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Senior Seminar

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Sediment Transportation in Copeland Creek

Abstract

Copeland Creek is a tributary of the Laguna de Santa Rosa; a Ramsar recognized wetland near Rohnert Park in the north San Francisco bay area. Sediment transportation in Copeland Creek has become an increasing problem for communities close to the stream and the Laguna de Santa Rosa. The Sonoma County Water Agency (SCWA) is interested in the sediment transportation of Copeland Creek because of the affects it will have on: restoration projects in the area, filling of the Laguna de Santa Rosa, issues with channel constrictions, flooding, and resultant damage to Sonoma State University and the surrounding community. This project aims to characterize the sediment transport and deposition of Copeland Creek as it passes through the streams alluvial fan. The study aims to address two questions: how much sediment is being transported through Copeland Creek at any given time, and whether Copeland Creek's bed is a source or sink of sediment as it carries through the alluvial fan. To facilitate future research of deposition and erosion in the fan, the study establishes three cross sectional surveys. The first concern is addressed through the installation of a bed and suspended load sediment trap in the appropriate areas in order to measure the amount of sediment that is being transported through the creek during a given time. The second concern is addressed two ways, first by comparing remotely sensed images from 2004 and 2012 which a comparison of the channel widths and sediment deposition of the streams through the alluvial fan. Our study will be based off the Helley-Smith sediment and Pit Trap designs. The study also developed a manual for operation of

the traps. This longitudinal study will allow ongoing research of sediment transportation throughout Copeland Creek.

Introduction

The city's designers and builders of Rohnert Park built the city without any regard for natural stream function. This disregard is particularly obvious when Rohnert Park officials have to deal with Copeland Creek's normal stream behavior seasonal flooding and sediment deposition. Sediment transport is a normal physical process that is responsible for stream form development, such as meandering and river braiding (Ballio and Tait 2012). Streams erode sediment from higher elevations and transport them to the base level which in many cases is the ocean. If this natural process is interrupted by stream control, channelization, stabilization, and dams, then the natural process cannot occur; and water ways will begin to fill with sediment causing flooding and damages to surrounding structures and roads. When streams are channelized many times their normal sediment transportation behaviors are also altered. Alluvial fans are depositional zones for streams that come from steep terrain and transition into a flat valley-- Copeland Creek is one such stream that starts at Sonoma Mt and works to deposit sediment into the alluvial fan that Rohnert Park is located on. However, human interference is keeping Copeland Creek from doing what it normally does.

Sediment transport is one of the main functions of streams and water ways and in order to determine how much sediment is running through the creek there are a few things that we need to be aware of. The first is water flow, most classical models in morphodynamics describe the flow field with a depth-or section averaged approach, the main variables being water depth, bulk water velocity, and time averaged shear stress on the channel boundary (Ballio Tait 2012).

Next is the bed geometry, which is how the stream bed looks and is formed. Macro geometry of the boundary is expressed by distributions of bed elevations; subscale geometry is modeled by means of bulk properties such as a resistance parameter expressing the average effect of the sediment boundary on the fluid and porosity term describing the average packing of the deposit. Normally the resistance to erosion is characterized by some deterministic threshold of motion. The Final element of sediment transportation is moving sediments. Sediment motion is described by means of mass fluxes across reference surfaces or, alternatively, by the average concentration and velocity of the moving sediments (Ballio Tait 2012).

To counteract these normal stream behaviors and make the rich land useable, the Soil Conservation Service and Army Core of Engineers stabilized and channelized Copeland Creek in order to keep the stream from meandering and turn the land into an agricultural area. Much of the sediment is being deposited in the Laguna de Santa Rosa, which is filling at an increased rate. Our problem is that much is deposited in the bed which is decreasing the ability to move storm water there for causing flooding in residential communities. Once these agencies determined that the steps they had taken to stabilize the creek were causing complications in the areas surrounding Copeland Creek, they turned over the troublesome sections of land to the SCWA who was given the task to maintain and improve these areas. The SCWA then wrote the Copeland Creek master plan that focuses on research to reverse the effects of channelization on Copeland Creek. Goal 5 of the Copeland Creek Master Plan looks to maintain hydraulic function of Copeland Creek for flood control protection of the Sonoma State University in a manner that combines flood control requirements with ecological restoration and water quality improvement (CCAC 2001). Specifically I am following implementation measure 5A.d. which looks to construct sediment filters and traps where feasible for future development projects. This aims to reduce non-point source pollution to Copeland Creek, future development projects shall install filters on storm drain catch basins, where practicable (CCAC 2001).

The Copeland Creek channel causes many issues with the deposition of Copeland Creek, in the areas west of the Laguna de Santa Rosa. The magnitude and volume of sediment deposition can be determined by measuring how thick the alluvial fan sediment is above the base level at Stoney Point Road; this is where the main channel of the Laguna de Santa begins and deposition is at its greatest. Urban development often produces with little regard for streams and fluvial processes until they become problematic for nearby communities. Many times this calls for people to take control over natural land forms in order to control and expand our usable land. This process although beneficial to the population many times impedes on many natural processes.

This study examines two main aspects of Copeland Creek: first, how much sediment is being transported through Copeland Creek at any given time, and second if Copeland Creek is a source of the sediment. I will install sediment traps to determine the amount of transported sediment. To determine if Copeland Creek is a source or sink of sediment erosion I will use satellite imagery to measure the Copeland Creek stream bed and compare them to past and present images. I will also construct a cross section of a certain area of the creek, which will allow future studies to determine how the creek has changed, and how much erosion has taken place in this location. By answering these questions, the SCWA should be able to better understand the dynamics of Copeland Creek in order to improve management of sediment loads, avoid flooding, and provide a linear path of research

Literature Review

The city of Rohnert Park, located in Sonoma County, has tried to control many streams that run through the town and are encountering various problems with flooding and eroding of areas close to the Copeland Creek stream bed. Copeland Creek, a tributary of the Laguna de Santa Rosa, has 3.98 square mile water shed, and originates on Sonoma Mountain, which has an elevation of 2,295 feet (CCAC 2001). Copeland Creek runs through the north side of Sonoma State University and is prone to flooding and can cause erosion throughout the University campus, if channel volume is not properly maintained. With Copeland creek running so close to the Sonoma State campus, the Sonoma County Water Agency has made it a high priority to properly maintain Copeland Creek's drainage capacity in order to protect the Sonoma State University campus.

Copeland Creek begins slightly above the Fairfield Osborne preserve which is located on the upper section of Sonoma Mountain. The stream flows westward through the forest, grazing lands, and vineyards of the Western Sonoma Mountain. Throughout this high gradient section there has been little human disturbance and the stream has kept its natural channel. With no disturbance Copeland creek has been able to form a natural alluvial fan, which is a low, cone shaped deposit formed by a stream issuing from mountains into lowland. There, it has the characteristics of a meandering stream which is a bend in the course of a stream developed through lateral shifting of its course toward the convex side of the bed (Easterbrook 1993). . Once the creek crosses Petaluma Hill Road and reaches Sonoma State and residential areas, it has been channelized and straightened in order to reduce the effects that the creek had on the surrounding communities. By disturbing the natural process and stabilizing Copeland Creek, the creek is not allowed to meander through the landscape. The study reach of Copeland Creek channel traverses the Sonoma State campus east to west for 1,120 meters. This intermittent section of Copeland Creek, which only bares water for certain parts of the year, and associated riparian habitat offers a natural space amenity to the campus as well as terrestrial and aquatic habit (CCAC 2001). Once the creek moves through the town of Rohnert Park and Cotati its drains into the Laguna de Santa Rosa, the Laguna is a 14-mile long wetland that drains a 254-square mile watershed that covers most of the Santa Rosa Plain in Sonoma County.

In order to determine the characteristics of the creek we need to classify the sediment supply using Reckings methods. Low sediment supply corresponds to a limited supply of the finer fractions (sand and gravels) that are stored below cobble and boulders and is available for transport only from local patches. Moderate sediment supply consists of channels seasonally fed by colluviums. In-channel sediments are loose, coarse and readily available for transport. High sediment supply corresponds to channels continuously fed with landslides or strong bank erosion events. It could also correspond to the period following a large flood when the bed structure had been totally destroyed and the finer sediment fraction is totally available for transport (Recking 2012). These classifications it will help us determine what type of sediment load is flowing through the creek.

In my observations, Copeland Creek has all three of these sediment classifications throughout the extent of the creek. The High sediment supply is located at the upper regions of the creek where the stream gradient is the highest. In this area I have observed many different mass movements, such as rock slides, mud flows and landslides that have introduced large amounts of sediment into Copeland Creek. As the creek flows off of Sonoma Mountain into the low lying alluvial fan and levels off we will find much more of the moderate and low sediment supply. This is because the gradient is low which slows down the movement and flow of the water in Copeland Creek. By being able to measure the amount of sediment that is running through Copeland Creek during a certain time, we should be able to roughly estimate how fast Sonoma Mountain is eroding into the surrounding low lying areas down to the base level, which is, the level below which a land surface cannot be reduced by running water (Esterbrook 1993).

Methods/Findings

Three methods are employed to characterize sediment transportation in the reach of Copeland Creek. The type of remote sensing that I will be using is satellite imagery, which consists of orthographic view of a specific area by a high definition satellite camera. I will use images from 2004 and 2012 and compare them.

The second aspect of this study is comparing past and present satellite images in order to determine if Copeland Creek is a source or sink of sediment. What we are looking for is that if the stream has gotten wider, then we know that this area is a source of sediment erosion and must be tended to in order to decrease the amount of sediment that is being transported through Copeland Creek. I used images from 2004 (Image 7) and 2012(Image 8) in order to determine the width of the stream. I was able to use the historical imagery function in the Google Earth program to locate past and present images of Copeland Creek. Then I used polygon tool to construct outlines of Copeland Creek between Petaluma Hill Road and Pressley Road so that we could determine if creek bed has changed over time and if so where the greatest change has occurred (Image 9).

When examining the Copeland Creek stream bed profiles from 2004 and 2012, I determined that the perimeter in 2004 was 13,241 feet and in 2012 it was 12,527. This shows that in the eight years between the two pictures the perimeter of the stream bed has decreased by 714 feet. I also determined that the area of the stream bed in 2004 was 267,752 square feet and in 2012 it was 180,240. By comparing the areas of the Copeland Creek stream beds; we can see that over the eight years the area has decreased by 87,512 square feet. This allows us to determine that the Copeland Creek stream bed is a sink and has been depositing sediment in the Laguna de Santa Rosa at an accelerated rate.

Image 7

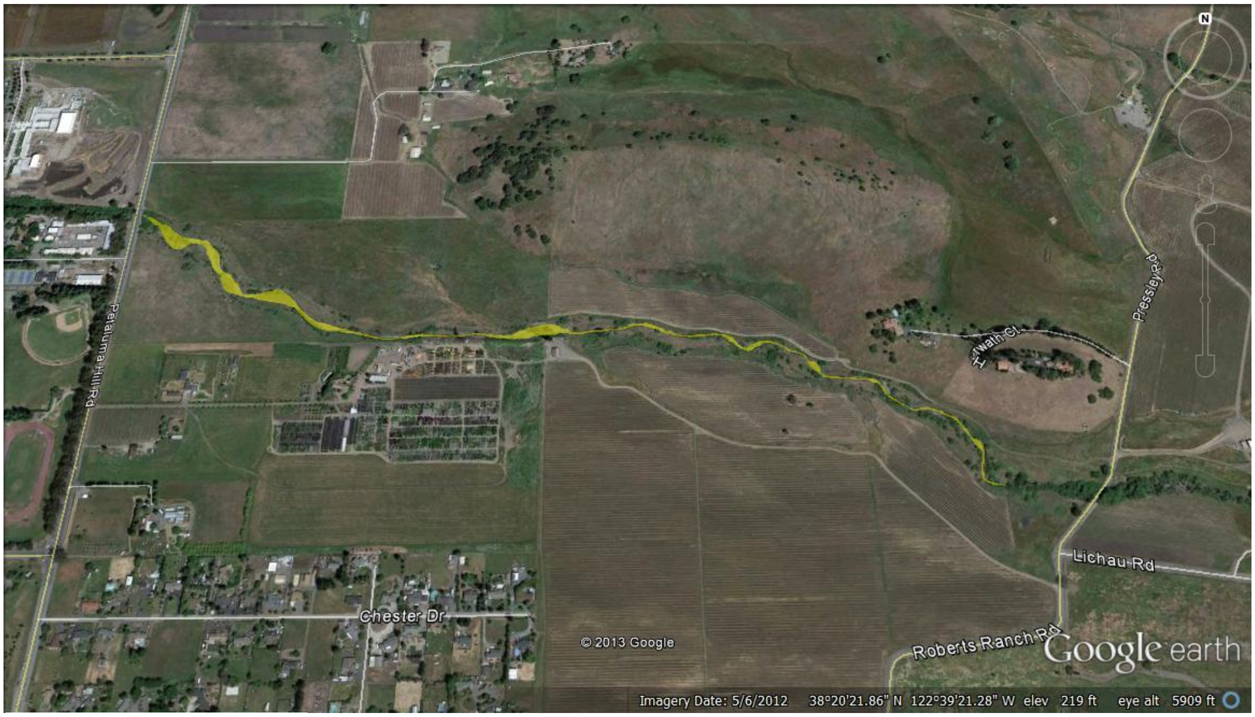


Image 8

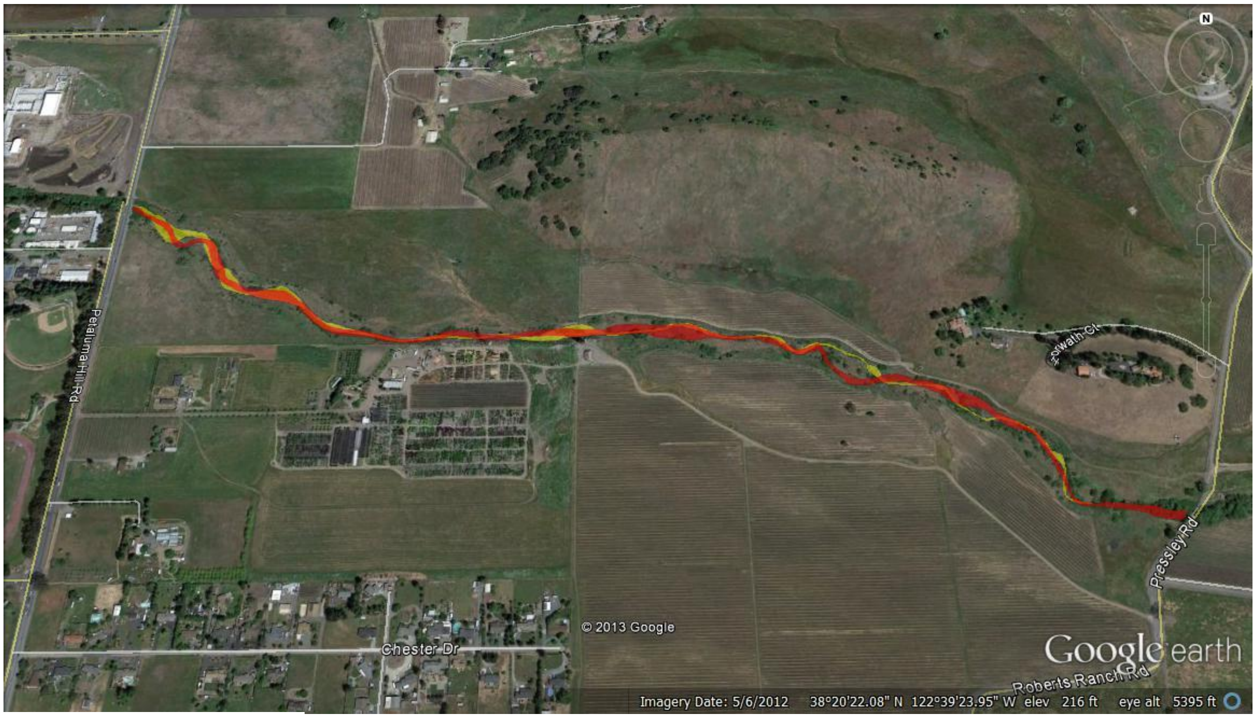


Image 9

In order to obtain a more accurate idea on how the Copeland Creek stream bed has changed over the years I established three cross sectional surveys of different sections of the creek bed. The cross sections will also allow future researchers to determine the channel width and calculate the volume of water that can be transferred through the creek.

The first cross section is constructed at 38 20' 28.926" N, 122 39' 52.662" W and 38 20' 28.926" N, 122 39' 52.662" W (Image 1) (Graph 1). This site was selected because it is located closest to Petaluma Hill Road and the Sonoma State Campus. It is located downstream from a meander and still in the Copeland Creek alluvial fan. Putting the cross section in this location allows us to see how Copeland Creek reacts when there is some type of channelization occurring downstream and also determine how much change take place when the creek continues to meander throughout this area. This section of the creek was completely dry during the spring when cross sections locations were chosen, but there was evidence that shows that the creek meanders through this area of the alluvial fan when water flows through it (Image 2).

The second cross section is constructed at 38 20' 28.926" N, 122 39' 52.662" W and 38 20' 23.583" N, 122 39' 42.790" W (Image 3) (Image 4) (Graph 2). This location was selected because it was located along a straight section of Copeland Creek and is also downstream from a manmade obstruction which runs through the creek bed and was used to transfer livestock from one property to another (Image 5). Even though this man-made obstruction does not reach the thalwag of the creek, it still is low enough in the creek bed that it can restrict large rocks and boulders from being transported down the creek. However the deep thalwag and large sized sediment located in the creek bed was evidence that this section of the creek has a high rate of flow when water is present. Placing a cross section here will allow future researchers to measure how much erosion takes place in a straight section of the creek and if the man-made obstruction has any effect on erosional and depositional properties of the creek.

The final cross section is constructed at 38 20' 24.061" N, 122 39' 35.347" W and 38 20' 23.417" N, 122 39' 35.395" W (Image 6) (Graph 3). This location was selected because on the south side of the creek bed there are dense invasive Himalayan blackberry bushes (Image 7). This will allow researchers to determine if sections of creek that have dense vegetation along the edges will resist the erosional and depositional properties of Copeland Creek.

Image 1

Image 2

Image 3

Image 4

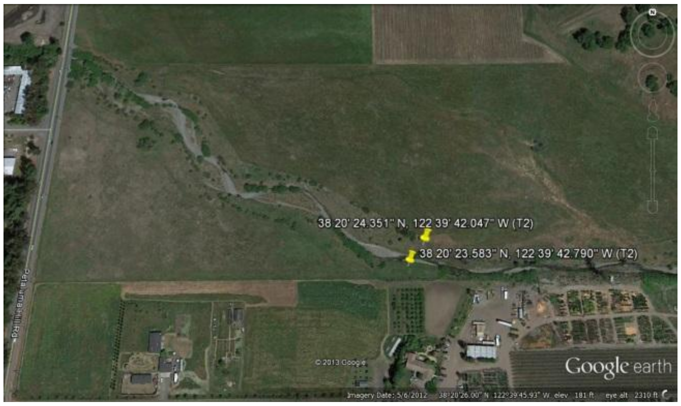


Image 5

Image 6

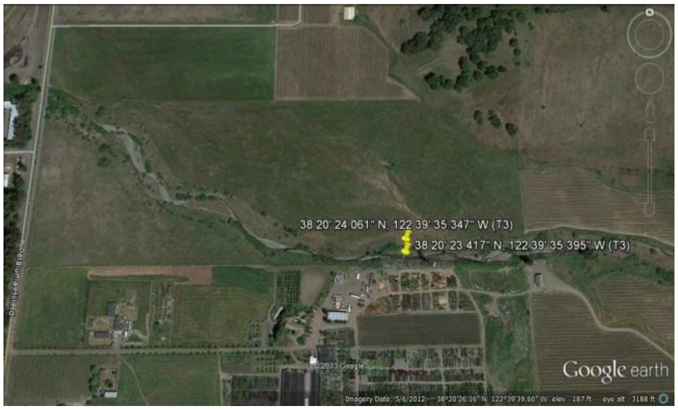
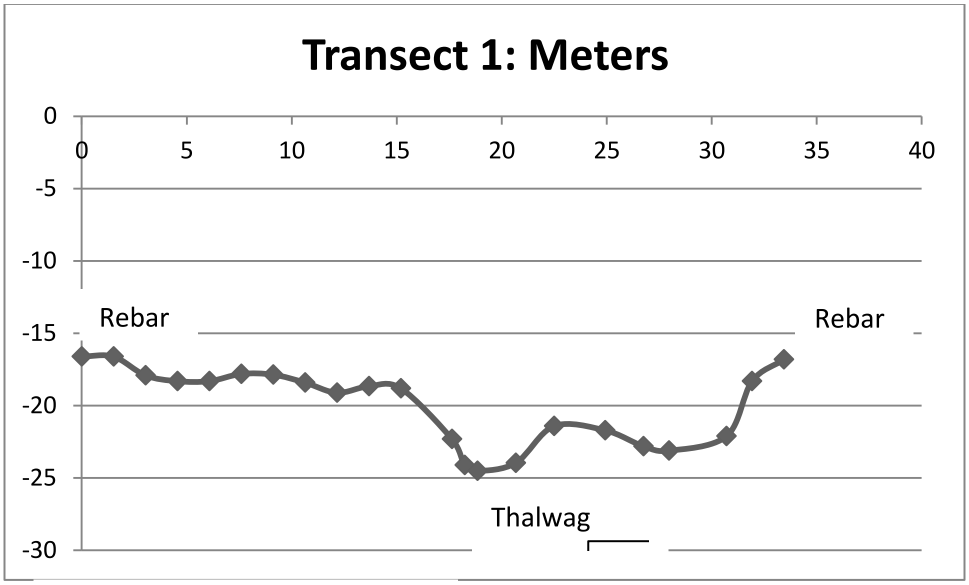
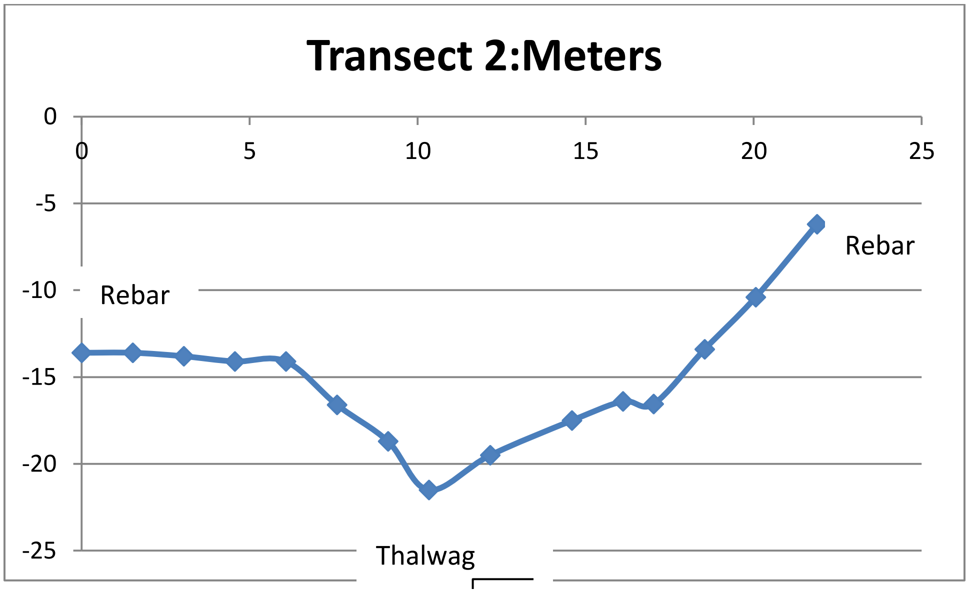


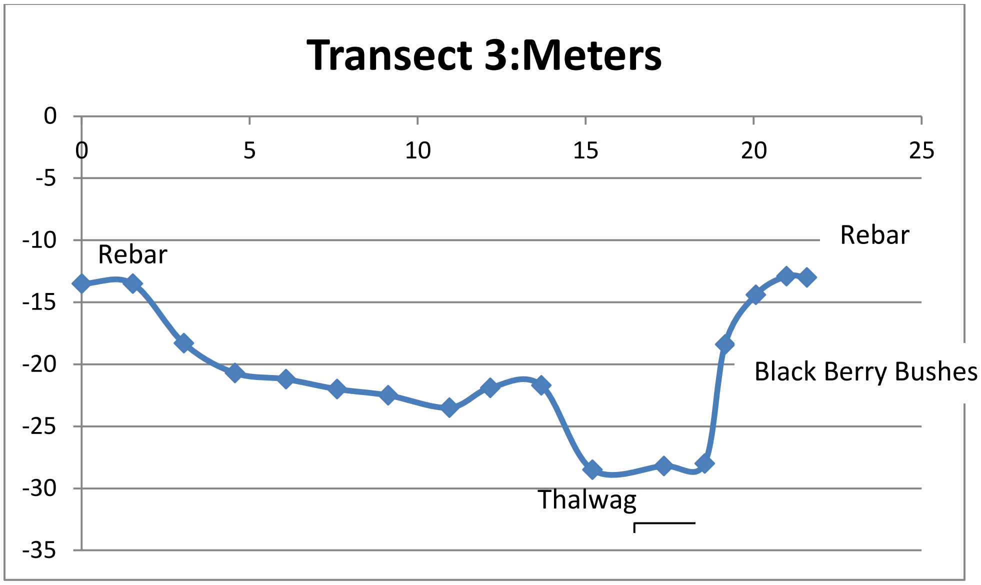
Image 7



Graph 1



Graph 2



Graph 3

The most important aspect of this study is to quantify sediment transportation through the reach of Sonoma State. To quantify the sediment transportation I will determine the ideal location to install the Helly-Smith, which measures the suspended load, and a pit trap that measures the bed load.   There are several constraints to the sediment trap site: it must be easy to access, have a close proximity to Sonoma State campus, and keep the sediment traps in the same place without being disturbed. This is important because if the traps are not installed in the proper location then we will not get an accurate sample of sediment being moved through the trap and our calculations on how much sediment is being transferred through the Creek will not be accurate. According to the reading the best sites to install the sediment traps are located

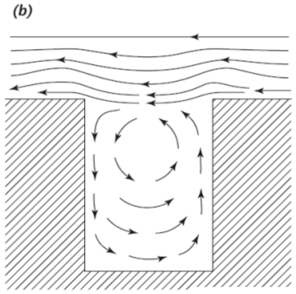


Figure 1

between meanders because the channel bed is the most stable in these areas. Next, the sediment traps should be located along a riffle, which is a short, relatively shallow and coarse bedded length of a stream over which the stream flows at a higher velocity and higher turbulence than in pools or glides (Easterbrook 1993). Finding an area with higher velocity and turbulence is important because it allows internal circulation of water inside the trap which will allow us to have the maximum amount of sediment to be deposited inside the trap. The effect of circulation within the trap depends on whether there is one circulation cell and a dead zone, or more than one circulation cell (Shannon Church 2002) (Figure 1). Traps were placed in the thalwag, the deepest part of the stream, which would allow the greatest amount of water containing sediment to flow over and into the traps. In order to receive the maximum accuracy in determining how much sediment is being transferred through the stream many studies recommend installing three sediment traps in a linear pattern in order to capture the most accurate sample of sediment. Results from all three of the sediment traps are then combined in order to produce a representative sample.

The one limitation of installing the sediment traps is that Copeland Creek is a migratory channel through the campus area for steelhead trout, a federally endangered species. Any construction or work to Copeland Creek below the top bank shall be limited to the period from June 15th through October 15th each year, unless otherwise authorized by National Marine Fisheries Services, Fish and Game, and Regional Water Quality Control (CCAC 2001). Because of these limitations I will not be able to start construction and begin collecting results on the sediment traps prior to May 2013.

Once the location of the sediment traps are determined the next step is to obtain the materials needed in order to make the pit trap. The materials that will be needed for the pit trap are: a 20-litre plastic bucket, a steel recovery cable, concrete culvert pipes, two hinges for the lid and fashioning screws to install the lid of the trap (Figure 2). The pit trap will be designed to capture mostly the bed load of the stream. In order to capture the dissolved and finer sediment a hand trap will be needed. There are many different designs of hand sediment traps that can be used but the Helley-Smith Hand-Held Sampler is proven to work for what we are trying to find (Figure 3). The Helley-Smith Hand sampler is specially designed for collecting suspended or saltating. It is ideal for collecting bed load materials which have partial sizes or density that does not allow great movement above or away from the stream bed. The sampler has a 3”x 3”entrance opening and a 3.22 expansion chamber that has a micron mesh bag made of nylon in order to trap the sediment. This trap and many like it can be purchased online from a number of different distributers.

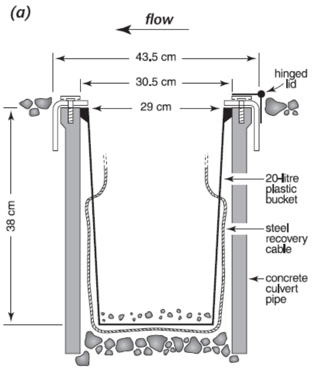
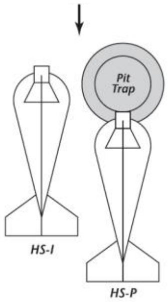


Figure 2

Figure 3



Once the sediment traps are installed we will be able to begin taking samples from the pit trap and hand sediment sampler. The results for the traps will help the Sonoma County Water Agency determine how much sediment is being eroded from Sonoma Mountain and what counter measures will need to take place in order to reduce the probability of flooding events and damage to local communities downstream. It will help them with future projects when it comes to determining if controlling and channelizing streams is the proper way to protect surrounding communities from the natural processes of stream functions. In order to make these determinations the SCWA will need to have ample amount of data collected to make an educated plan to control Copeland Creek. Because this is the start of a longitudinal study and the sediment traps will be in place for many years to come, I will only be able to collect a small amount of the data needed to make these decisions. The rest of the data collection will fall into the hands of future researchers who will rely on the accuracy of my research about the installation of the sediment traps and the ideal location to have the most accurate reading from the sediment traps.

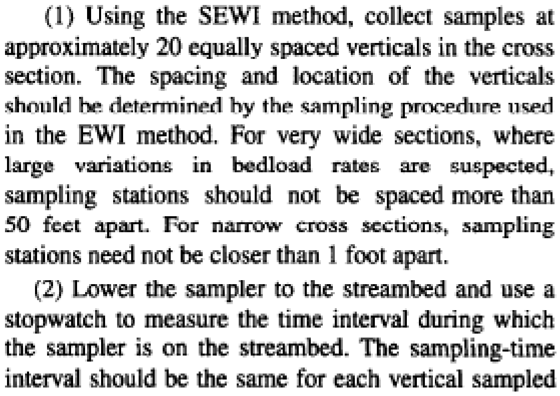
Future researchers will also have to re measure the three cross sections that I have placed along Copeland Creek. Re-measuring these cross sections will allow researchers to gather more information on how the creek is reacting to the channelization that is taking place downstream. It will also allow them to determine if erosion or deposition is occurring in this area and what steps they need to take in order to keep the downstream areas from flooding and damaging private propriety.

Discussion/Summary

In conclusion we have established longitudinal study that have follows the Copeland Creek Master Plan goal 5,which looks to maintain hydraulic function of Copeland Creek for flood control protection in a manner that combines flood control requirements with ecological restoration and water quality improvement. More specifically I followed goal 5A.d which states, construct sediment filters and traps where feasible for future development projects. To complete these requirements I used past and present satellite images to compare Copeland Creek’s stream bed in order to determine whether it was a source or sink of sediment. I also established tree cross sectional profiles in the Copeland Creek alluvial fan which will allow us to track the movement to the stream in the upcoming years. Finally I determined a proper location to install two types of sediment traps that will allow us to measure the suspended and bed load that is being transported through the stream. The SCWA is interested in the results of this study because it will allow them to determine the proper actions needed to restore sections of Copeland Creek to pre-cattle grazing conditions by eliminating disturbance factors within the riparian zone and allowing the creek to reestablish its historical patterns. The findings of this research will also help the SCWA reduce the large amounts of sediment that are being deposited in the Laguna de Santa Rosa, which causing it to reduce the amount of flood water space in the Laguna and causing localized flooding in the Laguna de Santa Rosa Watershed.

Appendix:

Helley-Smith sediment trap: Measurement and Techniques



(1) Using the SEWI method, collect samples at approximately 20 equally spaced verticals in the cross section. The spacing and location of the verticals should be determined by the sampling procedure used in the EWI method. For very wide sections, where large variations in bedload rates are suspected, sampling stations should not be spaced more than 50 feet apart. For narrow cross sections, sampling stations need not be closer than 1 foot apart.

(2) Lower the sampler to the streambed and use a stopwatch to measure the time interval during which the sampler is on the streambed. The sampling-time interval should be the same for each vertical sampled

in the cross section. The time required to collect a proper sample can vary from 5 seconds or less to several hours or more. Generally, a sampling time that does not exceed 60 seconds is preferred. Because of the temporal variations in bedload transport rates, there is no easy way to determine the appropriate sampling time. Several test samples (as many as 10 or more collected sequentially at a vertical with a suspected high transport rate) may be needed in order to estimate the proper sampling-time interval to be used. The sample time should be short enough to allow for the collection of a sample from the section with the highest transport rate, without filling the sample bag more than about 40 percent full. The sample bag may be filled to 40 percent full with sediment coarser than the mesh size of the bag without reducing the hydraulic efficiency of the sampler (Druffel and others, 1976). Sediment that is approximately equal to the mesh size may clog the bag and cause a change in the sampling efficiency of the sampler.

(3) One sample should be collected at each vertical, starting at one bank and proceeding to the other. It is recommended that, during this initial data gathering stage, a minimum of one transect using the SEWI method be used. The samples should be placed in separate bags for individual analysis and labeled with the vertical's station number. They may be composited into one or several sample bags for a composite analysis, but if composited, no information on cross-sectional variability can be obtained from the data.

(4) A second sample should be collected using the UWI or MEWI methods. Four or five verticals should be sampled four or five times each, obtaining a total of 20 samples. Samples should be collected using the same procedure as described in number 2 above, except that the sample time for each sample need not be the same. All samples should be bagged and tagged for separate analysis.

(5) The following data must be recorded on a field note sheet for each cross-section sample:

Station name/number
Date
Cross-section sample starting and ending times
Gage height at the start and end of sample collection
Total width of the cross section, including stations on both banks
Width between verticals (SEWI method)
Number of verticals sampled (SEWI method)
Station of verticals sampled (UWI or MEWI method)
Time sampler was on the bottom at each vertical
Type sampler used
Name of person collecting sample

In addition, the following information should be recorded on each sample container:

Station name
Date
Designation of cross-section sample to which the container belongs (that is, if two cross-section samples were collected, one would be "A" and the other "B")
Number of containers for that cross section (for example, "1 of 2" or "2 of 2")
Stations(s) of the vertical(s) the sample was collected from
Time sampler was on the bottom and at the vertical station
Clock time the sample was collected (start and finish if composite)
Collector's initials

Analysis of the first transect (SEWI method) will give some indication of the cross-sectional variability if individual verticals are analyzed separately. Analysis of the second set of transects (UWI or MEWI method) will give some indication of temporal variability. As stated before, the procedure described above should be considered the minimum to be followed when first collecting bedload data at a site. Additional samples and transects will help define the temporal and spatial variation at the site for all flow ranges. After a cross section has been sampled several times at different flow ranges using the above procedure, it should be possible to develop a sampling protocol that fits the site better.

Computation of Bedload-Discharge Measurements

The bedload transport rate at a sample vertical may be computed by the equation

$$R_i = \frac{KM_i}{t_i} \qquad (1)$$

where

R_i = bedload transport rate, as measured by bedload sampler, at vertical i, in tons per day per foot;

M_i = mass of the sample collected at vertical i, in grams;

t_i = time the sampler was on the bottom at vertical i, in seconds; and

K = a conversion factor used to convert grams per second per foot into tons per day per foot. It is computed as

$$K = (86{,}400 \text{ seconds/day}) \frac{1 \text{ ton}}{(907{,}200 \text{ grams})} \frac{1 \text{ foot}}{(N_w)} \qquad (2)$$

where

N_w is the width of sampler nozzle in feet. (For a 3-inch nozzle, $K = 0.381$; for a 6-inch nozzle, $K = 0.190$.)

The cross-sectional bedload discharge measured by the Helley-Smith sampler may be computed using the total cross-section, midsection, or mean-section method. The simplest method of calculating bedload discharge from a sample collected with a Helley-Smith type bedload sampler is the total cross-section method (fig. 54). This method should only be used if the following three conditions are met:

1. The sample times (t_i) at each vertical are equal.
2. The verticals were evenly spaced across the cross section (that is, SEWI or MEWI method used).
3. The first sample was collected at one-half the sample width from the starting bank.

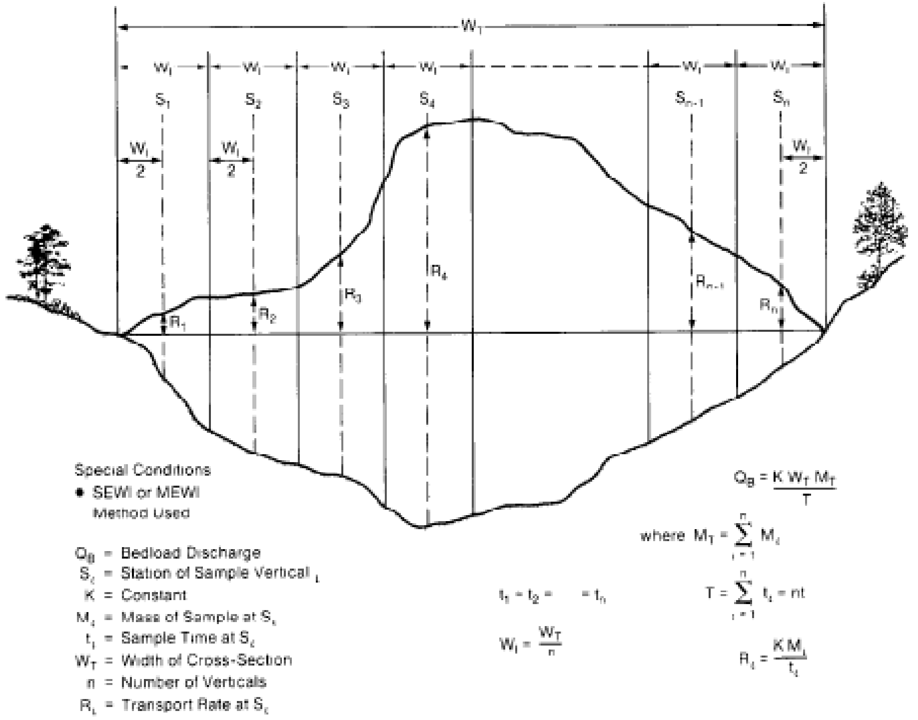


Figure 54. Total cross-section method for computing bedload discharge from samples collected with a Helley-Smith bedload sampler.

If these conditions are met, then

$$Q_B = K\frac{W_T}{t_T}M_T \qquad (3)$$

where

Q_B = bedload discharge, as measured by bedload sampler, in tons per day;

W_T = total width of steam from which samples were collected, in feet, and is equal to the increment width (W_i) times n (n = total number of vertical samples);

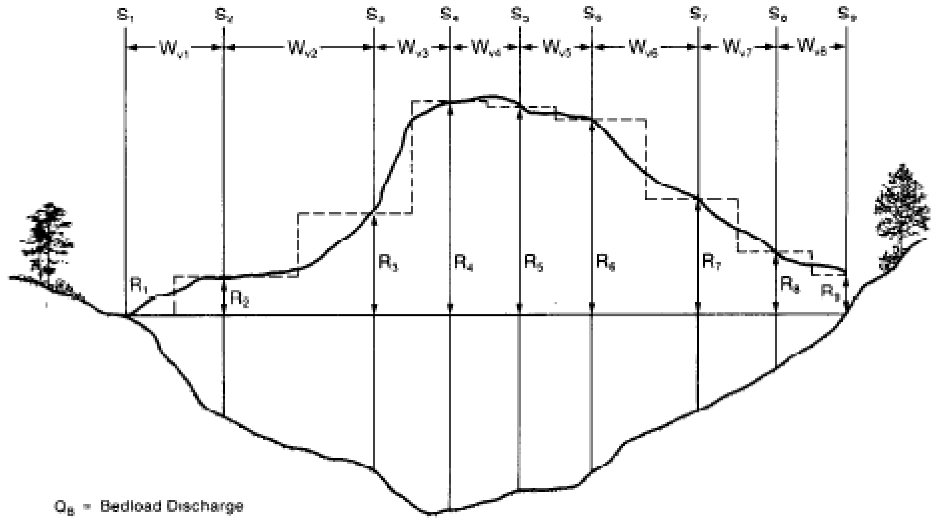
t_T = total time the sampler was on the bed, in seconds, computed by multiplying the individual sample time by n;

M_T = total mass of sample collected from all verticals sampled in the cross section, in grams; and

K = conversion factor as described in equation 2 above.

If any of the three conditions stated above are not met, then either the midsection or mean-section method should be used. Mathematically, the two methods, if used with no modifications, will produce identical answers. However, as indicated under the discussion of the UWI method, the placement of the sampling verticals with respect to breaks in the lateral cross-sectional distribution curve of mean bedload transport rate will somewhat dictate which method should be used. The midsection method (fig. 55) is computed using the following equation:

$$Q_B = \frac{R_1W_1}{2} + \sum_{i=2}^{n-1} R_i\left[\frac{(S_i - S_{i-1})}{2} + \frac{(S_{i+1} - S_i)}{2}\right] + \frac{R_nW_{n-1}}{2} \qquad (4)$$



Q_B = Bedload Discharge
S_i = Station of Sample Vertical $_i$
R_i = Transport Rate at S_i
K = Constant
M_i = Mass of Sample Collected at S_i
t_i = Sample Time at S_i
n = Number of Verticals
W_{vi} = Width Between Verticals $_i$ and $_{i+1}$

$$Q_B = \frac{R_1W_{v1}}{2} + \sum_{i=2}^{n-1} R_i\left[\frac{(S_i - S_{i-1})}{2} + \frac{(S_{i+1} - S_i)}{2}\right] + \frac{R_n W_{vn-1}}{2}$$
$$= \frac{K}{2}\left[\frac{M_1}{t_1}W_{v1} + \frac{M_n}{t_n}W_{vn-1} + \sum_{i=2}^{n-1}\frac{M_i}{t_i}(S_{i+1} - S_{i-1})\right]$$

Figure 55. Midsection method for computing bedload discharge from samples collected with a Helley-Smith bedload sampler.

where

W_i = width between sampling verticals i and i+1, in feet;

S_i = stations of the vertical (i) in the cross section measured from some arbitrary starting point, in feet; and

Q_B, n, R, and K have previously been defined,

You will note that equation 3 is very similar to the equation used to compute a surface-water discharge measurement. This method corresponds to the midpoint method currently used to compute surface-water discharge measurements (Buchanan and Somers, 1969). By combining equations 1 and 4 and rearranging terms:

$$Q_B = \frac{K}{2}\left[\frac{M_1W_1}{t_1} + \frac{M_nW_{n-1}}{t_n} + \sum_{i=2}^{n-1}\frac{M_1}{t_i}(S_{i+1} - S_{i-1})\right] \tag{5}$$

One advantage to using the midsection method is that the distance W_1 need not necessarily be equal to the distance between sampling verticals. At times, it may become apparent, due to local conditions, that a particular R_1 should not be applied over a width equal to halfway back to the last station and halfway forward to the next, but applied to some other width. This width, sometimes referred to as the effective width, is decided on by the user. Bridge piers, large boulders, abrupt changes in velocity or lateral bed topography, or other conditions that may obstruct or cause sudden changes to bedload transport rate will affect the selection of the effective width.

The third method, the mean-section method (fig. 56), is computed using the following equation:

$$Q_B = \sum_{i=1}^{n-1} W_i\,\frac{(R_i + R_{i+1})}{2}\,, \tag{6}$$

which is equivalent to:

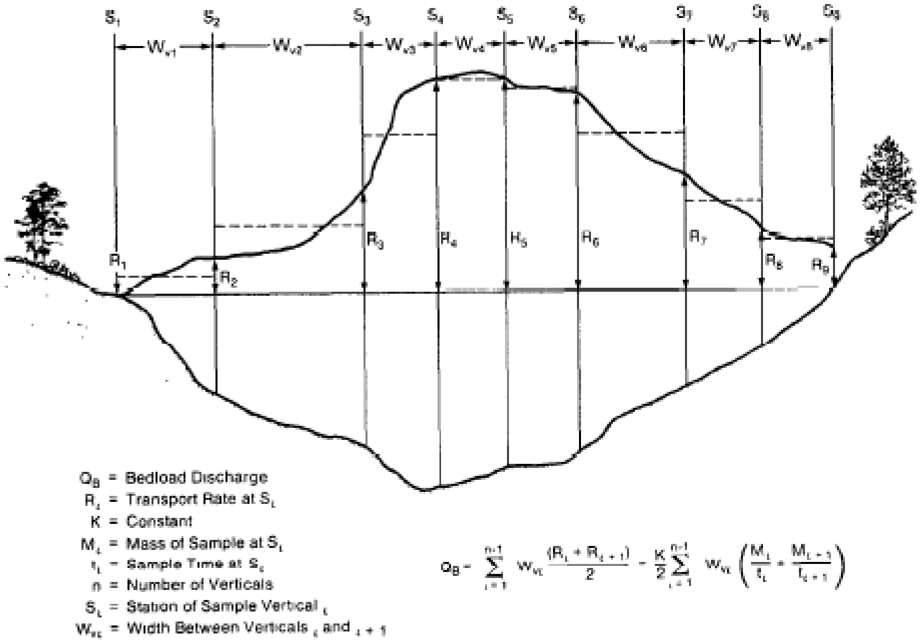


Figure 56. Mean-section method for computing bedload discharge from samples collected with a Helley-Smith bedload sampler.

$$Q_B = \frac{K}{2}\sum_{i=1}^{n-1} W_1\left(\frac{M_i}{t_i} + \frac{M_{i+1}}{t_{i+1}}\right) \tag{7}$$

All the above terms are the same as used in the midsection method. This method averages the two adjoining rates and applies the average rate over the distance between them. For this reason, it is important to try to place the sampling verticals at points where the trends in lateral mean bedload transport rate change. Under most field conditions, this might be difficult.

For situations where the total cross-section method cannot be used, it is recommended that the midsection method be used. This recommendation is made because of its similarity to the surface-water discharge-measurement method, which most field personnel are familiar with, and because of the flexibility in using the effective width concept.

Collecting bedload samples will generate 40 or more samples, creating a potential problem regarding transportation and analyses of so many samples. Carey (1984) adapted a procedure for measuring the submerged weight of bedload samples in the field and converting that measurement to dry weight from a laboratory procedure used by Hubbell and others (1981). The method uses the basic equation

$$W_{ds} = \frac{SG_s}{SG_s - 1} W_{ss} \tag{8}$$

where

W_{ds} = dry weight of the sediment;
SG_s = specific gravity of the sediment; and
W_{SS} = submerged weight of the sediment.

Measurements for Total Sediment Discharge

Total sediment discharge is the mass of all sediment moving past a given cross section in a unit of time. It can be defined as the sum of the (1) measured and unmeasured sediment discharges, (2) suspended-sediment discharge and bedload discharge, or (3) fine-material discharge (sometimes referred to as the washload) and coarse-material or bed-material discharge.

There are some sand-bed streams with sections so turbulent that nearly all sediment particles moving through the reach are in suspension. Sampling the suspended sediment in such sections with a standard suspended-sediment sampler represents very nearly the total load. Several streams with turbulent reaches are described in Benedict and Matejka (1953). Further discussion concerning total-load measurement also can be found in Inter-Agency Report 14 (Federal Inter-Agency Sedimentation Project, 1963b, p. 105–115). Turbulence flumes or special weirs can be used to bring the total load into suspension. Total load can usually be sampled with suspended-sediment samplers to a high degree of accuracy where the streambed consists of an erosion resisting material such as bedrock or a very cohesive clay. In such situations, most, if not all, the sediment being discharged is in suspension (or the bed would contain a deposit of sand).

Benedict and Matejka (1953) and Gonzales and others (1969) have described some structures used for artificial suspension of sediment to enable total-load sampling. However, most total-load sampling is usually accomplished at the crest of a small weir, dam, culvert outlet, or other place where the sampler nozzle integrates throughout the full depth of flow from the surface to the top of the weir.

Where such conditions or structures are not present, the unmeasured load must be computed by various formulas. The unmeasured load can be approximated by use of a bedload formula such as that of Meyer-Peter and Muller (1948), Einstein (1950), Colby and Hembree (1955), or Chang and others (1965). However, these computational procedures can give widely varying answers. The Colby and Hembree (1955) method [modified from Einstein (1950)] determines the total load in terms of the amount transported for different particle-size ranges. Colby and Hubbell (1961) later simplified the modified Einstein method to include the use of four nomographs in lieu of a major computational step. The essential data required for the Colby and Hubbell technique at a particular time and location are listed here:

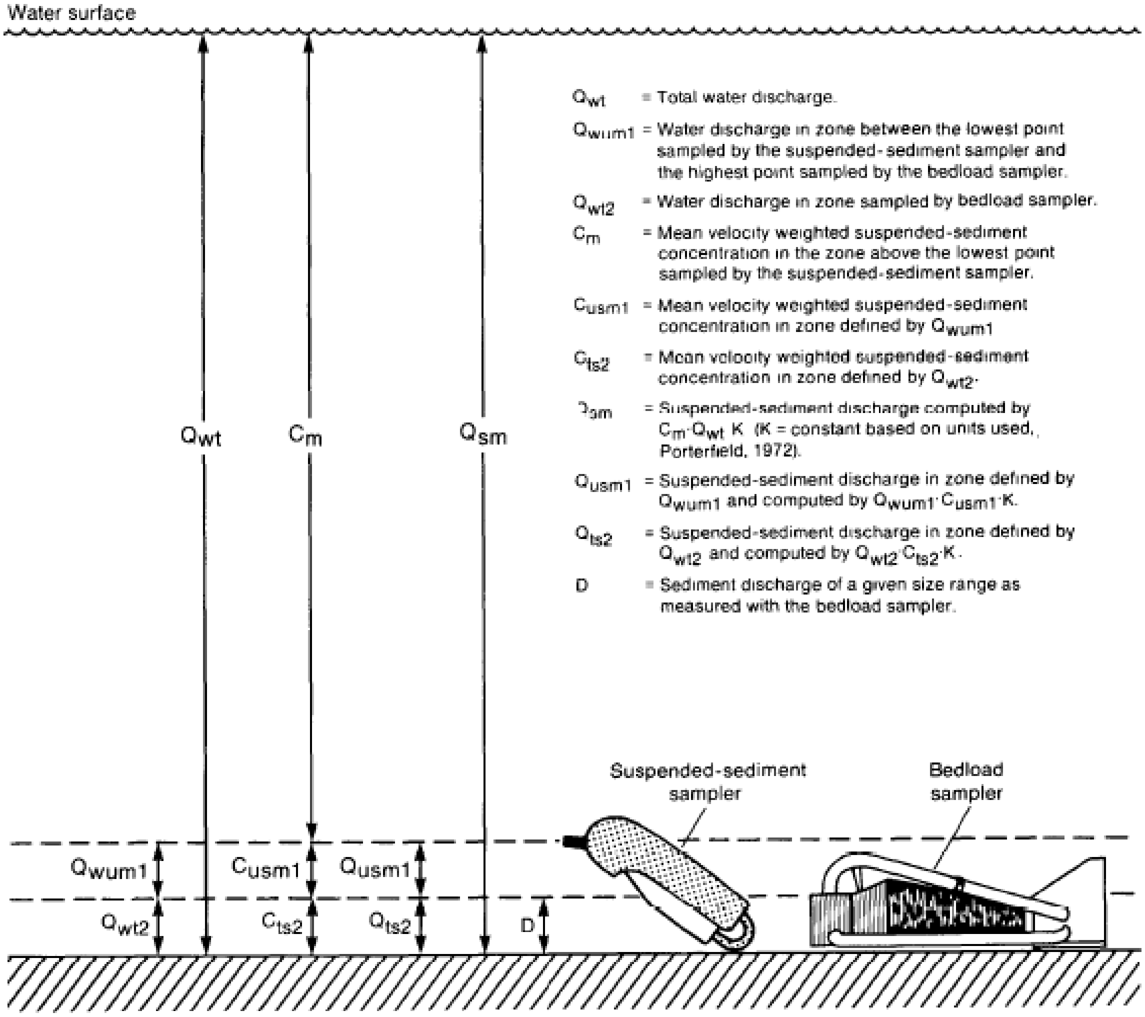
1. Stream width, average depth, and mean velocity.
2. Average concentration of suspended sediment from depth-integrated samples.
3. Size analyses of the suspended sediment included in the average concentration.
4. Average depth of the verticals where the suspended-sediment samples were collected.

5. Size analyses of the bed material.
6. Water temperature.

Stevens (1985) has developed two computer programs for the computation of total sediment discharge by the modified Einstein procedure. One program is written in FORTRAN 77 for use on the PRIME computer; the other is in BASIC and can be used on most microcomputers.

Hubbell (1964) gives the following formula for determining the total sediment discharge of a given size range from the measured suspended-sediment discharge and the discharge measured with any type of bedload apparatus (see fig. 57).

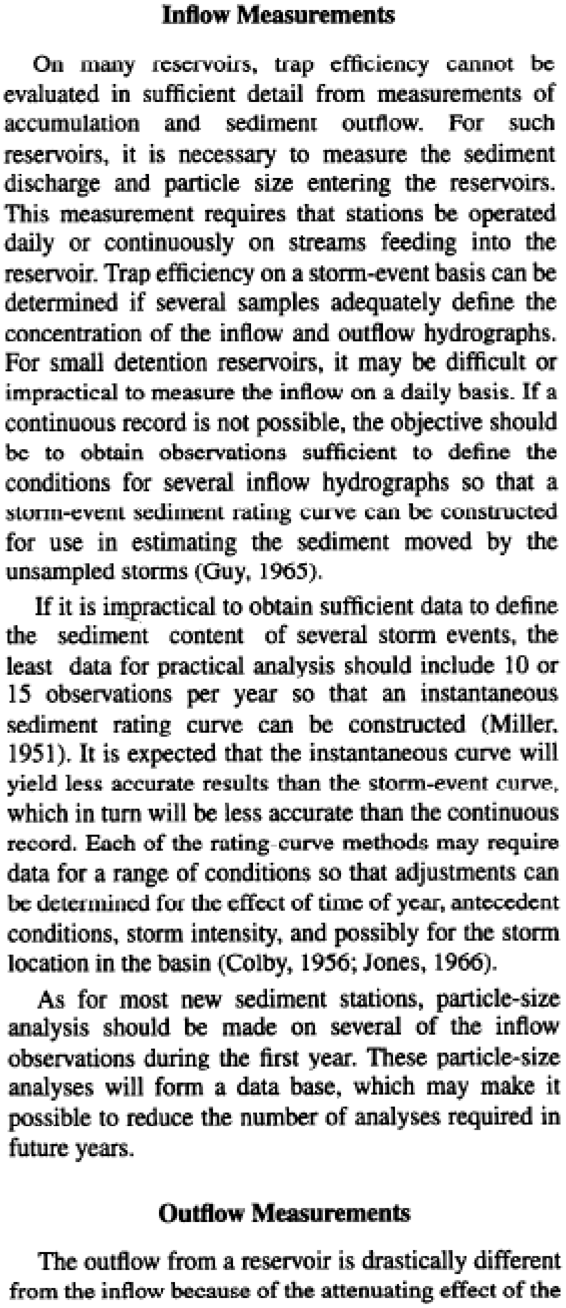
$$Q_T = \frac{Q_D}{eff} + Q_{sm} + Q_{usm1} - FQ_{sm} + (1 - E/e)Q_{ts2} \quad (9)$$



Q_{wt} = Total water discharge.
Q_{wum1} = Water discharge in zone between the lowest point sampled by the suspended-sediment sampler and the highest point sampled by the bedload sampler.
Q_{wt2} = Water discharge in zone sampled by bedload sampler.
C_m = Mean velocity weighted suspended-sediment concentration in the zone above the lowest point sampled by the suspended-sediment sampler.
C_{usm1} = Mean velocity weighted suspended-sediment concentration in zone defined by Q_{wum1}
C_{ts2} = Mean velocity weighted suspended-sediment concentration in zone defined by Q_{wt2}.
Q_{sm} = Suspended-sediment discharge computed by $C_m \cdot Q_{wt} \cdot K$ (K = constant based on units used, Porterfield, 1972).
Q_{usm1} = Suspended-sediment discharge in zone defined by Q_{wum1} and computed by $Q_{wum1} \cdot C_{usm1} \cdot K$.
Q_{ts2} = Suspended-sediment discharge in zone defined by Q_{wt2} and computed by $Q_{wt2} \cdot C_{ts2} \cdot K$.
D = Sediment discharge of a given size range as measured with the bedload sampler.

Figure 57. Zones sampled by suspended-sediment and bedload samplers and the unmeasured zone.

Pit Trap measurement and Techniques



Inflow Measurements

On many reservoirs, trap efficiency cannot be evaluated in sufficient detail from measurements of accumulation and sediment outflow. For such reservoirs, it is necessary to measure the sediment discharge and particle size entering the reservoirs. This measurement requires that stations be operated daily or continuously on streams feeding into the reservoir. Trap efficiency on a storm-event basis can be determined if several samples adequately define the concentration of the inflow and outflow hydrographs. For small detention reservoirs, it may be difficult or impractical to measure the inflow on a daily basis. If a continuous record is not possible, the objective should be to obtain observations sufficient to define the conditions for several inflow hydrographs so that a storm-event sediment rating curve can be constructed for use in estimating the sediment moved by the unsampled storms (Guy, 1965).

If it is impractical to obtain sufficient data to define the sediment content of several storm events, the least data for practical analysis should include 10 or 15 observations per year so that an instantaneous sediment rating curve can be constructed (Miller. 1951). It is expected that the instantaneous curve will yield less accurate results than the storm-event curve, which in turn will be less accurate than the continuous record. Each of the rating-curve methods may require data for a range of conditions so that adjustments can be determined for the effect of time of year, antecedent conditions, storm intensity, and possibly for the storm location in the basin (Colby, 1956; Jones, 1966).

As for most new sediment stations, particle-size analysis should be made on several of the inflow observations during the first year. These particle-size analyses will form a data base, which may make it possible to reduce the number of analyses required in future years.

Outflow Measurements

The outflow from a reservoir is drastically different from the inflow because of the attenuating effect of the flow through the reservoir or because of possible willful control in the release of water (Carter and Godfrey, 1960; Mitchell, 1962). Logically, the smaller reservoirs, which are likely to have fixed outlets and the poorest trap efficiencies, require the most thorough outflow measurement schedules. If an inflow-outflow relation for sediment discharge can be constructed, such a relation may change considerably in the direction of greater sediment output (lower trap efficiency) as the reservoir fills with sediment.

Normally, the particle size of sediment outflow is expected to be finer than for the inflow; and, therefore, the concentration of outflowing sediment should not fluctuate as rapidly as that of the inflow. The normal slowly changing outflow concentration may not occur if the outflow is from the vicinity of the interface involving a density current.

A desirable sampling schedule for outflow may vary from once a week for the large reservoir to several observations during a storm event for a small reservoir. The need for outflow particle-size data also will depend on the scale of the stream and reservoir system, the trap efficiency, and how well the inflow is defined. With respect to quality control, if the trap efficiency of a reservoir is expected to be more than 95 percent and if the sediment inflow can only be measured to the nearest 10 or 15 percent of its expected true value, it is not necessary to measure the sediment outflow in great detail unless there is a need to accurately define the amount of sediment in the flow downstream from the reservoir.

Sediment Accumulation

The small reservoir or detention basin can be used—if trap efficiency can be estimated or measured—to provide a measure of the average annual sediment yield of a drainage basin. This method is useful in very small basins where the inflow is difficult to measure and where the amount of water-inflow and sediment-concentration data is not important.

For small catchment basins or reservoirs on ephemeral streams (those that are dry most of the time), the determination of sediment accumulation involves a detailed survey of the reservoir from which stage-capacity curves can be developed—usually 1-foot contours for the lower parts of the reservoirs and 2- to 5-foot contours for the upper parts, depending on the terrain and size of the reservoir (Peterson, 1962). The accretion of sediment then can be measured either by monumented range lines in the reservoir or by resurvey for a new stage-capacity curve.

For reservoirs not dry part of the time, the sediment accumulation is usually measured by sounding on several monumented range lines spaced to provide a representative indication of the sediment accumulation between measurements. Methods for reservoir surveys are described by Heinemann (1961), Porterfield and Dunnam (1964), and Vanoni (1975). A summary of reservoir sediment deposition surveys made in the United States through 1975 was compiled by Dendy and Champion (1978). The period from 1976 to 1980 has been covered by the Inter-Agency Advisory Committee on Water Data's Subcommittee on Sediment (1983).

In order to convert the measurements of sediment volume found in reservoirs to the usual expression of mass of sediment yield, it is necessary that the sedimentation surveys of reservoirs include information on the volume-mass of sediment. Heinemann (1964) reports that this was accomplished in Sebetha Lake, Kansas, using a gamma probe and a piston sampler. From his data, obtained at 41 locations, he found that the best equation for predicting volume-mass is

$$V_M = 1.688d - 0.888c + 98.8 \tag{10}$$

where

V_M = the dry unit volume-mass, in pounds per cubic foot;

d = the depth of sample from the top of the deposit; and

c = the percentage of clay smaller than 0.002 mm.

On the basis of 1,316 reservoir deposit samples, Lara and Pemberton (1965) found the unit volume-mass to vary according to changes in reservoir operation and to the fraction of clay, silt, and sand. The Office of Water Data Coordination (1978) reported that refinements based on reservoir operation, sediment size, and compaction could be made to the estimates made by Lara and Pemberton (1965) and Lane and Koelzer (1943). The following formula, along with factors listed in table 4, may be used to estimate dry unit volume-mass:

$$V_M = V_{tc}P_c + V_{tm}P_m + V_{ts}P_s \tag{11}$$

where

V_M = dry unit volume-mass, in pounds per cubic foot;

V_t = dry unit volume-mass as computed in equation 12, in pounds per cubic foot;

c = clay-size material;

m = silt-size material;

s = sand-size material;

P = percent of total sample, by weight, in size class (clay, silt, sand); and

$$V_t = V_i + 0.43K\left[\frac{T}{T-1}(\log T) - 1\right] \qquad (12)$$

where

V_i = initial unit volume-mass, in pounds per cubic foot from table 4;

K = Lane and Koelzer (1943) factors from table 4, in pounds per cubic foot; and

T = time after deposition, in years.

Table 4. Initial dry unit volume-mass (V_1) and K factors for computing dry unit volume-mass of sediment deposits in pounds per cubic foot (Office of Water Data Coordination, 1978)

Type of reservoir operation	V_1 Clay	V_1 Silt	V_1 Sand	K Clay	K Silt	K Sand
1. Sediment submerged	26	70	97	16	5.7	0
2. Moderate to considerable annual drawdown	35	71	97	8.4	1.8	0
3. Normally empty	40	72	97	0	0	0
4. River sediment	60	73	97	0	0	0

OTHER SEDIMENT DATA-COLLECTION CONSIDERATIONS

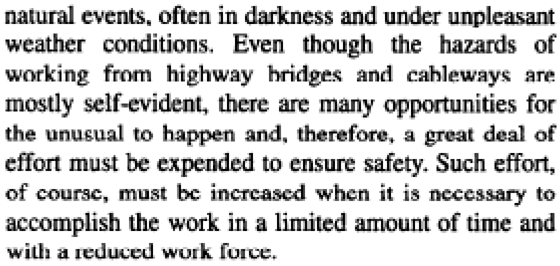
In retrospect, it must be emphasized that field methods for fluvial-sediment measurements must be coordinated with methods for other hydrologic and environmental measurements. With the ever-increasing requirements of a thorough data-acquisition system, together with advances in technology, it must be expected that methods will continue to change in the future. For example, because there is a foreseeable need for increasing water-pollution surveillance studies with respect to stream-quality standards, it is apparent that a continuous recording of some indicator of sediment conditions is badly needed at a large number of sites. Consequently, the F.I.S.P. has undertaken the development of sensors and automatic pumping-type samplers with a view toward continuously recording the concentration of sediment that moves in streams. The development of such automatic equipment is likely to enhance rather than detract from the need for conventional manual observations.

The authors sincerely hope that the material regarding the equipment and techniques for sampling presented herein will stimulate the ongoing development of better equipment and techniques for the future and, at the same time, help to standardize and make more efficient the day-to-day operations.

The opportunity certainly exists at the field level for many innovations for improving the end product or the sediment record. Some field people, for example, may like to carry a copy of the station stage-discharge rating curve, on which all particle-size analyses are recorded, showing date and kind of sample for each measuring site. As communications and river forecasting become more sophisticated, it may be possible to have better dialogue between the office and the field people or local observers, who are trying to obtain the maximum information at many sampling sites. Such communication is especially critical during periods of flooding, when timely data are most important.

In addition to increasing coordination of sediment-data activities with other related measurements, it is important to stress that adequate notes be obtained (including pictures) so that those involved in the laboratory analysis of the samples, those responsible for preparing the record, and especially those responsible for interpreting the data can properly read what happened at the sample site. The amount of new information to be obtained from data interpretation is seriously affected by the quality of the information with respect to timing and representativeness of the sediment measurements.

The authors further emphasize the need for a concerted and continuing effort with respect to safety in the measurement program. Aside from the hazards of highway driving, the work usually involves the use of heavy equipment during floods or other unusual



natural events, often in darkness and under unpleasant weather conditions. Even though the hazards of working from highway bridges and cableways are mostly self-evident, there are many opportunities for the unusual to happen and, therefore, a great deal of effort must be expended to ensure safety. Such effort, of course, must be increased when it is necessary to accomplish the work in a limited amount of time and with a reduced work force.

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