SEDIMENT CONTROL IN A TROPICAL, HIGH RAINFALL ENVIRONMENT

Michael L. Jacobs, P.E., Golder Associates Inc., Principal, mjacobs@golder.com
Todd White, PT Newmont Nusa Tenggara, Environmental Manager,
twhi1@corp.newmont.com

ABSTRACT

Controlling erosion and managing sediment at the Batu Hijau mine is a critical component to the success of this copper/gold project. As is common in tropical environments, the area experiences frequent high intensity rainfall events, resulting in significant erosion and sedimentation challenges associated with the overburden stockpiles that will ultimately store 2 billion tonnes of potentially acid generating rock and soil. The sediment control and management plan developed for the mine includes source control, concurrent reclamation and provides 9 million cubic meters of storage within several sediment control ponds. TSS concentrations measured in runoff from overburden stockpile areas exceeded 50,000 mg/l during the 1999-2000 wet season, but the sediment control system was successful in reducing TSS concentrations to less than 60 mg/l exiting the property.

Key Words: Sediment Control, Erosion, Tropical Environment, Seed Mixture

INTRODUCTION

PT Newmont Nusa Tenggara (PTNNT) is the owner and operator of the Batu Hijau mine located on Sumbawa Island, Nusa Tenggara Barat, Indonesia. Sumbawa Island is in the Lesser Sunda Island chain in the Indian Ocean, an area of high rainfall, at about latitude 9 degrees south, longitude 117 degrees east. Sumbawa is the third island east of Java. The Batu Hijau mine is located in the southwestern corner of Sumbawa, a heavily forested region that averages 2,500 millimeters (mm) of rainfall annually.

The ore body, a copper/gold porphyry, was discovered in 1990. Following feasibility studies and design, construction of the $1.9 billion project started in October 1996. The first concentrate shipment was made in December 1999. The mine produces copper and gold from an open pit, and the pit will ultimately be 900 meters below original ground surface. Daily mine production is 600,000 tonnes, and the daily plant production averages 142,000 tonnes. The estimated 2 billion tonnes of potentially acid generating overburden material will be placed in three separate stockpiles adjacent to the pit during the 17 year projected mine life. Controlling the sediment contained in the stormwater runoff from these overburden stockpiles, and areas disturbed during construction, is essential to the success of the project. PTNNT is required to limit total suspended solids (TSS) discharged from the mine property to less than 60 mg/l, which is less than values recorded during wet season flows prior to mine development. PTNNT contracted with Golder Associates Inc. (Golder) to assist them with sediment control at the Batu Hijau mine.

Topography in the mine area is rugged, with relief up to 700 meters and valley side slopes of 30 to 45 degrees. Numerous incised creeks dissect the side slopes. Residual soils that cover most of the valley side slopes are primarily low plasticity silt and saprolite covered by a thin (less than 500 mm) organic-rich topsoil layer. The residual soils and saprolite typically range from a depth of 0 meters in the watercourses to 20 meters on some ridge crests (and as deep as 40 to 50 meters at some locations). A gradation curve for a typical erodible soil sample is provided as Figure 1.

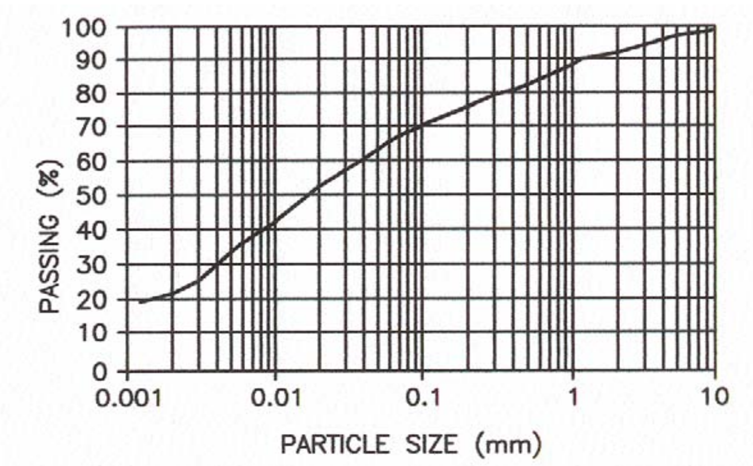

Figure 1: Gradation of Typical Surficial Soils

The soils usually have a very stiff to hard consistency below a 5-meter depth.

The vegetative cover is a dense, forest canopy typical of a moist, tropical environment. Erosion and sedimentation occur almost immediately once the canopy is removed. PTNNT revegatates areas as soon as practical following disturbances, but sediment control is essential until vegetation has been reestablished.

Batu Hijau experiences distinct wet and dry seasons. The wet season is the period from mid-October through the first of May, during which about 85 percent of the average annual rainfall occurs. Annual rainfall is much higher in inland areas than along the coast. The mine and overburden stockpile areas are located in these higher rainfall areas.

The average annual rainfall estimate for the mine area is 2,500 mm. A summary of average seasonal climatic conditions is shown in Table 1.

Table 1: Summary of Average Seasonal Climatic Conditions

	Wet Season (Oct.-April)	Dry Season (May-Oct.)	Average Annual
Temperature			
Typical Daily Max.	31 °C	27 °C	30 °C
Typical Daily Min.	21 °C	18 °C	20 °C
Precipitation	2,200 mm	300 mm	2,500 mm
Wind	2.5 m/s	2.9 m/s	2.7 m/s
Relative Humidity	91%	86%	88%
Pan Evaporation	4.5 mm/day	4.3 mm/day	4.4 mm/day

Of particular concern at Batu Hijau is rainfall intensity. Areas of the mine have experienced in excess of 50 mm of rainfall during a 15-minute period, and more than 200 mm over 24-hours. Peak storm depths by return period are shown in Table 2.

Table 2: Peak Storm Depths by Return Period

Duration		Recurrence Interval							
		2-Yr	5-Yr	10-Yr	20-Yr	25-Yr	50-Yr	100-Yr	500-Yr
(hours)	(min)	Storm Depth (mm)							
0.083	5	12	14	16	16	17	19	22	30
0.167	10	22	25	28	30	32	35	42	59
0.250	15	30	35	40	45	46	52	59	80
1.000	60	46	61	71	85	87	101	121	170
2.000	120	58	75	88	105	108	125	150	210
3.000	180	65	85	99	119	122	142	170	238
6.000	360	82	106	124	149	152	177	213	298
12.000	720	98	128	150	180	184	214	257	360
24.000	1440	115	150	175	210	215	250	300	420

The high average annual rainfall, coupled with extreme storm events, resulted in significant erosion and sedimentation during initial construction at the Batu Hijau mine. The addition of overburden stockpile soils further challenged the project, and PTNNT took significant steps to manage and control sediment. In several incidents during project development the TSS concentration of incoming flows exceeded 50,000 mg/l. This paper discusses the sediment control practices at Batu Hijau, and the concomitant infrastructure.

METHODOLOGY

Sediment management and control at Batu Hijau is the process of stabilizing disturbed land surfaces to minimize erosion, reestablish vegetation that is similar in structure to existing vegetation, construct infrastructure to collect and convey stormwater runoff, and detain sediment-laden runoff to reduce sediment loads. Some erosion is inevitable, and the resulting sediment contained in stormwater runoff is directed into large, sediment control reservoirs for collection and deposition prior to offsite discharge.

During construction of the mine and infrastructure, PTNNT constructed temporary sediment control facilities to manage erosion and sedimentation. These temporary structures were designed to manage runoff and erosion during a single wet season, or in some cases portions of the wet season. Measurements of rainfall, runoff and erosion were made during these periods, providing the opportunity to estimate the volume of runoff and sediment expected to be generated during mining and overburden stockpile construction.

Rainfall during project construction was average to above average at many locations at Batu Hijau. All temporary structures filled with sediment during the final wet season prior to completion of the permanent structures in December 1999. An estimated 400,000 cubic meters of sediment was generated from a disturbed area of about 500 hectares during the October 1998 to May 1999 wet season. Sediment generation has been greatly reduced as revegetation and additional surface water control features have been constructed, and the sediment management plan is in effect. An average of 100,000 cubic meters of sediment per year is expected over the life of the project.

Source control, surface water management and runoff detention are key components of the sediment management plan. Disturbed areas are revegetated as soon as practical to reduce erosion and sedimentation rates. The overburden stockpiles are also being constructed and managed to minimize and control sediment.

Overburden stockpiles are being constructed at angle of repose in 45-m lifts, and 45-m wide benches are being established every 45-m. Prior to revegetation, the angle of repose slopes will be pushed down, or additional waste rock will be added, to reduce slopes to 3H:1V. The horizontal bench widths will be reduced during this regrading to 11.25-m. The resulting interbench slope lengths will be no longer than 100-m. The resulting overall slope, including the benches, will be 3.25H:1V when regrading is complete. The benches will be graded such that water flows laterally along the toe of the next lift off the reclaimed area to channels in the surrounding undisturbed forest. These channels discharge to downstream control structures.

Primary long-term control of erosion is provided by vegetation, enhanced by the development of secondary soil structure, which is partly created by the growth and decomposition of roots. To retain soil during the development of vegetation, a combination of physical erosion control measures is applied – hydromulch over the entire slope surface, and erosion/flow breaks (referred to below as “rill breaks”) on horizontal contours, spaced at 10-m intervals on the slope surface.

These procedures were developed as an alternative to applying bonded fiber matrix (BFM) products or covering the entire slope surface with erosion control blankets. Perfectly installed blankets or BFM offer effective local surface protection, while allowing vegetation to develop. However, they are highly material- and labor-intensive, are prone to concealed rilling resulting from imperfect contact with the underlying surface, and are vulnerable to failure should incipient gullies develop on the 100-m slopes to be treated, or if the edges become detached. Therefore, alternate methods were developed and tested at Batu Hijau.

The procedures described herein have been successfully field-tested at Batu Hijau and shown to offer adequate slope surface protection. Wattling, fiber rolls, and geocellular confinement systems are available as even more effective contingencies, and for repair of local erosion problems, if any.

At a minimum, mulching includes application of hydromulch with cross-linked polysaccharide (gum) tackifier or the functional equivalent. As available, rice straw or chipped woody vegetation is blown over the hydromulched surface and bonded with tackifier.

Rill breaks are designed to limit the extent of erosion rills or gullies, and to slow flow velocity, effectively reducing the functional slope length. Two alternative methods have proven successful: row-sprigging and sugar palm fiber rolls. These may be applied together or alternatively, depending upon materials availability. Row-sprigging consists of planting cuttings (sprigs) at close spacing (15 to 20 centimeters) on surveyed contours, with horizontal stringers to inhibit the formation of incipient rills between springs. Functionally, these will be living filter fences. Fiber rolls will be fabricated locally of bound 25-cm diameter rolls of sugar palm fiber. These are buried at the soil surface and staked in place with live cuttings. For either type of energy break, a flow-dissipation apron consisting of a thin layer of sugar palm fiber held in place with jute netting is installed extending 2-m below the row or roll. Typical seed to be included in the hydromulch mixture (Table 3) will consist of soil-holding grasses, legumes for soil fertility, and woody species, and will vary depending on conditions. Materials and quantities will be subject to modification according to the results of ongoing field experimentation. Additional native species may be included subject to availability.

Table 3: Typical Hydromulch/Seed Mixture

Rate (kg/ha)	Substance or Species	Comments
10	*Cynodon dactylon* (hulled)	Optional. Deep rooting and strongly rhizomatous and stoloniferous.
30	*Axonopus* species	A. compressus preferred; affinis acceptable. Increase rate to 40 kg/ha if other perennial species are omitted.
(20)	*[Echinochloa esculenta]*	Rapid establishment; annual.
(10)	*Paspalum notatum*	Optional.
1	*Centrosema pascuorum*	
1	*Stylosanthes hamata*	
1	*Trema orientalis*	Fast growing native pioneer tree.
1	*Commersonia bartramia*	Fast growing native pioneer tree.
1	*Leucaena Glauca = leucocephala*	Fast growing native pioneer tree.
1	*Schoutenia ovata*	

In addition to hydromulching, coarse mulch composed of coarsely ground wood and other forest-derived green waste, or of coarse hay (10- to 40-cm length), is applied over hydromulched/seeded surface by blower or hand application. Coarse mulch is oversprayed with tackifier or held in place with loose biodegradable plastic or jute netting (1- to 3-cm openings, depending upon material).

In increasing order of effectiveness and cost, the following erosion control contingencies are effective. Measures 1 and 2 are substitutes for hydromulching as the overall means of surface protection; measures 3 and 4 are used in repair of any rills that develop, or for application to constructed areas where water flow is concentrated.

1. Bonded fiber matrix (such as EcoAegis or equivalent) is substituted for hydromulch and tackifier.
2. Netted straw/coir blankets (such as Bonterra C2, CS2, or North American Green SC150, or equivalent).
3. Wattling using live cuttings or suitable species.
4. Geocellular confinement systems.

To divert runoff and minimize impacts to revegetated areas, eleven kilometers of large diversion channels have been constructed into the hillsides above and around the overburden stockpiles. As the stockpiles grow, additional channels will be constructed. Over the life of the project 186 kilometers of channels and similar conveyance structures are planned on and around the 1,100 hectare mine and stockpile area.

The mine and stockpile areas are shown on Figure 2. All channels convey runoff to sediment control structures located in the two valleys draining the mine area, the Santong valley and the Tongoloka valley. All mine runoff is ultimately directed into the Santong valley, where the concentrator is located, for use in the beneficiation process, or discharged following final treatment.

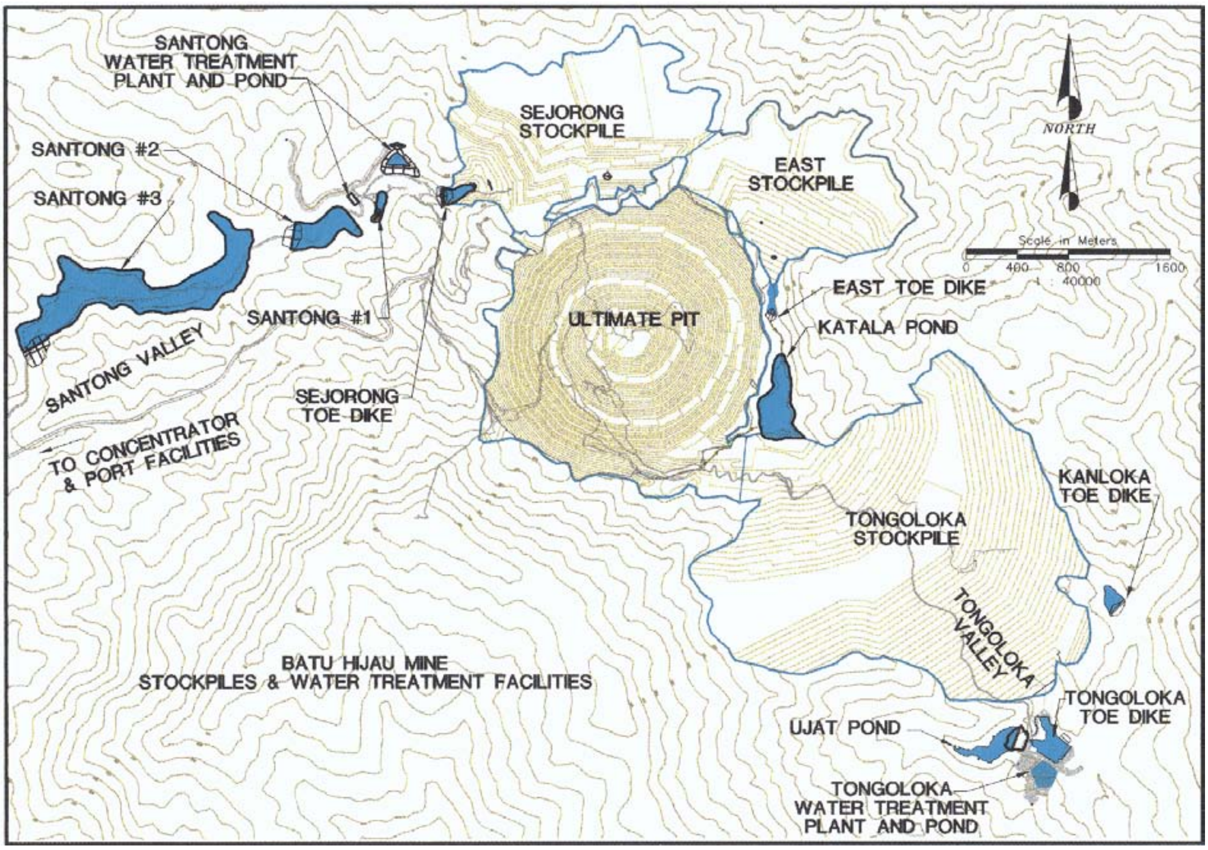

Figure 2: Mine and Stockpile Areas.

Runoff from disturbed areas in the Tongoloka valley, south of the mine, is captured in two large sediment control ponds and pumped to the Santong valley. Pumping rates as high as 750 liters per second are anticipated from the Tongoloka valley in the near term, and will eventually reach 2,300 liters per second by 2007.

Runoff from disturbed areas in the Santong valley, including the water that is pumped from the Tongoloka valley, is collected in three large sediment control ponds. The ponds are progressively larger from upstream to downstream. Water collected in the largest pond, Santong III, is used in the concentrator, or released if not required by the process and if water quality standards are satisfied. Pumping rates as high as 3,600 liters/second are anticipated from Santong III to the concentrator. In addition, as much as 2,000 liters/second of runoff from undisturbed areas is being diverted around Santong III through a 1.2 meter diameter HDPE pipeline to maintain flows in the Santong river downstream of the property.

The majority of sediment eroding from the overburden stockpiles is expected to be sands and coarse silts. Smaller sediment control structures have been constructed at the downstream toe of each overburden stockpile to intercept stockpile runoff. These structures are referred to as toe dikes. Toe dike structures can be emptied of sediment more readily than larger structures. The smaller structures should also ensure that only the coarser soil fraction is intercepted, which will be easier and less costly to remove than the finer silts and clays. Coarse sediment will typically be removed annually from the toe dikes, and much of the soil will be used for reclamation purposes. Runoff is also continuously decanted from the toe dikes and discharged to the much larger sediment control ponds further downstream. These ponds have a much larger storage capacity and hence provide a longer residence time to settle the finer fraction of eroded sediments. No sediment removal is planned from these larger structures.

In the Tongoloka valley, discharges from the upper stockpile are decanted from its Toe Dike into the downstream control structure referred to as Katala Pond. Katala Pond was created by stockpiling overburden soils across the original valley and lining the upstream face of the overburden material to limit infiltration. Its capacity is adequate to attenuate runoff from multiple storm events. Runoff collected in Katala Pond is used for dust suppression purposes in and around the mine, and excess runoff is eventually pumped to the Santong valley northwest of the mine for further treatment and possible use in the concentrator, or discharged once release criteria have been met. Pumping rates as high as 2,300 liters per second are expected.

Runoff from the southern, more downstream overburden stockpile in the Tongoloka valley discharges to the Tongoloka Toe Dike, as shown in Photo 1. It provides 800,000 cubic meters of storage, and water collected in this pond is immediately pumped to the Santong valley. Sediment will be removed annually during initial project development and every other year thereafter.

In the Santong valley to the west of the mine, three large sediment control ponds have been constructed in addition to the Toe Dike. The uppermost pond, Santong 1 (shown in photo 2), collects decanted water from the Toe Dike and runoff from mine facilities. Santong 2 (shown in photo 3), the second pond, collects discharges from Santong 1, pumped runoff from the Tongoloka valley, and runoff diverted around the stockpiles. The final pond, Santong 3 (shown in Photo 4), is the clarifying and polishing pond for the entire mine site and ultimately collects all runoff from disturbed areas in the mine and stockpile areas. Water collected in Santong 3 is expected to have minimal sediment, and this water is typically discharged downstream. However, water can be pumped to the concentrator for use in the beneficiation process at up to 3,600 liters per second. The size, storage capacity and pumping rates of the Batu Hijau sediment control ponds are summarized in Table 4.

Table 4: Pond Capacity & Pumping Rate

Pond	Capacity (m^3)	Pumping Rate (liters/second)
East Toe Dike	57,000	Gravity Pipeline
Kanloka Toe Dike	73,000	Gravity Pipeline
Tongoloka Toe Dike	800,000	750
Katala Pond	2,800,000	2,300
Sejorong Toe Dike	110,000	Decant System
Santong #1	160,000	Spillway
Santong #2	725,000	Spillway
Santong #3	6,000,000	3,600

Photo 1: The Tongoloka toe dike, water treatment plant and pond.

Photo 2: Santong #1 sediment control structure.

Photo 3: Santong #2 sediment control structure.

Photo 4: Santong #3 sediment control structure.

RESULTS AND CONCLUSIONS

All major sediment control structures were completed in late November and early December 1999. Vegetation planted during the 1999 dry season also began to have the desired effect by the end of 1999, and other source controls were in place.

Rainfall and the resulting runoff at the beginning of the 1999/2000 wet season filled all the sediment control ponds with water by early January 2000. At the end of January 2000, a thunderstorm with a rainfall intensity equivalent to the 50-year recurrence interval storm occurred over the mine area, resulting in the largest discharges from the control structures to date. During the storm event, an earthquake (totally unrelated but equally concerning) was also experienced at the site; this earthquake was the largest recorded in the ten years of project activity in southwestern Sumbawa. All structures performed as anticipated, and runoff released from the property was all within established discharge criteria.

As expected, concentrations of TSS as high as 50,000 mg/l were recorded entering the Santong sediment control system during the 50-year storm event, and during subsequent events. This was expected since disturbances were recent, and vegetation had not developed to maturity. The peak TSS concentration discharged from the property, however, was 28 mg/l, or 99.9% less than the incoming flow. During the 1999/2000 wet season, average TSS concentration reductions of 99% were achieved, and the peak concentration released from the property was 28 mg/l, well within the 60 mg/l discharge criteria.

Similar results were achieved in the Tongoloka Valley, but the TSS concentrations of the incoming flow were not as extreme. This was due to the regrading and revegetation program implemented in 1998, which had reached maturity prior to the 1999/2000 wet season.

Figure 3 shows inflow and discharge concentrations of TSS in the Santong Valley, and Figure 4 shows the same information in the Tongoloka Valley. The pumping system conveying runoff from the Tongoloka to Santong Valleys had not been completed during the period.

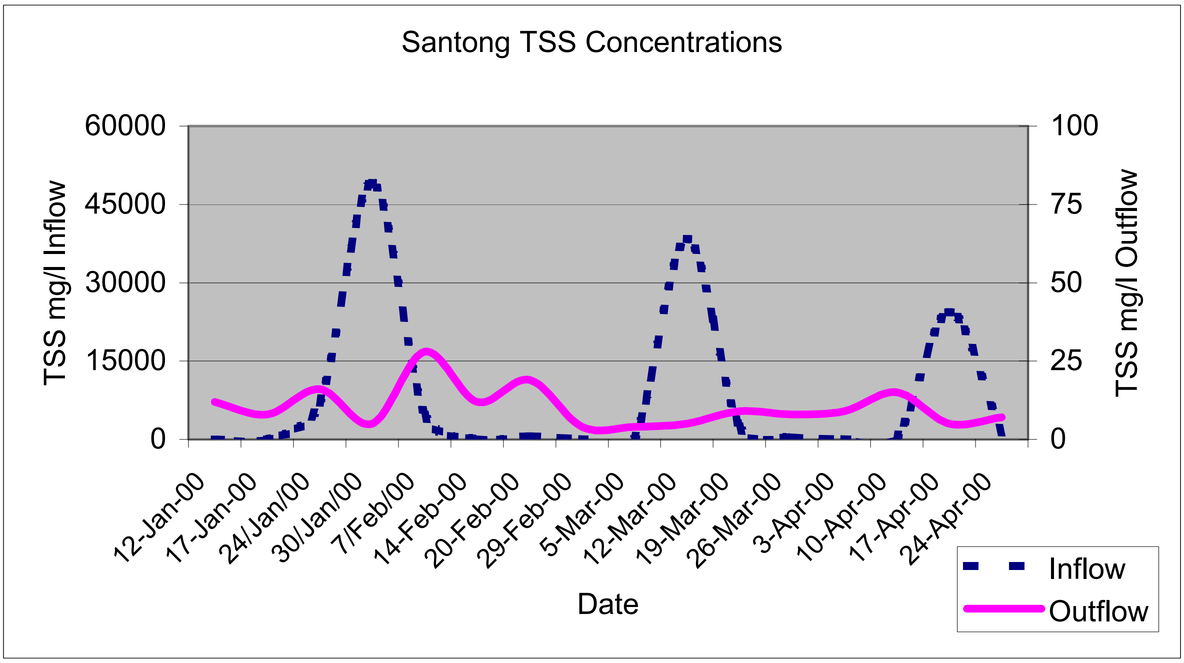

Figure 3: Santong TSS Concentrations

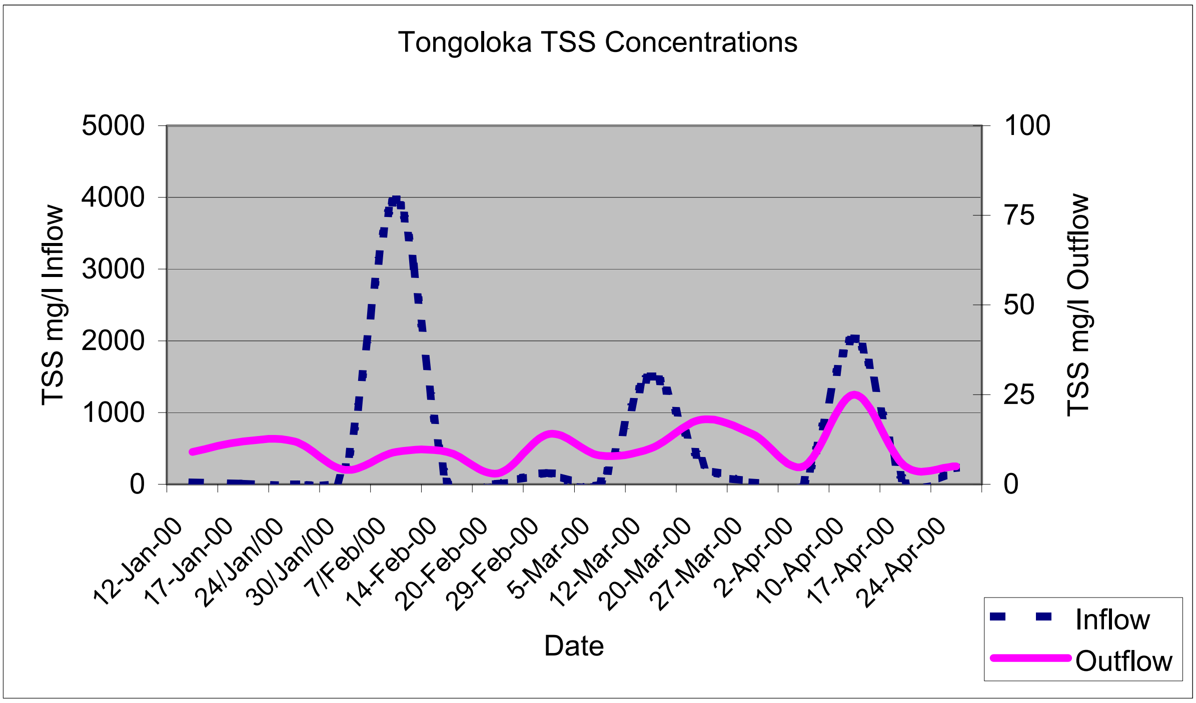

Figure 4: Tongoloka TSS Concentrations

The results of this effort conclude that target discharge TSS concentrations as low as 60 mg/l can be achieved, even in a tropical environment with high intensity storm events, with proper infrastructure and sediment management techniques. Source control, stormwater management and sediment control infrastructure are all necessary for a successful program.

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