthropogenic sources.

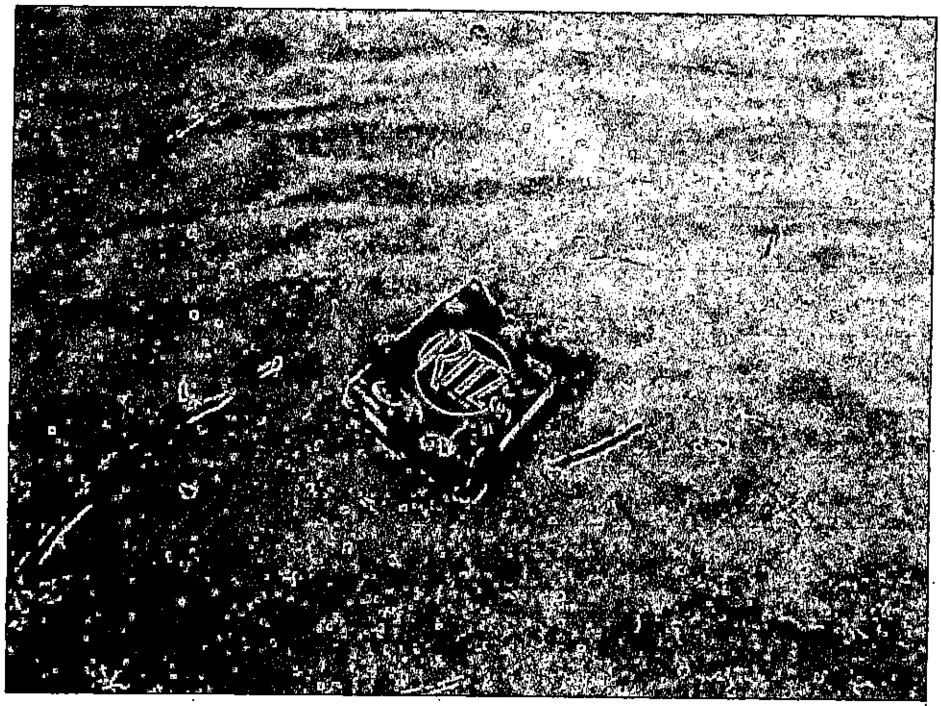

Photo #21: This is a box of RITZ crackers (Net Weight: 1 LB) found on the riverbed at Site 7. It is a source of SAP.

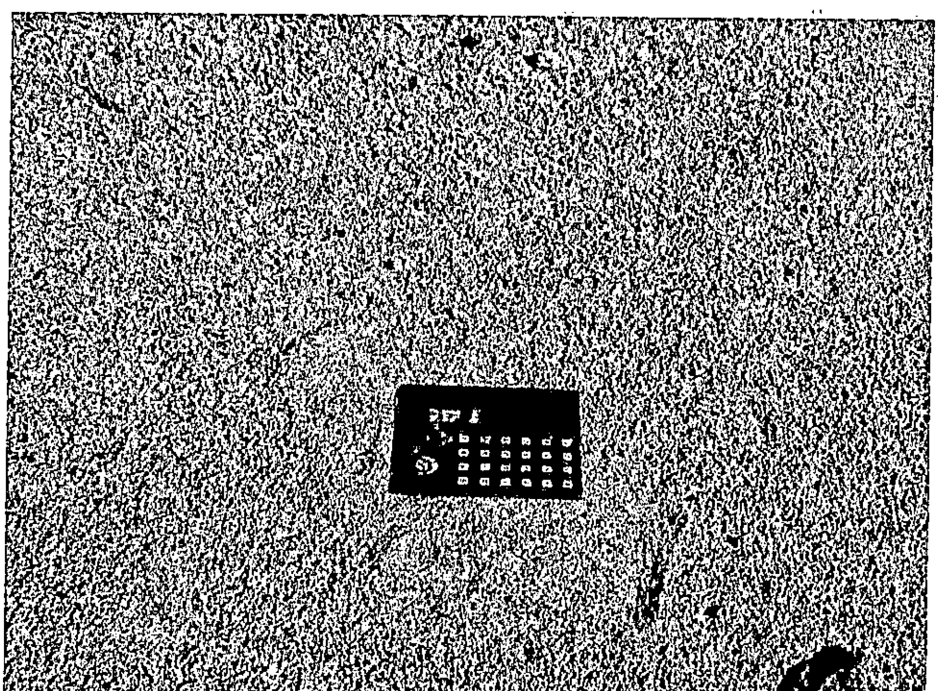

Photo #22: This is a cover of an calculator found on the riverbed at Site 7. It is an anthropogenic source.

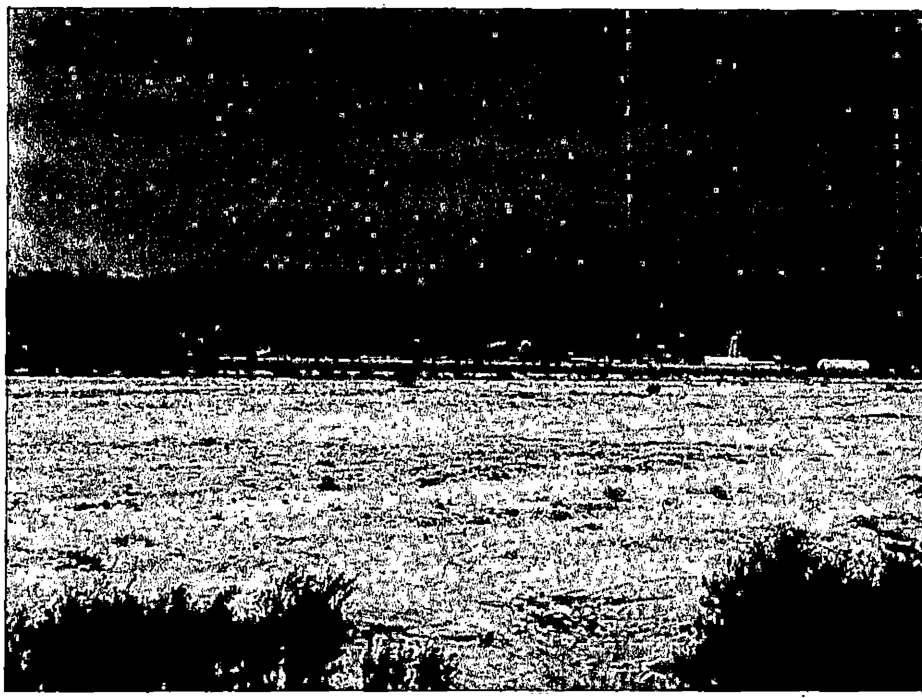

Photo #23: This is the riverbed at Site 8.

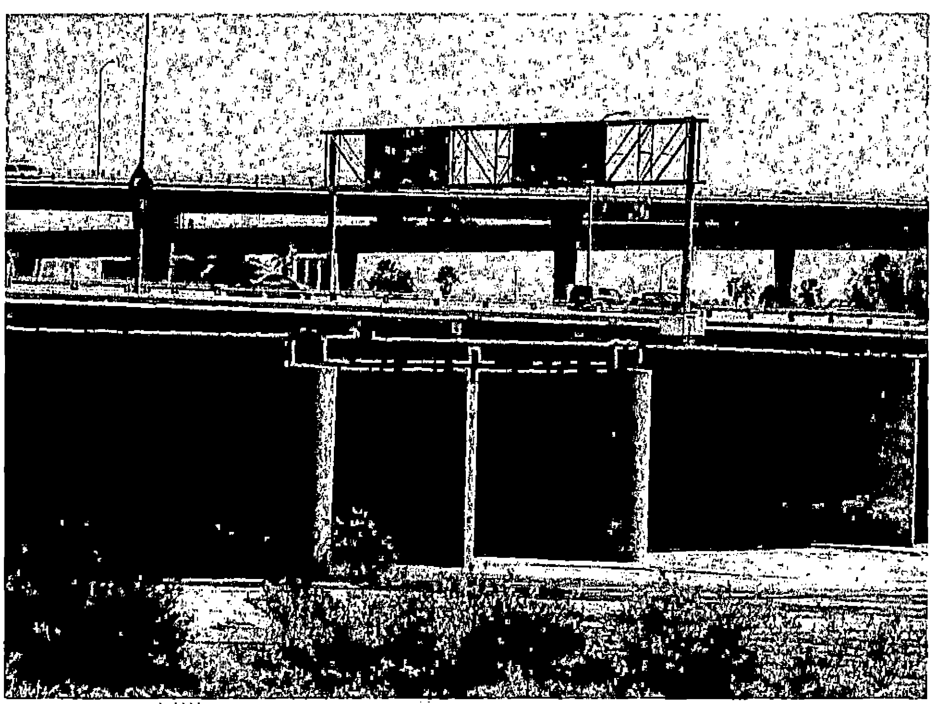

Photo #24: This is Site 9 which is located at the intersection of I-215 and I-10.

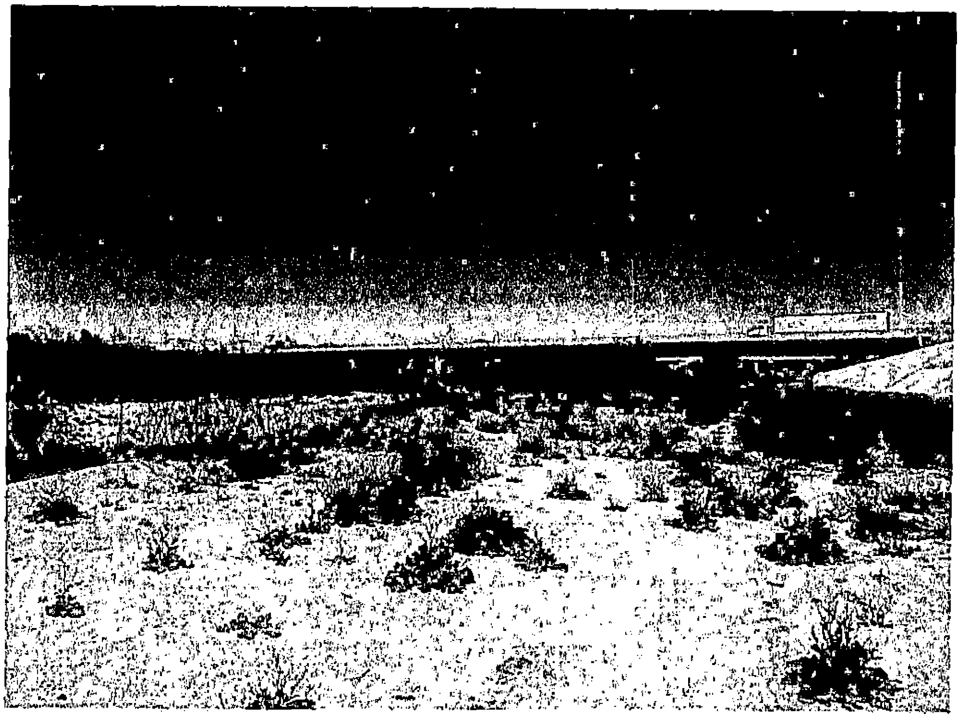

Photo #25: This is Site 10 which is located by
Market street in Riverside.

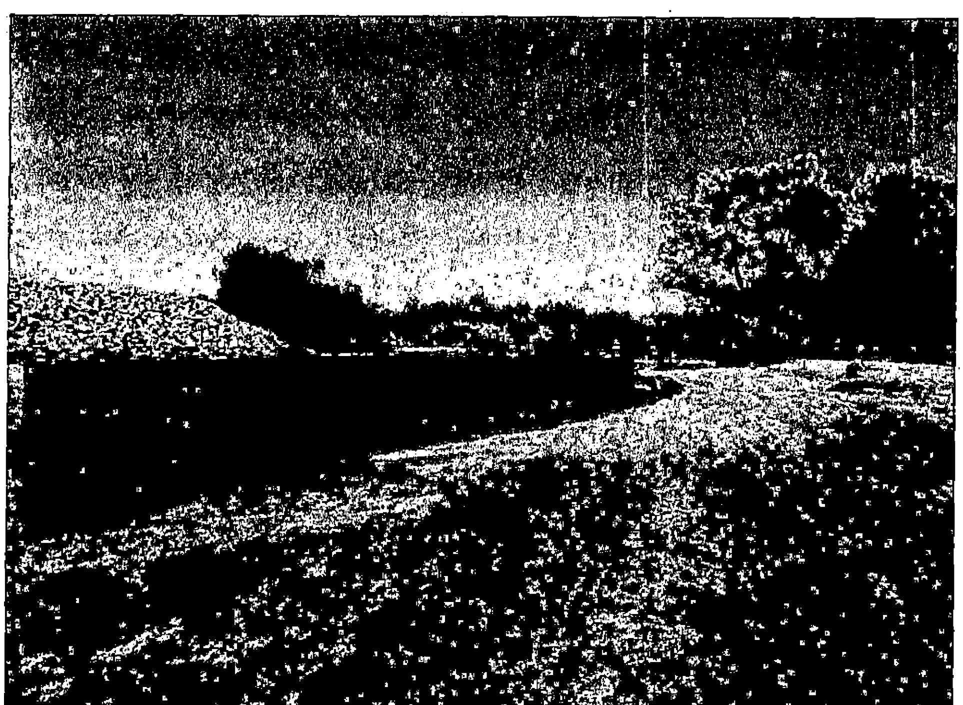

Photo #26: This is the stream at Site 11 by Hamner
Avenue between Norco and Eastvale.

Photo #27: This is another view at Site 11.

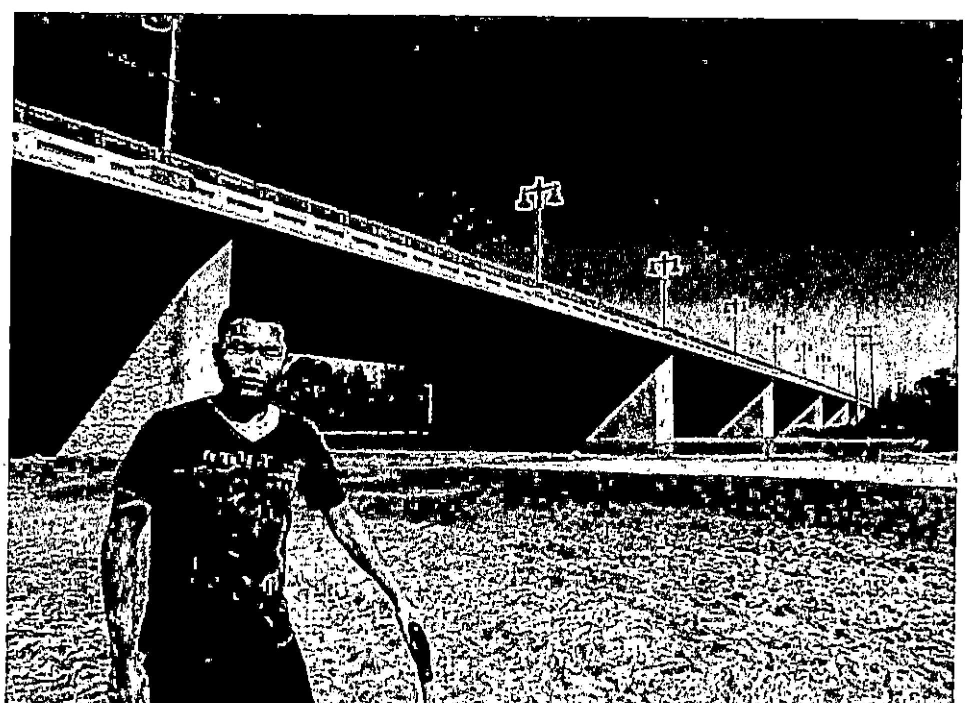

Photo #28: This is my friend Yebo Wang helping me sampling at Site 12.

Permission Letter

To whom it may concern,

I, Yebo Wang, gave Junjie Shen the permission to use my photo in his thesis.

Signature: Yebo

Date: 3/11/2013.

Photo #29: This is an introduction board of "The Value of Wetlands" on the Santa Ana River Trail, on which Site 13 is located.

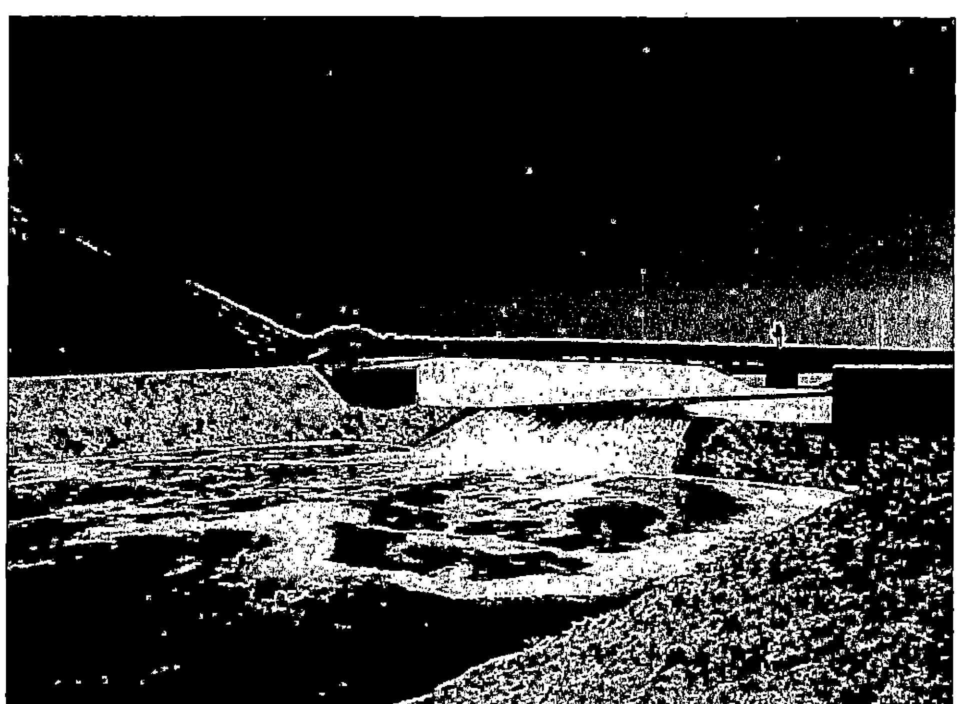

Photo #30: This is Site 14 right after the Prado Dam, where Highway-91 intersects with State Route 71.

Laboratory Photographs

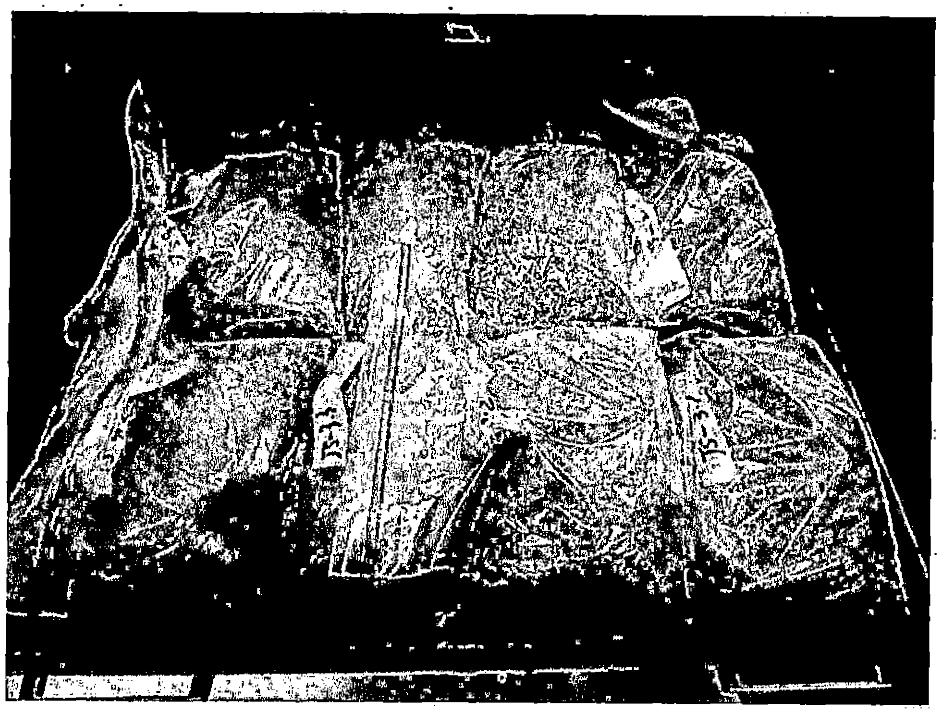

Photo #1: These are samples collected.

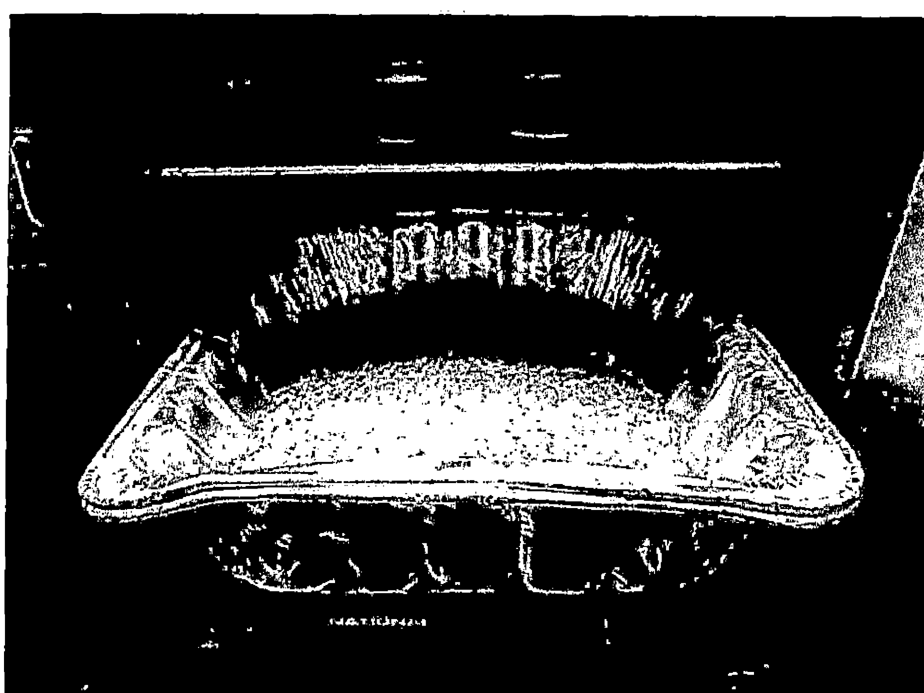

Photo #2: This is a sample drying in the oven.

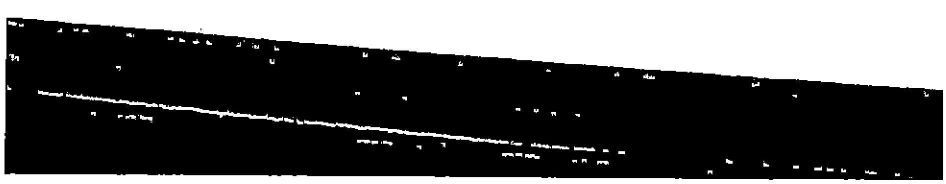

Photo #3: This is the sediment splitter.

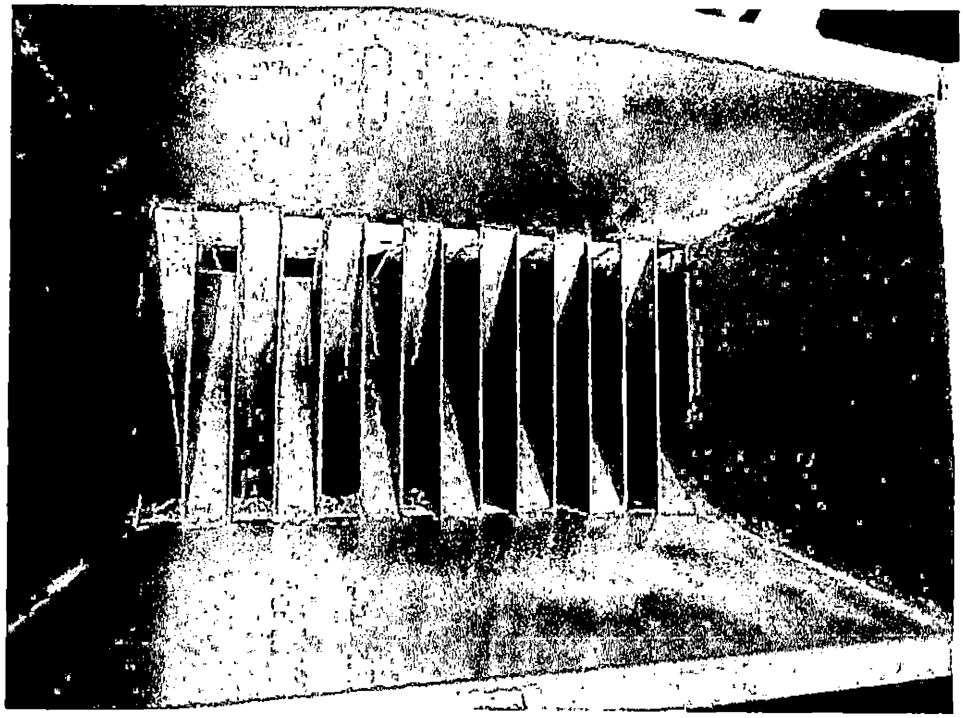

Photo #4: This is the inside of the sample splitter.

Photo #5: This is U.S.A. Standard Testing Sieve NO.60, with a 0.250 mm opening.

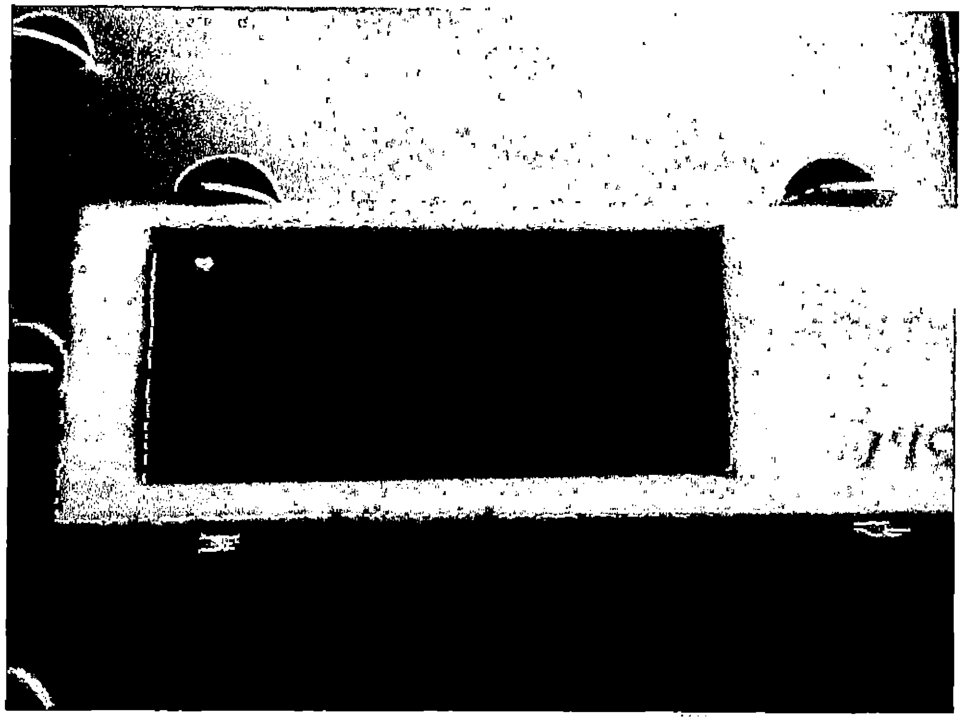

Photo #6: This is a piece of microscope slide, with identifiable or questionable particulates on it.

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