Geographical Information Analysis Unit

Supplement to the
Final Report
4/1995

Sediment Load in the Streams of the La Troya Watershed

Recommendations for the Reduction of the Point Source Contribution

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Recommendations

These pages supplement the Final Report 4/95: Sediment Load in the Streams of the La Troya Watershed, Quantification of Point Source and Subwatershed Contributions. They try to give an overview of the possibilities of reducing erosion and sediment load in the La Troya watershed. As shown in the Final Report, intensive agriculture (non point source) and point sources, such as quarries, are important contributors to the sediment load in the streams. This supplement focuses on some technical low-cost measures that are commonly used to reduce sediment load of waste water. Their usefulness in the particular situation of the Reventado watershed - where we find extraction of construction material and sand washing in the stream bed - is evaluated. Based on a study of Quebrador Ochomogo, one of the companies contaminating the Río Reventado, a scenario is developed where changes of the extraction and processing operations lead to a process optimization and a cut down of sediment load.

It was beyond the scope of this study to discuss agricultural soil conservation practices in detail. There are many organizations and programs with considerable financial resources that are dedicated to research in the field of soil loss from agricultural land and to implementation of conservation practices. Unfortunately, the efforts of the latter group have not been very successful. Acceptance of conservation practices at farm level is low. It might be a process of many years or generations before these practices will be internalized. Thus, it is even more appealing to start working on the reduction of sediment load from point sources: They are geographically well defined and limited in number, the processes and the operations involved are apparent, appropriate mitigation measures are known, and their implementation does not depend on hundreds and thousands of people, but only a few.

I Reduction of Sediment Load from Non Point Sources

As discussed in the Final Report, numerous studies confirm that erosion on agricultural land is a serious problem in the La Troya watershed. The author's USLE analysis shows peak values of 457 $t\ ha^{-1}y^{-1}$. Extreme erosion occurs, although best management and soil conservation practices are well studied. Villanueva (1987) recommends the implementation of physical and socio-economic measures to reduce soil loss in the zone to the north of Cartago. Drainage channels should be constructed to collect the water in order to reduce uncontrolled superficial runoff. Crops should be planted in contour line parallel rows to increase infiltration. He suggests classifying the area officially as 'highly susceptible to erosion' and recommends the inauguration of an office for soil conservation that is responsible for consulting, implementation of conservation measures and research. Cortés et al. (1987) list a comprehensive catalog of recommendations of how to reduce soil deterioration and soil loss. General strategies mentioned include agroforestry (mixed use) and shifting cultivation. The bulk of the recommendations consists of runoff control practices. Very few, like the construction of terraces, involve complex technical steps or require considerable financial resources. Living barriers or fences (trees, shrubs) in contour line parallel rows are a cheap and effective means to reduce runoff and to foster the forming of natural terraces. Planting and ploughing in a contour line parallel way serve the same purpose. Other practices reduce the periods of little or no vegetation cover and lacking root system. Fast growing nitrogen fixing species, such as clover, could be planted to bridge periods of barren soil. Rotational or intermittent planting aims at the continuous presence of some plants with dense canopy and extensive root system. In flat, exposed areas it is recommended planting trees or crops perpendicular to the prevailing direction of the wind. In 1993, Cortés and Oconitrillo tried to find out why even the simplest soil conservation practices had not been implemented. Their study revealed that - despite the activities of several organizations and despite programs designed to disseminate soil conservation practices - many farmers were still not aware of the appropriate techniques. In addition, no direct technical assistance seemed to be available. The majority of the farmers owns tiny parcels of land which are too small for effective erosion control measures. The channels designed to drain the agricultural plots and to collect the runoff need to be constructed over entire slopes and thus require the cooperation of several individuals. More than anything else, soil conservation practices oppose traditional cultivation methods and are thus not readily accepted and integrated. It is a challenge and a difficult, but necessary, task to pursue the implementation of the conservation practices further.

II Reduction of Sediment Load from Point Sources

2.1 Natural Point Sources

The reduction of the sediment load caused by natural point sources, such as landslides or slumps, is very difficult. In most cases the occurrence of a landslide or a slump can not be anticipated. Only permanent phenomena, such as the San Blas landslide, give the opportunity of implementing mitigation measures. Since mass movements are very often related to high water content and lack of vegetation cover, measures to accelerate runoff, to reduce infiltration, to drain the area and reforestation programs are recommended (see Chapter 4.1, Final Report).

2.2 General Mining Concessions

Generally, quarries show elevated erosion values, as they comprise huge areas of barren soil, destroyed soil structure and extreme slopes. Sediments stem from loose, uncovered material that is ubiquitous at the extraction site and that is carried away by superficial runoff during rainfall. The Environmental Impact Statements (EISs) of many concessions (see Chapter 3.2.1, Final Report) mention mitigation measures. They range from preventive to reactive. Similar to measures on agricultural plots, runoff should be channeled. Before the collected water enters an aquifer, sediment load could be reduced through sedimentation ponds which accelerate the deposition of the particles. Loose material should be collected and stored in depressions or places specifically designed to minimize the influence of runoff. Artificial or natural barriers which detain runoff and sediments and increase infiltration are easily built and very effective. Another goal is the spatial and temporal minimization of areas of barren soil. Reforestation programs should be scheduled for the final phase of the extraction activities.

2.3 Concessions for 'Cauce del Dominio Público'

In contrast to the point sources mentioned above, which contribute to sediment load during rainfall events only, the extraction and processing of construction material from and in stream beds cause a constant contamination of the rivers. The stream is polluted through the operation of heavy equipment in its bed, the washing of the sand in the stream and the cooling and flushing of the stone mills. A technical solution has to face two main problems. Firstly, a considerable part of the sediments produced consists of very fine material and is thus hard to deposit. Secondly, stream discharge varies over a broad range. The attempt to clarify the entire stream water would require complex and expensive technical installations.

2.3.1 Theoretical Aspects of Settling Processes

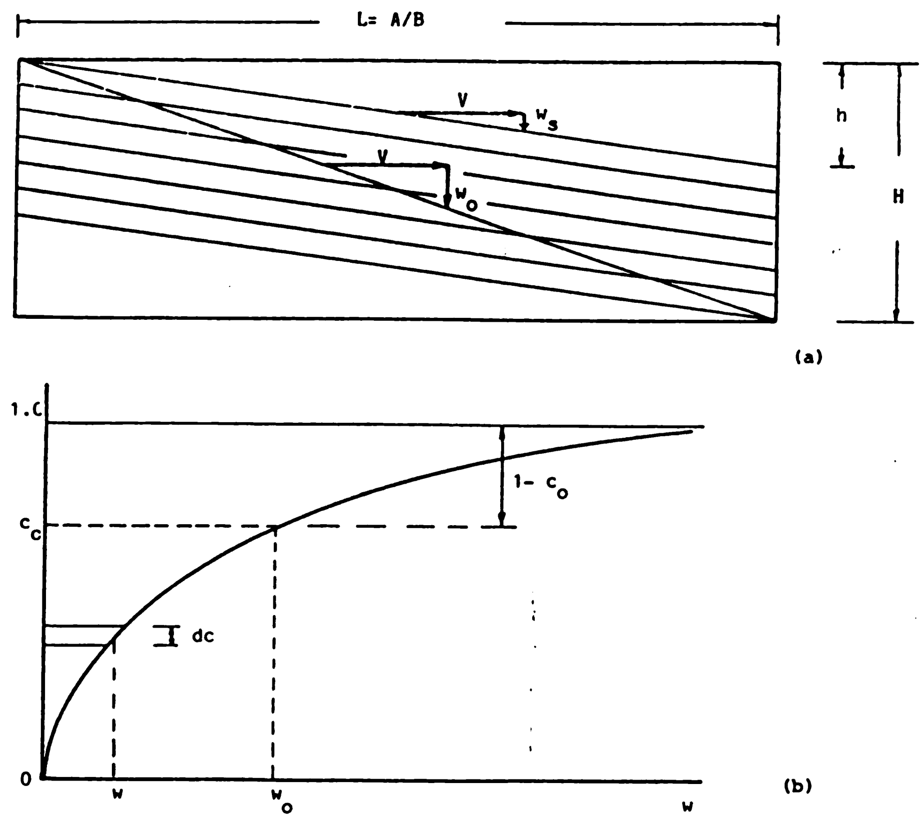
The most commonly used technical method to clarify particle contaminated water is the installation of sediment traps. Moreover, it is by far the cheapest one. In a simple sediment trap (sedimentation pond or tank) the particles are removed from the water column by settling. This is achieved through a reduction of the water flow velocity which results in a decrease of the sediment carrying capacity. Particles settle according to their fall velocity. Greater grain size particles deposit faster than smaller ones. The dimensioning of the settling ponds is based on the concept that a particle falls through the water at its fall velocity, w, and is carried forward at the velocity of the transport medium, V. Thus, if V was uniform throughout the depth, all grains of the size d_0 (or greater) with fall velocity w_0 (or greater) would have settled out over a length $L = H(V/w_0)$, where H is the depth of the water column. The removal of particles with $w \leq w_0$ is the settling efficiency ratio:

(1) $$E = w/w_0 = (wA)/Q$$

, where: A: tank surface area
Q: discharge

Figure 2.1 illustrates the idealized processes in a settling tank.

Figure 2.1: Settling in an Ideal Basin (a) and Settling Analysis from a Given Concentration/ Settling Velocity Distribution (b) (taken from Raudkivi, 1993)



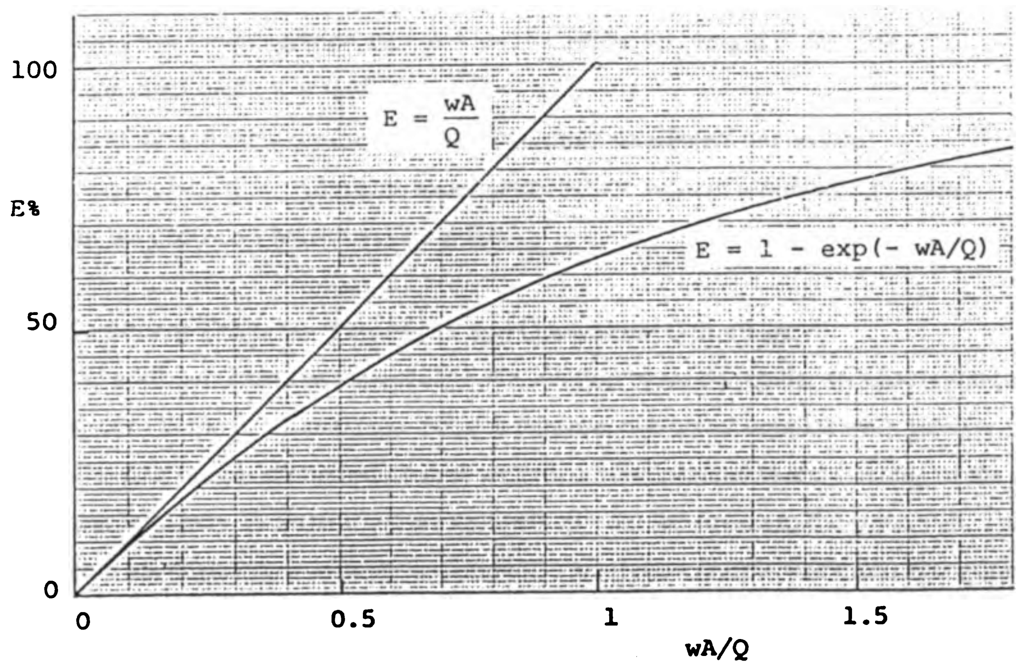
In reality, the processes involved are much more complex. The idealized concept outlined above is based on the assumption that there is a homogeneous concentration distribution of all particle sizes, a uniform fluid velocity over the depth, an interference-free settling process and that all particles reaching the bed remain there. Additionally, it disregards the effects of turbulent diffusivity. A better approximation of the efficiency ratio is

$$E = 1 - \exp(-wA/Q) \qquad (2)$$

, where: A: tank surface area
Q: discharge

Figure 2.2 compares the equations (1) and (2).

Figure 2.2: Comparison of the Expressions $E = (wA)/Q$ and $E = 1 - \exp(-wA/Q)$ for the Efficiency of Sediment Removal (taken from Raudkivi, 1993)



2.3.2 Modeling Settling in a Sedimentation Tank with TRAPØ

The 'Departamento de Hidráulica' of ICE uses a spreadsheet based model to design sediment traps. The numeric model was developed by Olsen (1991) at the Norwegian Institute of Technology in Trondheim and adapted by Jiménez (1993) of ICE. It allows to determine the trap efficiency for particles of a given size in a rectangular sedimentation tank with uniform velocity. The model solves for the following expression:

$$V(\partial c/\partial x) + w(\partial c/\partial y) = -\,\partial/\partial y(k_s(\partial c/\partial y))$$

, where:

- V: fluid velocity
- x: lateral vector
- c: sediment concentration
- y: vertical vector
- k_s: turbulent diffusivity coefficient of the particle

The fluid velocity is approximated through a logarithmic expression, the parameters of which are based on the formulas of Strickler and Mannings. For a more detailed description see Jiménez and Olsen (1993). The following parameters have to be specified in order to run the iterations:

- discharge [m^3/s]
- depth [m]
- grain size [m]
- alpha (turbulent diffusivity coeff.) = '0.11', constant
- Mannings-Strickler coefficient (1/Mannings) = '60', constant
- sediment discharge [kg/s]
- Δx [m], length of the integration step; $\Delta x = L/16$, where L is length of the tank
- Von Karman coefficient, κ = '0.39', constant

For the calculation of the sediment profile (deposits) two more parameters are needed:

- time step during which the sediments accumulate (before they are removed, e.g. 1 day)
- porosity of the deposits (between 0.3 and 0.6)

2.3.3 Designing Sediment Traps for Tajo Mena and Quebrador Ochomogo

The use of TRAPØ allows to examine the viability of a solution based on regular sedimentation tanks for the extraction activities in the Río Reventado. For this purpose, two water samples were taken at the extraction sites. The first sample contained process water from the lubrication and flushing of the stone mill of Tajo Mena. Approximately 10 l/s to 15 l/s are pumped up from the stream to the stone mill. The water returns to the stream via channels or as superficial runoff. The second sample was taken downstream of the mines in the Río Reventado (Site M, see Final Report). The granulometry of the samples was analyzed in the laboratory of the Departamento Hidrología at ICE. The results are illustrated in Figures 2.3 and 2.4.

Figure 2.3: Granulometric Analysis, Process Water Tajo Mena

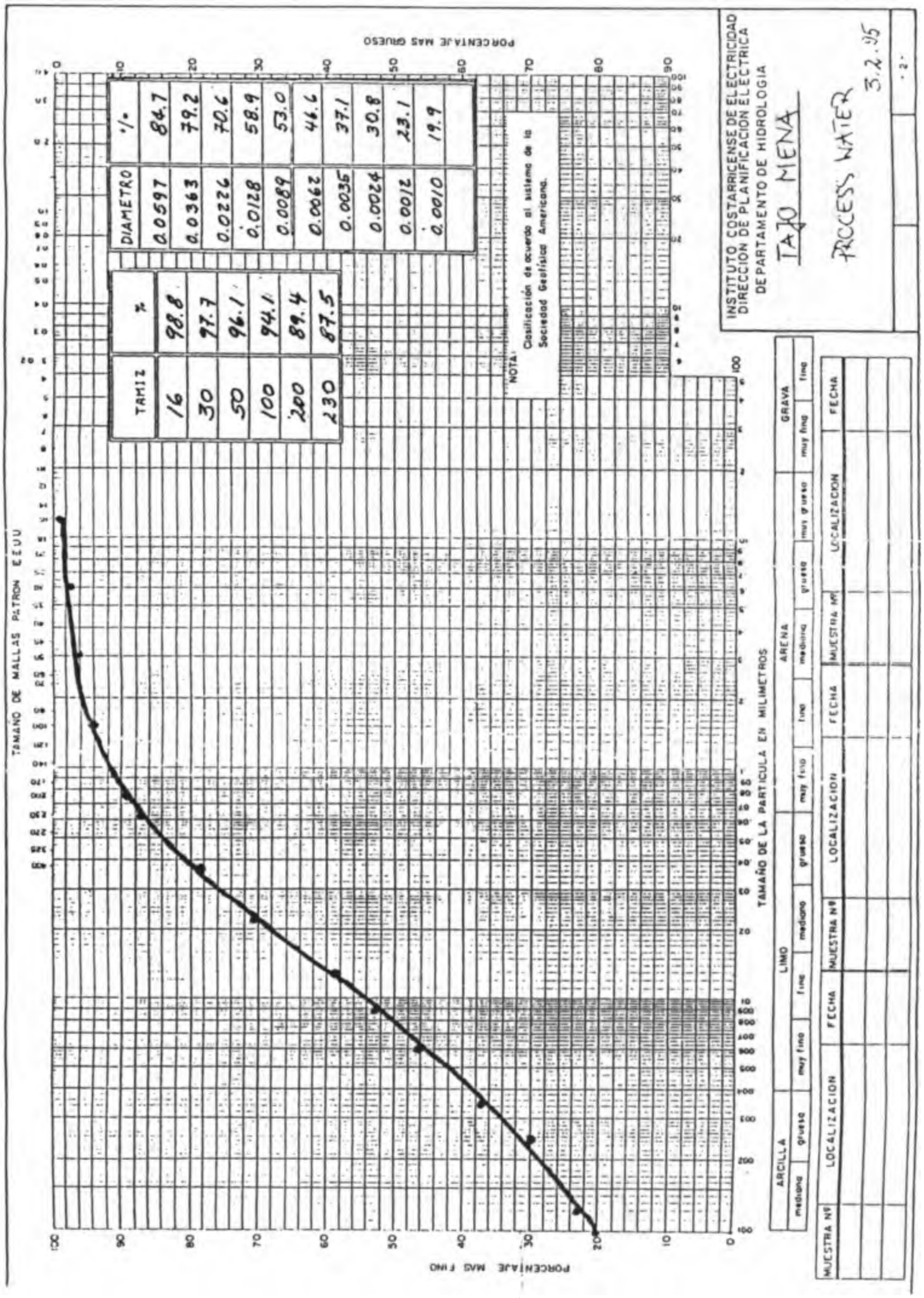
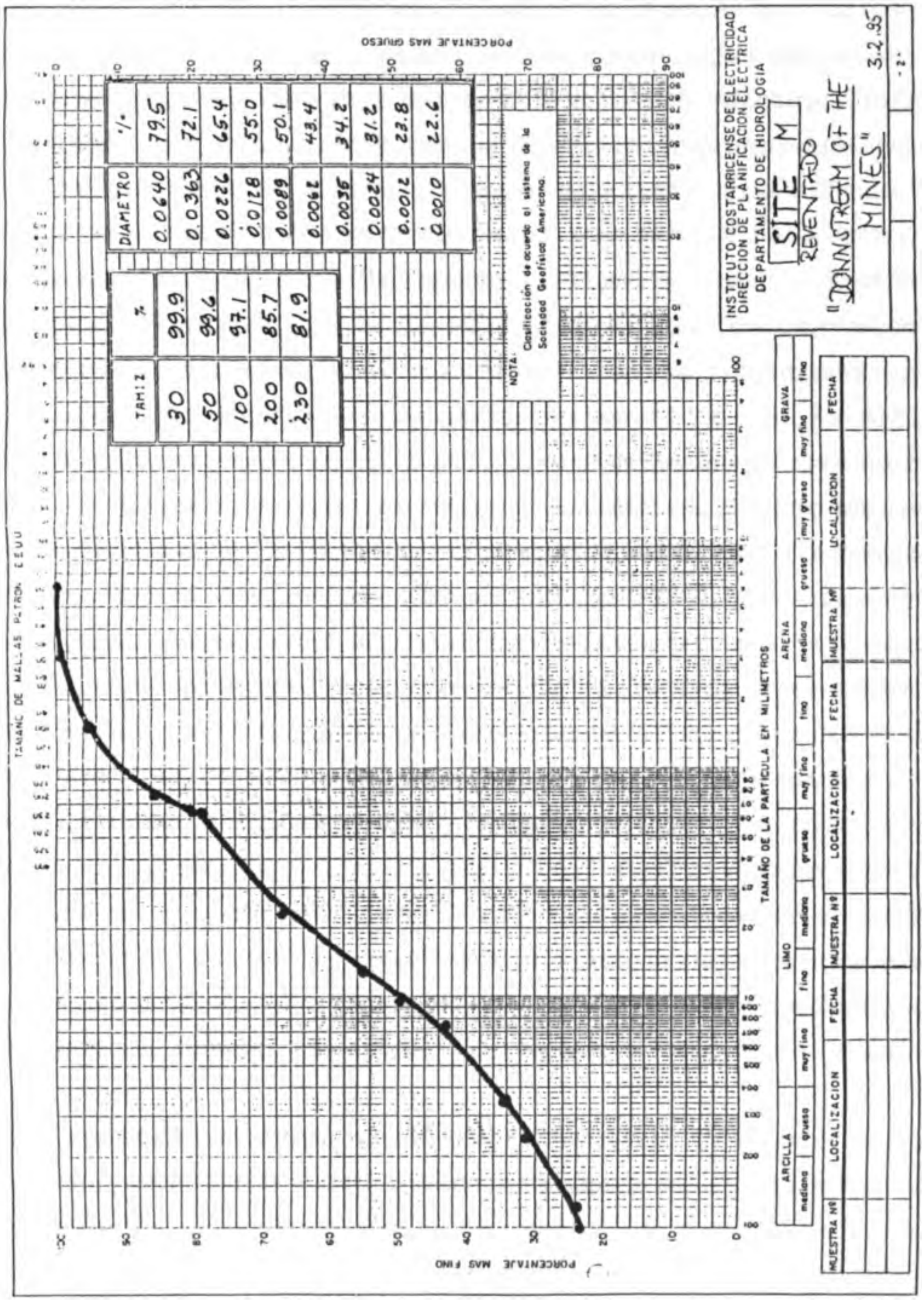


Figure 2.4: Granulometric Analysis Site M, Downstream of the Mines



At both sites most particles are extremely small. The stone mill produces waste water with 88 % of the particles being smaller than 63 µm (clay and silt fraction). The sample contains great amounts of stone dust from the milling process. The extraction of the construction material and the washing of the sand in the stream add bigger particles to the water. However, many of these settle before reaching Site M, Downstream of the Mines. There, 80 % of the particles are smaller than 63 µm. As described above, small particles are very hard to settle, mainly because they have a low fall velocity. In fact, test runs with TRAPØ showed that particles with grain sizes below 10 µm do not even settle at very low discharge in sediment traps with reasonable dimensions and conventional treatment. Thus, conventional treatment is limited to trapping the greater particles. The results of a test run are shown below as an illustration (Figures 2.5 through 2.7). The goal was to trap about 50 % of the particles (i.e. grain sizes of 8 µm and greater, see Figure 2.3) in the process water of Tajo Mena. The discharge is 10 l/s and the sediment concentration was estimated to equal at least 100,000 ppm. Thus, the sediment discharge is 1 kg/s. Cost minimization considerations favor shallow and wide traps. However, a uniform velocity distribution requires longer, narrow installations. A trap efficiency of 94 % is accomplished by a trap of 1.5 m depth, 3 m width and 100 m length. The costs of constructing such a trap can be estimated based on the costs per cubic meter of concrete, excavation, etc. With 0.2 m strong concrete walls and foundations and an appropriate intake the trap costs approximately US $ 45,000, at US $ 200 per m^3 of concrete. Remember that an installation of these dimensions only traps 50 % of the suspended solids at a discharge of 10 l/s, i.e. only the diverted process water is treated, not the stream water! The construction costs are supplemented by high operation costs. 55 m^3 of accumulated deposits have to be removed from the trap after every 24 hours of operation. The deposits have a very high water content and are very hard to handle. The trap efficiency is extremely grain size sensitive. If we confine ourselves to trapping particles of 40 µm and greater (less than 20 % of the sediment load of Tajo Mena's process water), the trap can be redimensioned to 1.5 m depth, 3 m width, and only 10 m length at an efficiency of 99 %. As only small amounts of process water have to be treated, another option should be evaluated. The high construction costs can be reduced considerably and the trap efficiency can be increased, if a so called 'tailing pond' is built. In addition to a reduction of the water velocity as a means to trap particles, a tailing pond is designed to increase the infiltration of polluted water. Thus, no foundation is needed. However, tailing ponds require big areas on well permeable ground. The high operation costs remain.

A second scenario 'Trapping 50 % of Stream Sediment Load at Discharge 100 l/s' illustrates that it is even more difficult to treat the polluted stream water. It confirms that a common sediment trap is not a viable solution for the removal of the suspended solids from the contaminated water in the Reventado - not even during the dry season at 100 l/s discharge. The sediment concentration was set to 50,000 ppm which results in a sediment discharge of 5 kg/s. An installation of 1.5 m depth, 5 m width, and 100 m length traps grains of 20 µm and greater with an efficiency of 95 %. Particles of this grain size range are responsible for 38 % of the total load. 266 m^3 of sediments are accumulated within 24 hours of operation. The width of the trap can be reduced to 2.5 m and its length to 20 m, if we aim at trapping only 20 % of the total load (i.e. particles of 65 µm and greater). Remember that these figures are only valid for a discharge of 100 l/s. The trap would completely fail during rises.

Since the particles are so extremely small, a special treatment of the contaminated water is necessary. Settling time and settling efficiency can be improved by adding flocculants. The flocculants attach themselves to the suspended solids forming fast settling agglomerates of particles. This is the only method to bring smaller size fractions of suspended solids to settle down. Generally, flocculants are synthetic, water soluble, high molecular weight, organic polyelectrolyte polymers. Most of them hydrolyze and degrade naturally, however, potential adverse environmental effects are an issue. Sedimentation tanks using flocculants can be designed much smaller. According to Jadair® Inc. (1991), polymer cost per ton of finished or washed product amounts to US $ 0.02 - $ 0.10. The use of flocculants is a viable solution for the clarification of a controlled amount of polluted water. Adding flocculants makes sense in the clarification process of diverted stream water that lubricates and flushes stone crushers or that is used in sand washing plants. It does not resolve the problem of the direct contamination of the Reventado through the operation of heavy equipment in the stream bed and the washing of sand in the stream.

Figure 2.5: TRAPØ Input-Output Data, Scenario
'Trapping 50 % of Process Water Sediment Load'

WORKSHEET FOR COMPUTATION OF SETTLING OF SEDIMENTS IN A SANDTRAP.

Author: Nils Olsen Changes: O. Jimenez Date: 01/11/93

INPUT DATA

The following parameters must be given by the user:

Project : Ventanas-Garita

Flow :	0.01	m3/s	
Depth:	1.5	m	
Width:	3	m	
Mannings-Strickler:	60	=(1/n)	
Grainsize:	8E-06	m	
Sediment discharge:	1	kg/s	
Alpha:	0.11		Coeff. for turbulent diffusivity
Delta-X:	6.25	m	Length of elements
Kappa:	0.39		Von Karman constant

Note: Total Length of Sandtrap: 16*(Delta-X)

DATA FOR BED CHANGE COMPUTATION:

Time Step 86400 s Porosity: 0.4

OUTPUT DATA

This is the output of the program. Note that iterations are neccessary to get a converged solution. Use the F9 button.

CHART 2: CONCENTRATION PROFILE AT INTAKE AND OUTLET
CHART 3: COMPARISON BETWEEN COMPUTATION AND THEORETICAL ROUSE DISTRIBUTION
CHART 4: BED PROFILE OF DEPOSITED SEDIMENTS

Trap efficiency: 0.94096 Note: Efficiency should be larger than
Length: 100.00 98% for design particle

Flow (m3/s):	0.01		Part. Reynolds N.	0.001
Velocity:	0.00222	m/s	Crit.Shear (kg/m2):	0.00609
Hyd. Radius (m):	0.75		T*(Van Rijn):	0.001
Energy slope:	2E-09	5E+08	D*(Van Rijn):	0.20234
Bottom shear:	1.5E-05	kg/m2	a (m):	0.0150
Shear velocity:	0.00012	m/s	C(bed,m3/m3):	4.1E-10
Z (Rouse exp.):	1.21131		Trap efficiency:	0.94096
Diffusion coeff.:	1E-05	m2/s	Length:	100.00
Equiv. Roughness:	0.00662		Beta factor:	1.44634
Fall velocity:	5.7E-05	m/s	Co(m3/m3):	0.03774

Figure 2.6: TRAPØ Concentration Profile at Intake and Outlet, Scenario
'Trapping 50 % of Process Water Sediment Load'

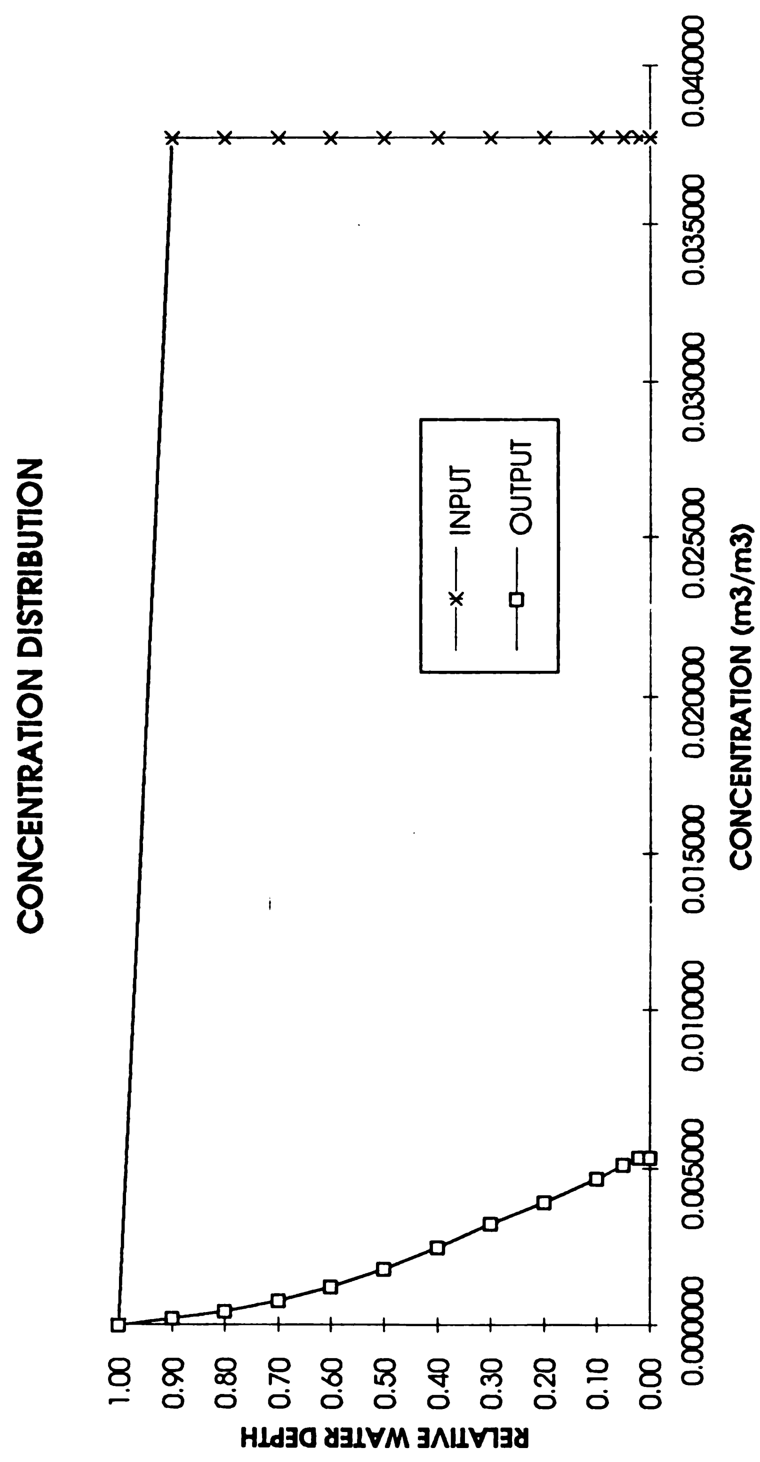
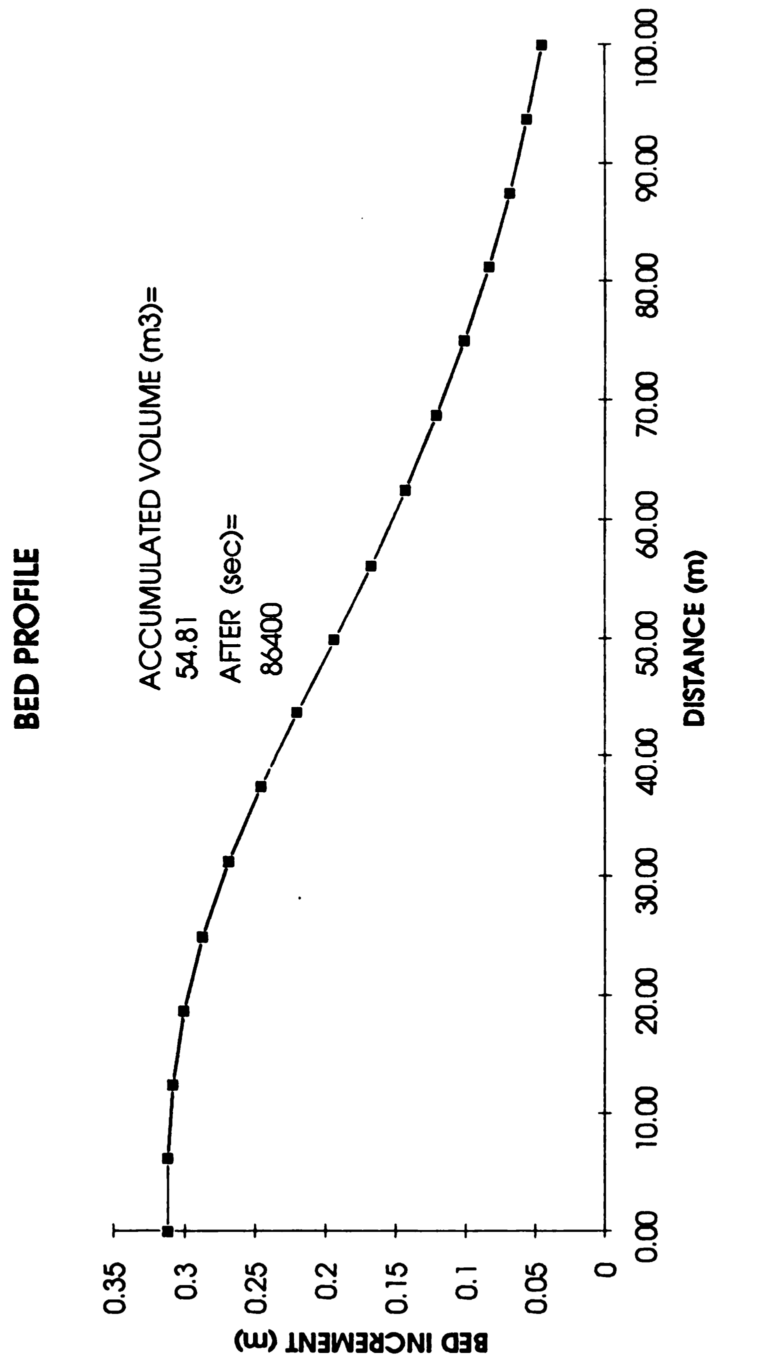


Figure 2.7: TRAPØ Bed Profile of Deposited Sediments, Scenario 'Trapping 50 % of Process Water Sediment Load'

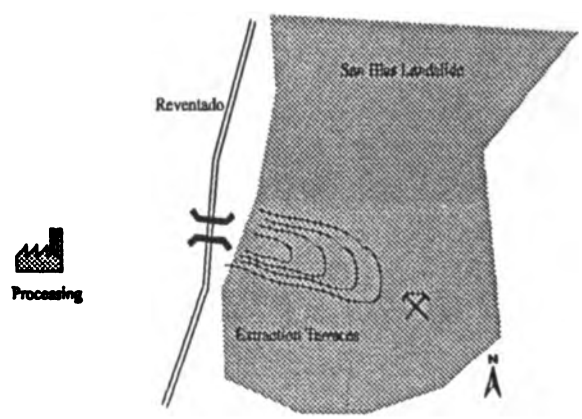


III Solution for Quebrador Ochomogo

As illustrated above, constructing regular sedimentation ponds is not the appropriate means to achieve a reduction of the pollution in the Río Reventado. A real improvement must be based on a cut of both the direct and the indirect contamination. Due to the characteristics and the discharge regime of the stream, it is impossible to clarify the entire stream with reasonable financial and technical efforts. Thus, concerning direct contamination, we have to turn our attention to preventive measures. Is a completely dry extraction possible? Can the washing process take place in a controlled environment?

Holderbank S.A. consultants examined the optimization potential of Quebrador Ochomogo in 1994 (see Final Report, Chapter 4.2.2). The recommendations made aim at increasing the independence of the extraction process from limiting natural factors and at improving product quality. The main obstacles to an optimized process are the unpredictable nature of the San Blas landslide and of the Río Reventado. Thus, measures are suggested to control the landslide movement which, at the same time, are designed to guarantee a continuous extraction process and independence from the water stage of the Reventado. These measures result in a reduction of the stream contamination, as the entire extraction process is relocated and reorganized. Currently, the operations take place at the foot of the San Blas landslide in the stream bed or immediately to the left of it. In order to control the movement of the landslide it is suggested to cut a big trench into the landslide which runs perpendicular to the main direction of its movement. Other measures, such as drainage and runoff acceleration, should support its detainment. Starting from the trench, landslide material is mined using terraces. The Río Reventado is left untouched, the extraction is dry. A bridge connects the left side of the river, where the material is extracted, with the right side, where the material is processed. Figure 3.1 outlines the plan.

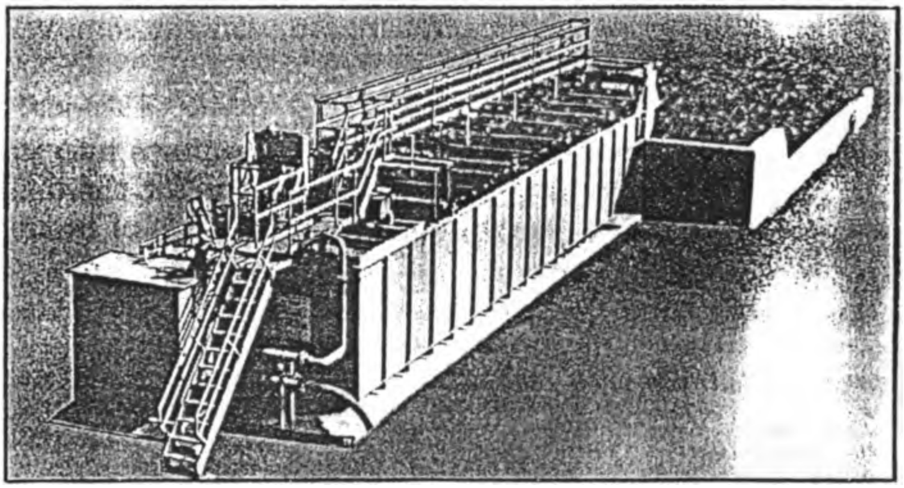
Figure 3.1: Dry Extraction, Concession Quebrador Ochomogo



The switch to dry extraction will considerably reduce sediment load. The second step is to transfer the sand wash process from the stream to a controlled environment where the process water is clarified and reused. More than a year ago, Ochomogo took a sand wash plant into operation that allowed to cut sand washing in the stream by 50 %. The sand wash plant is part of the optimization plan improving product quality and increasing independence from the variable stream discharge. Currently, its process water is clarified in a sedimentation pond that needs to be recharged once a week. The pond must be dredged regularly and the deposits are disposed of at the concession site. The sedimentation pond is operated without flocculants. Settling is inefficient and very slow. Several typical problems have been encountered resulting in high cleanout, maintenance and handling costs. The material deposited has a very high water content and is difficult to remove from the pond. Due to its composition and condition ('slime'), it cannot be used for other purposes and has to undergo a dewatering treatment before it is discarded.

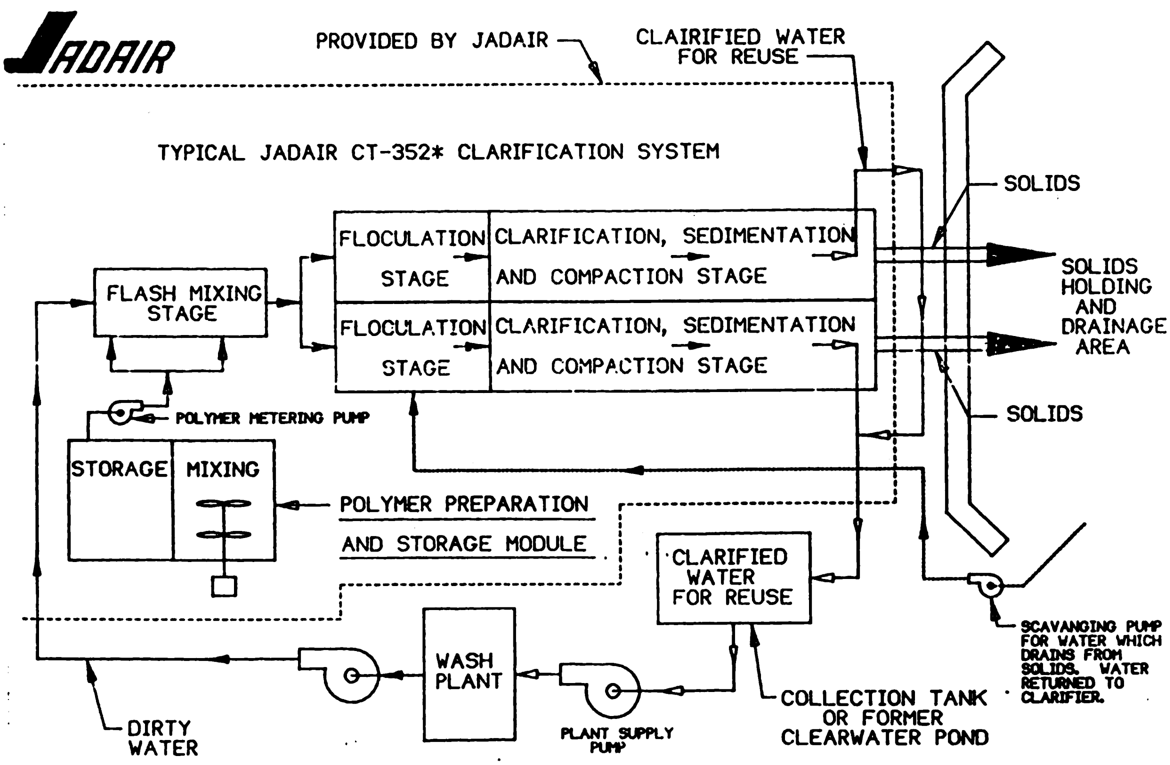
These problems can be solved using wash plants with integrated closed loop water clarifiers which eliminate the need for ponds. Quebrador Ochomogo is investigating the possibility of employing such systems. Among others, Jadair® Inc. offers a module based dual stage compact clarifier system (Picture 3.1).

Picture 3.1: Jadair® Water Clarifier Module



This compact module can be placed next to the wash plant and is easily integrated providing a closed loop process water system. It is available in nominal capacities of 300 - 1,500 gallons of polluted water per minute (approximately 20 - 90 l/s). However, thanks to the modular nature, expansion is no problem. The main advantages are that no settling ponds are needed and that the deposits have a low water content. Flocculants (polymers) are added to the polluted water which is clarified in two stages. The solids are removed in a thick 'cottage cheese like' form by a flight drag conveyor and are deposited to further dewater. Figure 3.2 shows the flow chart of the clarifier system which would guarantee Ochomogo (almost) complete independence from the Reventado water.

Figure 3.2: Wash Plant with Closed Loop Jadair® Clarifier



The solids from the clarifier are easily handled due to their low water content. In the U.S., the material has been used for various purposes: for manufacturing bricks, as specification cover for garbage landfills, and other fill applications. Mixed with screened overburden, they were even sold as topsoil (Jadair® Bulletins and Ads 1988-94). An economic cost benefit analysis for the installation of a water clarifier at Quebrador Ochomogo was beyond the scope of this report. According to Jadair®, the benefits outweigh the costs by far. Indeed, the advantages of a compact closed loop system are manifold and the contamination of the environment would be reduced considerably. Potential products and markets for the solids in Costa Rica could serve as additional incentives for the company to install such a system. A cooperation of several institutions is aimed at, so that a viable solution for Quebrador Ochomogo will be implemented that reduces both

the risk of a hazardous event due to the landslide and the contamination of the environment. There is no guarantee that the measures suggested lead to the definitive detainment of the landslide. However, based on the existing knowledge, the solution outlined above seems to be a reasonable compromise that accounts for security concerns of the people, the interests of the mining company, and environmental concerns.

IV Conclusions

The reduction of the sediment load in the rivers of Costa Rica should be a matter of national concern. Both point sources and non point sources of suspended solids must be addressed for several reasons: The fertility and productivity of important agricultural areas are at stake, the siltation of hydroelectric dams causes economic losses, and environment as well as life quality suffer severe damage. We need the cooperation of all people and institutions concerned including, among others, ICE, MIRENEM, MAG, the mining industry, the farmers, and people's groups. We further need leadership and long-term thinking. If Quebrador Ochomogo is willing to assume this role in the mining industry, new standards will be set for Costa Rica and others must follow. Eventually, the impacts will trickle as far down as to the level of manual extraction. Hopefully, the parties concerned will focus on the many goals they have in common and cooperate in an atmosphere of constructiveness. Then, changes are coming about.