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

INTRODUCTION

Anthropogenic watershed disturbance on steep, tropical islands, by industry, agriculture, deforestation, roads, and urbanization alters the timing, composition, and mass of sediment loads to coral reefs, causing enhanced sediment stress on corals near the outlets of impacted watersheds (Syvitski et al., 2005; West and van Woesik, 2001). Anthropogenic sediment disturbance may be exacerbated on tropical islands characterized by high rainfall, extreme weather events, steep slopes, erodible soils, and naturally dense vegetation, where land clearing alters the fraction of exposed soil much more than in regions with sparse vegetation. On Molokai, Stock et al. (2010) found that less than 5% of the land produces most of the sediment, and of that 5%, only 1% produces ~50% of the sediment, concluding that management should focus on mediating erosion hotspots (Risk, 2014). Successful reduction of sediment impacts to coral reefs requires identifying and quantifying key sources of terrigenous sediment to focus management efforts in the watershed and design mitigation measures. However, knowledge of fluvial SSY on most Pacific volcanic islands remains limited due to difficulties associated with in situ monitoring, however existing sediment yield models are not well-calibrated to the climatic, topographic, and geologic conditions found on steep, tropical islands (Calhoun and Fletcher, 1999). Developing reliable models that predict SSY from small, mountainous catchments is a significant contribution for local coral conservation, and can also further improve models applied at the regional scale (Duvert et al., 2012).

SSY generated by individual storm events (SSYEV) may correlate with various precipitation and discharge variables (“storm metrics”), including total precipitation, the Erosivity Index, total discharge, or maximum event discharge (Qmax), but the best correlation has consistently been found with Qmax. Qmax integrates the whole hydrological response of a watershed, making it a good predictor variable of SSYEV in diverse environments (Duvert et al., 2012; Rankl, 2004). High correlation between SSYEV and Qmax has been found in semi-arid, temperate, and sub-humid watersheds in Wyoming (Rankl, 2004), Mexico, Italy, France (Duvert et al., 2012), and New Zealand (Basher et al., 2011; Hicks, 1990), but this approach has not been attempted for steep, tropical watersheds on volcanic islands.

The anthropogenic impact on SSY may vary by storm magnitude, as documented in Mediterranean climates (White and Greer, 2006) and in Pacific Northwest forests (Lewis et al., 2001). As storm magnitude increases, water and/or SSY from natural areas may increase relative to human-disturbed areas, diminishing anthropogenic impact. While large storms account for most SSY in natural conditions, human-disturbed areas may show the most significant disturbance for smaller storms (Lewis et al., 2001). It is hypothesized that the disturbance ratio (DR) is highest for small storms, when background SSY from the undisturbed forest is low and erodible sediment from disturbed surfaces in the lower watershed is the dominant source. For large storms, it is hypothesized mass movements and bank erosion contribute to naturally high SSY from the undisturbed upper watershed, reducing the DR for large events.

This questions addressed include: How has human disturbance increased sediment loading to Faga’alu Bay? How do sediment contributions from human-disturbed areas and undisturbed areas vary with storm size? And Which is the best predictor of storm event suspended sediment yield (SSYEV): total precipitation, Erosivity Index, total discharge, or maximum event discharge?

STUDY AREA

The two study watersheds, Faga’alu (1.86 km2) and Nu’uuli (2.14km2), are characterized by large areas of undisturbed, steeply sloping, heavily forested hillsides in the upper watershed, and similarly steep topography with relatively small flat areas that are urbanized or densely settled in the lower watershed (Figure 1). This settlement pattern is typical for volcanic islands with steep topography in the south Pacific. Initial monitoring efforts focused on Faga’alu, which discharges to a sediment-impacted reef (Aeby et al., 2006). Faga’alu includes two unique features not found in “typical” watersheds in American Samoa: 1) an open aggregate quarry, and 2) a large impervious area associated with a hospital. Nu’uuli watershed is adjacent Faga’alu and is similar in precipitation, size, relief, and landcover, providing an opportunity to compare sediment loading from a more “typical” watershed and estimate the influence of the quarry and impervious area in Faga’alu.

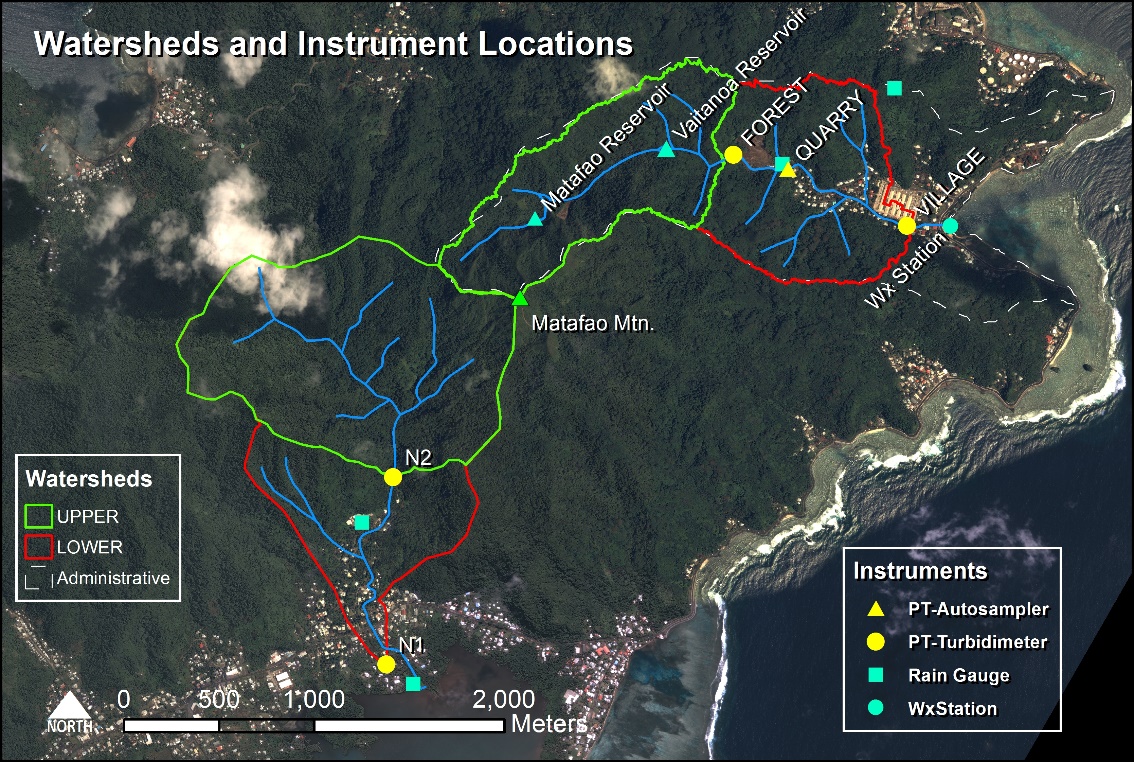
[](file:///C:\Users\Alex\AppData\Local\Desktop\samoa\GIS\maps\Fagaalu%20and%20Nuuuli%20Instruments%20subwatersheds.mxd)

Figure 1 Faga'alu and Nu'uuli watersheds showing upper (undisturbed) and lower (human-disturbed) subwatersheds.

Land use in both Faga’alu and Nu’uuli watersheds includes agriculture, roads, and urbanization (Table 1). The predominant land cover in the Faga’alu and Nu’uuli watersheds is undisturbed forest on the steep hillsides (85.7% and 93.3%). These forests are prone to natural landslides that can contribute 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 (“high intensity developed in Table 1, 4.6%), 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. In both Faga’alu and Nu’uuli, the NOAA Land Cover map (2.5m res.) classified the agricultural plots as “Grassland” due to the high grass cover in the plots (Table 1) (NOAA’s Ocean Service and Coastal Services Center, 2010). These plots are currently receiving technical assistance from the Natural Resource Conservation Service (NRCS) to mitigate erosion problems.

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| Table 1. Land use categories in Fag'alu and Nu'uuli watersheds. | | | | | | | | |
| **Watershed** | **Cumulative Area km2** | **%** | **% High Intensity Developed** | **% Developed Open Space** | **% Grassland**  **(agriculture)** | **% Forest** | **% Scrub/ Shrub** | **% Bare Land** |
| ***Faga’alu*** | | | | | | | | |
| *FOREST (UPPER)* | 0.90 | 48% | 0% | 0% | 0.1% | 82.4% | 17.1% | 0.4% |
| *QUARRY* | 1.17 | 63% | 0.2% | 0% | 0.2% | 84.7% | 13.3% | 1.6% |
| *VILLAGE (TOTAL)* | 1.78 | 95% | 3.2% | 0.9% | 0.2% | 85.7% | 9.0% | 1.1% |
| *Fag’alu total* | 1.86 | 100% | 4.6% | 1.1% | 0.2% | 84.5% | 8.6% | 1.0% |
| ***Nu’uuli*** | | | | | | | | |
| *Upper* | 1.49 | 70% | 0% | 0% | 0% | 94.8% | 5.2% | 0% |
| *Lower* | 2.14 | 100% | 2.0% | 0.8% | 0.1% | 93.3% | 3.7% | *0.2%* |

In Faga’alu there is an open-pit aggregate quarry (~2ha) that accounts for the majority of the 1.1% bare land area in Faga’alu watershed (). 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](#_ENREF_8)). The quarry operators have installed some sediment management practices such as silt fences and settling ponds (Horsley-Witten, 2011) but they are unmaintained and likely inadequate to control the large amount of sediment mobilized by the intense tropical rains (Horsley-Witten, 2012a). Longitudinal sampling of Faga’alu stream in 2011 showed significantly increased turbidity downstream of the quarry and of a new bridge construction site on the village road (Curtis et al., 2011). Construction of the bridge was completed March 2012 and no longer increases turbidity. There are several small footpaths and unpaved driveways, but most unpaved roads are stabilized with compacted gravel and do not appear to be a major contributor of sediment (Horsley-Witten, 2012b).

Three water impoundment structures were built in the upper Faga’alu watershed for drinking water supply and hydropower but only the highest, Matafao Reservoir, was ever connected to the municipal water system but has since fallen out of use (Tonkin & Taylor International Ltd., 1989). In Nu’uuli, no water impoundment structures were observed in the field or found in the literature.



Figure 4 Photos of the open-pit aggregate quarry in Faga'alu in 2012 (Top) and 2014 (Bottom). Photo: Messina