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TITLE:

to a coral reef?

Contributions of human activities to suspended sediment yield during storm events from a steep, small, tropical watershed

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ABSTRACT

Anthropogenic watershed disturbance by deforestation, agriculture, mining, roads, and urbanization ~~can~~ often increases ~~alter the mass, composition, and timing of~~ sediment yields, enhancing sediment stress on ~~marine~~ aquatic ecosystems ~~corals~~ near the outlets of impacted watersheds. ~~To quantify anthropogenically-increased sediment loading to a sediment-stressed coral reef in Faga'alu, American Samoa,~~ suspended sediment yields (SSY) from undisturbed and human-disturbed portions of a small, steep, tropical watershed (xx km²) ~~in A.S.~~ that drains to a bay containing sediment-stressed coral reef were measured during baseflow and storm events ~~of varying magnitude~~. Data on precipitation (P), water discharge (Q), turbidity (T), and suspended sediment concentration (SSC) were collected to calculate event-wise SSY (SSYEV) for 64 storms during three field campaigns and continuous monitoring of T and Q from January 2012 to March 2014. ~~A combination of paired- and nested-watershed study designs using~~ A sediment budget, ~~disturbance ratio~~, and sediment rating curve of ~~event-wise SSY~~ SSYEV ~~methodologies was~~ were used to quantify the contribution of human-disturbed areas to ~~total~~ SSY ~~from the watershed~~. SSC during both base- and stormflows was ~~significantly~~ xx % ~~times~~? higher downstream of ~~an open-pit aggregate~~ the quarry, ~~indicating the quarry is a key sediment source requiring sediment discharge mitigation. Comparing of event-wise SSY contributions showed~~ the ~~lower~~, human-disturbed watershed accounted fo~~r more than~~ 80% of total SSY on average, event-wise? Annual? and human activities ~~have~~ increased total sediment loading to the coast by 3.6x in table 2? over natural levels. Specific SSY (tons/area) from the ~~open-pit~~ quarry was over 120x higher than natural forest, and the quarry, which covers xx% of the wshed area, contributed nearly 45% of total SSY ~~from the watershed~~ and xx% of human-caused SSY. ~~Four storm event characteristics were tested as predictors of event SSY using Pearson's and Spearman's correlation coefficients~~. Similar to mountainous watersheds in semi-arid and temperate

Though only 5% of the watershed was disturbed, Disturbed areas accounted for only 5% of the area but 74% of the SSY.

The upper wshed is undisturbed forest and the lower subwatershed includes an aggregate quarry and a village (with a small area of agriculture?).

Natural 20 Human 80 Total 100

~~Table~~ Text on p29 says 51%

watersheds, SSY from both the undisturbed and disturbed watersheds had the highest correlation with event maximum discharge, Qmax, (Pearson's R=0.89 for both watersheds), compared with precip, total event Q, and ~~EI~~ an erosive index ~~and were best fit by a power law relationship (r^2=0.79 for both watersheds)~~. Annual sediment yields ~~were estimated by extrapolating SSY measurements and by predicting SSY from the Qmax-SSY model; estimates varied~~ varied from 29-70 tons/yr (xx tons/km²/yr) from the undisturbed watershed, and 341-450 tons/year from the human-disturbed watershed, (xx tons/km²/yr) sub? depending on the estimation method. ~~The resulting model of event-SSY~~ with ~~from Faga'alu is being incorporated as part of a larger project investigating relationships and interactions between terrigenous sediment, water circulation over the reef, and the spatial distribution of sediment accumulation under various conditions in a linked watershed and fringing-reef embayment.~~ Humans disturbed only 5% of the watershed ~~Human disturbance~~ area but increased sediment loading significantly (3.6x). Identification of hotspots like the quarry will help mitigation efforts.

Keywords:

Sediment yield, Mountainous catchments, Land use, Storm events, coastal sediment deposition, American Samoa

Introduction

Human activities including deforestation, agriculture, roads, mining, and urbanization alter the timing, composition, and amount of sediment loads to downstream ecosystems. ~~such as coral reefs~~ Sediment is a particular problem for coral reefs. Several article? Increased sediment loads can stress corals near the outlets of impacted watersheds by decreasing light for photosynthesis and increasing sediment accumulation rates (Syvitski et al., 2005; West and van Woesik, 2001; Fabricius et al. 2005). Anthropogenic sediment disturbance can be particularly high in the humid tropics, which are characterized by high rainfall, extreme weather events, steep slopes, erodible soils, and naturally dense vegetation, where land clearing alters the fraction of exposed soil more than in sparsely-vegetated regions. Such environments characterize many volcanic islands in the south Pacific, which also contain many coral reefs impacted by sediment.

Several studies have found that a large proportion of ~~the~~ a watershed's sediment yield can originate from relatively small, disturbed areas. In the Caribbean, Ramos-Scharron (2007) found unpaved roads were the dominant sediment source in disturbed watersheds on St. John, and increased sediment yield to the coast by 5-9 times, relative to undisturbed watersheds. ~~Even within disturbed areas, sediment yield can be much higher from certain types of disturbance.~~ In the Pacific Northwest, of the US several studies found most road-generated sediment can originate from a relatively small fraction of the road network (Wemple et al., 1996; Henderson and Toews, 2001; Megahan et al., 2001), and heavily used roads could generate 130 times as much sediment as abandoned roads (Reid and Dunne 1984). In a watershed on Molokai, Hawaii, disturbed by grazing, Stock et al. (2010) found that less than 5% of the land produces most of the sediment, and only 1% produces approximately 50% of the sediment (Risk, 2014), suggesting that management should focus on identifying, quantifying, and mediating erosion hotspots.

Who found? Stock or Risk?

~~Researchers and land~~ M managers most require ~~are interested in~~ linking land use changes and mitigation strategies to changes in sediment of sediment yields at the watershed outlet and subsequent ecosystem ~~coral health~~ impacts. A sediment budget quantifies sediment as it moves from key sources to its eventual exit from a watershed (Rapp 1960), and is a useful ~~means of~~ to characterize ~~characterizing~~ watershed response to land use change and management interventions (Walling, 1995). Walling (1999) used a sediment budget to show that sediment yield from watersheds can be insensitive to both land use change and erosion management due to high sediment storage capacity on hillslopes and in the channel. Sediment yield from disturbed areas can be large but may not be important compared to naturally high yields from undisturbed areas. Walling (2008) argues sediment control strategies should be based on a a holistic understanding of the sediment dynamics of the particular watershed. While a full description of all sediment production and transport processes are of scientific interest,the sediment budget needs to be simplified to be used as a management tool (Slaymaker 2003). Most management applications require only that the order of magnitude or the relative importance of process rates be known, so Reid and Dunne (1996) argue a management-focused sediment budget can be developed quickly in situations where the management problem is clearly defined and the management area can be divided into homogenous sub-units.

Knowledge of ~~fluvial~~ suspended sediment yield (SSY) under both natural + disturbed conditions on most Pacific volcanic islands remains limited due to the challenges of in situ monitoring, and existing sediment yield models are not well-calibrated to the climatic, topographic, and geologic conditions found on steep, tropical islands (Calhoun and Fletcher, 1999; Ramos-Scharron, 2005).

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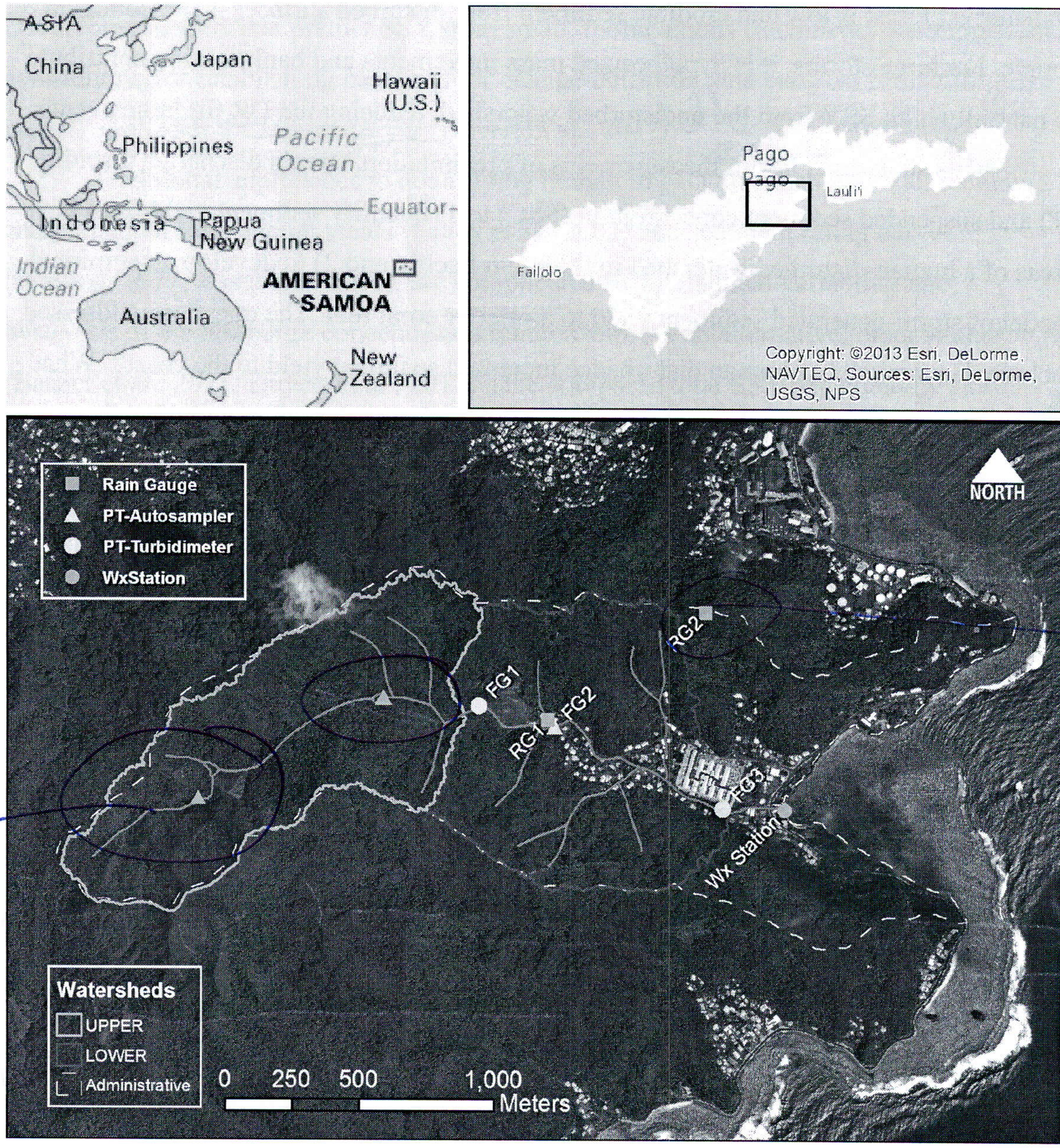

In BW, res looks like PT

Any data? If not remove.

Figure 1. Faga'alu watershed showing the Upper (undisturbed) and Lower (human-disturbed) subwatersheds. Blue triangles show the location of defunct reservoirs, see Appendix 2 for full description. Note the open-pit quarry between FG1 and FG2.

Climate on Tutuila

Precipitation is caused by several mechanisms including cyclones and tropical depressions, isolated thunderstorms, and orographic uplifting of trade-wind squalls over the high (300-600 m), mountainous ridge that runs the length of the island. Unlike many other Pacific Islands, the mountainous ridge runs parallel to the predominant wind direction, and does not cause a significant windward/leeward rainfall gradient. Average

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But isn't east dry west wet?

annual specific discharge (m^3/yr/km^2) shows little spatial variation across the island, irrespective of location or orientation (Dames & Moore, 1981). From 1903 to 1973, average annual precipitation over the island was 3,800 mm/yr (Eyre, 1994; Izuka, 2005). ~~However,~~ Precipitation increases with elevation, from an average 2,380 mm/yr at the shoreline to 6,350 mm/yr at high elevation. In Faga'alu watershed, rainfall records show average annual precipitation is 6,350 mm at Matafao Mtn. (653 m m.a.s.l), 5,280 mm at Matafao Reservoir (249 m m.a.s.l.) and about 3,800mm on the coastal plain (Craig, 2009; Dames & Moore, 1981; Tonkin & Taylor International Ltd., 1989; Wong, 1996, Perrault, 2010). Mean annual potential evapotranspiration follows the opposite trend, varying from 890 mm at high elevation to 1,150 mm at sea level (Izuka, 2005). Tropical cyclones are erratic but occurred on average every 1-13 years from 1981-2014 (Craig, 2009) and bring intense rainfall, flooding, landslides, and high sediment yield events (Buchanan-Banks, 1979).

There are two subtle rainfall seasons: a drier winter season, from June through September and a wetter summer season, from October through May (Izuka, 2005). During the drier winter season, the island is influenced by relatively stronger, predominantly East to Southeast Tradewinds, lower temperatures, lower humidity and lower total rainfall. During the wetter summer season the Inter-Tropical Convergence Zone (ITCZ) moves over the region, causing light to moderate Northerly winds, higher temperatures, higher humidity, and higher total rainfall. While total rainfall is lower in the drier Tradewind season, large rainfall events WC are still observed. Analysis of mean monthly rainfall data for the period 1971-2000 showed 75% of precipitation occurred in the wet seaons, October-May, and 25% occurred in the dry season, June-September (Perrault, 2010; Data from USGS rain gauges and Parameter-elevation Relationships on Independent Slopes Model (PRISM) Climate Group (Daly et al., 2006)). Analysis of 212 peak discharges at 11 continuous-record gaging sites (from 19xx to 1990 ~~up to 1990~~) showed 65% of annual peak flows occurred during the wet season and 35% of annual peak flows occurred during the drier Tradewind season (Wong, 1996).

Still 25% of the months

Land Use

Faga'alu watershed can be divided into two subwatersheds: 1) an upper subwatershed characterized by large areas of undisturbed, steeply-sloping, ~~heavily~~

8

xx km²

forested hillsides (UPPER), and 2) a lower subwatershed wtih similarly steep forested topography and relatively small flat areas that are urbanized or densely settled (LOWER) xx km² (Figure 1). This ~~settlement~~ OK pattern is typical in the South Pacific and other volcanic islands, where their small size and steep topography constrain development to areas near the coast (Begin 2013), ~~where there is less buffering capacity to store sediments before they reach receiving waters (Walling 1999)~~.

Repeats

Faga'alu watershed also includes two unique anthropogenic features not found in "typical" watersheds in American Samoa: 1) an open aggregate quarry, upstream of FG2 in Figure 1, and 2) a large impervious area associated with a hospital, adjacent FG3 in Figure 1. To separate these key features, the LOWER subwatershed can be further divided into a LOWER_QUARRY subwatershed, draining areas between FG1 and FG2, and a LOWER_VILLAGE subwatershed, draining areas between FG2 and FG3.

Insert Table 1 here

Land use data from?

Table 1. Land use categories in Faga'alu subwatersheds (NOAA Ocean Service and Coastal Services Center, 2010).

watershed (93.2%) including and shrubs (9?)

The predominant land cover in Faga'alu is undisturbed forest (84.5%) on the steep hillsides (84.5%)(Table 1), where natural landsliding can contribute large amounts of sediment during storm events (Buchanan-Banks, 1979; Calhoun and Fletcher, 1999). Compared to other watersheds on Tutuila, a relatively large portion of Faga'alu watershed is urbanized (4.6% "High Intensity Developed" in Table 1), due to large areas of impervious surface associated with the hospital and the numerous residences and businesses. A small portion of the watershed (1.1%) is developed open space, which includes landscaped lawns and parks. In addition to some small household gardens there are several small agricultural areas growing banana and taro on the steep hillsides. A land cover map (2.5 m resolution) classified the agricultural plots as "Grassland" due to the high fractional grass cover in the plots (Table 1) (NOAA Ocean Service and Coastal Services Center, 2010). ~~These~~ Farmers of these plots are currently receiving technical assistance from the Natural Resource Conservation Service (NRCS) to mitigate erosion. most (xx %) of roads are paved. There are several small footpaths and unpaved driveways in the village, but most unpaved roads are stabilized with compacted gravel and do not appear to be a major contributor of sediment (Horsley-Witten, 2012b). Longitudinal sampling of Faga'alu stream during baseflow conditions in 2011 showed

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significantly increased turbidity downstream of ~~a new~~ bridge construction site on the village road approximately 200 m downstream of FG2 (Curtis et al., 2011). Construction of the bridge was completed in March 2012 and no longer increases turbidity.

An open-pit aggregate quarry, covering 1.6 ha (5.7% of LOWER_QUARRY subwatershed) accounts for the majority of the 1.0% Bare Land in Faga'alu watershed (Table 1). The quarry has been in continuous operation since the 1960's by advancing into the steep hillside to quarry the underlying basalt formation (Latinis 1996). The

? overburden soil and weathered rock was either piled up on-site where it was eroded by storms, or was manually rinsed from crushed aggregate. With few sediment runoff controls in place, ~~the~~ sediment was discharged directly to the stream. In 2011, the quarry operators installed some sediment runoff management practices such as silt fences and settling ponds (Horsley-Witten, 2011) but they were unmaintained and inadequate to control the large amount of sediment mobilized during storm events (Horsley-Witten, 2012a). In 2013, additional control structures were installed to route the groundwater seep directly from the blast face into the stream, to prevent it from eroding sediment from the haul road into the stream. Crushed rock was also distributed over the haul road and landings to decrease erodible sediment, and some large piles of overburden were naturally overgrown by vegetation (Figure 2).

Need for this paper?

Need past?

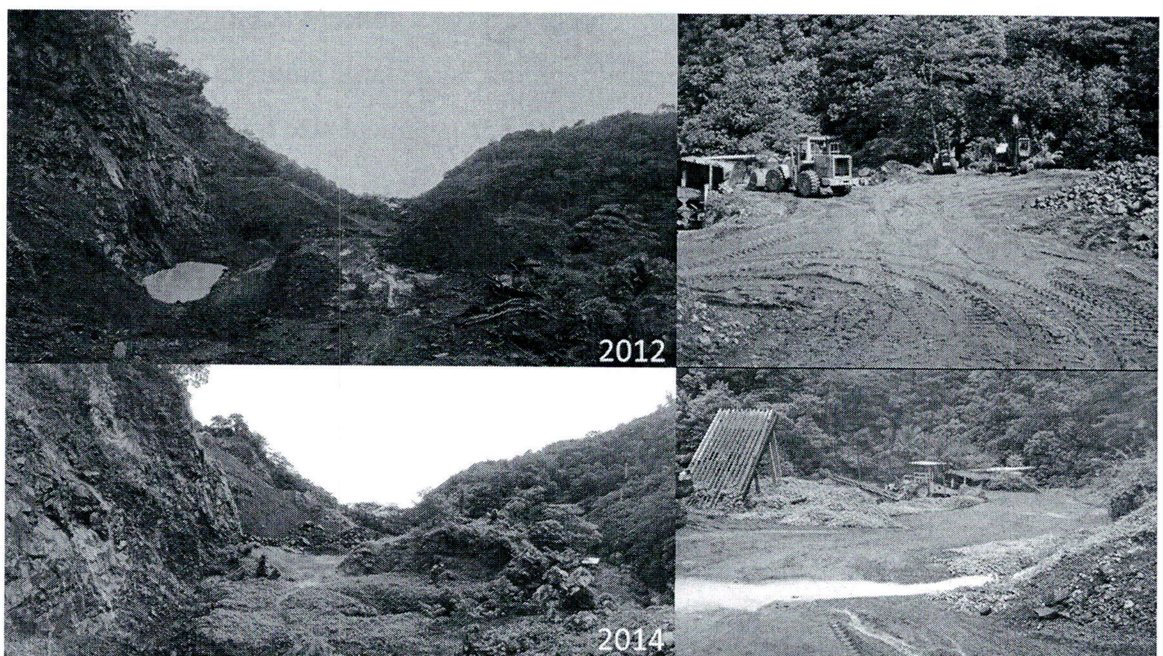

Figure 2. Photos of the open aggregate quarry in Faga'alu in 2012 (Top) and 2014 (Bottom). Photo: Messina

Need?

Three water impoundment structures were built in the UPPER subwatershed for drinking water supply and hydropower but only the highest, Matafao Reservoir, was ever connected to the municipal water system and has since fallen out of use (Tonkin & Taylor International Ltd., 1989)(Figure 1). The dam at FG1 has filled with bedload sediment and flows over the spillway even at the lowest flows. We assume the other reservoirs are similarly filled with coarse sediment and are not currently retaining fine suspended sediment. A full description of stream impoundments is in Appendix 2.

are at elevation

Methods

A nested-watershed approach was used to quantify sediment contributions from undisturbed and human-disturbed areas to the total sediment load to Faga'alu Bay during storm events of varying magnitude. The suspended sediment load (SSY) was calculated at three sampling points in Faga'alu stream that drain key land covers suspected of having different SSY: FG1 drains undisturbed forest in the UPPER subwatershed, FG2 drains undisturbed forest and the quarry in the LOWER_QUARRY subwatershed, and FG3 drains undisturbed forest and the village in the LOWER_VILLAGE subwatershed. Suspended sediment concentrations (SSC) in stream water samples collected at FG1, FG2, and FG3 were also examined for key differences between undisturbed and disturbed areas, using boxplots and water discharge-sediment concentration (Q-SSC) relationships. While steep, mountainous watersheds can discharge large amounts of bedload (Milliman and Syvitski, 1992), this research is focused on sediment size fractions that can be transported in suspension in the marine environment to settle on corals; this is generally restricted to silt and clay fractions (<16um) (Asselman, 2000).

Repeats p 7-8

Calculating suspended sediment yield from individual storm events (SSY_{EV})

SSY_{EV} at each sampling site was calculated by integrating continuous estimates of suspended sediment yield, calculated from measured or modeled water discharge (Q) and measured or modeled suspended sediment concentration (SSC) (Duvert et al., 2012):

$$SSY_{EV} = k\int_{t=0}^{T} Q(t) * SSC(t) * dt \qquad \text{Equation 1}$$

where SSY_{EV} is suspended sediment yield for an event (tons) from t=0 ~~=~~ at storm start to T=storm end, SSC is suspended sediment concentration (mg/L), and Q is water discharge (L/sec), and

k converts from mg to tons (10^{-6})

Storm events can be defined by precipitation (Hicks, 1990) or discharge parameters (Duvert et al., 2012), and the method used to identify storm events on the hydrograph can significantly influence the analysis of SSY_{EV} (Gellis, 2013). Complex graphical or rule-based techniques for hydrograph separation may be implemented (Dunne and Leopold, 1978; Perrault, 2010), but for this research the simple stage height threshold rule was used due to the flashy hydrologic response, low baseflow discharge, and short duration of recession curves between events (Lewis et al., 2001; Fahey et al., 2003;). A storm event was defined as the period of time when stream stage height exceeded a given threshold. The threshold was defined as the mean stage, plus one standard deviation. Complex storm events occurred when subsequent rain fell before the stream stage fell below the storm threshold. These events were separated manually into individual storms for analysis, but required the discretion of the analyst (Duvert, 2012). Where Q peaks were separated by at least a two hour period and Q was nearly at baseflow, complex storm events were separated into individual storm events.

~~The~~ Several small events that produced runoff were too small to be included as a storm event, but had signif impacts on SSC. The term "baseflow" then is used to designate ↓ Or ~~sp~~ sep out precip events for baseflow – Flow below the threshold. ~~In analysis~~, samples taken ~~of a rain event~~

Relationship of sediment load to sediment budget

We use the measured sediment load at three location to quantify the in-stream sediment budget. Other components of sediment budgets include channel erosion or channel or floodplain deposition (Walling and Collins, 2008). Sediment storage and remobilization can significantly complicate the interpretation of instream loads, and complicate the identification of a land use signal. In Faga'alu, the channel bed is predominantly large volcanic cobbles and coarse gravel, with no significant patches of fine sediment. Upstream of the village, the valley is very narrow with no floodplain. In the downstream reaches of the lower watershed, where fines might deposit in the floodplain, the channel has been stabilized with cobble reinforced by fencing, so overbank flows and sediment deposition on the floodplain are not observed. We therefore assume that channel erosion and channel and floodplain deposition are insignificant components of the sediment budget, so the measured sediment loads at the three locations reflect differences in hillslope supply of sediment. Minimal sediment storage also reduces the lag time between landscape disturbance and observation of sediment at the watershed outlet.

Good ✓

Quantifying SSY from disturbed and undisturbed subwatersheds human contribution to the

A main objective for this study was to quantify the ~~human~~ ~~increased total~~ SSY to Faga'alu Bay (SSY_{TOTAL}) ~~from human disturbed areas~~. Relative contributions from undisturbed and human-disturbed areas were assessed using two approaches : 1) comparing ~~percent~~ contributions of SSY from subwatersheds for each storm and the average of all storms, and 2) the Disturbance Ratio (DR).

The percent contributions to total SSY_{EV} from the UPPER and LOWER subwatersheds were calculated for each storm event by measuring SSY_{EV} at FG1, ~~FG2~~ and FG3 (Figure 1). Total SSY loading to the Bay was measured at FG3 (SSY_{TOTAL}= SSY_{FG3}). SSY from the UPPER subwatershed was measured at FG1 (SSY_{UPPER} = SSY_{FG1}). SSY from the LOWER subwatershed was calculated as ~~by subtracting SSY_{FG1} from SSY_{FG3}~~ (SSY_{LOWER}) ~~=~~ (SSY_{FG3}-SSY_{FG1}). Where SSY_{EV} data at FG2 were also available, the contributions from the quarry subwatershed (SSY_{LOWER_QUARRY} = SSY_{FG2}-SSY_{FG1}), and village subwatershed ($SSY_{LOWER\_VILLAGE}$ = SSY_{FG3}-SSY_{FG2}) were calculated separately. Percent contributions were compared event-wise, as well as the average of all storm events. Land cover in the LOWER watershed includes both undisturbed and disturbed surfaces.

To calculate SSY from the disturbed areas, SSY from the undisturbed areas was estimated using the specific SSY (sSSY tons/km^2) from the UPPER subwatershed multiplied by the undisturbed area in the LOWER subwatersheds. SSY from the undisturbed areas was subtracted from the measured SSY to determine SSY from disturbed areas:

shorter subscript

$$SSY_{disturbed} = SSY_{subwatershed} - (sSSY_{UPPER} * A\_undisturbed) \quad \text{Equation 2}$$

where SSYdisturbed is SSY from disturbed areas only (tons), SSYsubwatershed is (SSY_{FG3}, SSY_{FG2}) SSY measured from the ~~disturbed~~ subwatershed (tons), $sSSY_{UPPER}$ is specific SSY from the UPPER subwatershed (tons/km^2), and A_undisturbed is the area of undisturbed forest in the ~~disturbed~~ subwatershed (km^2). This assumes that sSSY from undisturbed forest in the UPPER subwatershed is the same as from undisturbed forest in the LOWER subwatershed. * Since precip is higher in the upper, Q and SSY from forest may be higher ~~from~~ in UPPER than LOWER, so the SSY dist is likely a conservative estimate.

The disturbance ratio (DR) is the ratio of SSY_{EV} from the total human-disturbed watershed under current conditions (SSY_{TOTAL}), to SSY under pre-disturbance conditions, calculated using ~~by the specific SSY from the UPPER subwatershed~~ ($sSSY_{UPPER}$):

Move to p 13

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Both Eq 2 and Eq 3 assume

$$\text{DR} = \frac{SSY_{TOTAL}}{Area_{TOTAL} * sSSY_{UPPER}} \qquad \text{Equation 3}$$

~~It is~~ assumed that the whole watershed was originally covered in forest, with sSSY from forested areas in the LOWER subwatershed being equal to sSSY from the undisturbed UPPER subwatershed. SSY estimated for the disturbed portions of the LOWER subwatershed (Equation 2) was used to calculate a DR for the disturbed areas in the LOWER subwatershed. OK

Predicting event suspended sediment yield (SSY_{EV})

SSY_{EV} may ~~be correlated with precipitation or discharge variables, so~~ Four storm metrics were tested to predict SSY_{EV}: total event precipitation (Psum), event rainfall erosivity (EI30) defined by a 30 minute rainfall intensity, (Hicks, 1990), total event water discharge (Qsum), and peak event water discharge (Qmax) (Duvert et al., 2012; Rodrigues et al., 2013). SSY_{EV} and the discharge metrics (Qsum and Qmax) were normalized by watershed area to compare different sized subwatersheds.

The relationship between SSY_{EV} and storm metrics ~~may be a linear function, but~~ is ~~most~~ often best fit by a ~~watershed-specific~~ power law function ~~of the form~~:

$$SSY_{EV} = \alpha X^{\beta} \qquad \text{Equation 4}$$

where X is a storm metric, and the regression coefficients α and β are obtained by ordinary least squares regression on the logarithms of SSY_{EV} and X (Basher et al., 2011; Duvert et al., 2012; Hicks, 1990). Model fits for each storm metric were compared using coefficients of determination (R^2) ? and Root Mean Square Error (RMSE). The correlation between storm metrics (X) and SSY_{EV} was also quantified using both parametric (Pearson) and non-parametric (Spearman) correlation coefficients. Differences in the power law parameters for undisturbed and disturbed subwatersheds were tested using

~~To determine if sediment contributions from human-disturbed areas and undisturbed areas~~ subwatersheds ~~varied with storm size (Lewis et al., 2001), an~~ Analysis of Covariance (ANCOVA) ~~was used to determine if the regression slopes were statistically different (Rankl, 2004)~~. ok If regression slopes for the UPPER and TOTAL watersheds are significantly different, it supports the conclusion that the effect of human-disturbance changes with storm size.

A difference in the intercept would indicate...
A difference in slope would indicate...

Annual estimates of SSY and sSSY

Annual estimates of SSY and sSSY are most commonly used to compare watersheds with other literature, however, a continuous annual time-series of SSY was not possible at the study site due to the discontinuous field sampling trips. Using continuous Q data for 2014 and the Qmax-SSY_{EV} model, SSY was predicted for all storms in 2014. Sediment mitigation structures were installed at the quarry in October 2014, greatly reducing SSY from the LOWER_QUARRY subwatershed (personal observation), so the Qmax-SSY relationship developed prior to the mitigation was used. For storms with no Qmax data at FG3, Qmax was predicted from a linear regression between Qmax at FG1 and Qmax at FG3 for the study period.

Annual SSY and sSSY were also estimated by extrapolati~~on~~ng SSY from measured storms by the ratio of annual storm precipitation to the precipitation measured during sampled storms:

why "expected"?

$$SSY_{annual} = SSY_{measured} * \frac{measured\ precip}{expected\ annual\ storm\ precip} \quad \text{Equation 5}$$

where SSYannual is estimated SSY from storms, SSYmeasured is SSY measured in storms ~~(all, Tables 2 and 3)~~ haven't talked about field component yet., measured precip is precip measured during the sampled storms, and expected annual storm precip is the precip measured during all storms measured in 2014, where a storm occurs when Q > threshold.

For instance, if precipitation during the measured storm events was 50% of the ~~expected~~ annual storm precipitation, the measured SSY was multiplied by two to estimate annual SSY. Continuous discharge and precipitation data showed approximately 60% of annual precipitation falls during larger storms that produce discharge so annual storm precipitation would be 60% of measured annual precipitation, and ~~This approach assumes that~~ 40% of precipitation occurred as low-intensity events that did not cause a rise in stream stage high enough to exceed the defined storm threshold and is not counted in annual SSY estimates. Considering most SSY is discharged during a few, relatively large events, it is assumed that small events do not significantly contribute to annual SSY (Stock and Tribble, 2009). This approach also assumes that the sediment yield per mm ~~of~~ storm precipitation is constant over the year, and the size distribution of storms has no effect, though there is some evidence that SSY rises exponentially with storm size.

others? Yours?

explain ~~annu~~ annual storm precip.

above the flow threshold

→ put after Turbidity-SSC relationships

Estimating Uncertainty

Uncertainty in SSY_{EV} estimates arises from both measurement and model errors, including models of stage-discharge (stage-Q) and turbidity-suspended sediment concentration (T-SSC) (Harmel et al., 2006). The Root Mean Square Error (RMSE) method estimates the "most probable value" of the cumulative or combined error by propagating the error from each measurement and modeling procedure to the final SSY_{EV} estimate (Topping, 1972). The resulting cumulative probable error (PE) is the square root of the sum of the squares of the maximum values of the separate errors:

$$PE = \sqrt{\sum (E^2_{Qmeas} + E^2_{SSCmeas}) + (E^2_{Qmod} + E^2_{SSCmod})} \qquad \text{Equation 6}$$

where PE is the cumulative probable error for individual measured values (±%), E_{Qmeas} is uncertainty in Q measurements (±%), $E_{SSCmeas}$ is uncertainty in SSC measurements (± %), E_{Qmod} is uncertainty in Q modeled by the Stage-Q relationship (RMSE, as ±% of the mean observed Q), and E_{SSCmod} is uncertainty in SSC modeled by the T-SSC relationship (RMSE, as ± % of the mean observed SSC)(Harmel et al., 2009).

E_{Qmeas} and $E_{SSCmeas}$

~~Errors from each measurement and modeling approach are quantified with the description of the particular method below.~~ ~~Error from manual water discharge measurements, stream water sampling procedures, and lab procedures~~ are considered ~~"measurement errors" and~~ were estimated using lookup tables (LUT) from the DUET-H/WQ software tool (Harmel et al., 2006). ~~These measurement errors (RMSE (%)) were combined with the modeling errors (RMSE (%)) from the stage-Q and T-SSC relationships to calculate PE for each storm event, to add a statistical measure of uncertainty to SSY_{EV} (± %).~~ The effect of uncertain SSY_{EV} estimates may complicate conclusions about contributions from subwatersheds, anthropogenic impacts, and SSY_{EV}-Storm Metric relationships. This is common in sediment yield studies where successful models estimate SSY with ± 50-100% accuracy (Lewis, 2001; Duvert et al., 2012). ? Preliminary data and field observations suggested the difference in SSY_{EV} from the upper and lower subwatersheds is significantly larger than the ranges of uncertainty in the SSY estimates.

OK-

~~E_{Qmod} was from the RMSE of the stage Q, and E_{SSCmod} from RMSE of the~~

Data Collection

Data on precipitation (P), water discharge (Q), suspended sediment concentration (SSC) and turbidity (T) were collected during three field campaigns: January-March, 2012, February-July 2013, and January-March 2014, and several intervening periods of unattended instrument monitoring. Field sampling campaigns were scheduled to coincide with the period of most frequent storms in the November-May wet season, though large storms were sampled throughout the year.

Precipitation

Precipitation (P) was measured at three locations in Faga'alu watershed using two Rainwise RAINEW tipping-bucket rain gages (RG1 and RG2) and a Vantage Pro Weather Station (Wx)(Figure 1). Data at RG2 was only recorded January-March, 2012, to determine a relationship between elevation and precipitation. The total event precipitation (Psum) or P_{EV}? and event rainfall erosivity (EI30) were calculated using data from RG1, with data gaps filled by 15 min interval precipitation data from Wx.

Water Discharge

~~Water discharge (Q) is needed to calculate SSY (Equation 1)~~. At FG1 and FG3, Q was calculated from 15 minute interval stream stage measurements, using a stage-Q rating curve calibrated to manual Q measurements made under baseflow and stormflow conditions (Figures 3 and 4). Q was measured in the field by the area-velocity method (AV) using a Marsh-McBirney flowmeter to measure flow velocity, and simultaneous channel surveys to measure cross-sectional area (Harrelson et al., 1994; Turnipseed and Sauer, 2010). Stream stage was measured with non-vented pressure transducers (PT) (Solinst Levelogger or Onset HOBO Water Level Logger) installed in stilling wells at FG1 and FG3. Barometric pressure data collected at Wx were used to calculate stage from the pressure data recorded by the PT's. Data gaps in barometric pressure were filled by data from stations at Pago Pago Harbor (NSTP6) and NOAA Climate Observatory at Tula (TULA). Priority was given to the station closest to the watershed with valid barometric pressure data. Barometric data were highly correlated and the source data made little (<1cm) difference in the resulting water level.

Possible to put on map in upper right corner Fig 1?

Stream gaging sites were chosen to take advantage of an existing control structure (FG1) and a stabilized stream cross section (FG3). Area-velocity Q measurements could not be made at high stages at FG1 and FG3 for safety reasons, so stage-Q relationships were constructed to ~~generate~~ ~~contro~~ ~~extrapolated~~ estimate continuous Q record. ~~and peak stages were much higher than the highest Q measurements. A power law can be used to extrapolate the stage-Q rating curve above manual measurements, however, the channel conditions at FG1 required alternative methods described below, and a~~ ~~physical~~ Manning's ~~equation was used for FG3.~~

At FG3, the ~~stream cross-section is a channelized~~ channel is rectangular ~~channel~~ with stabilized rip-rap banks and bed (Appendix Figure 1). Recorded stage varied from 1 to 147 cm. Area-velocity Q measurements (n= 14) were made from 30 to 1,558 L/sec, covering a range of stages from 6 to 39 cm. The highest recorded stage was much higher than the highest stage with measured Q so the rating could not be extrapolated by a power law ~~mathematical methods~~. Stream conditions at FG3 fit the assumption for Manning's ~~flow velocity~~ equation, so the stage-Q rating at FG3 was ~~extrapolated~~ created using Manning's equation, calibrating Manning's n to the Q measurements (0.067) (Figure 3). ~~Kept~~ n constant?

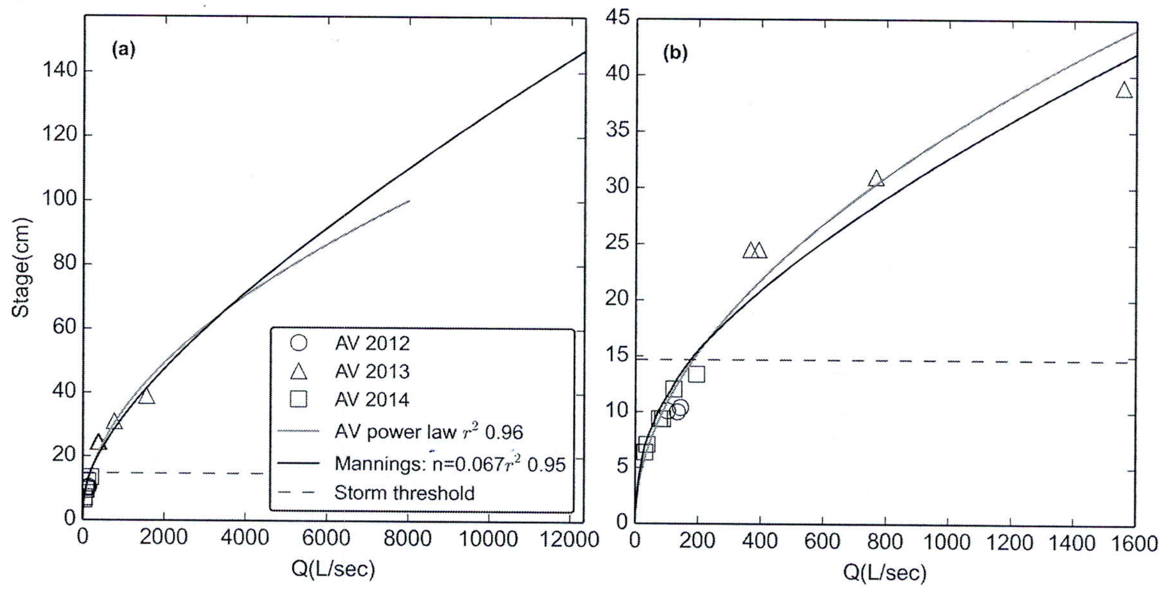
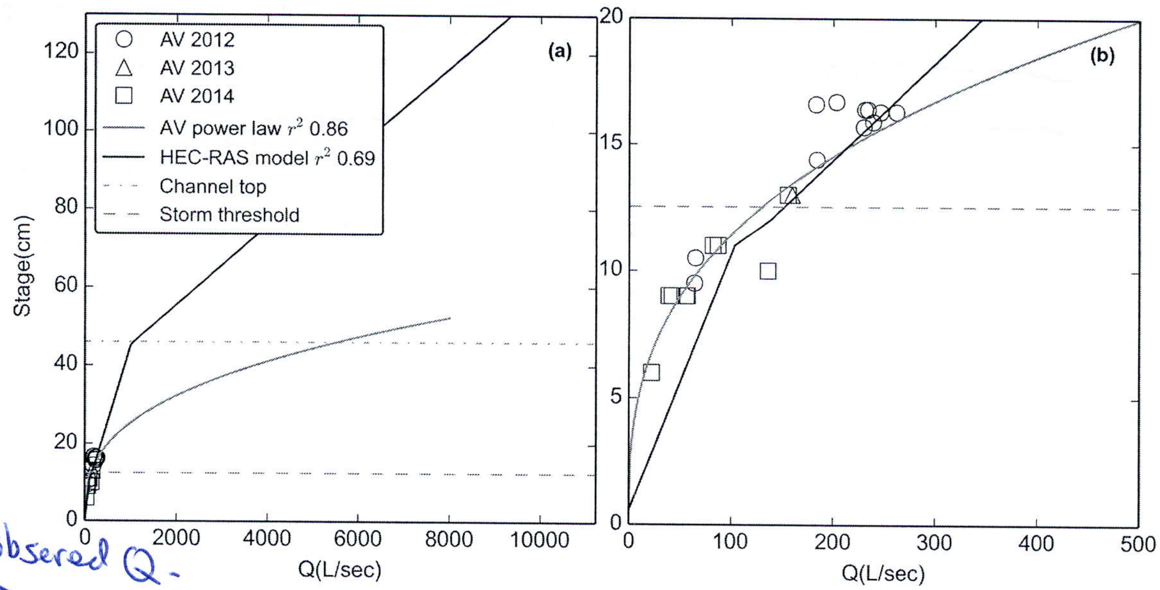


Figure 3. Stage-Discharge relationships for stream gaging site at FG3 for (a) the full range of observed stage and (b) the range of stages with AV measurements of Q. RMSE was 93 L/sec, or 32% of observed Q.

At FG1, the flow control structure is a masonry ogee spillway crest of a defunct stream capture. The structure is a rectangular channel 43 cm deep, then transitions abruptly to gently sloping banks, causing an abrupt change in the stage-Q relationship

(Appendix Figure 2). At FG1, the PT recorded stage height ranging from 1 to 120 cm, while area-velocity Q measurements (n= 22) covered stages from 6 to 17 cm. Since the highest recorded stage (120 cm) was higher than the highest stage with measured Q (17 cm), and there was a distinct change in channel geometry above 43 cm the rating could not be extrapolated by mathematical methods like a power law. The flow structure did not meet the assumptions for using Manning's equation to predict flow so the HEC-RAS model was used (Brunner 2010). The surveyed geometry of the upstream channel and flow structure at FG1 were input to HEC-RAS, and the HEC-RAS model was calibrated which params? to the ~~area-velocity~~ Q measurements (Figure 4). While a power function fit Q measurements better than HEC-RAS for low flow, HEC-RAS fit better for Q ~~at high Q~~, above the storm threshold used in analyses of SSY (Figure 4).



of observed Q.

Figure 4. Stage-Discharge relationships for stream gaging site at FG1 for (a) the full range of observed stage and (b) the range of stages with AV measurements of Q. RMSE for Q > storm threshold?? was 31 L/sec, or 22%. "Channel Top" refers to the point where the rectangular channel transitions to a sloped bank and cross-sectional area increases much more rapidly with stage. A power-law relationship is also displayed to illustrate the potential error that could result if inappropriate methods are used.

Water discharge at FG2 was calculated as the product of the specific water discharge from FG1 (Q m^3/0.9 km^2) and the watershed area draining to FG2 (1.17 km^2). This assumes that specific water discharge from the subwatershed above FG2 is similar to above FG1 ~~and rainfall does not vary over these areas~~. Discharge may be higher from the quarry surface, which represents 5.7% of the LOWER_QUARRY subwatershed, so

Q, and thus SSY from the quarry are a conservative, lower bound estimate. The quarry surface is continually being disturbed, sometimes with large pits excavated and refilled in the course of weeks, as well as intentional water control structures being implemented over time. Given these changes in the contributing area of the quarry, ~~E~~efforts to model water yield from the quarry were ~~considered too time-consuming~~ infeasible and uncertain ~~to be useful~~.

The measurement error (RMSE) for Q measurements (same for both FG1 and FG3) from the DUET-H/WQ LUT (Harmel et al., 2006) was 8.5 % overall, and was used to calculate the total Probable Error. This measurement error accounted for error in the area-velocity measurements (6%), continuous Q measurement in a natural channel (6%), pressure transducer error (0.1%), and streambed condition (firm, stable bed=0%). The model errors (RMSE) for the stage-Q rating curve were 32% at FG3 using Manning's equation, and 22 % at FG1 using HEC-RAS. The RMSE for Q at FG1 was also applied to Q at FG2 because the specific water yield at FG1 is used to predict Q at FG2.

Put in results, combine with uncty analysis of SSC.

Continuous Suspended Sediment Concentration

Continuous SSC at 15 minute intervals ~~intervals to calculate SSY_{EV} (Equation 1)~~ was estimated from 1) 15 minute interval turbidity data (T) and a T-SSC relationship calibrated to stream water samples collected over a range of Q and SSC, and 2) linear interpolation of SSC from ~~grab and autosamples~~ water samples.

Stream water samples were collected by grab or "dip" sampling with 500 mL HDPE bottles at FG1, FG2, and FG3. At FG2, water samples were also collected at 30 min intervals during storm events by an ISCO 3700 Autosampler triggered by a stage height sensor. Samples were analyzed for suspended sediment concentration (SSC) on-island using gravimetric methods (Gray et al., 2000). Water samples were vacuum filtered on pre-weighed 47mm diameter, 0.7 um Millipore AP40 glass fiber filters, oven dried at 100 C for one hour, cooled and weighed to determine SSC (mg/L). From January 6, 2012, to October 1, 2014, 610 water samples were collected and analyzed for SSC: FG1 (n=55), FG2 (n=91 grab samples, n=186 from the Autosampler), and FG3 (n=154).

Interpolated grab samples

Continuous SSC from interpolated grab samples could only be calculated if more than three stream water samples were collected during the storm event, and if they adequately captured the SSC dynamics of the storm event, particularly the peak SSC. SSC was assumed to be zero at the beginning and end of each storm if no grab sample data was available for those times (Lewis 2001). The measurement errors (RMSE) to calculate Probable Error from interpolated SSC measurements were taken from the DUET/WQ LUT, where RMSE was 12.4% for sample collection, and 3.9% for sample analysis. These measurement errors account for error attributed to using an autosampler with single-intake (11%), interpolating over a 30 min interval (5%), sampling during stormflows (3%), and measuring SSC by filtration (3.9%).

Move to results, uncty analysis.

Turbidity-SSC relationships

Turbidity (T) was measured at FG1 and FG3 using three types of turbidimeters: 1) a Greenspan TS3000 (TS), 2) a YSI 600OMS with 6136 turbidity probe (YSI), and 3) a CampbellSci OBS500 (OBS). All turbidimeters were permanently installed in protective PVC housings near the streambed where the turbidity probe would be submerged at all flow conditions, with the turbidity probe oriented downstream. Despite regular maintenance, debris fouling during storm and baseflows was common and caused data loss during several storm events (Lewis et al., 2001). Storm events with incomplete or invalid T data were not used in the analysis. A three-point calibration was performed on the YSI turbidimeter with YSI turbidity standards (0, 126, and 1000 NTU) at the beginning of each field season and approximately every 3-6 months during data collection. Turbidity measured with 0, 126, and 1000 NTU standards differed by less than 10% (4-8%) during each recalibration. The TS turbidimeter at FG1 was vandalized in 200x. and removed from service before recalibration ~~was needed~~. All turbidimeters were regularly cleaned following storms to ensure proper operation.

At FG3, the YSI turbidimeter recorded T (NTU) at 5 min intervals from January 30, 2012, to February 20, 2012, and at 15 min intervals from February 27, 2012 to May 23, 2012, when it was damaged during a large storm. The YSI turbidimeter was replaced with an OBS, which recorded Backscatter (BS) and Sidescatter (SS) at 5 min intervals from March 7, 2013, to July 15, 2014. No data was recorded from August 2013-January 2014 when the wiper clogged with sediment. A new OBS was installed at FG3 from January, 2014, to August, 2014. To correct for some periods of high noise observed in the BS and SS data recorded by the OBS in 2013, the OBS installed in 2014 was programmed to make a burst of 100 BS and SS measurements at 15 min intervals, and record Median, Mean, STD, Min, and Max BS and SS. All BS and SS parameters were analyzed to determine which showed the best relationship with SSC, but mean SS showed the highest r^2 and is a physically comparable measurement to NTU measured by the YSI and TS (Anderson 2005).

At FG1, a TS turbidimeter recorded T (NTU) at 5 min intervals from January 2012-July 2012, when it was vandalized and destroyed. The YSI turbidimeter previously deployed at FG3 in 2012 was repaired and redeployed at FG1 and recorded T (NTU) at 5 min intervals from June 2013 to October 2013, and January 2014 to August 2014. T data was resampled to 15 min intervals to compare with SSC samples for the T-SSC relationship, and corresponding to Q for calculating SSY (~~Equation 1~~). instrument,

The T-SSC relationship can be unique to each region, ~~each~~ stream, or even each storm event (Lewis et al., 2001), and can be influenced by water color, dissolved solids and organic matter, temperature, and the shape, size, and composition of sediment. However, T has proved to be a robust surrogate measure of SSC in streams (Gippel 1995), and is most accurate when a unique T-SSC relationship is developed for each instrument separately, using in situ grab samples under storm conditions (Lewis et al., 1996). A unique T-SSC relationship was developed for each turbidimeter, at each location, using 15 min interval T data and SSC samples from storm periods only (~~8~~). A "synthetic" T-SSC relationship (~~SRC~~) was also developed by placing the turbidimeter in a black tub with water, and sampling T and SSC as sediment was added, but results ~~from the SRC's~~ were not comparable to T-SSC relationships developed under actual storm conditions and were not used in further analyses.

n=5 samples? storms?

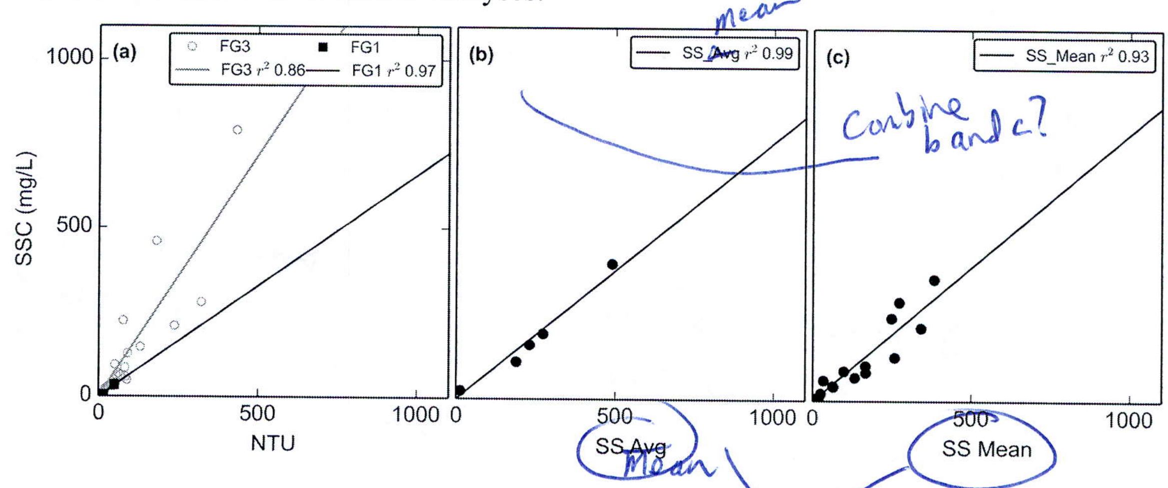


Figure 5. Turbidity-Suspended Sediment Concentration relationships for a) the YSI turbidimeter deployed at FG3 (02/27/2012-05/23/2012) and the same YSI turbidimeter deployed at FG1 (06/13/2013-12/31/2014). b) OBS500 turbidimeter deployed at FG3 (03/11/2013-07/15/2013) and c) OBS500 turbidimeter deployed at FG3 (01/31/2014-03/04/2014) ~~what about~~ ~~what about the TS?~~ OK.

The T-SSC relationships varied among sampling sites and sensors but all showed acceptable r^2 values (0.86-0.97). Lower scatter was achieved by using grab samples collected during stormflows only. It is assumed that suspended sediment during storms is a mix of lighter-colored, smaller particles from the quarry and darker-colored, larger particles from natural areas, altering the color, particle sizes, and composition and the relationship between T and SSC compared to low flows that may be dominated by sediment only from the quarry. need? For the TS deployed at FG1, the r^2 value was fairly high (0.96) but the ranges of T and SSC values used to develop the relationship were considered too small (0-12 NTU) compared to the maximum observed during the deployment period (1,077 NTU) to develop a robust relationship for higher T values. Instead, the T-SSC relationship developed for the YSI turbidimeter installed at FG3 (Figure 5) was used to convert T data from the TS to SSC at FG1. For the YSI ~~600OMS~~ turbidimeter, more scatter was observed in the T-SSC relationship at FG3 than at FG1 (Figure 5), but this could be attributed to the higher number and wider range of values sampled, as well as the contribution of multiple sediment sources sampled at FG3.

The model errors (RMSE) of the T-SSC relationships for calculating Probable Error were 25.0% (5 mg/L) for the YSI and TS at FG1, 66.0% (82 mg/L) for the YSI at FG3, and 30.0% (37 mg/L) for the OBS at FG3. Total Probable Error (RMSE %) for SSY estimates at FG1, FG2, and FG3 were calculated from the measurement errors for Q (8.5%) and SSC grab samples (16.3%), and the model errors of the stage-Q and T-SSC relationships for that location. Total Probable Errors in SSY are presented with the SSY results below. Move to results... or to uncty in methods

The OBS turbidimeter had ~~very~~ high r^2 values and was stable between the two periods of deployment (Fig 5b,c).

Results

Field Data Collection

Precipitation

with

Annual precipitation measured at RG1 (gaps filled with data from Wx) was 3,349 mm, 3,443 mm, and 3,765 mm in 2012, 2013, and 2014, respectively. These annual rainfall amounts are approximately 93% of long-term rainfall (=3,800 mm) from PRISM data (Craig, 2009). No ~~orographic relationship~~ difference in P was found between RG1 and Wx, or RG1 and RG2, so ~~precipitation~~ P was assumed to be homogenous over the watershed for all analyses. Rain gauges could only be placed as high as ~300 m (RG2), though the highest point in the watershed is ~600 m. Long-term rain gage records show a strong precipitation gradient with increasing elevation, with average precipitation of 3,000-4,000 mm on the lowlands, increasing to more than 6,350 mm at the high elevations (>400 m.a.s.l.) around the harbor (Craig, 2009; Dames & Moore, 1981; Wong, 1996). Rainfall data measured at higher elevations would be useful to determine a more robust orographic rainfall relationship. For this analysis, however, the absolute values of total rainfall in each subwatershed are not ~~as~~ important since precipitation is only used as a predictive storm metric~~, assuming the proportion of rainfall over the subwatersheds is similar~~.

N=?

mean elev of upper + lower?

Water Discharge

Discharge at both FG1 and FG3 was characterized by periods of low but perennial baseflow (FG1: 4-165 L/sec; FG3: 21-364 L/sec), punctuated by short, flashy hydrograph peaks (FG1: max 8,356 L/sec, FG3: max 13,071 L/sec) (Figure 6). Though Q data was unavailable for some periods, storm events appeared to be generally smaller, ~~and~~ but more frequent in the October-April wet season. Storm events during the May-September dry season were less frequent but larger ~~events~~. The largest event in the three year study was observed in August 2014.

Log plot better?

Dots show what? Add to legend.

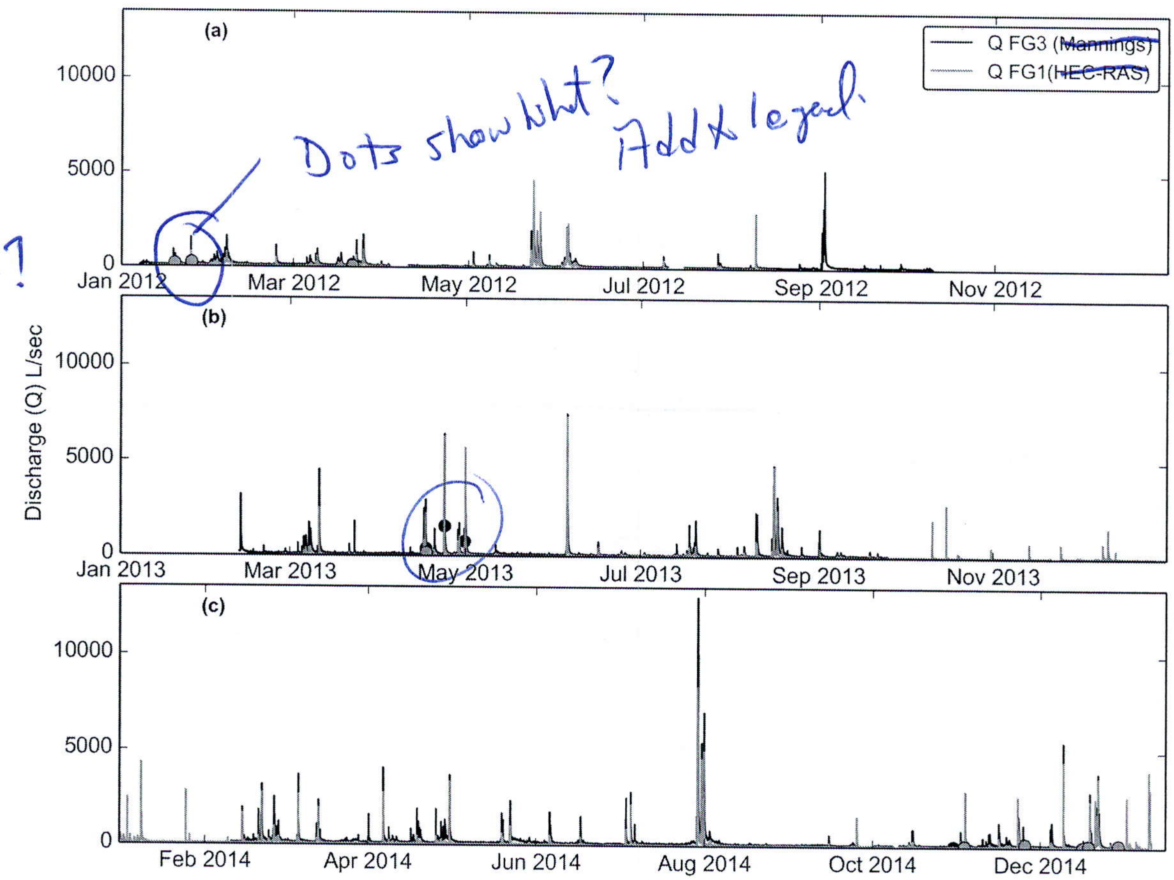


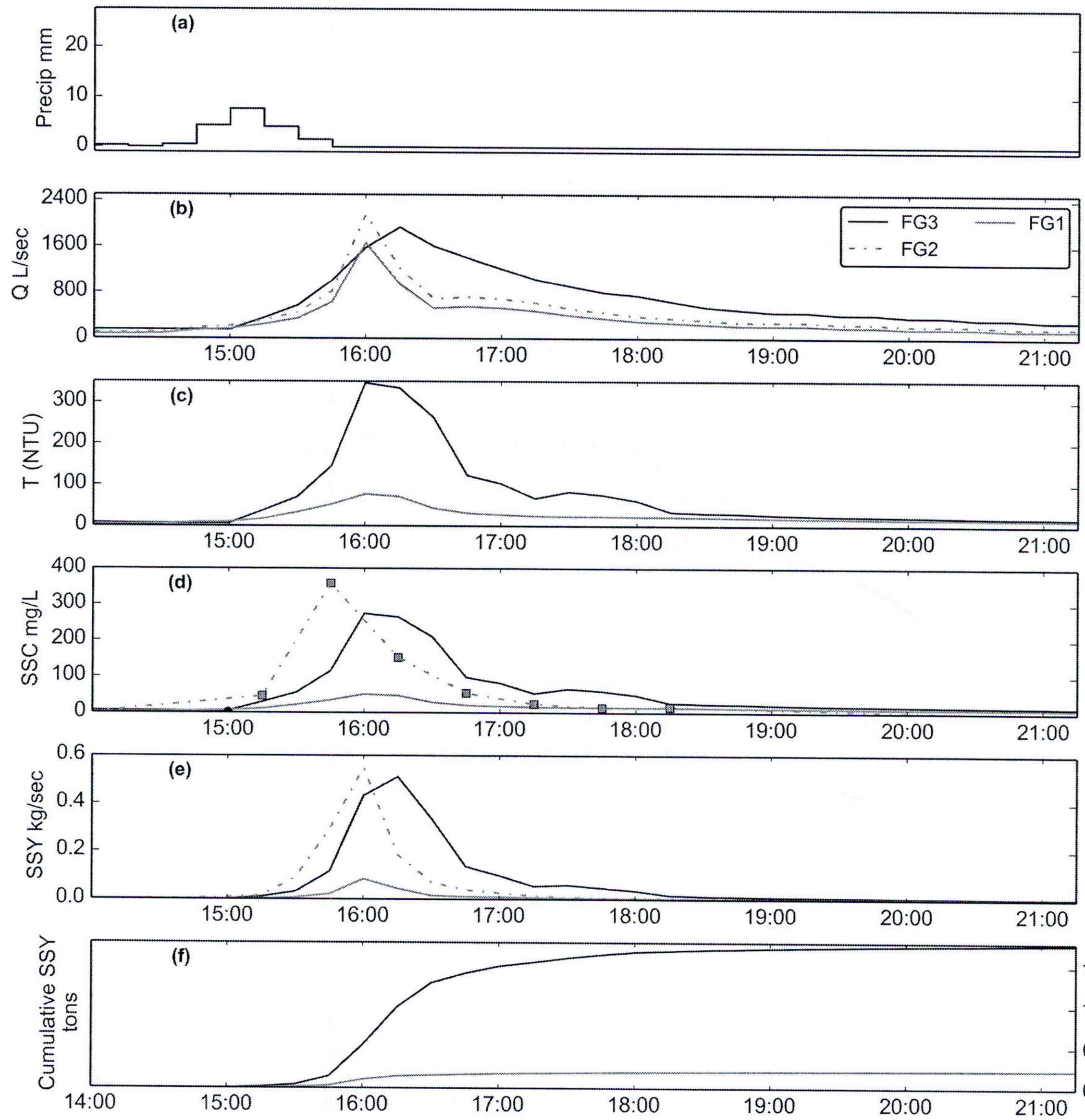
Figure 6. Time series of water discharge (Q), calculated from measured stage and the stage-discharge rating curves in a) 2012 b) 2013 and c) 2014.

Storm Events

Using the stage threshold method and manual separation of complex storm events, 99 storm events were identified from Q data at FG3 from January, 2012, to July 2014. Valid Q data was recorded during 97 events at FG1, and 99 events at FG3 (Appendix 3, Table 1). Valid SSC data from T and interpolated grab samples was recorded during 64 events at FG1, and 55 events at FG3. Of those storms, 28 events had valid P, Q, and SSC data for both the FG1 and FG3 to calculate and compare SSY from the UPPER and LOWER subwatersheds. ~~Valid~~ SSY data from interpolated grab samples was collected at FG2 for 8 storms to compare with SSY from FG1 and FG3 ~~directly~~. Storm event durations ranged from 2 hours to 5 days, with mean duration of 13 hours.

Most storm events showed a typical pattern, where a short period of intense rainfall caused a rapid increase in SSC downstream of the quarry (FG2) while SSC remained low ~~downstream of~~ at the undisturbed forest site (FG1)~~, indicating sheetwash of~~

~~sediment from the quarry into the stream~~ (Figure 7). The highest SSC was typically observed at FG2, with slightly lower and later peak SSC observed at FG3. SSC downstream of the undisturbed forest (FG1) typically increased more slowly, remained lower, and peaked later than the disturbed sites downstream of the quarry (FG2) and the village (FG3). Though peak SSC was highest at FG2, the total SSY was highest at FG3 due to the addition of storm runoff from the larger watershed draining to FG3. Storm flow at FG3 included both storm runoff and sediment from disturbed areas of the quarry and village, and the undisturbed forest on the steep hillsides in the LOWER subwatershed.



26

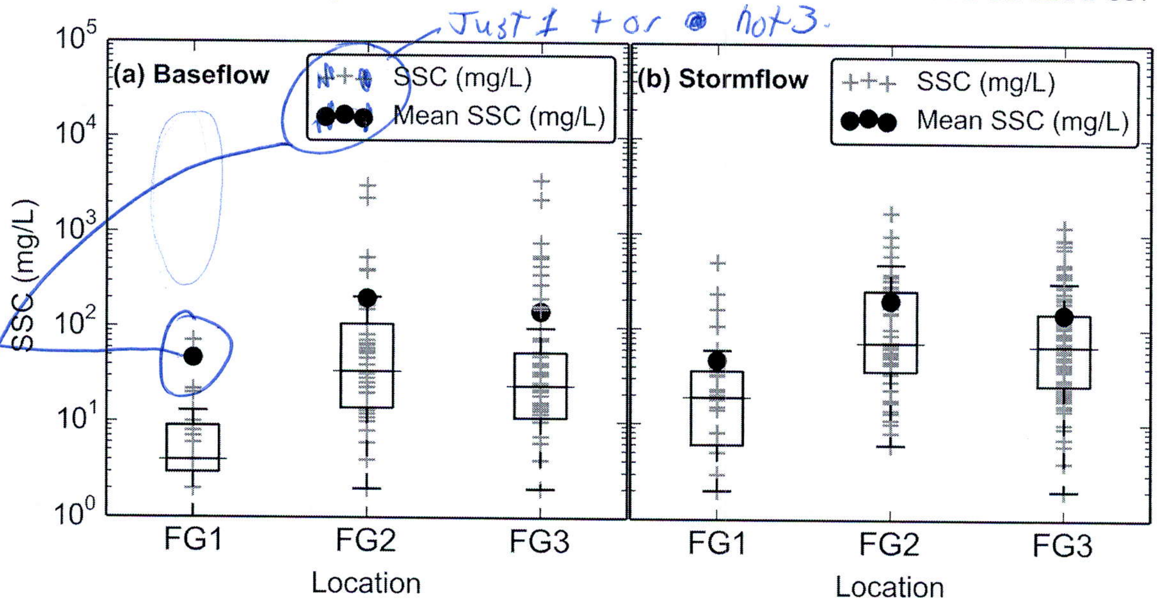
Figure 7. Example of storm event (02/14/2014). SSY at FG1 and FG3 calculated from SSC modeled from T; SSY at FG2 from SSC samples collected by the Autosampler.

Suspended Sediment Concentration

Mean and maximum SSC of water samples, collected during low flow and stormflow by grab and autosampler, were lowest at FG1 (μ=31 mg/L, max=500 mg/L), highest at FG2 (μ=334 mg/L, max=12,600), and in between at FG3 (μ=152 mg/L, max=3,500 mg/L). At FG1, 42% of grab samples (n=23) were collected during baseflow conditions (Q_FG1<165 L/sec), mean SSC: 9 mg/L (Figure 8a); 58% of grab samples (n=32) were collected during stormflow conditions, mean SSC: 47 mg/L (Figure 8b). At FG2, 49% of grab samples (n=45) were collected during baseflow conditions (Q_FG1<165 L/sec), mean SSC: 200 mg/L; 51% of grab samples (n=46) were collected during stormflow conditions, mean SSC: 471 mg/L. At FG3, 42% of samples (n=65) were collected during baseflow conditions (Q_FG3<364 L/sec), mean SSC: 145 mg/L; 58% of samples (n=89) were collected during stormflow conditions, mean SSC: 163 mg/L. This pattern of SSC values suggests that little sediment is contributed from the forest upstream of FG1, then there is a large input of sediment between FG1 and FG2, and then SSC is diluted by addition of stormflow with lower SSC between FG2 and FG3.

√ Good

Just 1 + or ● not 3.



Mean is an outlier?

Figure 8. Boxplots of Suspended Sediment Concentration (SSC) from grab samples only (no Autosampler) at FG1, FG2, and FG3 during (a) baseflow and (b) stormflow. Note the values are plotted on a logarithmic axis to display the full range of sampled values.

On fig 9 there is a value at 10^4 — for FG2 is it covered up here?

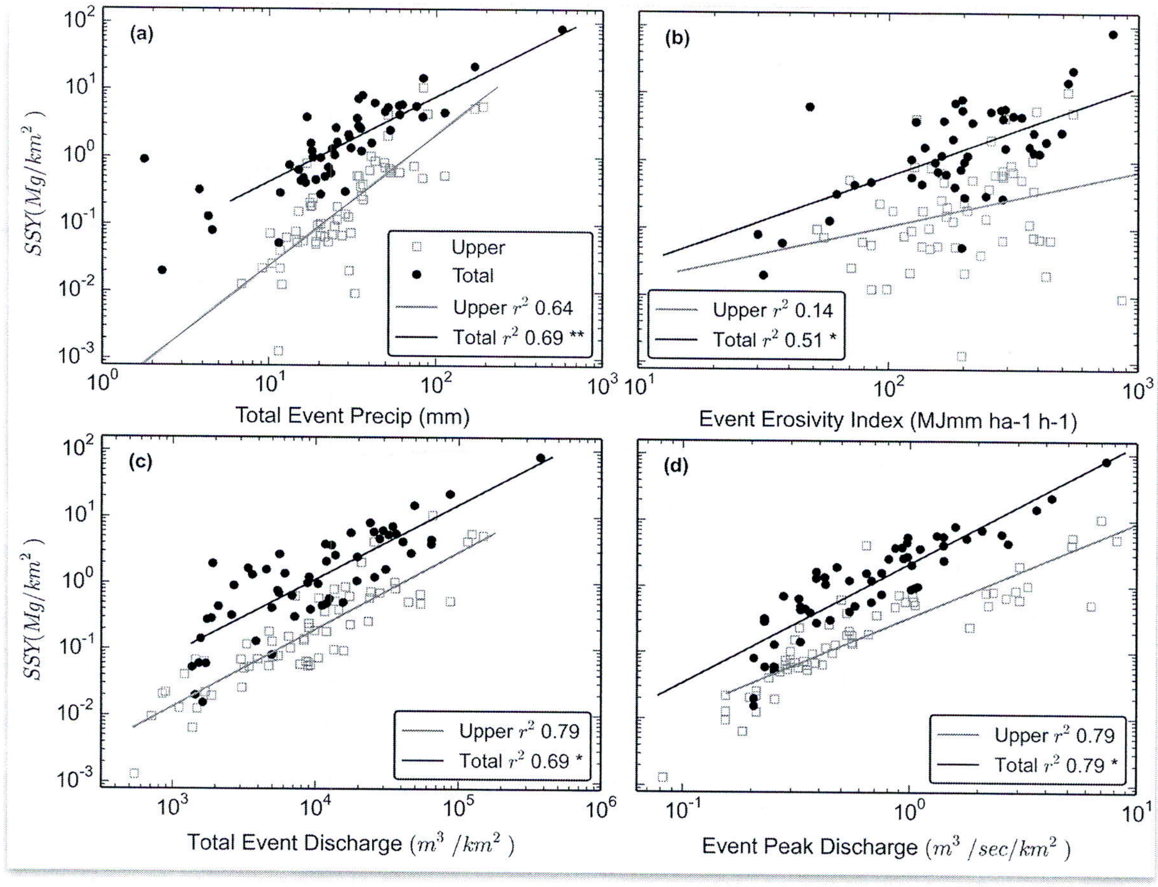


Figure 10. SSY rating curves for predictors. Each point represents a different storm event. **=slopes and intercepts were statistically different, *=intercepts were statistically different.

Pearson and Spearman correlation coefficients were fairly similar, meaning the relationships were mostly linear in log-log space. The exception was Qmax for the UPPER subwatershed (Pearson's: 0.89 vs. Spearman's: 0.94). Only EI30 had a higher Pearson's correlation coefficient than Spearman's, but both were low (Pearson's: 0.72 vs. Spearman's: 0.58).

Precipitation metrics (Psum and EI30) showed lower correlation coefficients with SSY_{EV} compared to the discharge metrics (Qsum and Qmax) over the full range of storm sizes. SSY_{EV} is calculated from measured Q so it is expected that discharge metrics are more closely correlated, and has been observed in other studies (Rankl, Duvert etc.). EI30 was the least correlated with SSY_{EV} of the storm metrics.

Insert Table 6 here

Table 6. Goodness-of-fit statistics for SSY_{EV}-storm metric relationships.

Predicting SSY_{EV} from storm metrics

SSY_{EV} from the UPPER and TOTAL watersheds correlated with each of the four storm metrics tested (Figure 10). Significant scatter was observed for all models, which reflects the changing sediment availability at the quarry and village, and the natural variability in the watershed response for different storm events. Qmax was ~~selected as~~ the best predictor of SSY_{EV} for both the UPPER and TOTAL watersheds in Faga'alu. The Qmax model for both UPPER and TOTAL watersheds showed the highest coefficient of determination (r^2), lowest RMSE, and highest Pearson and Spearman correlation coefficients. Qsum showed an equally high r^2, ~~but only~~ for the UPPER subwatershed, and Qsum in both sub watersheds showed higher RMSE than Qmax.

In all models, SSY_{EV} from the TOTAL watershed was higher than the UPPER subwatershed for the full range of measured storms with the exception of a few events that are considered outliers. These events could be attributed to measurement error but are likely related to landsliding events in the UPPER subwatershed and the increased sediment supply for that specific event. Storm sequence and antecedent conditions may also play a role. While the climate on Tutuila is tropical, without strong seasonality, periods of low rainfall can persist for several weeks, altering the water and sediment dynamics in the subsequent storm events.

LOWER_VILLAGE subwatersheds and TOTAL watershed was 19, 178, 47, and 53 tons/km^2, respectively. sSSY from LOWER_QUARRY and LOWER_VILLAGE was 9.17 and 2.4 times higher, respectively, than sSSY from UPPER subwatershed, suggesting human disturbance has significantly increased SSY over natural levels, particularly at the quarry. sSSY from the TOTAL watershed was 2.7 times higher than the UPPER subwatershed, similar to the larger range of storms in Table 2, where specific SSY was 3.6 times higher.

Insert Table 5 here

Table 5. Sediment yield from disturbed portions of subwatersheds in Faga'alu

Bare land ~~area~~ in the LOWER_QUARRY subwatershed clearly increased sSSY significantly, and contributed the majority of SSY from disturbed areas in Faga'alu watershed. Human disturbance in the LOWER_VILLAGE subwatershed also increased SSY above natural levels but the magnitude of disturbance was much lower than the quarry. SSY from undisturbed areas in the LOWER_QUARRY and LOWER_VILLAGE subwatersheds was: 4.9 and 10.5 tons, respectively (Table 5). SSY from the 0.018 km^2 and 0.070 km^2 of disturbed areas in the LOWER_QUARRY and LOWER_VILLAGE subwatersheds was 43.18 and 18.2 tons, respectively. SSY from the disturbed areas accounted for 90% and 64% of total SSY from those watersheds, respectively. sSSY from disturbed areas in the UPPER, LOWER_QUARRY, and LOWER_VILLAGE subwatersheds was 19.4, 2,460.6, and 255.3 tons/km2, respectively, suggesting that disturbed areas increase sSSY over forested conditions by 126.6x and 13.1x in the LOWER_QUARRY and LOWER_VILLAGE subwatersheds, respectively.

Same sig figs

A very small fraction of the watershed accounted for the majority of the sediment load. Roughly 90% and 64% of SSY from the LOWER_QUARRY and LOWER_VILLAGE subwatersheds, respectively, was from disturbed areas, despite the disturbed areas only accounting for 6.5% and 11.7% of the subwatershed area, respectively. Similarly, despite only 5.2% of the TOTAL watershed being disturbed, SSY from disturbed areas accounts for 65% of the SSY from the TOTAL watershed. for the 8 storms, and 74% for the 24 storms (Table 2)

For the events with Q and SSC data for both FG1 and FG3, (Table 2)

~~SSY from the UPPER and LOWER subwatersheds for the measured storms was 21.1 and 130.4 tons, respectively, and corresponding sSSY was 23.5 and 148.1 tons/km², respectively~~. The UPPER and LOWER subwatersheds are similar in size (0.90 km² and 0.88 km²) but SSY_{UPPER} accounted for an average of just 14% and SSY_{LOWER} for 86% of SSY at the watershed outlet (Table 2). The DR estimated from $sSSY_{UPPER}$ and $sSSY_{LOWER}$ suggests sSSY has been increased by 6.3x in the LOWER subwatershed, and 3.6x for the TOTAL watershed.

total SSY was 151.4 tons, with 21.1 tons (23.5 tons/km²) from UPPER and 130.4 tons (148.1 t/km²) from LOWER

Using the measured sSSY from ~~similar forest areas in~~ forested the UPPER watershed (~~$sSSY_{UPPER}$=~~23.5 tons/km²), SSY from the undisturbed forest areas in the LOWER watershed was 18.6 tons (Table 3), and SSY from the disturbed areas was 111.8 tons. For the measured storms, roughly 86% of SSY from the LOWER subwatershed is from disturbed areas, despite the disturbed areas only accounting for 10.1% of the subwatershed area (0.089 km²). Similarly, despite only 5.2% of the TOTAL watershed being disturbed, SSY from disturbed areas accounts for 74% of the SSY from the TOTAL watershed. Estimated sSSY from disturbed areas in the LOWER subwatershed is 1,257.7 tons/km², suggesting human disturbance has increased sSSY by 54x over undisturbed, forest conditions.

Good.

Insert Table 3 here

Table 3. Sediment yield from disturbed portions of subwatersheds in Faga'alu

subscript

SSY_{EV} data measured at FG2 was available for 8 ~~of~~ the storms, so SSY_{EV} from the LOWER subwatershed including the quarry (SSY_{LOWER_QUARRY}) and the village areas below the quarry ($SSY_{LOWER\_VILLAGE}$) could be calculated ~~to determine the relative sediment contribution from these sources~~ (Table 4).

Insert Table 4 here

Table 4. Sediment yield from subwatersheds in Faga'alu

for the 8 storms was

with an average of

SSY at FG3 was 94 tons, ~~averaging~~ a 19% from the UPPER subwatershed, 51% from LOWER_QUARRY subwatershed, and 30% from the LOWER_VILLAGE subwatershed (Table 4). sSSY from the UPPER, LOWER_QUARRY, and

Good take-home. Abstract?

Abstract says 45%

with high SSC 28

~~with~~

stage above the storm threshold, but generated ~~sediment-rich~~ runoff from the quarry and 2) washing fine sediment into the stream during rock crushing operations at the quarry.

possible to separate these 2 with P data?

The maximum SSC sampled at FG2 (12,600 mg/L) and FG3 (3,500 mg/L) were sampled during the same precipitation event (03/05/2012), but during low Q (Q_FG3=287 L/sec)(Figure 9b and c). During this event, a brief but intense rainfall caused high sediment loading from the quarry, but did not increase Q above the defined storm threshold. The low amount of Q from forested areas draining to FG2 was too low to dilute the high amount of sediment from the quarry and village, causing the extremely high SSC. SSC was diluted further downstream at FG3 by the addition of runoff with lower SSC from impervious surfaces in the village.

Given the close proximity of the quarry to the stream, SSC downstream of the quarry can be highly influenced by mining activity like rock extraction, crushing, and/or hauling operations. During 2012, a common practice for removing fine sediment from crushed aggregate was to rinse it with water pumped from the stream. In the absence of retention structures the fine sediment was then discharged directly into the stream, causing high SSC during interstorm periods. Riverine discharge of fine sediment rinsed from aggregate was discontinued in Jan? March? 2013, corresponding with a lack of high SSC grab samples during low Q in 2013 (Figure 9b and c). In 2013 and 2014, waste sediment was piled on-site and severe erosion of these changing stockpiles caused high SSC during storm events.

Comparing SSY from disturbed and undisturbed subwatersheds

A main objective for this study was to determine the SSY contributions from the undisturbed, UPPER watershed (SSY_{UPPER}), and the disturbed LOWER watershed (SSY_{LOWER}), to determine how much total SSY to Faga'alu Bay (SSY_{TOTAL}) has been increased by human-disturbance. SSY_{UPPER} was measured at FG1, SSY_{TOTAL} was measured at FG3, and SSY_{LOWER} was calculated by subtracting SSY_{UPPER} from SSY_{TOTAL} (Table 2), and the Disturbance Ratio (DR) was calculated by Equation 2.

Was in methods

Insert Table 2 here

Table 2. Sediment yield from subwatersheds in Faga'alu

Probability plots of the SSC data showed they were highly non-normal, so non-parametric tests for statistical significance were applied. The Kruskall-Wallis test showed SSC ~~samples~~ from all three locations were significantly different ($p<0.01$) for low flows ($p<10^{-6}$) ($p=0.000$) and storm flows ($p<$ ...) ($p=0.000$). The pair-wise Mann-Whitney test showed SSC samples were significantly different ($p<0.01$) between FG1 and FG2 (low flows, $p=0.000$; stormflows, $p=0.000$), but were not significantly different ($p<0.05$) between FG2 and FG3 (low flows, $p=0.149$; stormflows, $p=0.266$).

I like that term better b/c it doesn't imply hydrological pathway

SSC varied by several orders of magnitude for a given Q at all three sites (FG1, FG2, FG3) due to significant hysteresis observed during storm periods (Figure 9). At FG1, variability of SSC ~~samples~~ during stormflows from year to year was assumed to be caused by randomly occurring landslides during large storm events. The maximum SSC sampled downstream of the undisturbed forest, at FG1 (500 mg/L), was sampled on 04/23/2013 at high discharge (Q_FG1= 3,724 L/sec)(Figure 9a). Anecdotal and field observations reported higher than normal SSC upstream of the quarry during the 2013 field season, possibly due to landsliding from previous large storms (G. Poysky, pers. comm.).

Possible to flag events after rain? Confusing...

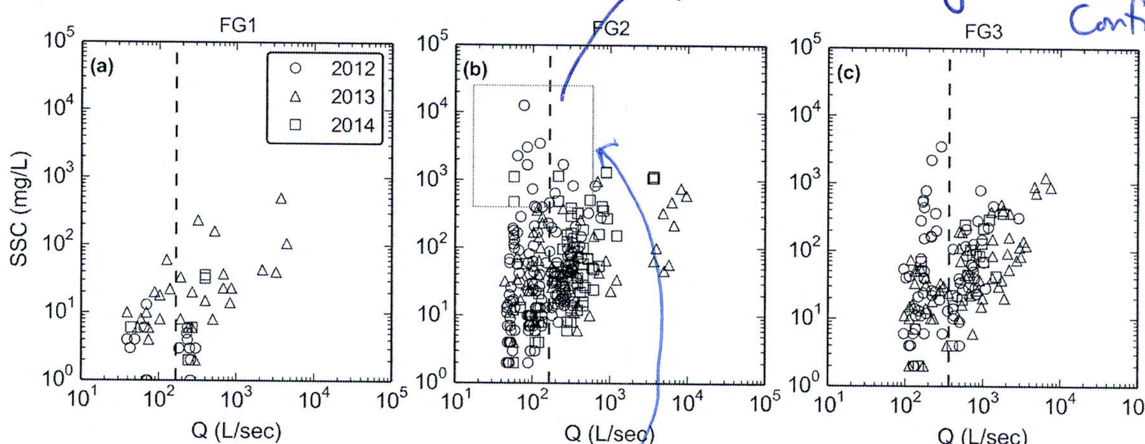


Figure 9. Water Discharge vs Suspended Sediment Concentration at FG1, FG2, and FG3 during baseflow and stormflow periods. ~~Samples from Autosampler are included with grab samples at FG2.~~ Box indicates... Why box also covers stormflow?

At FG2 and FG3, additional variability in the Q-SSC relationship was due to the changing sediment availability associated with quarrying operations and construction in the village. The high SSC values observed downstream of the quarry (FG2) during low Q were caused by two mechanisms: 1) rainfall events that did not result in a rise in stream

Annual estimates of SSY and sSSY from storms in Table 4

Storms with measured SSY at FG1, FG2, and FG3 (Table 4) included a total precipitation of 537 mm, or 24% of expected annual storm precipitation. Annual storm precipitation is roughly 4 times the precipitation measured for these storms, so annual SSY and sSSY are estimated to be roughly 4 times the measured SSY and sSSY. Annual SSY from the UPPER, LOWER_QUARRY, LOWER_VILLAGE, and TOTAL watersheds were estimated to be 70, 190, 120, and 380 tons/year, respectively. Annual sSSY from the UPPER, LOWER_QUARRY, LOWER_VILLAGE, and TOTAL watersheds were estimated to be 80, 710, 190, and 210 tons/km^2/year, respectively.

These values are likely the least accurate, since they are based on the fewest storms. They are presented here to provide an estimate of SSY annual for the quarry and village separately.

Discussion

Methods for quantifying human impact

In contrast to other methods like USLE-based models, traditional sediment rating curves, or the traditional sediment budget, event-wise correlation of SSY and storm metrics was advantageous for quantifying increased sediment loading to coral reefs from human impact in the study watershed. Unconstrained USLE-based models are not well-calibrated for use in steep, tropical watersheds with human disturbance (Calhoun and Fletcher, 1999), and have high uncertainty in the sediment delivery ratio. Using a ~~traditional~~ relationship between water discharge and sediment concentration to estimate continuous sediment load was problematic in the study watershed, due to the significant hysteresis and changing sediment availability in the quarry and village. While the Q-SSC relationship was useful to illustrate large differences in SSC downstream of the quarry and the remediation of high SSC at low Q, using this approach to quantify total sediment contributions would not be possible. ~~Developing a full sediment budget would have been useful to quantify sediment contributions from various sources within the subwatersheds, particularly the LOWER_VILLAGE, but not practical in this situation or required to answer the research questions. Sediment budget development requires significant time, effort, and funding, but this level of detail and certainty was not needed.~~

Excluding these values, the range of SSY annual is relatively small for UPPER (29-44) and ~~Lower~~ TOTAL (341-450). Together,

Reid and Dunne (1996) argue that in cases where there is a clear management question and the study area can be divided into sub-units, a sediment budget can be rapidly developed with only a few field measurements and limited field monitoring. In

Fagaalu, ~~the study watershed,~~ and other similar steep watersheds, human-disturbance is constrained to the lower watershed, and sediment yields from these key sources can be measured separately. Sampling at Fagaalu ~~in the study watershed~~ targeted key sediment sources, and the disturbance signal was very large. Other examples in the literature document similar large disturbances where roads and mining vastly increased sediment yields ~~downstream~~ (Reid and Dunne, 1984; Hettler et al., 1997; Ramos-Scharron, 2005; Stock et al., 2010). Analyzing event-wise SSY allows comparison of similar size storms to determine change over time without problems of interannual variability in precipitation totals, and eliminates the need for long-term continuous field work to measure annual totals. From a management perspective, this approach is cheaper since it does not require multiple or even a single full year of monitoring, and it can be rapidly conducted if mitigation or disturbance activities are already planned. By developing a predictive model of SSY from an easily monitored storm metric like maximum event discharge, SSY can be modeled in the future to compare with either post-mitigation or post-disturbance SSY.

Interpreting slope and intercept of the Qmax-SSY relationship

Several researchers have attempted to explain the difference in α (intercept) and β (slope) coefficients according to watershed characteristics. A traditional sediment rating curve (Q-SSC) is considered a 'black box' model, and though the α and β coefficients have no physical meaning, some physical interpretation has been ascribed to them. High α values suggest high availability of easily eroded sediment sources in the watershed. High β values suggest that small changes in stream discharge lead to large increases in sediment load due to the erosive power of the river or the availability of new sediment sources at high Q (Asselman, 2000). ~~Similar analysis has been done on event-based sediment yield curves (Qmax-SSY$_{EV}$ models)~~. Rankl (2004) found that β coefficients were not statistically different between watersheds, where? Europe? Humid, semi-arid? and he assumed that the β exponent was a function of rainfall intensity on hillslopes. Rankl (2004) hypothesized that variability in α ~~(the intercept)~~ was a function of sediment availability and erodibility in watersheds, ~~but~~ Duvert et al. (2012) argued that α values are also dependent on the regression fitting method, arguing that, for instance, ~~the~~ Nonlinear fitting methods results in a model fit to higher SSY values at lower discharge compared to Linear fitting methods.

34

~~SSY from measured storms and the fraction of annual storm precipitation~~. ~~Continuous Q and P data showed that~~ storm precipitation was 2,279 mm in 2014, representing 57% of annual total precipitation in 2014 (=3,765 mm). Repeats methods? Same as # in methods?

Annual estimates of SSY and sSSY using the Qmax-SSY relationship

The Qmax-SSY relationships ~~developed above~~ were used to predict SSY from Qmax of 61 storms identified at FG3 in 2014 (Table 7). Predicted annual SSY in 2014 from the UPPER and TOTAL watersheds was 29 and 392 tons/year, respectively. Predicted annual sSSY in 2014 from the UPPER and TOTAL watersheds, was 33 and 220 tons/km^2/year, respectively.

Insert Table 7 here

Table 7. Annual SSY and sSSY estimates

Annual estimates of SSY and sSSY from all measured storms

All storms with measured SSY at FG1 from 2012-2014 included 2,780 mm of precipitation, or 122% of expected annual storm precipitation. Annual storm precipitation is roughly 20% less than precipitation measured during those storms, so estimated annual SSY and sSSY from the UPPER subwatershed were 44 tons and 49 tons/km^2/yr, respectively. All storms with measured SSY at FG3 from 2012-2014 included 2,766 mm of precipitation, or 121% of expected annual storm precipitation. Estimated annual SSY and sSSY from the TOTAL watershed were 341 tons and 191 tons/km^2/yr, respectively.

Annual estimates of SSY and sSSY from storms in Table 2

Storms with measured SSY at both FG1 and FG3 (Table 2) included a total precipitation of 1,123 mm, or 49% of expected annual storm precipitation. Annual storm precipitation is roughly 2 times the precipitation measured during those storms, so annual SSY and sSSY are estimated to be roughly 2 times the measured SSY and sSSY. Estimated annual SSY from the UPPER, LOWER, and TOTAL watersheds was 40, 390, and 450 tons/year, respectively. Estimated annual sSSY from the UPPER, LOWER, and TOTAL watersheds was 50, 300, and 170 tons/km^2/year, respectively.

Combine this and previous parag.

Discharge metrics showed much higher correlation coefficients than the precipitation metrics in the UPPER subwatershed, but had similar coefficients in the LOWER watershed. This suggests that sediment production processes are more related to discharge processes in the UPPER subwatershed, and more related to precipitation processes in the LOWER subwatershed, influencing the correlation coefficients for the TOTAL watershed. SSY from the LOWER subwatershed is hypothesized to be mostly generated by surface erosion at the quarry, dirt roads, and agricultural plots, whereas SSY from the UPPER subwatershed is hypothesized to be mainly from channel processes and mass wasting. Mass wasting can contribute large pulses of sediment during large precipitation events, which can be deposited near or in the streams and entrained at high discharges during later events. Given the high correlation coefficients for Qmax in both subwatersheds, Qmax may be a promising predictor that integrates both precipitation and discharge processes.

ANCOVA was used to compare ~~the slopes of~~ ~~intercepts and~~ slopes regression coefficients of the UPPER and TOTAL SSY models, to determine if the percentage sediment contribution from human-disturbed areas changed with storm size. The model slopes were only significantly different ($p<0.05$) for the Psum-SSY_{EV} model, but all model intercepts were significantly different ($p<0.05$). It was hypothesized that for large storms, SSY_{EV} from the UPPER watershed may become ~~the dominant source of~~ a relatively more important ~~source~~ for total SSY to Faga'alu Bay, however, the models show conflicting results. The Psum-SSY_{EV} models indicate that for larger storm events ~~the~~ SSY ~~contributions~~ from the UPPER and TOTAL watersheds are more similar, as the regression lines converge at higher Psum values. Conversely, the Qsum- and Qmax-SSY_{EV} models show no change in relative contributions of SSY over the range of storm sizes (Figure 10). In that case, the discharge models (Qsum and Qmax) support the conclusion that human disturbance does not diminish with storm size, while the Psum model supports the conclusion that human-disturbance does diminsh with storm size. Hmm why? ~~Large P~~ Make plot of P vs. Qmax.

But you're not directly testing for this %. Can you plot % Lower vs. event size? The slopes just tell if the increase in SSY for a given change in Qmax is similar for LOWER UPPER

Annual estimates of SSY and sSSY

~~To compare with SSY from other watersheds, annual SSY was estimated by two approaches: 1) using Q data from 2014 and the developed Qmax-SSY_{EV} relationship to predict SSY (2014 was the only year with continuous Q available), and 2) using total~~

Already in methods

Slopes comparison still valuable.

~~Tot~~ Title says 0.45-22km^2 37

Duvert et al. (2012) compiled Qmax-SSY results from twenty-eight watersheds (0.45-1,538km^2) and found β coefficients (slope in the log-log plots) that ranged from 1.06-2.45, and α coefficients (intercepts in the log-log plots) that ranged from 25-5,039. The α coefficients for the Qmax-SSY$_{EV}$ models in Faga'alu were 0.353 and 1.380, and β coefficients were 1.44 and 1.81 in the UPPER and TOTAL Faga'alu watersheds, respectively. The β coefficient values are very consistent with the watersheds presented in Duvert 2012, but the α coefficient for the undisturbed subwatershed is an order of magnitude lower than the lowest values in Duvert (2012). This suggests that sediment availability is relatively low in Faga'alu, likely due to the dense forest cover over the majority of the watershed. Duvert site included disturbed badlands — more discussion here Rankl's values?

in humid (France) and semi-arid (Spain) watersheds

Duvert Abstract says 0.9-1.9

Present in same order as previous sentence.

Wow — 4 orders of magnitude! Check units in Duvert -- did he do exp α? (yes)

$e^{0.353} = 1.42$

$e^{1.38} = 3.97$

In Faga'alu, SSY was least correlated with the Erosivity Index (EI30). Duvert et al. (2012) also found low correlation coefficients with 5 min rainfall intensity for 8 watersheds in France and Mexico. Rodrigues et al. (2013) hypothesized that EI30 is poorly correlated with SSY due to the effect of previous events on antecedent moisture conditions and in-channel sediment storage. Cox (2006) found EI30 was more correlated with soil loss in an agricultural catchment than a forested watershed, and Faga'alu is mainly covered in dense forest. Similar to other studies (Hicks et al., 1990; Fahey et al., 2003; Rankl, 2004; Basher et al., 2011; Duvert et al., 2012; Rodrigues et al., 2013) the highest correlations with SSY were observed for discharge metrics, particularly Qmax which had the highest overall correlation ~~with a Spearman correlation coefficient of 0.94 for the UPPER subwatershed and 0.89 for the TOTAL watershed~~.

SSC in Duvert watersheds were several times higher than observed in Faga'alu (mean 450 mg/L) (40 mg/L FG1, 100 mg/L - 200 mg/L FG3).

Comparing sSSY and SSC in other small Pacific Island watersheds

Sediment yield is generally controlled by climate and geology, with human disturbance playing an increasing role in the 20th century (Syvitiski et al, 2005). Sediment yields in tropical Southeast Asia range from ~10 tons/km^2/yr in the granitic Malaysian Peninsula to ~10,000 tons/km^2/yr in the tectonically active, steeply sloped island of Papua New Guinea (Douglas 1996). Data in Milliman and Syvitski (1992) suggests there is unusually high average sSSY for watersheds (10-100,000 km^2) on high-standing, South Pacific Islands on the order of 1,000-3,000 tons/km^2/year, however, they acknowledge the roles of sediment erodibility, geology, vegetation cover, and human activity~~, for controlling sSSY in individual watersheds~~. Sediment yields from Faga'alu are

Why focus there? Similar rainfall?

? their term?

Next parag says 13 tons/km^2/yr

Section needs reorganization.

But high compared to 13 tons/km²/yr in next parag.

Create a table with this data

relatively low compared to these larger watersheds, with sSSY of 33-80 tons/km^2/yr from the undisturbed watershed, and 170-380 tons/km^2/yr from the total disturbed watershed.

Check, see comment on Table 7

Milliman and Syvitski~~'s~~ (1992) ~~models to~~ estimate sSSY from basin area and maximum elevation, and in Oceania predict 13 tons/km^2/year from watersheds with peak elevation 500-1,000 m (highest point of UPPER Faga'alu subwatershed is 653 m), but 68 tons/km^2/year for max elevations of 1,000-3,000 m. Given the high vegetation cover and lack of human activity in the UPPER Faga'alu subwatershed, it is assumed that specific SSY should be several orders of magnitude lower than watersheds presented in Milliman and Syvitski (1992) but sSSY from the forested UPPER Faga'alu subwatershed was several times higher. (2.5x - not alot) ~~However,~~ the UPPER subwatershed is also a smaller watershed than they included in their analysis, and high scatter above their model is observed for smaller watersheds in their Figures 5e and 6e. and likely has less sediment storage...? (Range...)

But last paragraph says 1000-3000

Were their watershed disturbed? They should also have high veg cover, no?

In Hanalei watershed on Kauai (54 km^2), which has similarly steep relief and high rainfall (varies from 2,000-11,000 mm with elevation), Calhoun and Fletcher (1999) and Stock and Tribble (2010) estimated sSSY was 140 ±55 tons/km^2/year and 525 tons/km^2/yr, respectively. In Kawela watershed on Molokai (14 km^2), a similarly disturbed, sub-humid watershed (precipitation varies with elevation from 500-3,000 mm), Stock and Tribble (2010) estimated sSSY was 459 tons/km^2/yr. In comparison, the sSSY from the forested Faga'alu subwatershed is an order of magnitude lower, but sSSY from the human-disturbed subwatershed is similar to these larger watersheds. Which larger? Size? Hanalei and Kawela? In Hanalei, ~~Kauai,~~ Stock and Tribble (2009) found average SSC was 63 mg/L, with a maximum value of 2,750 mg/l ~~(at an instantaneous flow of 399 m^3/sec)~~. In Kawela, ~~on Molokai,~~ they found average SSC was 3,490 mg/L, with a maximum value of 54,000 mg/L (at an instantaneous flow of 1.614 m^3/sec) ~~on Molokai~~. — How compares w/ Faga'alu?

Has a quarry? Specify land use.

Annual? 2461 ~~sSSY from the disturbed fraction of the LOWER_QUARRY subwatershed was 2,460.6 tons/km^2 (Table 4).~~ for the measured storms Annual sSSY from the disturbed quarry was estimated to be ~~roughly 4 times the measured storms,~~ approximately 9,800 tons/km^2/year. The quarry surfaces are comprised of haul roads, piles of overburden, and steep rock faces which can be described as a mix of unpaved roads and cut-slopes. Literature values show measured sSSY from cutslopes varying from 0.01 tons/km^2/yr in Idaho (Reid, 1981) to 105,000

Location	Rainfall	Land use	~~Sediment~~ Wshed size (km²)	Rock type	Sed yield	Ref
eg. Hanalei, Molokai, Hawaii	~~200~~ 2-11m	?	54	?	140±55, 525	Calhoun, Stock

tons/km^2/yr in Papua New Guinea (Blong and Humphreys 1982), so the sSSY ranges measured in this study are well within the ranges found in the literature.

Comparison with other kinds of sediment disturbance

Other studies in small, mountainous watersheds have documented one to several order of magnitude increases in SSY from small land use disturbances. Urbanization and mining increase sediment yield in stable terrain by two to three orders of magnitudes in catchments of several km^2 but yields from construction sites can exceed those from the most unstable, tectonically active natural envrionments ~~of SE Asia~~ Southeast Asia (Douglas 1996). In Kawela watershed on Molokai, Stock et al. (2010) found that less than 5% of the land produces most of the sediment, and only 1% produces ~50% of the sediment (Risk, 2014). In three basins on St.John USVI with varying levels of development, Ramos-Scharron et al (2005) found unpaved roads increased sediment delivery rates ~~by 3-6 times for Lameshur Bay, 5-9 times for Fish Bay, and 4-8 times for Cinnamon Bay~~ 3-9 times. Disturbances at larger scales have had similar increases in total SSY to coral environments. The development of the Great Barrier Reef (GBR) catchment since European settlement (ca.1830) led to increases in SSY by an estimated factor of 5.5 (Kroon et al.,2012). Mining activity has been a major contributor of sediment in other watersheds on volcanic islands with steep topography and high rainfall (Hettler et al., 1997, Thomas et al., 2003). In contrast to other land disturbances like fire, logging, or urbanization where sediment disturbance decreases over time, the disturbance from mining is persistently high. Disturbance magnitudes are similar to the construction phase of urbanization (Wolman year), or high-traffic unpaved roads (Reid and Dunne, 1984), but persist or even increase over time.

Conclusion

Human disturbance has increased sediment yield to Faga'alu Bay by 3.6x over pre-disturbance levels. The human-disturbed subwatershed accounted for the majority (86%) of total sediment yield, and the quarry (xx% of watershed area) ~~was shown to be the most significant sediment source in the watershed,~~ contributed almost half of total SSY to the Bay. The relative contribution from the human-disturbed watershed was hypothesized to diminish with increasing storm size but the results from precipitation metrics and discharge metrics

Move to after "Qmax" paragraph see next page.

were contradictory. The Psum-SSY_{EV} model showed that the relative contribution of SSY_{EV} from the human-disturbed watershed decreases with storm size, but the Qmax-SSY_{EV} model shows no change in relative contributions over increasing storm size.

Qmax was the best predictor of SSY_{EV}. The slopes of the Qmax-SSY_{EV} relationships were comparable with other studies, but the α coefficients were an order of magnitude lower than ~~other~~ semi-arid to semi-humid watersheds in the literature. This suggests that sediment availability is relatively low in the Faga'alu watershed, either because of the heavy forest cover, or volcanic rock type.

Management has responded to data on sediment loading in Faga'alu. In August 2012, preliminary results of the significant SSY_{EV} contributions from the quarry and its impact on coral reef health in the Bay were communicated to US Federal and local environmental management and conservation groups including the Faga'alu village community, NOAA Coral Reef Conservation Program, American Samoa Environmental Protection Agency, and the American Samoa Coral Reef Advisory Group. In February 2013, Faga'alu watershed was designated by the US Coral Reef Task Force as a Priority Watershed Restoration site, with the main objective to reduce sediment yields to the adjacent coral reefs. These groups developed a sediment management plan for the quarry operators and village residents. The sediment runoff management plan for the quarry was implemented in October 1, 2014, and completed in December 2014. Storm monitoring is currently in progress and results documenting the successful reduction of sediment yields to the Bay will be presented in a forthcoming paper. This work provides an example of a ~~successful~~ environmental management project which could only be accomplished by the effective partnerships between community groups, local industries, educational institutions, and government regulatory and funding agencies.

Don't have data yet!

Acknowledgements

? But also through territorial grant, right?

Funding for this project was provided by NOAA Coral Reef Conservation Program (CRCP) through the American Samoa Coral Reef Advisory Group (CRAG). ~~We would like to acknowledge~~ Kristine Bucchianeri at CRAG and Susie Holst at NOAA CRCP ~~for~~ provid~~ing~~ed funding and support ~~for this project. We would like to thank~~ Christianera Tuitele, ~~and~~ Tim Bodell at American Samoa Environmental Protection Agency (ASEPA), and Phil Wiles (currently at Secretariat of the Pacific Regional Environment Programme) and Fatima Sauafea-Leau and Hideyo Hattori at NOAA, ~~for their~~ provided support and advice. ~~We~~

Journals usually request brief acknowlegemnts.

~~would also like to thank~~ Dr. Mike Favazza ~~for~~ provid~~ing~~ed critical logistical assistance in American Samoa, and Robert Koch at the American Samoa Coastal Zone Management Program (ASCMP) and Travis Bock at ASEPA ~~for their~~ assista~~nce~~ed in accessing geospatial and water quality data. ~~We would like to thank all those who~~ Many others helped and supported field and laboratory work including Professor Jameson Newtson, Rocco Tinitali, and Valentine Vaeoso at American Samoa Community College (ASCC), Meagan Curtis and Domingo Ochavillo at American Samoa Department of Marine and Wildlife Resources (DMWR), Don and Agnes Vargo at American Samoa Land Grant, Christina Hammock at NOAA American Samoa Climate Observatory, and Greg McCormick at San Diego State University. ~~We would also like to acknowledge~~ George Poysky, Sr., George Poysky III, and Mitch Shimasaki at Samoa Maritime Ltd. ~~for~~ provid~~ing~~ed unrestricted access to the Faga'alu quarry site, and historical operation information. Faafetai tele lava.

APPENDIX 1. Channel cross sections

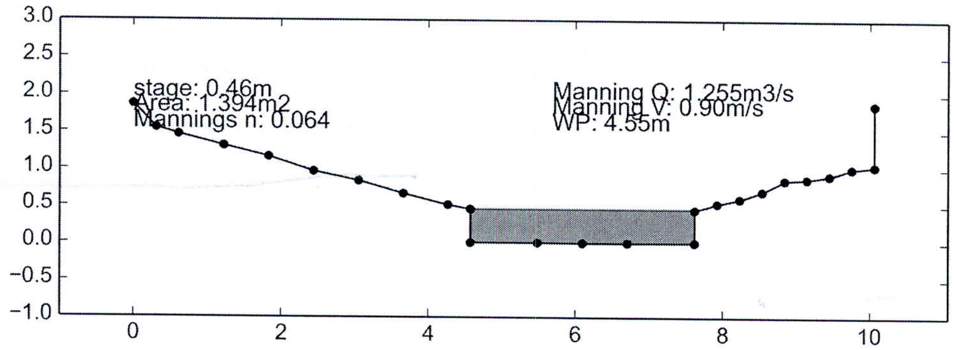


Figure 1. Stream cross-section at FG1

A1.1

Appendix

Fig #

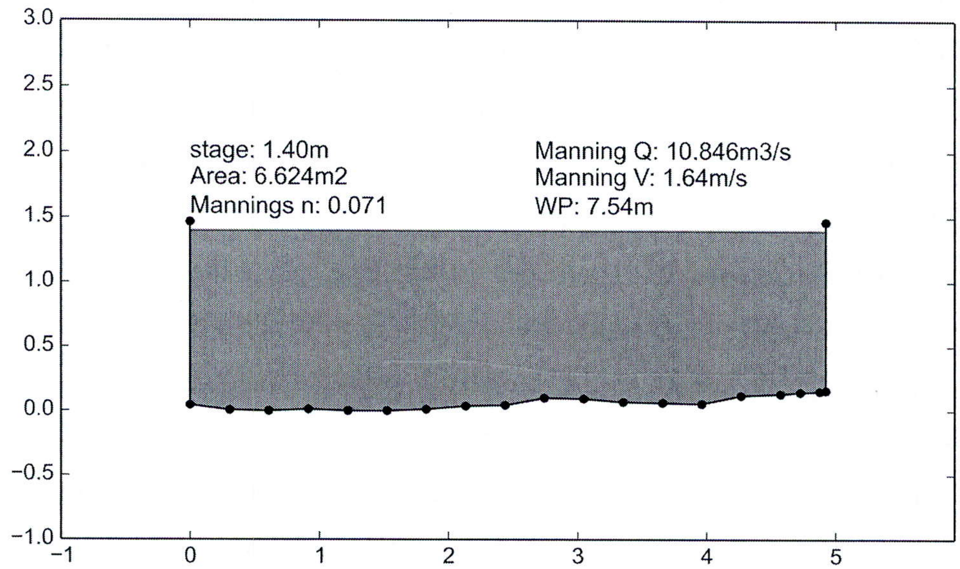


Figure 2. Stream cross-section at FG3

A1.2 etc.

APPENDIX 2. Dams in Faga'alu watershed

Faga'alu stream was dammed at 4 locations above the village: 1) Matafao Dam (elevation 244 m) near the base of Mt. Matafao, draining 0.20 km^2, 2) Vaitanoa Dam at Virgin Falls (elevation 140 m), draining an additional 0.44 km^2, 3) a small unnamed dam below Vaitanoa Dam at elevation 100m, and 4) Lower Faga'alu Dam (elevation 48 m), immediately upstream of a large waterfall 30 m upstream of the quarry, draining an additional 0.26 km^2 (Tonkin & Taylor International Ltd. 1989). A 2012 aerial LiDAR survey (Photo Science, Inc.) indicates the drainage area at the Lower Faga'alu Dam is 0.90 km^2. A small stream capture/reservoir (~35 m^3) is also present on a side tributary that joins Faga'alu stream on the south bank, opposite the quarry. It is connected to a ~6 cm diameter pipe but it is unknown when or by whom it was built, its initial capacity, or if it is still conveying water. During all site visits water was overtopping this small structure through the spillway crest, suggesting it is fed by a perennial stream.

Matafao Dam was constructed in 1917 for water supply to the Pago Pago Navy base, impounding a reservoir with initial capacity of 1.7 million gallons (6,400 m^3) and piping the flow out of the watershed to a hydropower and water filtration plant in Fagatogo. In the early 1940's the Navy replaced the original cement tube pipeline and hydropower house with cast iron pipe but it is unknown when the scheme fell out of use (Tonkin & Taylor International Ltd. 1989; URS Company 1978). Remote sensing and a site visit on 6/21/13 confirmed the reservoir is still filling to the spillway crest with water and routing some flow to the Fagatogo site, though the amount is much less than the 10 in. diameter pipes conveyance capacity and the flow rate variability is unknown. A previous site visit on 2/21/13 by American Samoa Power Authority (ASPA) found the reservoir empty of water but filled with an estimated 3-5 meters of fine sediment (Kearns 2013). Interviews with local maintenance staff and historical photos confirmed the Matafao Reservoir was actively maintained and cleaned of sediment until the early 70's.

The Vaitanoa (Virgin Falls) Dam, was built in 1964 to provide drinking water but the pipe was not completed as of 10/19/89, and a stockpile of some 40 (8 ft length) 8 in. diameter asbestos-cement pipes was found on the streambanks. Local quarry staff recall the pipes were removed from the site some time in the 1990's. The Vaitanoa Reservoir had a design volume of 4.5 million gallons (17,000m^3), but is assumed to be full of sediment since the drainage valves were never opened and the reservoir was overtopping the spillway as of 10/18/89 (Tonkin & Taylor International Ltd. 1989). A low masonry weir was also constructed downstream of the Vaitanoa Dam, but not connected to any piping.

The Lower Faga'alu Dam was constructed in 1966/67 just above the Samoa Maritime, Ltd. Quarry, as a source of water for the LBJ Medical Centre. It is unknown when this dam went out of use but in 1989 the 8 in. conveyance pipe was badly leaking and presumed out of service. The 8 in. pipe disappears below the floor of the Samoa Maritime quarry and it is unknown if it is still conveying water or has plugged with sediment. The derelict filtration plant at the entrance to the quarry was disconnected prior to 1989 (Tonkin & Taylor International Ltd. 1989). The original capacity was 0.03 million gallons (114 m^3) but is now full of coarse sediment up to the spillway crest. No reports were found indicating this structure was ever emptied of sediment.

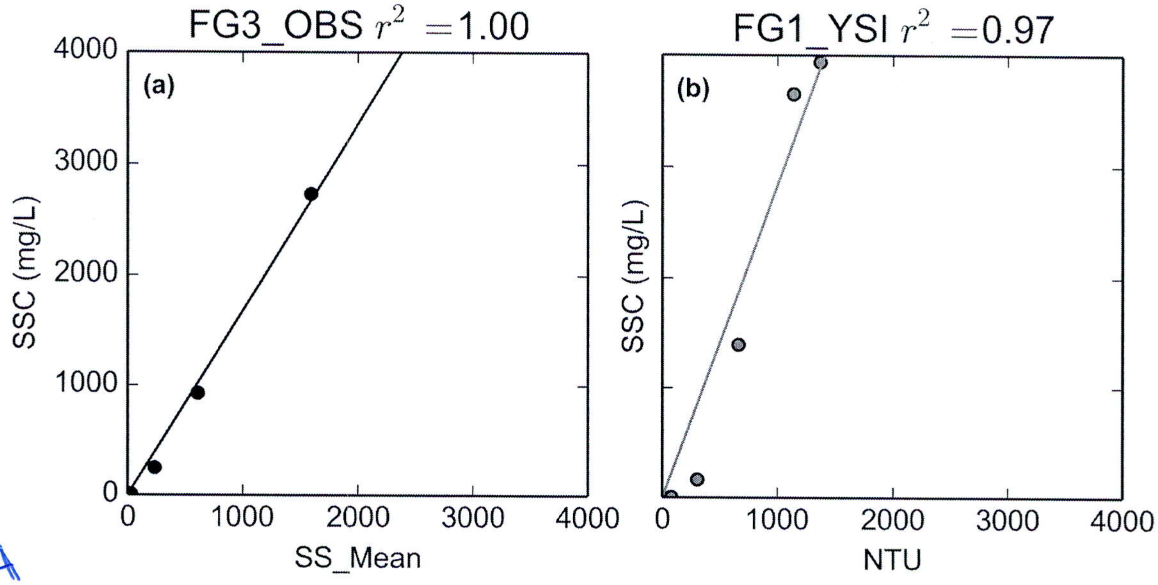
APPENDIX 3. Water discharge during storm events

Insert Table 1 here

~~Table1~~ A. Water discharge from subwatersheds in Faga'alu

Table A3.1

APPENDIX 4. Synthetic rating curves for turbidimeters in Faga'alu



A

Figure 3. Synthetic Rating Curves for (a) OBS turbidimeter deployed at FG3 and (b) YSI deployed at FG1.

Can't get this as 392 − 29?

Represents what?

Storm precip?

Table 7. Annual SSY estimates (tons)

	SSY Qmax (2014)	SSY Table 2	SSY Table 4	SSY ALL
Precip(mm)	2279	1123 (49%)	537 (24%)	2780 (122%)
UPPER	29	40	70	44
LOWER	-	390	310	- =341 − 44?
LOWER_QUARRY	-	-	190	-
LOWER_VILLAGE	-	-	120	-
TOTAL	392	450	380	341

Annual sSSY estimates tons/km²

	sSSY Qmax (2014)	sSSY Table 2	sSSY Table 4	sSSY ALL
~~Precip(mm)~~	~~2279~~	~~1123 (49%)~~	~~537 (24%)~~	~~2780 (122%)~~
UPPER	33	50	80	49
LOWER	- =(392−29)/A	300	350	- =(341−44)/A?
LOWER_QUARRY	-	-	710	-
LOWER_VILLAGE	-	-	190	-
TOTAL	220	170	210	191

Corresponds to a table?

Include footnotes for each column here.
Eg. SSY Qmax (2014)[a]

a - Annual SSY estimates from Qmax − SSY regression and Qmax series from 2014

b.

~~There are~~ 2 Table 1's.

Is this table mentioned?

OK Table A3.1

Table 1. Water discharge from subwatersheds in Faga'alu

Storm Start	Storm#	Precip (mm)	UPPER m3	LOWER m3	TOTAL m3	% Upper	% Lower
02/02/2012	1	16	8277	13002	21279	38	61
02/03/2012	2	24	14229	20385	34614	41	58
02/05/2012	3	19	7983	11793	19776	40	59
02/05/2012	4	83	48860	65642	114502	42	57
02/23/2012	5	17	8088	9804	17892	45	54
03/08/2012	6	23	3552	2884	6436	55	44
03/09/2012	7	18	8870	7174	16044	55	44
03/16/2012	8	22	4247	5607	9854	43	56
03/17/2012	9	30	4536	6319	10855	41	58
03/21/2012	10	14	5833	6334	12167	47	52
03/22/2012	11	35	10405	14119	24524	42	57
03/25/2012	12	49	25404	24618	50022	50	49
05/02/2012	13	30	762	2633	3395	22	77
05/08/2012	14	25	2966	3046	6012	49	50
05/22/2012	15	33	12357	10607	22964	53	46
05/23/2012	16	88	103982	18346	122328	85	14
05/24/2012	17	34	40234	18628	58862	68	31

Where is Table with annual total
- Precip
- Q storm (m³ and mm)
- Q total (m³ and mm)
- ~~%~~ Upper + Lower?

See AGU poster.

Add Q in mm.

ERROR

How possible that "SSY Table 3" is highest of all (450) but sSSY is lowest of all (170)? Shouldn't they all have same order?

Table 4. cont.

OK.
Where is 3.6x from abstract?

06/05/2013	5	170	4.69	30.6	4.13	39.42	11.0	77.0	10.0
02/14/2014	6	18	0.22	0.98	0.56	1.76	12.0	55.0	31.0
02/20/2014	7	29	0.12	1.14	2.5	3.76	3.0	30.0	66.0
02/21/2014	8	51	1.84	3.91	3.81	9.56	19.0	40.0	39.0
Total/Avg:	8	537	17	48	29	94	19	51	30
Tons/km2			19	178	47	53	-	-	-
DR			1.0	9.17	2.4	2.7	-	-	-

~~do~~ annual? Total Table 4?

Table 5. Sediment yield from disturbed portions of subwatersheds in Faga'alu

	UPPER	LOWER_QUARRY	LOWER_VILLAGE	TOTAL
fraction disturbed (%)	0.4	6.5	11.7	5.2
SSY from forested areas (tons)	17.4	4.9	10.5	32.8
SSY from disturbed areas (tons)	0.1	43.18	18.2	61.5
% SSY from disturbed areas	0.4	90	64	65
sSSY from disturbed areas (tons/km2)	19.4	2460.6	255.3	664.2
DR for sSSY from disturbed areas		126.6	13.1	34.2

Total SSY

Pearson + Spear ~~and~~ aren't goodness of fit stats.

Table 6. Goodness-of-fit statistics for SSYEV-storm metric relationships.

Model	Pearson	Spearman	r2	RMSE(tons)	alpha	Beta
Psum_upper	0.80	0.80	0.64	2.85	0.000	1.95
Psum_total	0.83	0.86	0.69	2.36	0.041	1.26
EI_upper	0.37	0.35	0.14	5.40	0.002	0.82
EI_total	0.72	0.58	0.51	3.41	0.002	1.32
Qsum_upper	0.89	0.89	0.79	2.26	0.000	1.17
Qsum_total	0.83	0.82	0.69	2.64	0.000	1.13
Qmax_upper	0.89	0.94	0.79	2.25	0.353	1.44
Qmax_total	0.89	0.89	0.79	2.22	1.380	1.81

Lower tons / Total

Upper PE

06/05/2013	19	170	4.69	28	34.73	39.42	int. grab	36	11.0	88.0
06/16/2013	20	28	0.13	38	0.42	0.55	T-OBS	39	23.0	76.0
02/14/2014	21	18	0.22	38	1.54	1.76	T-OBS	52	12.0	87.0
02/15/2014	22	11	0.02	38	0.5	0.52	T-OBS	52	3.0	96.0
02/18/2014	23	11	0.0	38	0.09	0.09	T-OBS	52	1.0	98.0
02/20/2014	24	29	0.12	38	3.65	3.76	T-OBS	52	3.0	96.0
02/21/2014	25	51	1.84	38	7.71	9.56	T-OBS	52	19.0	80.0
02/24/2014	26	20	0.06	38	0.44	0.5	T-OBS	52	12.0	87.0
02/25/2014	27	60	0.53	38	6.96	7.49	T-OBS	52	7.0	92.0
02/27/2014	28	35	0.24	38	1.94	2.17	T-OBS	52	10.0	89.0
Total/Avg:	28	1123	21.1	33	130.4	151.4		60	14	86
Tons/km2			23.5		148.1	85.1			-	-
DR			1		6.3	3.6			-	-

Abstract says 80%

Suspended (ssy) → but not just disturbed - also UPPER - annual? During storms in Table 2?

Table 3. Sediment yield from disturbed portions of subwatersheds in Faga'alu

	UPPER	LOWER	TOTAL
fraction disturbed (%)	0.4	10.1	5.2
SSY from forested areas (tons)	21.0	18.6	39.6
SSY from disturbed areas (tons)	0.1	111.8	111.8
% SSY from disturbed areas	0.4	86	74
sSSY from disturbed areas (tons/km2)	23.5	1,257.7	12,08.1
DR for sSSY from disturbed areas	-	54	51

Total ssy (add row for Total ssy)

? → $\frac{111.8}{(111.8+39.6)}$

Comma

More detail in caption. "... for events with ~~samples~~ ssc data at all 3 sampling locations. ~~Excludes~~ All events also included in Table 2!!

Table 4. Sediment yield from subwatersheds in Faga'alu

Storm Start	Storm#	Precip (mm)	UPPER tons	LOWER_QUARRY tons	LOWER_VILLAGE tons	TOTAL tons	% UPPER	% LOWER_QUARRY	% LOWER_VILLAGE
03/06/2013	1	21	0.06	0.23	0.61	0.9	6.0	25.0	67.0
04/16/2013	2	53	0.53	3.49 ok	0.39 ok.	4.41	12.0	79.0	8.0
04/23/2013	3	83	9.55	7.06	9.8	26.41	36.0	26.0	37.0
04/30/2013	4	112	0.48	0.68	6.89	8.05	5.0	8.0	85.0

~~Why not also in Table 2~~? OK

There is repetition of storms and data. ~~Re~~

Could make table more compact.

0.27 + 0.60 = 0.88? Rounding?

Grass or ag? Possible to separate?

92.1 + 0.9 = 93.5?? Should add up. oh, grass?

Table 1. Land use categories in Faga'alu subwatersheds (NOAA Ocean Service and Coastal Services Center, 2010)

Subwatershed (pourpoint)	Cumulative Area km2	Cumulative %	Area km2	% of area	% Bare Land	% High Intensity Developed	% Developed Open Space	% Grassland (agriculture)	% Forest	% Scrub/ Shrub	% Disturbed	% Undisturbed
UPPER (FG1)	0.9 (48%)	48.2	0.90	48.0	0.4	0.0	0.0	0.1	82.4	17.1	0.4	99.6
LOWER_QUARRY (FG2)	1.17 (63%)	63.0	0.27	14.5	5.7	0.7	0.1	0.5	92.1	0.9	6.5	93.5
LOWER_VILLAGE (FG3)	1.78	95.5	0.60	32.5	0.0	9.0	2.6	0.2	87.6	0.6	11.7	88.3
LOWER (FG3)	1.78	95.5	0.88	47.3	1.8	6.4	1.8	0.3	89.0	0.7	10.1	89.9
TOTAL (FG3)	1.78	95.5	1.78	95.7	1.1	3.2	0.9	0.2	85.7	9.0	5.2	94.8
Fagaalu Stream	1.86	100.0	0.08	4.5	1.0	4.6	1.1	0.2	84.5	8.6	6.8	93.2

~~upper + lower~~ UPPER and LOWER

Same as title for Table 4. What's the difference?

Table 2. Sediment yield from subwatersheds in Faga'alu

Storm Start	Storm# Event?	Precip (mm)	UPPER tons	UPPER PE %	LOWER tons	TOTAL tons	SSY data source	TOTAL PE %	% SSY UPPER from	% SSY LOWER from	Q (mm) UPPER	~~Lower~~ Total
02/02/2012	1	16	0.05	31	0.82	0.87	T-YSI	75	5.0	94.0		
02/03/2012	2	24	0.08	31	1.82	1.90	T-YSI	75	4.0	95.0		
02/05/2012	3	19	0.05	31	0.76	0.81	T-YSI	75	6.0	93.0		
02/05/2012	4	83	0.44	31	6.54	6.98	T-YSI	75	6.0	93.0		
03/08/2012	5	23	0.06	31	2.28	2.34	T-YSI	75	2.0	97.0		
03/09/2012	6	18	0.17	31	2.0	2.16	T-YSI	75	7.0	92.0		
03/16/2012	7	22	0.05	31	1.2	1.25	T-YSI	75	3.0	96.0		
03/17/2012	8	30	0.07	31	2.37	2.44	T-YSI	75	2.0	97.0		
03/21/2012	9	14	0.14	31	1.01	1.15	T-YSI	75	12.0	87.0		
03/22/2012	10	35	0.33	31	4.35	4.67	T-YSI	75	7.0	92.0		
03/25/2012	11	49	0.63	31	7.66	8.29	T-YSI	75	7.0	92.0		
05/02/2012	12	30	0.02	31	3.45	3.46	T-YSI	75	0.0	99.0		
05/08/2012	13	25	0.1	31	2.84	2.94	T-YSI	75	3.0	96.0		
05/22/2012	14	33	0.47	31	6.12	6.59	T-YSI	75	7.0	92.0		
03/06/2013	15	21	0.06	28	0.85	0.9	int. grab	36	6.0	93.0		
04/16/2013	16	53	0.53	28	3.88 OK	4.41	int. grab	36	12.0	87.0		
04/23/2013	17	83	9.55	28	16.86	26.41	int. grab	36	36.0	63.0		
04/30/2013	18	112	0.48	28	7.57	8.05	int. grab	36	5.0	94.0		

Differs by site -- include source for upper too.

Event-mean SSC Upper	~~Total~~

05/26/2012	18	40	32284	21696	53980	59	40
06/03/2012	19	19	12091	7830	19921	60	39
06/04/2012	20	49	32590	11482	44072	73	26
06/04/2012	21	52	48663	39327	87990	55	44
06/06/2012	22	12	7995	5111	13106	61	38
06/07/2012	23	10	9456	6328	15784	59	40
07/08/2012	24	33	3863	3470	7333	52	47
07/27/2012	25	28	1607	2548	4155	38	61
07/27/2012	26	2	1391	1201	2592	53	46
08/09/2012	27	36	14363	6557	20920	68	31
03/05/2013	28	33	3658	12948	16606	22	77
03/06/2013	29	21	7731	20126	27857	27	72
03/07/2013	30	34	23148	59587	82735	27	72
03/11/2013	31	43	17176	35679	52855	32	67
03/21/2013	32	15	1074	2654	3728	28	71
03/23/2013	33	1	540	4236	4776	11	88
04/16/2013	34	53	9476	25403	34879	27	72
04/17/2013	35	42	15630	38115	53745	29	70
04/20/2013	36	27	3867	18748	22615	17	82
04/23/2013	37	83	59162	28128	87290	67	32
04/30/2013	38	112	79137	35623	114760	68	31
05/11/2013	39	0	959	1840	2799	34	65
06/05/2013	40	170	134031	20593	154624	86	13
06/16/2013	41	28	7519	5181	12700	59	40
07/17/2013	42	11	1334	1274	2608	51	48
07/17/2013	43	25	10739	20923	31662	33	66
07/19/2013	44	51	23106	54199	77305	29	70
08/05/2013	45	14	4923	5259	10182	48	51
08/10/2013	46	73	21896	57456	79352	27	72
08/15/2013	47	27	2719	5881	8600	31	68
08/16/2013	48	192	110915	126802	237717	46	53
08/19/2013	49	36	13122	24668	37790	34	65
09/01/2013	50	40	6501	10338	16839	38	61
02/14/2014	51	18	8061	7584	15645	51	48
02/15/2014	52	11	1521	1807	3328	45	54
02/18/2014	53	11	487	1945	2432	20	79
02/20/2014	54	29	4466	16654	21120	21	78
02/21/2014	55	51	18868	38930	57798	32	67
02/22/2014	56	0	1242	1650	2892	42	57

02/24/2014	57	20	1298	1822	3120	41	58
02/25/2014	58	60	21531	50910	72441	29	70
02/27/2014	59	35	21133	25064	46197	45	54
03/06/2014	60	43	14636	20282	34918	41	58
03/13/2014	61	14	3095	4164	7259	42	57
03/13/2014	62	20	6021	7580	13601	44	55
03/14/2014	63	16	12159	17707	29866	40	59
03/14/2014	64	11	1088	2170	3258	33	66
04/01/2014	65	32	640	4595	5235	12	87
04/06/2014	66	54	15600	30873	46473	33	66
04/08/2014	67	19	2851	6040	8891	32	67
04/09/2014	68	10	2761	5445	8206	33	66
04/11/2014	69	6	998	2299	3297	30	69
04/17/2014	70	9	802	1958	2760	29	70
04/18/2014	71	17	4262	9356	13618	31	68
04/19/2014	72	36	15826	47596	63422	24	75
04/25/2014	73	20	6642	11828	18470	35	64
04/26/2014	74	0	1186	1530	2716	43	56
04/27/2014	75	23	6216	15953	22169	28	71
04/28/2014	76	16	2095	6699	8794	23	76
04/28/2014	77	41	11787	43250	55037	21	78
04/30/2014	78	34	20007	41709	61716	32	67
05/19/2014	79	25	3356	6627	9983	33	66
05/20/2014	80	13	2918	6750	9668	30	69
05/22/2014	81	62	9900	35741	45641	21	78
05/23/2014	82	4	1551	5268	6819	22	77
05/23/2014	83	4	2162	6659	8821	24	75
05/24/2014	84	2	604	1959	2563	23	76
05/29/2014	85	3	1368	3247	4615	29	70
06/05/2014	86	76	17013	47985	64998	26	73
06/17/2014	87	16	5837	15001	20838	28	71
07/03/2014	88	59	8095	23353	31448	25	74
07/05/2014	89	36	13729	29176	42905	31	68
07/06/2014	90	17	1807	6255	8062	22	77
07/29/2014	91	568	323584	341941	665525	48	51
10/15/2014	92	17	2716	5576	8292	32	67
10/15/2014	93	17	5877	11503	17380	33	66
11/02/2014	94	16	3922	7106	11028	35	64
11/03/2014	95	43	25518	10960	36478	69	30

11/12/2014	96	1	977	3040	4017	24	75
11/12/2014	97	13	3182	10209	13391	23	76
11/16/2014	98	27	10840	21016	31856	34	65
11/18/2014	99	5	3324	8890	12214	27	72
11/19/2014	100	3	2241	6845	9086	24	75
11/22/2014	101	78	48962	24578	73540	66	33
11/24/2014	102	20	6570	7245	13815	47	52
12/04/2014	103	65	15835	42695	58530	27	72
12/09/2014	104	34	34531	9412	43943	78	21
12/19/2014	105	62	33251	26884	60135	55	44
12/21/2014	106	143	90980	104181	195161	46	53
-	-	-	-	-	Average:	0	0