SECTION G
SEDIMENT BUDGET

INTRODUCTION

A sediment budget has been constructed for the Garcia WAU for the time period 1952-2000. The purpose of the sediment budget is to determine the relative importance of different sediment sources, to assign priorities for erosion control, and evaluate stream channel conditions in relation to sediment deposition and transport. A sediment budget provides quantification of sediment delivery, transport, and storage in a watershed. This quantification is useful for source analysis, numeric targets, and allocation of responsibility as needed in a Total Maximum Daily Load (TMDL) for 303(d) listed rivers, such as the Garcia River. A TMDL requires numeric standards for non-point source pollution. When the non-point source pollutant in question is sediment, a sediment budget becomes a logical analytical technique for the watershed.

This module presents the methods, results and interpretation of a sediment budget created for the Garcia WAU. Input and change in storage for the sediment budget were determined from aerial photograph interpretation, field observations and predictive erosion equations.

Sediment Budget Defined

A sediment budget is an accounting of the sources and deposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin (Reid and Dunne, 1996). The sediment budget takes the form of:

Input + Change in Storage = Output

Input in the Garcia WAU is from erosion delivered to watercourses from mass wasting, road surface erosion, surface erosion of mass wasting scarps, and skid trail surface erosion. Storage in the Garcia WAU is sediment stored in stream channel terraces and stream channel obstructions, such as debris dams. The change in storage is observed from stream bank erosion, downcutting of streamside terraces, narrowing or widening of the stream channel, or increase in the stream bed height. The change in storage is difficult to determine and is not presented in all locations, only where observations could be interpreted.

In theory the components of the sediment budget should balance if the sediment in the watershed is in equilibrium. This equilibrium can be distorted both by natural and land management induced impacts creating changes in any of the budget constituents of input, storage or output. It is important to discern the difference for appropriate interpretation of the sediment budget results.

The components of the sediment budget are inter-dependent. For example, large increases in input can overwhelm output of sediment in a watershed, creating large changes in storage. For this reason, a sediment budget can be a powerful tool in interpreting impacts to a watershed.

METHODS

This section presents the methods used in determining the various components of the sediment budget for the Garcia WAU. The methods for determining the input and change in storage in the sediment budget are presented in the following sub-sections of this Methods section and in the modules of this report. Output was not measured in this study.

Input

Input in the Garcia WAU is from erosion delivered to watercourses from mass wasting, hillslope surface erosion, road surface erosion, surface erosion of mass wasting scarps, and skid trail surface erosion. The methods for quantification of these estimated inputs are discussed in the surface and point source erosion and mass wasting modules of this report.

The inputs are broken into estimated proportions of fine and coarse sediment. It was assumed that the soils of the area consisted of 30% coarse (>2 mm in diameter) particles and 70% fine particles (<2 mm in diameter)(OCEI, 1997). For mass wasting inputs the proportion of sediment delivery was assumed to be 70% fine particles and 30% coarse particles. For road and skid trail inputs, field observations determined that 60% of the sediment delivered was from sheet wash on the road surface (fine particles) and 40% was from erosion of the road fill. Only the erosion from the road fill was assumed to have coarse particles associated with it. Based on these observations the total road and skid trail delivered sediment is assumed to be 12% coarse particles and 88% fine particles.

Output

The output of sediment in the Garcia River was estimated in the Garcia River Gravel Management Plan (Phillip Williams and Assoc., 1996). They estimate the sediment transport rate at Connor Hole on the Garcia River, site of the river flow gage. This provides an indication of the sediment transport at the mouth of the watershed. In the upper tributaries of the watershed, where this WAU occurs, that estimate is not considered reliable. Issues of sediment supply, particle attrition and transport capacity makes the information at the mouth of watershed difficult to accurately interpret in upper watershed areas.

Change in Storage

Sediment storage in the WAU was determined in streamside terraces and in storage sites of the stream bed, such as behind woody debris dams. Terrace volumes of individual discrete terraces are calculated by measuring length, width, and depth values with pace and tape measuring techniques. Large continuous terrace volumes (usually at the mouths of sub-basins of the WAU) are calculated by averaging width and depth of the terrace and measuring the length on the map. Channel storage volumes are determined by measuring the length, width, and depth of the active channel with the same techniques used on terraces. Depth is the limiting measurement in the accuracy of these techniques. For this study the depth of terrace deposition was assumed to be the distance from the deepest scour in the active channel to the top of the terrace surface. Field evidence used to determine depth of channel storage includes the depth of scour pools and depth measured at the downstream side of debris dams. When this information is not available a channel storage depth of one foot is assumed, an approximate average streambed scour depth. These techniques underestimate terrace and stream channel depths and thus storage volume must be recognized as a minimum estimate.

Cumulative terrace and channel storage volume is then calculated as a sum of individual terrace and stream data collected in the field. This data is used to extrapolate storage volumes to stream reaches not visited in the field. Field collected and extrapolated data is combined to calculate terrace and stream channel storage totals for each hydrologic unit. Based on field observations, the terraces in the response reaches of the hydrologic units in the WAU, with the exception of the main stem of the Garcia River, are assumed to have been created 30-40 years ago. This assumption is based primarily on even-aged alder stands about 30-40 years old found on the terraces. Furthermore, logging debris such as cut logs and truck tires are observed in the terrace stratigraphy, suggesting initial terrace deposition was during the period of modern forest management in the Garcia WAU, from the 1950's to the present. The stratigraphy of the terrace deposits show many layers of sediment ranging in thickness from 1 inch to 10 inches. Each individual layer is composed of a characteristic clast size. Clast sizes range from sand to gravel to cobble. The cobble layers are angular in shape, suggesting they have not been transported very far and were probably derived from hillslope erosion processes. We estimate the terraces were deposited over a few years to as much as 15 years, and represent multiple flood and sediment transport events. Hydrologic data for the Garcia River shows numerous flood events (magnitude > 2 yr. return interval) within the last 30-40 years, that are capable of moving large sediment loads, creating terraces as the flood wave recedes.

RESULTS AND DISCUSSION

Total Coarse Sediment Budget

The results of the coarse sediment inputs and estimated storage for select hydrologic units for South Fork and Rolling Brook planning watersheds for the time period 1952-2000 for the Garcia WAU, is presented in Table G-1. The input column represents the mass of the total coarse sediment inputs over the entire analyzed time period, 1952-1997. The terrace storage column represents the mass of coarse sediment that is currently in storage at the present. Terrace storage is assumed to have 80% coarse particles, based on bulk samples taken in the stream channel throughout the watershed. The net change column represents whether the difference in total coarse sediment inputs and terrace coarse sediment storage is a positive or negative value. A negative value could suggest input sediments are primarily being stored in streamside terraces and not available for routing through the channel network. A positive value could suggest that input sediments are being routed through the channel network, not held in storage, thus having a greater likelihood of influencing channel morphology. The estimated channel storage is the mass of the coarse sediment estimated to be within the active channel. Channel storage is assumed to have 80% coarse particles, based on bulk samples taken in the stream channel throughout the watershed. The channel storage is presented to allow interpretation of sediment routing in the context of the sediment budget. Due to the potential inaccuracies of the estimates of input and sediment storage no estimates of output based on the sediment budget were attempted.

Table G-1. Coarse Sediment Budget Components for Select Hydrologic Units for the South Fork Garcia River and Rolling Brook Planning Watersheds for the Garcia WAU, 1952-1997.

Planning Watershed	Hydrologic Unit	Input (tons)	Terrace Storage (tons)	Channel Storage (tons)	Net Change (+ or -)
Rolling Brook	Rolling Brook	37260	48437	8698	-
	Lee Creek	8580	3165	2503	+
	No Name Creek	28964	38149	17830	-
South Fork Garcia	South Fork	42446	31222	33356	+

Change in coarse sediment storage information was not available for Hutton Gulch, every Main Stem tributary, and North Fork Garcia in the WAU, so it could not be presented.

Both Rolling Brook and No Name Creek show a negative net change between total coarse sediment inputs and terrace storage. Observations of current channel morphology in both of these hydrologic units (see Table E-3, Stream Channel Condition) suggest the channels are currently degrading. The sediment budget data and channel observations suggest that high coarse sediment levels are not currently impacting channel conditions. However, in both Rolling Brook and No Name Creek there is still a high amount of coarse sediment stored in streamside terraces. These stored coarse sediments will likely be routed through the streams following bank erosion of the streamside terraces over time. Provided that the terrace sediments are released slowly and future coarse sediment inputs are not abnormally high, coarse sediment should not present a problem to channel conditions in Rolling Brook or No Name Creek. However, this will need to be monitored over time.

South Fork of the Garcia River showed a positive net change between total coarse sediment inputs and terrace storage. This high level of coarse sediment within the channel network is affecting current channel morphology and streambed substrate. It could be many years before this high level of coarse channel sediments are routed through the channel network and the morphology of the South Fork returns to a less aggraded condition.

Lee Creek also showed a positive net change between total coarse sediment inputs and terrace storage. Lee Creek had been recently impacted with several large mass wasting events which has provided a large component of coarse sediment in the channel network. Observations of the lower response reach of this hydrologic unit were not available due to lack of access. However, this hydrologic unit is very steep and likely will route coarse sediment quickly. The recent mass wasting is what is currently providing the high level of channel coarse sediments compared to inputs and terrace storage.

Background Sediment Yield

The determination of background or natural sediment yield in a managed watershed is difficult. The difficulty comes when determining if sediment yield was created from a management impact or from a natural process. Often these two types of sediment yield are difficult to distinguish.

The mass wasting analysis has estimates of mass wasting delivery during a relatively unmanaged time period in the WAU, pre-1952. These estimates are presented to provide an indication of a possible background sediment yield in the Garcia WAU.

Prior to 1952 there was little forest management occurring in the Garcia WAU. Mass wasting was inventoried and quantified from 1952 aerial photographs. A rate from small inner gorge landslides, not observable in aerial photographs, was determined from current field observations (see Mass Wasting assessment). This rate was added to the mass wasting rate determined from aerial photographs. We then make the assumption that the mass wasting and inner gorge estimates from the pre-1952 mass wasting analysis could represent an indication of a background sediment yield. Assuming that 20 years of mass wasting is observed in the aerial photographs a rate of sediment yield was calculated (Table G-2).

Table G-2. Background Sediment Yield Estimate by Garcia River Mass Wasting.

Estimate Method or Data Source	Planning Watershed	Rate (tons/sq. mi./yr.)
Pre-1952 Mass Wasting and Inner Gorge Sediment Delivery	South Fork	700
Pre-1952 Mass Wasting and Inner Gorge Sediment Delivery	Rolling Brook	680

The estimates of background sediment yield for the Rolling Brook and South Fork planning watersheds are similar. The estimates of background sediment yield are only from mass wasting, not included in this estimate is natural surface erosion (which is difficult to estimate). Because of this it is assumed that the estimates of background sediment yield are at the low end of the range in natural sediment yields. How much higher the natural sediment yield could be is difficult to say, but it is safe to assume that there would be tremendous variability annually based on both climatic and physical conditions. Therefore, an average input rate approaching the natural background sediment yield is a reasonable goal. But, sediment input rates should not be interpreted for any given year against this estimated background rate.

Inputs

The sediment inputs for the Garcia WAU are from road erosion, skid trail erosion, mass wasting, and erosion of scarps from mass wasting. The inputs from each of these sources is summarized by time period and planning watershed in Chart G-1 and Table G-3.

Chart G-1. Total Estimated Sediment Input Rate by Time Period for L-P Ownership in each Planning Watershed of the Garcia WAU.

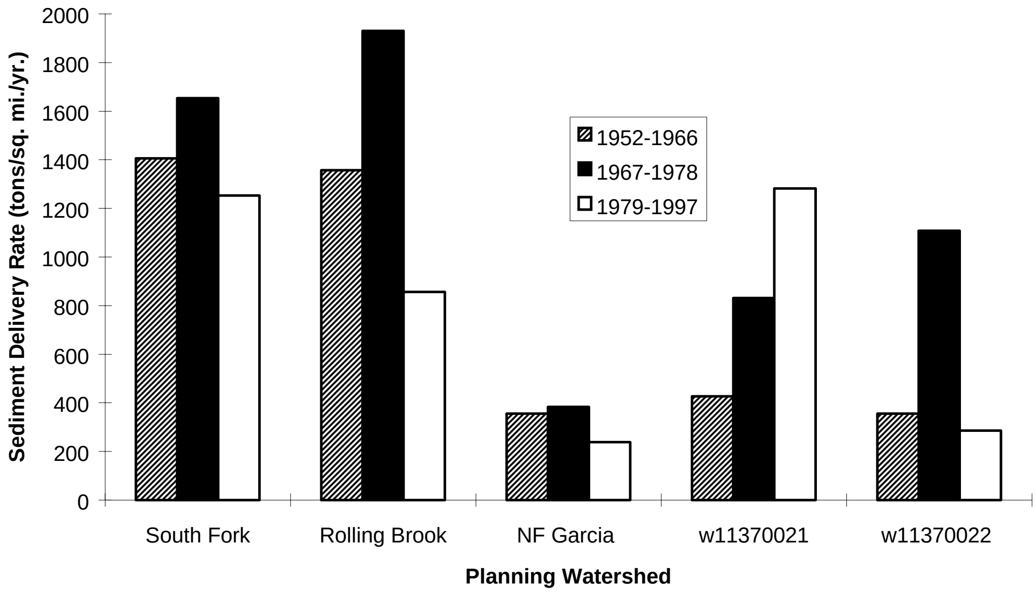

Table G-3. Sediment Inputs by Source and Time Period for MRC Ownership in Planning Watersheds of the Garcia WAU.

Planning Watershed	Time Period	Mass Wasting ($t/mi^2/yr$)	Roads ($t/mi^2/yr$)	Skid Trails ($t/mi^2/yr$)	Scarps ($t/mi^2/yr$)	Total ($t/mi^2/yr$)
South Fork	1952-1966	668	407	368	10	1453
	1966-1978	1333	398	130	15	1876
	1978-2000	730	367	159	4	1260
Rolling Brook	1952-1966	801	256	347	10	1414
	1966-1978	1670	259	180	15	2123
	1978-2000	602	226	152	4	985
NF Garcia	1952-1966		0	356		356
	1966-1978	110	112	155	15	392
	1978-2000		82	157		239
E. Eureka Hill	1952-1966		71	356		427
	1966-1978	573	88	155	15	831
	1978-2000	1043	78	157	4	1282
Inman Creek	1952-1966		0	356		356
	1966-1978	2045	198	155	15	2413
	1978-2000		129	157		286

In every planning watershed, except for one, the rate of sediment delivery is lower in the most recent time period (1979-2000). The planning watershed East of Eureka Hill was the only planning watershed showing a large increase in the sediment delivery rate in 1979-2000. This was due to high mass wasting inputs in the East of Eureka Hill planning watershed during the 1979-2000 time period.

The majority of the Garcia WAU shows a decreasing trend in sediment delivery. The mass wasting inputs identified in the 1996 photo analysis increased by 25% due to field observations. The road erosion rate is increased by up to 100% on certain roads due to field observations. If field observations would have been available for the earlier time periods (1952-1966, 1967-1978) the sediment delivery rates would be much higher. This would give a greater contrast to the decreasing trend in sediment delivery in the WAU, with the current rates being lower relative to earlier rates.

In every planning watershed, except for East of Eureka Hill, the rate of sediment delivery is greatest in the 1966-1978 time period. This is due to a large sediment delivery from mass wasting during that time period. We hypothesize that heavy tractor logging and road building in the 1950's and 1960's left many unstable road and skid trail areas. This combined with a large hydrologic event in 1974 (about 30 year recurrence interval) created a large influx of mass wasting sediment observed in the 1978 photos. If this is the case much of the sediment from the 1966-1978 time period could be attributed to the 1950's and 1960's. However, we do not have field observations to prove this, it can only be hypothesized.

In every planning watershed except the South Fork of the Garcia River the current sediment input rates (1979-1997) are approaching or below the estimated background sediment rate (approximately 680-700 tons/sq. mi./yr.). Future forest management operations should be performed such that sediment input rates in the Garcia WAU are closer to a natural background sediment rates. Many of the prescriptions developed in this Watershed Analysis should help achieve this goal.

In all but one planning watershed of the Garcia WAU mass wasting is the largest source of sediment delivery (Table G-4). In the North Fork Garcia River skid trails have provided the highest sediment delivery since 1952. In these two planning watersheds the ownership is very small, and is primarily on upper slopes near ridges where few mass wasting events were observed. Because of this skid trails were the primary source for sediment delivery to watercourses.

Table G-4. Percent of Total Sediment Delivered from 1952-1997 by Input Source for MRC Ownership in each Planning Watershed of the Garcia WAU.

Planning Watershed	Mass Wasting	Roads	Skid Trails	Mass Wasting Scarps
South Fork	59%	26%	15%	1%
Rolling Brook	67%	17%	15%	1%
NF Garcia	9%	20%	69%	1%
East of Eureka Hill	66%	9%	24%	1%
Inman Creek	62%	12%	25%	0%

It must be emphasized that the percentages presented in Table G-4 are derived from the entire time period of modern forest management in the Garcia WAU, from the 1950's until the present (see appendix for percentages by time period). The percentage of sediment delivery must be interpreted as such. The current California Forest Practice Rules mandate high road standards, greater use of cable yarding, and restrictions near watercourses. All of these standards will alter the amount and responsibility of sediment delivery in the Garcia WAU currently and in the future.

LITERATURE CITED

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