FINAL REPORT

RIVER CATCHMENTS AND MARINE PRODUCTIVITY IN TIMOR LESTE
(AN ATSEF PROJECT)
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1.0 Overview

There is considerable concern within Timor Leste that upland land use practices have led to marked increases in erosion and landslides with a subsequent increase in sedimentation and nutrient pollution in waterways, estuaries and the adjacent coastal zone, however no scientific studies had been done to evaluate this hypothesis.

This report is a final report for the River Catchments and Marine Productivity in Timor Leste pilot project. The central tenet of the project is to verify concern that river catchments, especially upland land-use practices, have resulted in serious erosion with subsequent increases in downstream sedimentation and coastal sediment deposition in embayments. In addition, a second pilot project is proposed for the Caralun catchment with the expectation of a 3-year proposal briefly outlined here and can be formulated in finer detail after the second pilot phase to better understand cause & effect, and to develop management strategies and appropriate techniques for their implementation to alleviate adverse effects of catchment land practices. The Project site is in Manatuto District, centred on the Laclo River system. Scientists from Australia and Timor-Leste have carried out field visits/work for information exchange/gathering in a methodical approach to understand the biophysical and social elements of the Laclo River system.

The identification of social capital for potential change in land-use management was explored through community consultation meetings held in various sub-districts and villages. Preliminary qualitative surveys through community consultation for economic drivers of current land-use practices were also explored. Biophysical sampling of topsoil in the catchments was also carried out to “fingerprint” catchment soil and its transport downstream as river sediment, and finally as coastal embayment sediment accumulation.

This pilot project is an initial study of the effect of land use practices on river and coastal productivity of the Laclo river system in Timor Leste. The study explores management options to minimize degradation of natural resources in this catchment and coastal systems including

Figure 1.1: Laclo and Caraulun Catchments, Timor Leste
contaminants to the adjacent seas. The focus of this study is to confirm the level of amelioration of human impacts in the restored catchments in order to formalize sustainable management plans, particularly with regard to protection of the catchments, conservation and optimal management of living resources, and social and economic impacts.

Findings from this study provide the community and the government with reliable information on actions and consequences that will serve as the base for advocacy and policy formulation. Awareness was raised in the community and Government to understand the technical dimension of the environmental and social issues. This was complemented by the formation of a community advocacy groups to inform this project of their views of environmental processes and social values and policies pertinent to land use and natural resources extraction. Through the involvement of community and government in this process have established linkages between community advocacy groups and relevant government entities.

2.0 The Laclo River Catchment and Adjacent Coast
The Laclo River catchment lies on the northern side of the median mountain range of Timor Leste (Fig 2.1). The catchment has an area of 1386 km² and a maximum elevation of 2300m above sea level.

The rocks of the Laclo catchment fall into three main groups (Audley-Charles, 1968):
Aileu Formation - Permian age shale, phyllite, and some metamorphosed volcanic rocks. The rocks are highly deformed and metamorphosed near the northern catchment boundary.
Metamorphism declines southward where the Aileu Formation grades into the Maubisse Formation.

Maubisse Formation  Permian dense limestone, tuff and basic volcanics

Lolotoi Complex  pre-Permian phyllite, schist, and mettababbro.  This is a folded sequence of metamorphosed sedimentary and volcanic rocks.

Aitutu Formation  Triassic shale, calcareous shale, calcilutites, calcarenite, and quartz sandstone that have been folded at many different scales.

The soils of the catchment have been classified according to the FAO scheme (Faculdade de Arquitectura and GERTIL, 2002). The most widespread soil type is the Cambisol, a soil with moderately differentiated horizons and of agricultural value. The Cambisols occur on the Aitutu Formation, the Lolotoi Complex, the Maubisse Formation and a small part of the Aileu Formation. Over most of the Aileu Formation are both Cambisols and Acrisols, the latter being an acid highly weathered soil which often presents formidable challenges to agriculture because of the high toxicity of aluminium released by high acidity. There are also area of Vertisols, particularly on the Aitutu Formation. These soils have weak horizonation, are clay rich and are difficult to cultivate, because of their shrink/swell behaviour. Along the major rivers are bodies of alluvium that have undergone slight soil formation to produce Fluvisols. They are widely used in the catchment for paddy.

The hilltops of the catchment are generally steep, often reaching 30°. Hillslopes on the Lolotoi Complex are consistently steeper than elsewhere in the catchment (Faculdade de Arquitectura and GERTIL, 2002). Small floodplains occur along the major rivers, and hillslopes usually directly adjoin the smaller river channels that are not flanked by floodplains. Sediment eroded from hillslopes can therefore easily reach the rivers where there are no intervening floodplains. The rivers almost all have gravel beds that are braided. Gravel fragments are sub-angular to angular and are usually less than 10cm on their intermediate axis. Braided reaches on the Laclo River are the widest, reaching a maximum of 1.2km.
The modern vegetation has been altered by clearing, firewood collection and burning. The assumed original vegetation of the catchment was: thorn forest in a coastal strip from Manatuto east; dry deciduous forest over most of the lower hills and valley floors; and moist deciduous forest and semi-evergreen rainforest at higher altitude (Sandlund et al, 2001). Evergreen rainforest only occurs south of the central range where rainfall is higher than north of the range.

The already degraded forests of the catchment have been even more degraded in recent decades (Bouma and Kobryn, 2004). Forest and dense forest (dry deciduous forest and moist deciduous forest) in Aileu and Manatuto Districts changed slightly between 1989 and 1999 but degraded woodland (dry deciduous forest) significantly increased. These changes occurred after significant deforestation during the Indonesian period, and the removal of large numbers of commercially valuable trees during the Portuguese period.

Annual precipitation along the north coast is 591 mm at Manatuto rising to 2000 – 3000m in the highlands. The wet season on the north coast occurs between November and March. In the highlands, the wet season is longer, lasting between October and April (Asi a Development Bank, 2004).

The Pitman hydrological model has been used to estimate the mean monthly and annual runoff for the major rivers of Timor Leste. The annual estimate for the Laclo River is 918 x 10^6 m^3 (708 mm/yr) with a peak monthly runoff value in March (Asian Development Bank, 2004). This model result is consistent with the seasonal flows for a gauging station on the Laclo River where the catchment area is 1297 km^2 (http://www.gov.east-timor.org/MAFF/ta300/ta302Monthly%20Streamflow.pdf). The March mean monthly flow for the period 1952 to 1974 was 20m^3/sec.

The Laclo River has not formed a delta, unlike a few rivers on the north coast and most on the south coast. The absence of a delta is presumably because the offshore slope is very steep, and sediment has not accumulated sufficiently to reach the water surface. Ten
kilometres from the mouth of the Laclo River, water depth is 2000m; a gradient of 1m in 0.2m at a near-constant slope. For comparison, water depth 10km from the mouth of the Caraulun River on the south coast is only 500m. The Caraulun River has built a delta, even though the wave climate on the south coast is much more energetic than on the north coast.

Along the coast between Dili and Manatuto, the intertidal zone is composed of sandy beach with rocky outcrops, and most the shallow subtidal zone (Figure 2.2) is composed of fringing coral reefs; there appears to be little live coral cover in many areas. Most of this relict coral is covered with at least five species of seagrass and seaweed (dark patches in photo) that appears to be the location of subsistence fishing by villagers. Mangroves occur in patches along the north coast, especially at Metinaro where the total mangrove forest area is estimated at 24 km².

During the dry season a sand bar forms across the mouth of the Laclo River, and the river’s baseflow is directed to a fast-flowing channel on the western side of the bar. During the wet season the bar is not present, and large flows produce turbid plumes that move eastward.

### 2.1 Tectonic Setting

Timor Leste and West Timor are the deformed northern margin of the Australian continent (Karig et al, 1987; Harris et al, 2000) resulting from collision between Australia and the Banda Arc (i.e. the line of volcanic islands that extends from Java to Wetar). Timor has been uplifted above sea level very rapidly during the Pliocene-Quaternary (i.e. the last 5 million years, Ma). Rates of vertical uplift of the land are spatially highly variable, but broadly the rates are similar to the pattern of relief across the island and the adjoining ocean basins (Karig et al, 1987).

Uplift is also occurring at the deformation front, just offshore on the south coast,. Further south, subsidence dominates in the Timor Trough. Uplift at the deformation front is several mm/yr (Karig et al, 1987). Over the last 2Ma, uplift in the Maubisse nappe has been between 1.2 and 2mm/yr, and further north in the Aileu Formation exhumation rates (the combination of uplift and denudation) over the last 5.5Ma has been very fast at 3 to 5mm/yr (Harris et al, 2000). Raised Pleistocene coral reefs, on the north coast of Timor Leste between Hau and

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Figure 2.3: Dili to Manututo typical coast line
Lautem, have been uplifted over the last 200,000 at an average rate of 0.5mm/yr near Hau falling to zero near Dili where there are no raised reefs (Chappell and Veeh, 1978). In West Timor, reefs have been raised near Kupang at 0.3mm/yr during the last 150,000 yrs (Merritts et al, 1998).

On the north coast of Timor Leste, uplift within the recent past is not evident west of Hau (see above), although over the last 5.5 Ma uplift in the adjacent Aileu Formation has been rapid. The steep cliffs and steep offshore gradient along this part of the coast imply a major fault and therefore subsidence offshore.

Much of the Laclo River catchment is therefore undergoing rapid uplift, at several mm/yr. In such a system, natural erosion rates are very high, involving downcutting by rivers and rapid erosion of steep hillslopes. This should be a system in which physical erosion processes (landslides, river downcutting, sheet erosion) dominate and the release of fine-sediment by erosion of weathered rocks is minimal.

3.0 Community Consultations

Each community consultation began with welcomes from local administrators and other government officials. Then an introduction by Narcisso Almeida de Carvalho (Director Fisheries, Ministry of Agriculture, Forests and Fisheries, Government of East Timor) set the boundaries of our investigations. He stressed our interest in erosion and river sediments, nutrients and the possible link between coastal fisheries and export from the river of sediments and nutrients. He then made it clear that we wanted to hear the views of the local people, and that these views would help MAFF develop management policies.

The introductions and audience input was almost all in the Tetum language, although some local languages were also used. The discussion was translated into English for the benefit of the Australian contingent, and notes taken simultaneously with the translation. When points made by the community were either not clear or required further investigation, member of the investigating team from MAFF or Australia would ask a question. Also, important matters raised at an earlier consultation were tested on later groups. For example, the idea of a commemorative ceremony to ‘lay to rest’ the souls of the dead in the catchment arose at Laclo but was tested at each subsequent meeting; and the observation raised at the Manatuto meeting that the Laclo River is widening and shallowing was tested at every other meeting.

Meetings were held as follows:

- Manatuto 26th September 2005 – lowlands
- Laclo 27th September 2005 – lowlands / low hills
Aileu  8th September 2005 – uplands
Liquidoa  29th September 2005 – uplands
Remexio  29th September 2005 – uplands

The groups included farmers, fishers, small business men, village chiefs, and government officials. Only two women participated in all of the meetings despite invitations. At the Aileu meeting, only government officials were present because of a misunderstanding about the time of the meeting. As a result, villagers had gone home before the meeting began. Nonetheless, the government officials had wide experience of this area.

Figure 3.1: Community consultation(Manituto)

Manatuto Meeting (21 people)

- Laclo River and Sumasse River are different colours during the wet season, and the Laclo flows improve productivity of paddy and fisheries more than flows from the Sumasse River.
- The Aileu river has year round flow, and contributes the major source of river flow during the dry season. Other tributaries such as the Labutto and Sumasse rivers (Laclubar) are non-perennial.
- Sumasse River has widened since one man’s grandfather’s time. Fields now stranded in floodwater during the wet season. Rimbor settlement has become an island in the river channel.
- Laclo River has widened in its lower part by about 100m in about 45 years. Deep water often strands people on riverbanks.
- Good fish catches are found at the mouth of the Laclo River in the sea, including mackerel and Spanish mackerel.
- Immediately east of the Laclo River mouth, the shore has receded by about 300m in a lifetime and former rice land has been lost.
• Laclo riverbed has been rising since 1985 when the bridge at Manatuto was built. Floods now nearly reach the bridge roadway. Estimated rise of riverbed is 1.5 to 2 m between 1985 and 2005.
• Shifting agriculture is the primary cause of erosion and poor water quality.
• Increased agricultural activity in the uplands has increased the amount of river sediment downstream. How can the upland farmers be informed of their effect and impact?
• Traditional management (tarabandu) applied to well defined parts of the area. This system was disturbed during the Indonesian period, and the local people want to re-establish it including the festival that begins the prawn season.
• Fish and prawns (baixaon) are very important to the local people. Mostly caught within 100m of the shore after the wet season. Some fish caught in mangroves. The prawns (two species) are subject to ritual management of the Manatuto based Sau clan and appear in numbers after the main wet season. People have observed a decline in the abundance of the prawns since the 1960s.
• Large fish were easily caught 30-40 years ago but this is no longer the case.
• The people of Aileu want to be able to claim the benefits of fishing at the mouth of the Laclo River because the river begins near Aileu. The people of Manatuto disagree arguing that the river is replenished by springs along its channel.
• Paddy fields on the margin of the Sumasse River are being eroded at about 5m/yr at Rembor.
• Burning is for hunting, new grass, and is sometimes accidental. During Indonesian period, areas around military camps were burned.
• Mangrove fishing for grouper, snapper, lobster, crab and mangrove jack.
• Conflicting community views on the source of the annual arrival of river prawns.

Laclo Meeting (28 people)
• Laclo River near Laclo has widened in the last few decades. Before 1960 the river was about 50m wide, and after 1960 about 300m wide, quite destructive and difficult river to cross during floods. Described as running like a cicak. People would like to reduce the scale of flooding.
• Concern that shifting agriculture is causing erosion and more sediment in the river. But there is also the recognition that people have to live and it will only be through improved upland agriculture and production that shifting cultivation practices will change.
• River floods and erosion have increased following the killing of combatants during periods of warfare. Many bad deaths (Tetum: mate mean -red deaths) occurred in
the area including one particular atrocity against the Japanese during Second World War and reprisals against Timorese during the Indonesian period. A ceremony is essential, and a monument, to acknowledge the deaths and resolve the spiritual suffering that contributes to the ‘wildness’ of the river. Need to link upland and lowland communities in this activity.

- Hunting and the associated practice of burning the grasslands to flush out game is now widely reported within the catchment but is traditionally practiced in the neighbouring Laleia watershed.
- During Indonesian times there was extensive burning of the catchment grasslands and forests, especially by the Indonesian Military in their efforts to curtain and restrict the activities of Timorese armed resistance groups. Subsequently the practice of burning off has become much more commonplace in recent years.
- Among local Galolien speaking communities there is a widespread practice of public sanctions against burning, known as bandu rea (in Tetum bandu rai – land prohibition). People are enjoined not to burn and if they are seen to do so they are subject to fines and social opprobrium.
- Mention was also made of the increased sediments below the Manatuto bridge and the concern that unless the gravel was cleared the river could flood over the bridge this wet season. Another example of increased sediment loads is a settlement in Laclo located beside the river that was formerly sited above the river flow but is now actually below the river channel and threatened by flooding.

**Aileu Meeting (10 people)**

- During the Portuguese time there were many cattle, and many trees were cut down during the Indonesian time. Major erosion occurred after the tree cutting.
- The river widened after the tree cutting from about 4m to 10m.
- Need to re-vegetate the riverbanks and not cultivate close to the river.
- There are many sources of impact on the river, including; lowland agriculture, deforestation, gravel and rock collection from the riverbanks, shifting agriculture and burning by increasing the amount of sediment in the river.
- Causes of burning were listed: lack of knowledge about its effects; lack of control of what was meant to be a small fire; hunting; discarded cigarettes; good grass for cattle; make firewood collection easier.
- Many gullies (hoda’an in the Mombae language) appeared during Indonesian time, but there were some earlier during the Portuguese time.
- Increasing population has led to more houses along the river and small landslides (bahoa in the Mombae language) along the river.
• If the leaders of the traditional management system (tarabandu) break the rules, how can they be punished?
• Trying to re-establish tarabandu, but there is a problem of defining village boundaries.
• There was no commercial logging in this area during the Portuguese time, and strong traditional methods of management persisted. How can these be re-established after disturbance during the Indonesian time?
• Most income for shifting agriculturalists comes from firewood collection to support families. So preserving trees is difficult.
• Burning is the result of human attitudes
• How can incomes be maintained while conserving and solving problems? How can the community be made to understand the importance of forests? How can the community be helped to reafforest and fertilize the land by using tree legumes. How can an integrated program be developed?
• There is conflict over water, for paddy or fish
• The major focus of upland people is income. But upland people are prepared to cooperate to help solve the problems of lowland people but do not know what to do.
• A small area in the uplands could be used to demonstrate the benefits of integrated forest and agricultural management.
• Tarabandu is village-based but should also be at the district level for management of rivers. Traditional links between the people of Aileu, Laclo (Illimanu) could help to establish district-level tarabandu. But these links have not been active for 50 years.

Liquidoa Meeting (17 people)

• Organic fertilizers were used on cultivated areas before the Indonesian period. Indonesians introduced chemical fertilizers and pesticides. Now only organic fertilizers are used, and productivity has fallen.
• Many trees were removed during the Indonesian period. Springs have dried up. Small rivers no longer flow during the dry season. Some people now have to walk 1 to 2 hours to get water from the large river.
• Deforestation of about 80% of the area during the Indonesian time. Gullies developed which continue to get deeper and grow upslope.
• Deforestation was followed by growth of Cromolena which kills everything underneath it and makes erosion worse. Also, not much grass for cattle as a result.
• Very interested in ways of stabilizing gullies.
Laclo River has widened from about 20m to 100m in Suco Faturileu. This widening of the gravel part of the river has caused the erosion of paddy along the river edge. Also some river deepening, has destroyed an irrigation canal.

- Gullies near roads are difficult to control, and roads are very important. Revegetation of gullies away from roads maybe possible.
- Burning has stopped since 2003 because the community has decided that it is damaging, although some people in distant places still burn for hunting.
- The cessation of burning is based on tarabandu with community, church and government support.
- Tarabandu means many things: not to burn, not to steal, when to burn and fish and how much, how much timber to collect, not to graze other people’s land, etc; all of which reduces social conflict.
- Communities in different villages communicate and distribute ideas and information.
- Upland farmers understand the effect on the lowlands of their activities. For example; river water at Manatuto in the Laclo River comes from their land; erosion from the uplands goes downstream and adds sediment to rivers.
- Erosion of the uplands is worse in some areas and it is here that water is scarce.

Remexio Meeting (26 people)

- Shifting agriculture in the uplands may have the largest impact in this area.
- Shifting agriculture is producing less and less, and rotations have in some places stopped.
- Rivers are getting wider and deeper in this area, but cannot estimate the amount of change. This is not a very important issue for this area.
- Many coffee trees die after planting
- How can people be protected from changes of rivers? And how can agricultural productivity be improved?
- Worried about erosion on steep slopes.
- Do not want to cut down any more trees, and need advice on planting
- Water and sediment in small rivers accumulates to erode riverbanks and widens the river. Upland people are worried about disasters downstream caused by the river. Must start planting trees now.
- Deforestation during the Indonesian period was by local people and by Indonesians.
- Fish and prawns have gone from the local river.
- Many cultural practices stopped during the Indonesian period and more natural disasters have resulted.
- Keen to develop tarabandu across the area.
• Tarabandu is unequally applied in various sub-Districts. More regional tarabandu is needed so that, for example, burning in one area does not affect another area.
• Perhaps tarabandu should be based on a legal agreement.
• A river catchment tarabandu agreement ceremony should be held in the river in the centre of the catchment so people from all over can participate.
• Do not want to burn, but some will probably happen.
• How will tarabandu work and who will be responsible for it?
• A problem for burning bans is knowing where land borders occur.
• Most natural disasters not human made so how can they be controlled?
• When the price of coffee increased, people stopped growing vegetables. This is a problem.
• Also want a ceremony to honour the dead of the Second World War and Indonesian period.

4.0 Key Issues raised during Community Consultations

The messages provided by the community consultations (Section 3.0) have been analysed and grouped in various ways in what follows. Each major grouping is now considered by drawing upon both the results of the consultations and the observations and analyses of the research team.

4.1 Land Use, Deforestation, Erosion and River Sedimentation

A long-standing issue of concern in Timor Leste is deforestation, land use, soil erosion, river sedimentation and nutrient pollution of rivers, estuaries and adjacent seas (e.g. Sandlund et al, 2001). As noted in the summary of the proposal for this Pilot Activity, scientific studies of these phenomena and their relationships have not been performed in Timor Leste. This section analyses this connected set of phenomena.

We begin by reviewing the results of the community consultations.

4.1.1 Key Messages from Community Consultation

The key messages relevant to the catchment are as follows:
• many trees removed during the Indonesian period, and also previously during the Portuguese period;
• major erosion occurred after tree cutting during the Indonesian period, including large gullies near Liquidadoe, but some gullies are older;
• deforestation was followed by Chromolaena odorata which kills everything under it, thereby worsening erosion. This has also made grazing for cattle difficult;
• shifting agriculture also is a major cause of soil erosion and poor water quality, along with (settled) agriculture, in the uplands;
• burning damages the land
• chemical fertilisers are needed to improve agricultural productivity in the uplands;
• some river channels in the uplands have deepened, while downstream there is general agreement that the rivers have widened;
• at Manatuto, the bed of the Laclo River is accumulating sediment and is getting higher. It has aggraded by 1.5 to 2.0m in 20 years (average rate of 7.5 to 10cm/yr);
• in a few places the river has deepened;
• estimates of widening are: 100m in ~ 45 years in the lower Laclo, 5m/yr at Rembor and on the Sumasse River, 6m/yr near Laclo on the Laclo River, five times increase of the Laclo River width in Suco Faturileu;
• paddy fields along the margins of the large rivers are being eroded as the river widens; irrigation canals also being damaged; and
• after tree removal during the Indonesian period, springs in the uplands dried up and small rivers no longer flow during the dry season. Some people now have to walk 1 to 2 hours to get water from a large river.

4.1.2 Interpretation of the Key Messages
There are four groups of key messages that are coherent linked sets of ideas. The linking was done by the local people during the community consultations, rather than by retrospective analysis by the research team. The groups of linked ideas are:

a) Deforestation during the Indonesian period led to: serious erosion, particularly by gullying and some landsliding; small channel deepening and widening in the uplands; accumulation of gravel in the larger rivers and channel widening; erosion of paddy fields and floodplains; damage to irrigation canals; greater flooding downstream; and more difficult passage across rivers during the wet season. Shifting agriculture and burning also contribute to upland erosion.

b) Deforestation has led to the cessation of both spring flow and dry season flow in the small upland rivers. Water is now much more difficult to acquire, requiring long walks to and from the large rivers during the dry season.

Figure 4.1: Chromolaena odorata (Siam Weed) (http://www.ehs.cdu.edu.au/chromolaena/siamhome.html)
c) On grazing land, deforestation was followed by invasion of the Chromolaena odorata weed which suppresses all ground vegetation. Cattle suffer and erosion increases.

d) Chemical fertilisers were available during the Indonesian period but are not now. Productivity has declined and fertilisers are needed again.

Given the purpose of this report, we will focus on group #1 and provide some minor comment on the other groups.

4.1.3 Deforestation, Erosion and Channel Change - Observations

This set of linked ideas was also identified during consultations by Sandlund et al (2001) as one of the major environmental issues perceived by the rural population. Watershed (catchment) management (including deforestation, erosion and flash floods) is perceived as a major environmental issue by District and National administration officers. Deforestation is also an issue for the urban population, but mainly because of the prospect of running out of firewood.

During field traverses, evidence was found for widespread sheet erosion, on both grazed land and on land used for shifting agriculture, in the form of soil accumulations upslope of grass tussocks, rocks, and pieces of wood lying on the ground. Deep gullies also are common, especially on the Aileu Formation in the uplands. Shallow landslides (<1m deep) occur, and a few deep (>1m deep) landslides. But they are not as common as claimed in some reports. Riverbank erosion along the large rivers is clearly evident as fresh scars on fine-grained floodplain margins. In the uplands, small channels are actively undercutting their high banks, especially near Aileu.

The local people are very clear that erosion worsened after deforestation during the Indonesian period. Deep gullies and landslide scars near Liquidoe are said to have occurred after deforestation although they observed that some gullies pre-date deforestation. Certainly this area is currently experiencing serious gully erosion. Evidence from elsewhere supports the idea that erosion increased after deforestation (e.g. Liebault et al, 2005). The local people link widening and aggradation of the major rivers to the increased erosion in the uplands. This is supported by experience from elsewhere (Liebault et al, 2005), and by a
qualitative model of channel change drawn from sites in several countries (Schumm, 1969). In this model, an increase of channel width, decreased channel depth, increased width/depth ratio, increased channel slope, and decreased channel sinuosity if the channel is free to adjust its planform. This model however, needs to be treated cautiously because an increase of bedload is usually accompanied by increased discharge for which we have no evidence in the Laclo catchment. But increased discharge can increase width and depth, and decrease channel slope. The empirical evidence from several countries of Liebault et al (2005) is, however, clear that deforestation increases erosion of steeplands and that channels widen and shallow when bedload amounts increase.

4.1.4 The Beginnings of a Sediment Budget for the Laclo River Catchment

While there is coherence in the views of local people about the links between deforestation, erosion, sedimentation in river channels, and export of material to the coast, there are differing opinions about the sources of sediment.

Varying emphasis is given to gullies, landslides and the sheet erosion of land used for shifting agriculture. Also, views are clear that sedimentation of rivers has led to their widening, causing erosion of riverbanks (mostly small floodplains) and therefore paddy fields along the river margins. But no views were expressed about sedimentation on floodplains, a possible means by which some of the (supposed) increased sediment load in the rivers is stored.

The way to reduce these uncertainties, and thereby provide the basis for properly targeted management, is to construct a sediment budget for the Laclo catchment. A budget could also be constructed for carbon and the nutrients phosphorus and nitrogen, all of which are important for primary productivity of the rivers and coastal waters, and, if in sufficient quantities, can be pollutants.

A sediment budget is a quantitative accounting of the sources of transported sediment in a river catchment, the distribution of the sediment in a catchment, and the amount that leaves the catchment at the downstream end. Figure 4.1 depicts the sources of sediment of the catchment into which transported sediment is deposited (known as sinks), and the export of sediment from the catchment (the yield) into the ocean.

Ideally, each component of the budget should be quantified so that the catchment system can be understood and managed effectively. If, for example, sheet erosion of hillslopes caused by shifting agriculture is identified as the major source of sediment reaching the Laclo River,
then a clear target for management has been identified if the amount of sediment in a river is to be reduced. Quantifying sinks can also be important for catchment management. For example, following an increase of sediment supply to a river, sedimentation can occur both in channels and on adjacent floodplains. If sedimentation on the floodplain is faster than in the channel, flooding will not worsen; assuming that the frequency and magnitude of floods does not change. If channel sedimentation increases faster than floodplain sedimentation, flooding can worsen.

Neither resources nor time were available in this Pilot Study to construct a complete sediment budget, however progress has been made in identifying sources, aspects of sinks, and yield.

**Sources**
Sheet erosion occurs on hillslopes and moves topsoil in the Laclo catchment. Sheet erosion occurs on all hillslopes, but is clearly evident on hillslopes where primary vegetation has been removed, where shifting agriculture is practiced, and on areas of permanent cultivation.

Topsoils contain, within the top 10cm or so, two radionuclides that can be used as tracers. A product of nuclear weapons testing, $^{137}$Cs, is one of these tracers. The other, $^{210}$Pb (excess), is the result of natural processes. (Wasson, et al, 1987; Wallbrink et al, 1998).

<table>
<thead>
<tr>
<th>Sources</th>
<th>Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet Erosion (hillslopes)</td>
<td>roads</td>
</tr>
<tr>
<td>Landslides</td>
<td></td>
</tr>
<tr>
<td>Gullies</td>
<td></td>
</tr>
<tr>
<td>River channels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colluvium (hillslope deposits)</td>
</tr>
<tr>
<td></td>
<td>Gully floors and fans</td>
</tr>
<tr>
<td></td>
<td>River channels</td>
</tr>
<tr>
<td></td>
<td>Floodplains</td>
</tr>
<tr>
<td>Yield (to the ocean)</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.3 Major Components of a Sediment Budget for the Laclo Catchment**

$^{210}$Pb is produced by radioactive decay of $^{238}$U. One of the intermediate decay products between $^{238}$U and $^{210}$Pb is $^{226}$Ra which produces $^{222}$Rn(radon) in soils. This gas decays to
$^{210}$Pb both in soils and in the atmosphere. The atmospheric fraction falls back to earth either during wet or dry deposition, and can be quantified in topsoils as the difference between total $^{210}$Pb and $^{226}$Ra. This atmospheric component is known as $^{210}$Pb(excess) and, because it occurs only in topsoils, it is a tracer of topsoil transport through a river catchment (Wasson et al, 1987).

If $^{210}$Pb (excess) and $^{137}$Cs can be detected in the fine (suspended) sediment of a river, then a measurable quantity of topsoil has reached the river by sheet erosion. If however no $^{210}$Pb(excess) or $^{137}$Cs can be found in river sediment, then processes other than sheet erosion dominate the delivery of sediment to the river. Because the topsoil tracers do not penetrate far into soils, erosion processes that mobilise large amounts of subsoil (which is not labelled by the radionuclide tracers) will deliver sediment to a river either poor in, or completely devoid of, the tracers.

The presence or absence of the topsoil tracers in the fine sediments of the Laclo River therefore allows identification of the importance of sheet erosion versus gullying, landslides and channel bank erosion as sources of sediment. In summary, the technique allows an answer to the question: is sheet erosion an important source of sediment in the Laclo River?

Four samples of the surface layer of topsoils were taken (Table 4.1). At Hera, topsoil moved by sheetwash has collected upslope of grass tussocks and pieces of wood. This sample has the highest concentration of $^{137}$Cs. At Sananai, small aggregates of mobilised surface soil have the second highest $^{137}$Cs concentration. $^{210}$Pb(excess) is highest at both Hera and Sananai where land use is restricted to grazing, timber collection, and burning. At Maubisse a steep slope, that has in the past been used for shifting agriculture, has detectable $^{137}$Cs and $^{210}$Pb(excess) in the 0-0.5cm surface layer. Also at Maubisse, an accumulation of soil on a creek-side bench is the result of wash from a cultivated slope above. The sample is from the top 10cm of the accumulation, and while both tracers are detectable the $^{137}$Cs concentration is very low; probably as a result of cultivation which has mixed soil from well below the surface, that is either poorly labelled or unlabelled by the tracers, with surface labelled soil.

![Figure 4.4: Deep gully erosion near Maubisse](image)
All analyses are for the <20μm fraction, except for ET3, 4, 5 which are for the <10μm fraction. ET3,4,5 were sampled in 2003, and the remainder in 2005.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location</th>
<th>$^{137}$Cs (Bq/kg)</th>
<th>$^{210}$Pb (ex) (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topsoil Samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ET11</td>
<td>Maubisse, cultivated field</td>
<td>0.99±0.64</td>
<td>21.9±5.2</td>
</tr>
<tr>
<td>ET12</td>
<td>Maubisse, uncultivated hillslope, secondary vegetation</td>
<td>1.4±0.6</td>
<td>19.7±5.7</td>
</tr>
<tr>
<td>ET18</td>
<td>Sananai, uncultivated, burned hillslope</td>
<td>4.0±0.8</td>
<td>136.8±6.1</td>
</tr>
<tr>
<td>ET34</td>
<td>Hera, uncultivated hillslope</td>
<td>7.3±1.0</td>
<td>134.6±8.2</td>
</tr>
<tr>
<td>River Sediment Samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ET3</td>
<td>Sumasse R., just upstream of Laclo R. junction</td>
<td>-0.02±0.06</td>
<td>-0.99±1.46</td>
</tr>
<tr>
<td>ET4</td>
<td>Laclo R. at Manatuto</td>
<td>-0.14±0.16</td>
<td>-0.82±3.0</td>
</tr>
<tr>
<td>ET5</td>
<td>Tributary of Sumasse River</td>
<td>0.19±0.16</td>
<td>-0.17±2.84</td>
</tr>
<tr>
<td>ET10</td>
<td>Small creek at Betfu, near Maubisse</td>
<td>0.38±0.46</td>
<td>-2.0±5.1</td>
</tr>
<tr>
<td>ET13</td>
<td>Mantane R., ~2km downstream of Aileu</td>
<td>0.43±0.88</td>
<td>1.80±5.94</td>
</tr>
<tr>
<td>ET14</td>
<td>Laclo R., at Manatuto</td>
<td>0.13±0.60</td>
<td>-8.70±3.40</td>
</tr>
<tr>
<td>ET15</td>
<td>Laclo R., at Manatuto</td>
<td>0.53±0.95</td>
<td>-1.50±4.68</td>
</tr>
<tr>
<td>ET16</td>
<td>Sumasse R., upstream of Laclo junction</td>
<td>0.01±0.49</td>
<td>-6.2±3.50</td>
</tr>
<tr>
<td>ET17A</td>
<td>Laclo R., upstream of Sumasse junction</td>
<td>0.27±0.61</td>
<td>-7.50±4.28</td>
</tr>
<tr>
<td>ET17B</td>
<td>Small creek, Sananai</td>
<td>0.29±0.47</td>
<td>8.50±3.88</td>
</tr>
<tr>
<td>ET19</td>
<td>Sumasse R., Sananai</td>
<td>0.47±0.55</td>
<td>-12.10±3.10</td>
</tr>
<tr>
<td>ET33</td>
<td>Susan River, Hera</td>
<td>0.05±0.70</td>
<td>15.30±8.13</td>
</tr>
</tbody>
</table>

Table 4.1 Topsoil Tracer Results

The Sananai sample also contains detectable amounts of $^7$Be, a short-lived radionuclide (half-life of 53 days) that shows this soil has received rainfall and therefore probably moved within the 100 days prior to measurement in January 2006. (Olley et al 1993).

The remainder of the analyses reported in Table 4.1 are for fine sediment in river channels of the Laclo catchment.

With the exception of a small creek draining the Lolotoi Complex at Sananai (ET17B) and a small river draining largely deforested hills at Hera (ET33), there is no detectable $^{137}$Cs or $^{210}$Pb(excess) in the Laclo River, the Sumasse River, or in the Mantane River. The small rivers, referred to above, include low levels of topsoil, based on a comparison of the
concentrations in the topsoil samples (ignoring ET11) with the river sediment concentrations. The Sample ET11, from a cultivated site, is ignored because permanent cultivation constitutes a very small proportion of the Laclo catchment (2% in Aileu District and 7% in Manatuto District, W.Langeraar pers. comm. 2006) and therefore is unlikely to contribute much sediment to the rivers. Small rivers are likely to receive topsoil because hillslopes are adjacent to channels given that there are no intervening floodplains (e.g. Susan River at Hera). Also, larger catchments include many more subsoil sources as gullies and landslides.

In addition, topsoil erosion cannot be the main cause of channel aggradation downstream because most of the channel aggradation is by coarse gravel. Topsoils do not contain much coarse gravel.

**Sinks**

It has already been noted that the bed of the Laclo River at Manatuto is aggrading; by 1.5 to 2.0m since 1985. Local people have observed aggradation elsewhere in the large rivers. Note that incision of rivers, in the uplands, spoken of at the Alileu community consultation, is not inconsistent with aggradation downstream.

Changes to runoff and valley-floor vegetation (and hence resistance to erosion) can lead to incision, the sediment from which accumulates downstream. The downstream channels are therefore sinks under current conditions.

Floodplains are another major (potential) sink. Within the resources available for the Pilot Study, only one floodplain site could be examined. At Malengreng (just downstream of the Manatuto bridge on the right bank) a section in the floodplain was examined.

The section is as follows:

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>grey-brown loam</td>
</tr>
<tr>
<td>10-30</td>
<td>grey-brown loam, slightly mottled</td>
</tr>
<tr>
<td>30-46</td>
<td>grey-brown loam, slightly mottled</td>
</tr>
<tr>
<td>46-65</td>
<td>grey-brown very fine sandy loam, some mottling</td>
</tr>
<tr>
<td>65-74</td>
<td>grey-brown loam, red-brown mottling</td>
</tr>
<tr>
<td>74-96</td>
<td>grey-brown loam, very fine sandy loam, red-brown mottling</td>
</tr>
<tr>
<td>96-111</td>
<td>grey-brown clay loam, red-brown mottling</td>
</tr>
<tr>
<td>111-120</td>
<td>grey clay loam, slight brown mottling</td>
</tr>
<tr>
<td>120-131</td>
<td>grey clay loam, few red-brown mottles</td>
</tr>
<tr>
<td>131-150</td>
<td>river gravels with a sandy matrix</td>
</tr>
</tbody>
</table>

*Table 4.2: Soil profile at Malengreng*
Each of the described units appears to be a single flood layer. The section coarsens slightly upwards, possibly caused by an increasing load of coarse sediment from upstream. This change may also be accompanied by an increased rate of sedimentation, which could be the result of upstream deforestation.

To test this hypothesis, samples in 10 cm slices were analysed for $^{210}$Pb(excess) from 0 to 130 cm. The results are shown in Table 4.3.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Depth (cm)</th>
<th>$^{137}$Cs (Bq/kg)</th>
<th>$^{210}$Pb (ex) (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET20</td>
<td>0-10</td>
<td>0.25 ± 0.71</td>
<td>-2.4 ± 4.2</td>
</tr>
<tr>
<td>21</td>
<td>10-20</td>
<td>0.42 ± 0.71</td>
<td>-0.8 ± 3.7</td>
</tr>
<tr>
<td>22</td>
<td>20-30</td>
<td>0.28 ± 0.54</td>
<td>-3.6 ± 2.9</td>
</tr>
<tr>
<td>23</td>
<td>30-40</td>
<td>0</td>
<td>2.0 ± 3.1</td>
</tr>
<tr>
<td>24</td>
<td>40-50</td>
<td>0.42 ± 0.71</td>
<td>-0.8 ± 3.7</td>
</tr>
<tr>
<td>25</td>
<td>50-60</td>
<td>0</td>
<td>3.1 ± 3.8</td>
</tr>
<tr>
<td>26</td>
<td>60-70</td>
<td>0</td>
<td>-1.0 ± 3.8</td>
</tr>
<tr>
<td>27</td>
<td>70-80</td>
<td>0</td>
<td>1.2 ± 3.4</td>
</tr>
<tr>
<td>28</td>
<td>80-90</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>90-100</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>100-110</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>110-120</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>120-130</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 $^{210}$Pb and $^{137}$Cs results for floodplain section at Malengreng for <20μm fraction.

The approach in this case depends upon detecting the atmospheric input to the floodplain site of $^{210}$Pb(excess). As the floodplain accumulates, $^{210}$Pb(excess) is deposited on its surface from rainfall. The nuclide also decays radioactively so that if there is no input of $^{210}$Pb from upstream (attached to particles deposited on the floodplain) then a negative exponential depth function of $^{210}$Pb(excess) will result. This can be used to estimate the age of sediments in the floodplain over about the last 100 years (half-life of $^{210}$Pb is 22.4 years).

However, there is no $^{210}$Pb(excess) in the floodplain sediment (Table 4.2). Also, there is no $^{137}$Cs. The nuclides $^{228}$Ra and $^{228}$Th were also measured in the 0-80 cm section. $^{228}$Ra is produced by radioactive decay of $^{238}$Th in the floodplain sediment, $^{228}$Th is in turn a decay product of $^{228}$Ra. The greater solubility of $^{228}$Ra compared to $^{228}$Th causes a disequilibrium between $^{228}$Th and $^{228}$Ra in surface sediment which disappears with depth (and therefore time) as $^{228}$Ra is produced and not removed from the soil by dissolution. This disequilibrium requires a permanent water body, such as a lake, as a medium to remove the surface $^{228}$Ra and to provide a reservoir of “excess” $^{228}$Th to be deposited on the surface sediments. If the floodplain water evaporates, the dissolved $^{228}$Ra may be deposited along with the already settled $^{228}$Th and no disequilibrium may therefore be evident. If disequilibrium does exist, the
production of equilibrium is fast, given that the half-life of $^{228}\text{Th}$ is only 1.91 yrs. No disequilibrium was found in the Malengreng floodplain, so the surface of this floodplain site is either older than about 10 years or the lack of disequilibrium is a product of the generally dry conditions of this site. The sediments at the surface of the floodplain may be at least 100 years old, given that there is no $^{210}\text{Pb}$ (excess), or the recently arrived sediments are sourced predominantly from gully erosion, in which case the surface sediments would not be expected to be labelled with these radionuclide tracers.

One other explanation of the absence of $^{210}\text{Pb}$ (excess) and $^{137}\text{Cs}$ at this site is erosional stripping of the floodplain surface. But there is no evidence of stripping, either physically or in the testimony of the local people. On the contrary, the local people say that the floodplain has steadily accumulated over the last 40 or so years. The absence of $^{137}\text{Cs}$ and $^{210}\text{Pb}$ (excess) therefore is most likely due to gully eroded sediment, deficient in these tracers, providing most of the recently arrived sediment on the floodplain.

While the surface of the floodplain appears to be aggrading, and is flooded most years to a depth up to 1m according to the local people, lateral erosion is evident. This lateral erosion is removing the floodplain, and each year (and sometimes twice a year) the inlet canal to a local irrigation system has to be re-built. The lateral erosion is probably a response to channel aggradation, as seen at other sites, but may also be exacerbated by flow deflection from the piers of the bridge just upstream. The local people certainly make this association.

This floodplain, like almost all others visited in the Laclo catchment, has become a source of sediment rather than a sink.

**Riverine inputs to the coastal zone**

The topsoil tracers $^{210}\text{Pb}$ (excess) and $^{137}\text{Cs}$ have been used to show that almost all of the fine-grain sediment in the Laclo River where it meets the ocean is produced by erosional processes that entrain subsoil in sufficient quantity to dilute the topsoil component so that it approaches zero. This is a useful contribution to the sediment budget and has profoundly important management implications.

The next step in the construction of the sediment budget is to estimate the yield of the catchment, that is, the amount exported to the ocean.

There are no comprehensive measurements of sediment concentrations in the Laclo River which could be combined with discharge measurements to estimate the quantity of sediment
reaching the ocean. Therefore, indirect methods have been used to provide an estimate of mean annual sediment yield.

Milliman et al, (1999) derived a statistical relationship between mean annual suspended sediment load and catchment area for nine rivers in Papua New Guinea, Java and the Phillipines. Each of these catchments has a maximum elevation >1000m above sea level and therefore fall into the global category of ‘mountain rivers’ (Milliman and Syvitski, 1992), permitting comparison with the Laclo River which is also a ‘mountain river’.

Land use in the catchments of the nine rivers ranges from almost unaltered in the case of Papua New Guinea to intensely cultivated in the case of the rivers in Java. Yet they form a coherent set of data that provides the best means of estimating the suspended sediment yield of the Laclo River. The regression relationship for the nine rivers is:

\[ y = 3.5x^{0.76} \quad r^2=0.77 \]

where \( y \) is mean annual suspended sediment load (\( x 10^6 \) t/yr) and \( x \) is catchment area (\( 10^3 \) km\(^2\)). With a catchment area of 1386 km\(^2\), the calculated load (or yield) at the mouth of the Laclo River is \( 4.5 \times 10^6 \) t/yr. This is a specific yield (i.e. mean annual yield / catchment area) of 3240 t/km\(^2\)/yr. The specific yield is a convenient way of normalizing for catchment area so that comparisons with other catchments can be made, but it should not be assumed that each square kilometre of the Laclo River catchment produces 3240 t each year on average. There is almost certainly high spatial variability of erosion rates in the catchment, and of course the steep land will yield more than the less steep land.

This estimate of yield is, as already made clear, for suspended load; the fine-grain sediment that travels in suspension in the river flow. In addition, the Laclo and most other rivers in East Timor carry a large bedload; the coarse-grain sediment that bounces and rolls along the bed of a river. The wide expanses of gravel and sand left on the riverbed after the wet season is testimony to this process.

![Figure 4.4: Coarse riverbed material – Laclo River, Manituto](image)

Figure 4.4: Coarse riverbed material – Laclo River, Manituto
It is customary to assume that the bedload component is 10% of a river’s total sediment load. This figure comes from those few rivers (largely temperate rivers in tectonically stable areas) where bedload transport rates have been measured.

It is highly likely that the bedload component of the Laclo’s total load is much higher than 10%, but there are no measurements. In a tectonically active landscape, such as East Timor (see Section 2.1), uplift induces natural erosion so that the river achieves the ‘graded’ state where the supply of sediment equals the transport capacity. Weathering of rock is incomplete in such a landscape, rivers cut into bedrock, and hillslope erosion mobilises partly or unweathered rock. Bedload can be the major component of total load in such a system.

A conservative estimate of 30% bedload is assumed for present purposes. Therefore, the mean annual total load of the Laclo River is estimated to be 6x 10^6 t/yr (4330 t/km²/yr). If we assume a bulk density of 2.6 for the rocks of the catchment, recognising that soils are thin and contribute a small part of the total load, then this estimate of load equates to a mean denudation (i.e. lowering) rate of 1.7m/1000yrs (1.7mm/yr).

The Laclo catchment has been significantly disturbed by cultivation, shifting agriculture, construction of roads, villages and towns, and, most importantly, deforestation. Therefore, the current mean annual total sediment load is almost certainly higher than the pre-disturbance (or ‘natural’) load. No data exist for East Timor from which the increase can be estimated. Studies in other parts of SE Asia show that suspended sediment load can increase by a factor of between 4 and 20 following deforestation (Lyons et al, 2002). Therefore, in the case of the Laclo River, the pre-disturbance suspended sediment load could have been between 1.1 x 10^6 and 0.2 x 10^6 t/yr. It is likely that the higher figure of 1.1 x 10^6 t/yr is the most accurate because a four-fold increase of load following major land use change is more likely for a catchment of the size of the Laclo’s.

The measured sediment loads in SE Asia and the calculated load for the Laclo River are based on a few years to decades of data. It is likely that rare events of high magnitude transport large quantities of sediment but they are not usually captured by a few years of measurements. For example, intense rain following a wet period when catchment soils are saturated could trigger landslides and/or gully extension.

There is evidence of such a large event at Usu-un (known as Pasir Putih during the Indonesian period) about 5km west of Metinaro on the north coast. Even though this site is outside the Laclo catchment, the lessons learned are likely to apply elsewhere in East Timor.
A steep 1 km$^2$ catchment drains into the ocean between two fringing coral reefs. There are three obvious phases of deposition and incision in this small catchment:

1. A bouldery deposit with a red-brown loamy matrix stands up to 10m above the modern creek.
2. Set within the trench cut into the high deposit is a bouldery deposit with a grey loamy matrix. This deposit stands up to 3m above the modern creek.
3. Within the trench cut into the second highest deposit is the youngest accumulation of boulders, sand and loam which is only 1.5m thick. This deposit is currently being incised by the modern creek, and at one site has the following characteristics:
   - 0-65cm bouldery deposit with a grey-brown matrix of pebbly loamy sand. The boulders and pebbles are unoriented, suggesting debris flow caused by landslides.
   - 65-73cm grey-brown sandy loam. Large pieces of transported charcoal in lower half of the deposit.
   - 73-133cm pebbly gravel with grey-brown sandy and granule gravel matrix. Gravel is flat-bedded, indicating that it was deposited by streamflow.

This deposit can be traced laterally to alluvial fans along the coast near Metinaro, where it includes blocks of marble from the Aileu Formation.

The charcoal in the 65-73cm layer at Usu-un has been dated by the radiocarbon method to $332\pm35$ radiocarbon years before present (BP) (ANU 28021). This is equivalent to a calendar age of $392\pm56$ years cal BP or $1558\pm56$ AD. So about 450 years ago a large amount of sediment was available for transport to this small, steep catchment. This was near the beginning of the Portuguese period in East Timor, but presumably before most of the land-use changes effected by the Portuguese. Even though agriculture is known to have begun in East Timor about 4000 years ago (Pannell and O’Connor, 2005), this site is neither favourable for agriculture nor does it show any signs of it. The large sediment yield implied by the 450 year old deposit was therefore a ‘natural’ event unrelated to human activities. Similar events must have occurred in the Laclo Catchment during the Portuguese and Indonesian periods, but the estimates of modern sediment yield do not include them.

The current best estimate for the suspended sediment yield is $4.5 \times 10^6$ t/yr at the Laclo mouth. The mean annual suspended sediment concentration is estimated at 4.5 g/l at the gauging station where the catchment has an area of 1297km$^2$, the mean annual sediment yield is $4.26 \times 10^6$ t/yr, and the mean annual discharge is $918\times10^6$ m$^3$/yr. Although much lower than the threshold value of $\geq 40$ g/l for the production of hyperpycnal flows (i.e. negatively buoyant fluvial discharges that are denser than sea water and therefore sink below the ocean
surface), the observed sharp outer boundary to the wet season plume at the mouth of the Laclo River suggests hyperpycnal behaviour (Milliman and Kao, 2005). Laboratory experiments suggest that hyperpycnal flow can occur when suspended sediment concentrations are as low as 1 g/l (Parsons et al, 1992). The estimated mean annual concentration for the Laclo is likely to be lower than the concentration during large flow events in the wet season.

It is therefore likely that much of the suspended sediment, and almost all of the bedload, are transported quickly into deep water offshore from the Laclo River mouth.

Yield: Particulate Organic Carbon (POC) input to the coastal zone
Using measured quantities of POC transported by rivers draining the high-standing islands of New Zealand, Taiwan, and Papua New Guinea, Lyons et al, (2002) derived a statistical relationship between the specific yield of POC and catchment area, as follows:

\[ y = 1.11x^{-0.34} \quad r^2=0.75 \]

where \( y \) is POC yield (t/km²/yr) and \( x \) is catchment area (km²).

At the mouth of the Laclo River, this equation predicts a mean annual specific yield of POC of 0.095 t/km²/yr or a mean annual load of 132 t/yr. This represents a mean concentration of POC of 0.003% in the 4.5 x 10⁶ t/yr mean annual suspended load at the Laclo’s mouth.

The source of the POC in the Laclo River has not been investigated, but vegetation and organic matter in soils and rocks are the obvious sources. In poorly weathered catchments where physical erosion dominates the production of sediment, POC can often be largely derived from rock. Komada et al, (2004) found a statistical relationship between the \( \Delta^{14}C \) content (an indicator of carbon source) of POC and suspended sediment yield, as follows:

\[ y = -0.21x + 10 \quad r^2=0.82 \]

where \( y \) is \( \Delta^{14}C \) (‰) for POC in sediment and \( x \) is sediment yield (10⁶ g/km²/yr). The amount of POC is also related to \( \Delta^{14}C \), as follows:

\[ y = -517x + 49 \quad r^2=0.85 \]

where \( y \) is \( \Delta^{14}C \) (‰) and \( x \) is wt% POC⁻¹. These relationships have been derived from rivers in Taiwan, Papua New Guinea, California and for the Amazon River.

Most POC is modern (i.e. has a positive \( \Delta^{14}C \) value coming from vegetation and soils) in rivers with low sediment yield. Conversely, rivers that discharge large quantities of suspended sediment have low POC content which is largely derived from ‘old’ carbon (i.e. \( \Delta^{14}C \) is negative) found in rocks.
In the case of the Laclo, these statistical relationships predict a $\Delta^{14}C$ value of $-899_{-00}^{+00}$, indicating that most of the POC is old. Rock-derived POC is likely to be resistant to degradation, possible due to association with clay minerals, and/or to molecular structure (Komada et al, 2004). Leithhold and Blair (2001) suggest that catchments dominated by physical erosion with high sediment loads export kerogen in the POC which survives because oxidation is slow relative to erosion rates.

These calculations obviously need to be checked by measurement of the isotopic composition of the POC in the Laclo River, and the implications for primary productivity in the river and ocean of old carbon which is resistant to degradation need further investigation.

**Yield: Total Nitrogen (TN) input to the coastal zone**

A modelling study by Green et al (2004) is relied upon here for an estimate of the TN export from the Laclo catchment to the coastal zone. The model is based on a mass balance that include estimates of: atmosphere input to the land, input as feed products and food, consumer use, fixation on land, fertiliser inputs, input from livestock, delivery coefficients from land to rivers, and river transport of N.

The results suggest <1 x $10^6$ t/yr of TN is delivered to the ocean from each of the major rivers of Timor-Leste. The largest source of N is fixation from the atmosphere because fertiliser use and livestock inputs are small. The proportion of fixed nitrogen reaching river mouths in Indonesia and Timor-Leste is between 40 and 60%, that is, between 60 and 40% (respectively) of fixed N remains on the land because of steep gradients, high runoff and short residence times for chemical and biological processing of N on land.

**Review of the Sediment Budget**

Figure 4.1 can now be reviewed. Turning first to sources, sheet erosion (mainly of hillslopes because roads are not common and therefore are unlikely to yield much sediment) is not a significant source of river sediment. Therefore, swidden agriculture, permanent agriculture, and burned hillslopes are not producing the sediment that is leading to shallowing and widening of the riverbeds. The river sediment is coming from gullies and channel incision (in the uplands), a few landslides, and from erosion of floodplains. Under current circumstances, floodplains are not sinks but have become sources as the channels aggrade.
The major sinks examined during this investigation are channel aggradation and the ocean. Quantification of channel aggradation has only been possible at one site, namely at the Manatuto bridge.

Yield has been estimated for suspended sediment, bedload, POC and TN. It is believed that most particulates leaving the Laclo mouth are transported quickly to the deep ocean.

4.1.5 Deforestation, spring flow, and river low flow.
This topic emerged from community consultations as one of four groups of key messages (see Section 4.1.2 # 2). The observation that springs have dried up in the uplands and the low flow (baseflow) of small streams has declined or ceased since deforestation during the Indonesian period was strongly made by local people. Water at Liquidoe, for example, can now be obtained by walking for up to 2 hours to and from a large stream where low flow still occurs during the dry season.

The failure of springs and low flow following deforestation has been observed elsewhere, for example, the Himalayas of India and Nepal. At first glance, the observation that deforestation reduced groundwater amounts (and therefore spring and river low flow) is counter-intuitive. Trees transpire water from the soil and so the amount of rainfall that infiltrates into groundwater stores should increase after deforestation (Calder, 1999). However, if runoff increases after deforestation, as a result of surface sealing of soils and reduced vegetation cover, then the fraction of rainfall that infiltrates will decrease. Also, gullying drains water from soils by providing many more locations for seepage outflow.

This topic deserves attention because the lives of local people in the uplands are being adversely affected by the change of water availability.

4.1.6 Weed Invasion, pasture deterioration, and erosion
Chromolaena odorata invasion of grazing, hunting, and swidden land is said to suppress ground vegetation and thereby reduce the quality of pasture for cattle (#3, Section 4.1.2). This change is also likely to increase sheet erosion on hillslopes because ground vegetation is reduced or eliminated. There are however no measurements to confirm this hypothesis.

If erosion is increased then soil quality will decline because of the loss of organic matter and organic nutrients. This in turn may reduce the vigour and possibly cover of any surviving ground vegetation following the (hopefully) successful eradication of Chromolaena odorata.
The results of topsoil tracing shows that sheet erosion is not a significant source of river sediment. So the hypothesised links between weed growth and erosion is only likely to be important on hillslopes and for pastoral land uses. Almost all of this is speculative, and deserves further attention.

### 4.1.7 Chemical fertilizers, agriculture, and aquatic productivity

The lack of chemical fertilizers following Independence (§4, Section 4.1.2) is clearly of great concern to the agriculturalists in the catchment. From a catchment management perspective, the possible future availability of chemical fertilizers could have the following effects: 1, improve agricultural productivity and thereby support a growing population that will have demands for other resources such as timber; 2, possibly reduce erosion of dryland agricultural fields by producing a more vigorous plant growth, although loss of soil during early wet season rains will probably not be affected; 3, any erosion of fertilized soils could transport some nutrients (in particulate form) to the river, although the amount is likely to be small relative to other sources because erosion of cultivated land is not an important source of river sediment; 4 if a large fraction of fertilizer-derived nutrients is in dissolved form in runoff, they are likely to reach rivers and the sea, possibly altering freshwater and marine productivity.

### 4.2 Water quality

Replicate water samples were taken upstream from the mouth of the Laclo River and at Metinaro to determine the nutrient status and quality of both freshwater and seawater along the north coast. The samples were taken by hand, using sterile plastic syringes and filtered through 0.45 µm Minisart filters into acid-washed plastic test tubes. Samples were kept in the dark and cold until freezing upon return to AIMS. Analyses for dissolved inorganic nutrients were performed using standard automated techniques (Ryle et al., 1981; Ryle and Wellington, 1982).

<table>
<thead>
<tr>
<th>Location</th>
<th>(\text{NH}_4^+) (µM)</th>
<th>(\text{NO}_2^-+\text{NO}_3^-) (µM)</th>
<th>(\text{PO}_4^{3-}) (µM)</th>
<th>(\Sigma\text{CO}_2) (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8°29.938'S, 125°59.903'E</td>
<td>1.98 ± 1.03</td>
<td>8.65 ± 1.32</td>
<td>0.54 ± 0.01</td>
<td>4.60 ± 0.05</td>
</tr>
<tr>
<td>8°29.952'S, 125°59.912'E</td>
<td>2.28 ± 0.50</td>
<td>6.22 ± 0.58</td>
<td>0.48 ± 0.02</td>
<td>4.57 ± 0.01</td>
</tr>
<tr>
<td>8°30.063'S, 126°00.210'E</td>
<td>2.73 ± 0.78</td>
<td>7.74 ± 2.10</td>
<td>0.48 ± 0.07</td>
<td>4.79 ± 0.05</td>
</tr>
<tr>
<td>8°30.248'S, 126°00.135'E</td>
<td>4.66 ± 1.32</td>
<td>6.46 ± 0.49</td>
<td>0.43 ± 0.04</td>
<td>4.99 ± 0.07</td>
</tr>
<tr>
<td>8°30.504'S, 126°00.088'E</td>
<td>3.60 ± 0.48</td>
<td>9.08 ± 1.61</td>
<td>0.56 ± 0.06</td>
<td>5.00 ± 0.01</td>
</tr>
<tr>
<td>8°31.028'S, 126°00.152.1'E</td>
<td>4.04 ± 0.93</td>
<td>8.22 ± 0.38</td>
<td>0.49 ± 0.09</td>
<td>5.31 ± 0.02</td>
</tr>
<tr>
<td>8°30.003'S, 125°47.101'E (Metinaro)</td>
<td>0.80 ± 0.09</td>
<td>0.05 ± 0.00</td>
<td>0.05 ± 0.01</td>
<td>5.54 ± 0.01</td>
</tr>
</tbody>
</table>

**Table 4.4. Concentrations (mean ± 1SE) of dissolved inorganic nutrients in Laclo River water and seawater off Metinaro.**

The results (Table 4.4) indicate concentrations of dissolved ammonium ranging from 1.98-4.66 µM in river water with higher concentrations of nitrite + nitrate. Phosphate
concentrations ranged from 0.43-0.56 µM and total dissolved carbon dioxide concentrations ranged from 4.57-5.31 mM.

Compared with similar data from other tropical rivers that are not significantly impacted by human activities (Eyre, 1994; Mitchell et al., 1997; Robertson et al., 1998), the nutrient concentrations in the Laclo River in the dry season are not elevated and well within the range obtained from these other rivers. Similarly, the tidal waters at Metinaro have concentrations of dissolved inorganic nutrients typical of those obtained from unpolluted mangrove waters in Australia (Alongi et al., 1992). This statement is supported by the fact that the dissolved N:P ratio in these waters ranges narrowly from 17-22, which is within the range of values expected from both freshwater and seawater. Therefore, it is reasonable to conclude that the waters reaching the mouth of the Laclo river and coastal waters in the vicinity of Metinaro, are not polluted by human impacts such as fertilizer use and other wastes.

4.3 Coastal Impacts and Marine Resource Use

Shore Fisheries

As noted earlier, the coastal zone between Dili and the Laclo River is dominated by sandy beaches, fringing coral reefs, rocky outcrops at headlands, and mangrove forests within small embayments to the leeward of rocky capes. Below mean sea level, the sea floor is dominated by mostly relict coral reefs and flats inhabited by diverse assemblages of seagrass and seaweed species. From our meetings and interviews with coastal villagers and our own observations, subsistence fishing is small-scale, confined mostly to the coral reef—seagrass—seaweed habitats within 100-200 m off the beach. Fishing within mangrove waterways is limited, but mangrove-associated fish (snapper, mangrove jack grouper, crabs) form an important supplementation to the diets of these coastal villagers. With the seagrass-coral complexes, sardines, Spanish mackerel and small pelagics are caught, with penaeid shrimps caught mostly after the rainy season. Reef fish communities are diverse, but impacted by the subsistence fishery (Deutsch, 2004). It is unclear where fish and shrimp spawn, but it is feasible that their life cycles are physically linked to reefs, mangroves, and seagrass beds.

Mangroves

In order to determine the nutrient status, human use, and health of the mangroves along the north coast, three sampling stations were set up in the largest expanse of tidal forests at Metinaro. The first station (“TL1”) was seawards of the other sites and was composed mostly of *Rhizophora apiculata* with some *Bruguiera gymnorhiza*. The second site (“TL2”) consisted mostly of mature *Ceriops tagal* and *C. decandra*. At this site, we observed that nearly half of the existing stem density was cut down for fuel. We were told that this clear-
felling occurred about 7 yrs ago. During sampling, we observed a number of women digging extensively throughout the forest, collecting bivalves and the snail, *Telescopium telescopium*, for food. The women indicated that this forest is a prime location for edible shellfish. The third station (“TL3”) was a shunted *C. decandra* stand with some large *Avicennia marina*. Unlike the other two sites, the forest floor was heavily carpeted with leaf litter, indicating that this location is rarely inundated by tides.

![Figure: 4.5: Metinaro Mangroves](image)

At each site, measurements were made for species identification, basal area and diameter-at-breast height (DBH) using the angle count cruising method (Cintron and Novelli, 1984; Clough, 1997). These data were used to calculate stem density (stem ha⁻¹) which in turn was used to estimate biomass (t ha⁻¹) based on the allometric relationships for each species in Clough and Scott (1989) for single-stemmed trees and Clough et al. (1997) for multi-stemmed trees.

The results indicate a typical decline in total above-ground forest biomass from the low intertidal to the higher seascape (Table 4.4). This decline is most likely the result of increasing salinity of the interstitial water (Table 4.5). The biomass estimate for Station TL1 is roughly equal to that predicted from known biomass-latitude relationships for tropical mangrove forests (Saenger and Snedaker, 1993). Station TL2 has suffered a loss of approximately one-third of forest biomass as a result of cutting for fuel wood; station TL3
has a small biomass for such a high tree density, again suggesting severe physiological stress from high salinities. The average diameter-at-breast height values are higher than those for most other high-salinity mangrove forests (Alongi et al., 2000) suggesting that these forests are very mature and may be near their terminal successional stage. Although net primary production was not measured, it is however likely that net canopy production for these forests is in the range found for similar high-salinity forests, on the order of 5,000-8000 mol C ha⁻¹ d⁻¹.

<table>
<thead>
<tr>
<th>Station/species</th>
<th>Stand density</th>
<th>DBH</th>
<th>BA</th>
<th>TAGB</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL1</td>
<td>3,859</td>
<td>12.5</td>
<td>33</td>
<td>211.4</td>
</tr>
<tr>
<td>R. apiculata</td>
<td>2,157</td>
<td>11.5</td>
<td>15</td>
<td>114.6</td>
</tr>
<tr>
<td>B. gymnorrhiza</td>
<td>1,025</td>
<td>13.5</td>
<td>10</td>
<td>50.7</td>
</tr>
<tr>
<td>C. tagal</td>
<td>677</td>
<td>13.8</td>
<td>8</td>
<td>46.1</td>
</tr>
<tr>
<td>TL2 (live C. tagal)</td>
<td>12,781</td>
<td>18.4</td>
<td>19</td>
<td>116.9</td>
</tr>
<tr>
<td>TL2 (cut C. tagal)</td>
<td>991</td>
<td>10.9</td>
<td>15</td>
<td>57.7</td>
</tr>
<tr>
<td>TL3</td>
<td>7,643</td>
<td>3.6</td>
<td>11</td>
<td>101.3</td>
</tr>
<tr>
<td>A. marina</td>
<td>109</td>
<td>22.7</td>
<td>4</td>
<td>70.9</td>
</tr>
<tr>
<td>C. tagal</td>
<td>7,534</td>
<td>3.4</td>
<td>7</td>
<td>30.4</td>
</tr>
</tbody>
</table>

Table 4.5 Stand density (stems ha⁻¹), DBH (cm), BA (basal area, m² ha⁻¹), and total above-ground biomass (t dry weight ha⁻¹) at the three mangrove locations.

Measurement of anaerobic microbial activity and edaphic characteristics sheds some light on the biomass changes in the mangroves with increasing height above mean sea-level. At each of the three stations, cores were taken for interstitial temperature, salinity, dissolved inorganic nutrients and trace metals, total carbon dioxide, total soil organic carbon and nitrogen, rates of bacterial sulfate reduction and sedimentation rate, using methods summarised in Alongi et. al. (2004).

Figure 4.6: Mangrove sediment coring - Metinaro Mangroves
The soil chemistry (Table 4.6) shows increasing interstitial water salinity from the most seaward site, TL1 to the most landward site, TL3. These salinities are very high compared with seawater and suggest that these mangrove soils are infrequently flushed by tides. Clearly, plant growth would be restricted by such high salinities so it is logical to suggest that these mangrove forests are very mature, probably on the order of at least 50 yrs to as old a century. Unfortunately, it is not possible to accurately date these species as they do not lay down clear annual growth rings. The soil data indicates fairly typical distributional patterns of concentrations of pore water nutrients and dissolved metals, such as sulphur, iron, manganese, and molybdenum. The increase in the concentrations of most chemical species with increasing tidal height indicates less tidal flushing. The molar C:N and C:P ratios range from 30:1 to 66:1, and from 648:1 to 1377:1, with increasing distance from the coast, probably reflecting slow, mostly marine, sedimentation (see below) and increasingly refractory organic carbon landwards. These ratios are most similar to those measured in the mangrove forests of Hinchinbrook Island, Queensland, Australia (Alongi, 1996). The Australian mangroves are also very mature and receive particulate matter originating nearly solely from marine sources, and such may be the case for the Metinaro mangroves. Indeed, the high concentrations of TOC and TN and molar ratios suggest that most organic materials in these soils are fibrous tree roots and rhizomes.

<table>
<thead>
<tr>
<th>Properties</th>
<th>TL1</th>
<th>TL2</th>
<th>TL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>43</td>
<td>53</td>
<td>69</td>
</tr>
<tr>
<td>$\text{NH}_4^+$ (µM)</td>
<td>24.6 ± 2.8</td>
<td>55.4 ± 4.8</td>
<td>42.5 ± 3.6</td>
</tr>
<tr>
<td>$\text{NO}_2^-$+NO$_3^-$ (µM)</td>
<td>28.7 ± 12.1</td>
<td>11.7 ± 6.6</td>
<td>2.6 ±1.6</td>
</tr>
<tr>
<td>PO$_4^{3-}$ (µM)</td>
<td>3.4 ± 0.06</td>
<td>1.6 ± 0.06</td>
<td>1.1 ± 0.1</td>
</tr>
<tr>
<td>Si(OH)$_4^+$ (µM)</td>
<td>64.0 ± 3.8</td>
<td>102.6 ± 1.6</td>
<td>243.2 ± 3.1</td>
</tr>
<tr>
<td>Dissolved S</td>
<td>1059 ± 0</td>
<td>1378 ± 4</td>
<td>1795 ± 10</td>
</tr>
<tr>
<td>Dissolved Fe</td>
<td>0.13 ± 0.13</td>
<td>1.04 ± 0.01</td>
<td>6.44 ± 0.26</td>
</tr>
<tr>
<td>Dissolved Mn</td>
<td>0.03 ± 0.0</td>
<td>0.12 ± 0.0</td>
<td>1.16 ± 0.01</td>
</tr>
<tr>
<td>Dissolved Mo</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>0.03 ± 0.01</td>
</tr>
<tr>
<td>TOC</td>
<td>12.6 ± 0.1</td>
<td>15.9 ± 4.6</td>
<td>18.8 ± 3.7</td>
</tr>
<tr>
<td>TN</td>
<td>0.49 ± 0.02</td>
<td>0.56 ± 0.06</td>
<td>0.33 ± 0.03</td>
</tr>
<tr>
<td>Total P (µg g$^{-1}$)</td>
<td>503 ± 9</td>
<td>579± 122</td>
<td>354 ± 27</td>
</tr>
</tbody>
</table>

Table 4.6. Edaphic characteristics of the mangrove soils at Metinaro. Dissolved metal units = mg l$^{-1}$. Total Organic Carbon (TOC) and Total Nitrogen (TN) units = % sediment dry weight.

Organic matter (represented in this study by TOC) in soils is broken down mostly by bacteria. Aerobic (oxygen requiring) bacteria decompose organic matter in surface sediments and in linings of animal burrows, but in most cases, the bulk of decomposition occurs in
deeper waterlogged soils where oxygen cannot penetrate. Anaerobic (without oxygen) decomposition occurs by a wide variety of bacterial functional groups. Sulfate-reducing bacteria are most often the major anaerobic bacterial group in mangrove soils, and the process by which they break down organic matter is called sulphate reduction, which at its simplest is,

$$\text{CH}_2\text{O} + \text{SO}_4 \rightarrow \text{H}_2\text{S} + \text{CO}_2$$

whereby organic matter (CH$_2$O) is oxidised to CO$_2$ as bacteria reduce sulfate to sulphide.

![Figure 4.7: Foraging in Metinaro mangroves(left) and remnants of timber harvesting(above).](image)

... that sulfate reduction is highest at Site TL1, closest to the sea (see Figure 4.7), and that at all three locations most bacterial activity occurs just below the soil surface. Integrated with soil depth, rates of sulfate reduction average 35.6, 3.0 and 6.2 mol m$^{-2}$ d$^{-1}$ at sites TL1, TL2 and TL3, respectively. The rates of anaerobic activity at site TL1 are typical of *Rhizophora* mangrove forests in Asia (Alongi et al., 2001, 2004), but the rates of activity at the other two sites are very low, suggesting very low anaerobic metabolism due to either slow rates of organic matter input (sedimentation) or soils too dry and saline to support significant microbial activity, or both, similar to mangrove soils in the dry tropics (Alongi et al. 2000). These data suggest that mangrove soils landward of the zone of *Rhizophora*-dominated mangroves do not participate in nutrient cycling as actively as wetter soils further seaward. Moreover, the activity of people cutting trees and digging for food is another likely explanation for the lack of anaerobic activity, as these human distances would help to oxidise the soil horizons and destroy the delicate chemical gradients from the surface to deeper soils. What direct effect digging for soil fauna has on forest health beyond the question of faunal sustainability is unclear.
To properly assess the cycling of nutrients and the origin of organic matter input to the mangroves, we estimated mass sediment accumulation rates from gamma spectrometric measurements of $^{210}$Pb, $^{226}$Ra and $^{137}$Cs made on sequentially sliced duplicate 50-65 cm-long cores using a 1.5 m long (6 cm I.D.) stainless steel corer.
Interpretations of the radiochemical profiles were done with several sub-models incorporating weighted least-squares regression analysis (Robbins, 1978, 1979). These models utilize a sediment mixed layer thickness, a decadal-century scale average input of excess $^{210}\text{Pb}$ (total $^{210}\text{Pb}$ minus parent $^{226}\text{Ra}$), and diffusion coefficients for $^{210}\text{Pb}$ and $^{137}\text{Cs}$ in marine sediments (Li and Gregory, 1974). These MAR estimates were multiplied by average TOC and TN content in the same cores (Table 4.5) to provide estimates of TOC and TN accumulation.

Our data show that only one of four cores (Figure 4.3.2) produced interpretable vertical profiles of radionuclides. This is core no. 3764 from Site TL1. The core indicates a sedimentation rate of $0.85 \pm 0.2 \text{ kg sediment DW m}^{-2} \text{ yr}^{-1}$. Fallout $^{137}\text{Cs}$ is in the expected upper portion of the profile, supporting the accumulation rate (MAR) calculated from $^{210}\text{Pb}$. Compared with our sedimentation data from other mangroves in Asia, the MAR for site TL1 was low, which is what would be expected in mangroves receiving only marine-derived material and little or no riverine particles (Alongi et al. 2001, 2004). This interpretation is supported by the low rates of microbial activity in two of the sites, as well as low values of excess $^{210}\text{Pb}$ and $^{137}\text{Cs}$. In other Asian forests, rates of MAR range from 2.2 to 62 kg m$^{-2}$ yr$^{-1}$, with most values lying between 3-7 kg m$^{-2}$ yr$^{-1}$. Also, the concentrations of the radionuclides at other Asian sites are significantly greater than those measured in the Metinaro cores. The radionuclide data from the other cores provides evidence of down-core mixing, with either no discernible slope of decline in excess $^{210}\text{Pb}$ or lack of support from the $^{137}\text{Cs}$ profile, or both. This result is not surprising given the fairly intensive digging by people in these forests. It is reasonable to suppose, however, that there is little or no net sedimentation at Sites TL2 and TL3 given their infrequent tidal inundation frequencies.
For Site TL1, a mean sedimentation rate of 0.85 kg sediment DW m\(^{-2}\) yr\(^{-1}\) equates to a burial rate of organic carbon of 25 mmol C m\(^{-2}\) d\(^{-1}\). Using the model of steady-state carbon flow (Berner, 1980)

\[
OC_{IN} = OC_{OUT} - OC_{ACCUMULATION}
\]

that is, summing the sulfate reduction rate (assuming 2 moles C per 12 mol S reduced) and the above burial rate, we derive a total organic carbon input rate to these soils of 96.2 mmol C m\(^{-2}\) d\(^{-1}\). This value is at the low end of the range of values measured in other Asian mangrove forests. The burial efficiency (burial rate divided by the total rate of input) averages 26\%, which is well within the median value for these other Asian mangrove stands. What this means is that most (74\%) of the organic carbon depositing in these mangrove soils is decomposed by bacteria and lost to the atmosphere as respired CO\(_2\). In sum, the microbial community (at least at Site TL1) is as active metabolically as in other healthy mangrove forests. As noted earlier, Site TL2 has suffered significant clear-felling and site TL3 appears to be in or entering very mature (and natural) successional stages towards a terrestrial montane forest.

5.0 Socio-economic drivers of changes documented during community consultations

Population and settlement characteristics.

The Laclo Catchment (1386 km\(^2\)), is the second largest in Timor Leste after the Loes River catchment (Bobonaro). A number of villages (Suco) lie wholly or partially within the catchment and are included in the listing below, Figure 5.1
At this stage it is not possible to provide an accurate statement of the resident population of the catchment. Based on the recent Timor Leste Census (2004), and the fact that only portions of the sub districts of Ailieu and Manufahi lie within the watershed, it is estimated that up to 30,000 people may live within the catchment. This represents an average population density within the catchment of approximately 14 persons/km$^2$. However, given that a significant proportion of the resident population live within the main towns and sub district centres, the actual population density over much of the catchment is likely to be significantly lower with numerous unpopulated areas.

Of the recorded total population approximately 70% live within the boundaries of the district of Manatuto. Population growth trends in the catchment are estimated to be around 16.5% pa, especially in the lower catchment where factors associated with the Manatuto township and its environs have been important drivers of growth. There is, however, significant spatial variation in population growth trends. Laclubar sub-district is relatively stable with just 2.9% increase in population since 2001, while Lequidoe in the upper catchment has experienced a remarkable 42.1% increase in population over the same period (2004 Census). The Lequidoe figures are attributed to a combination of high natural birth rates (the peace bonus) and the return of numerous refugees and former residents from Dili and West Timor.
The significant increase in population growth in this area and the primary focus on upland agriculture and extensive livestock grazing has implications for land disturbance, erosion and management strategies. At this stage a more complete analysis of population data and trends from the 2004 Census awaits the release of the disaggregated figures.

The only sub-district that lies wholly within the Laclo catchment is Laclo itself. Table 5.1 lists the settlements and population data for the sub-district based on the recent 2004 Census.

<table>
<thead>
<tr>
<th>Village</th>
<th>Aldeia (Hamlet)</th>
<th>Households</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacmesac</td>
<td>Nacaleu</td>
<td>143</td>
<td>629</td>
</tr>
<tr>
<td></td>
<td>Readodok</td>
<td>67</td>
<td>266</td>
</tr>
<tr>
<td></td>
<td>Tahagamu</td>
<td>92</td>
<td>413</td>
</tr>
<tr>
<td></td>
<td>Hatucanan</td>
<td>79</td>
<td>291</td>
</tr>
<tr>
<td></td>
<td>Labubu</td>
<td>96</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Umanaruc</td>
<td>Uma naruk</td>
<td>76</td>
<td>242</td>
</tr>
<tr>
<td></td>
<td>Uma surat</td>
<td>66</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>Fahi lakar</td>
<td>33</td>
<td>273</td>
</tr>
<tr>
<td></td>
<td>Bua</td>
<td>33</td>
<td>267</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uma Caduac</td>
<td>Haihoho</td>
<td>133</td>
<td>583</td>
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<tr>
<td></td>
<td>Condar</td>
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<td>431</td>
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<td></td>
<td>Ilimano</td>
<td>361</td>
<td>1612</td>
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<td></td>
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</tr>
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<td>Hohorai</td>
<td>Hatu ermera</td>
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</tr>
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<td></td>
<td>Mirihuhun</td>
<td>22</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Anica alaun</td>
<td>24</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>Hatu anahun</td>
<td>23</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>TOTALS</td>
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<td>1,411</td>
<td>6,155</td>
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Table 5.1 : Sub District Laclo Households and Population (2004).

What is striking about the Laclo data is the wide variation in population distributions. For example, among the hamlets (aldeia) that comprise the four constituent villages of Laclo, compare the 22 households of Mirihuhun in the upper catchment, and the 361 households of Ilimano. This diversity in hamlet population reflects particular settlement histories and the strong sense of identification with local area homelands among resident groups who are often unwilling to accept administrative reorganization. In addition to the official settlements, the local administration acknowledges but does not formally include a settlement of Uma Heuk villagers who live in the catchment but are recorded as members of Ili Heu village in the sub district of Manatuto. This arrangement has historical precedents apparently and may explain why our estimated total population of Sub-District Laclo is 6,338 and not 6,155 as listed in Table 5.1 based on the census.
Another feature of settlement patterns within the catchment is a comparatively high degree of dispersal among the households. The core grouping in Timorese social life is generally the hamlet cohort with kin and alliance networks extending out to surrounding settlements. But even at the Aldeia level of settlement administration, households may be quite dispersed within local territories. This trend is even more pronounced during the wet season when households typically disperse to spend long periods of time in their food gardens, visiting their main houses only occasionally. Indeed the pattern of rural residential dispersal has been a feature of post-independence Timor Leste in many regions, as populations which had been dislocated or translocated under Indonesian government programs, are seeking to return to former homelands and territories to which they assert customary land tenure. The extent to which this trend is occurring in the Laclo is an empirical one that would need to be assessed through survey sampling. Lequidoe in the upper catchment is exemplary in this respect.

One of the constraints to more widespread return of rural populations to former settlement areas is the availability of services and communication infrastructure. While there is relatively good road access to the main population settlements within the Laclo catchment wet season rains and localised flooding can limit vehicle access to more remote locations such as Laclubar, Laclo and Turiscai for extended periods of time. For these reasons it is unlikely that there will be any major increase in rural population densities within the Laclo catchment although growth of existing settlement centres is likely to continue.

**Farmer livelihoods**

The majority of residents of the Laclo catchment are smallholder farmer households pursuing a mix of extensive upland swidden cultivation with limited areas of irrigated rice cultivation adjacent to the main river channels. Most of the irrigated farming occurs in the lower catchment between the Manatuto and Laclo sub district centres. Significant investment in the rehabilitation of irrigation infrastructure has been made in recent years under the auspices of donor funding through phases of the ARP (Agriculture Rehabilitation Program) through the Ministry of Agriculture, Forestry and Fisheries. Although fertilizer inputs were subsidised and widely used during the Indonesian period of government, applications and availability has declined significantly post Independence (see Section 4.1).

Upland farming is predominantly focused on wet season maize production which provides the food staple for most rural families. Maize is typically also cultivated with varieties of pumpkin, sweet potato, cassava, and beans with limited tree crop production of coconut, papaya, bananas and mangos, all mostly for local consumption. Regional markets remain subdued and the high cost of transport reduces competitive advantage. Some limited
production of upland and rain fed rice is reported as well as small areas of coffee production in highland areas of the catchment, particularly Laclubar and Ailieu.

The short growing season experienced by many farming households within the catchment means that a variety of supplementary income producing activities are pursued during the long dry season. In the lower catchment proximity to the coast provides supplementary fishing and gleaning opportunities, particularly out of Manatuto, as well as limited commercial salt production (JICA n.d). In the upper catchment a variety of small scale trading activities are pursued. They include limited production of dry season vegetables mostly for local consumption and sale, handwoven textiles, livestock trading, some palm wine (tuak) manufacture and sale and opportunistic off-farm labouring. These activities are likely to form the main source of supplementary dry season incomes.

Resident farming populations are also likely to be heavily dependent upon livestock as a store of wealth and income. As in the rest of Timor Leste, a reliance on poultry and pigs is widespread along with herds of Bali banteng cattle, buffalo, sheep and goats. Based on observations within the catchment, the comparatively harsh and dry conditions that prevail over much of the catchment during the year are particularly suited to goat husbandry. Goats are common in the catchment and graze freely around the margins of settlements. The negative impact of goats on both vegetation cover and land degradation may well be significant on steeper slopes and areas surrounding population centres. Goats and their grazing regimes represent a key management issue for the Laclo catchment, particularly in the middle and upper portions, mainly for biodiversity conservation and pastoral productivity than as a cause of erosion that contributes significantly to stream sediments.

**Cultural Institutions**

An important factor governing land use decisions and customary land management more generally is the persistence of traditional patterns of social organization and relation. Although not officially recognized in formal administrative structures, the protocols and historically nested relationships between local clans (suku) and their constituent lineages or house groups (uma lulik / uma fukun) continue to play a significant role in political and social life at the village (suku) and hamlet (aldeia) levels. This is particularly evident in matters of customary land tenure as well as associated entitlements and claims to natural resources in one form or another. It also finds expression in a range of cultural land management practices discussed further below. One of the implications of the persistence of customary relationships and practices is that strategies to develop improved catchment management practices are likely to be more effective when they recognize and engage customary socio-
political groupings than if they subsume them within externally derived models of management.

An example of this issue is the relationship between the two senior Galolien speaking clans (suku) of Manatuto township, Sau and Ma’abat. These groups represent the traditional land owners (Rea obon) of the area and view themselves in terms of siblingship (elder–younger, maun-alin). Traditionally the Ma’abat (elder) clan group holds the position of Liurai (ruler) of Manatuto, formerly a powerful indigenous political domain from early Portuguese colonial times. Land in Manatuto is divided between these two suku, Sau controlling areas on the western and eastern side of the lower Laclo River, Ma’abat lands lie further to the east. According to information received, all land in the area remains the common property of the clans whose members have rights of cultivation and use. Non-affiliates need the express approval or blessing of senior members of the clan to pursue cultivation or other forms of use. Any proposals to introduce new or modified land use practices are more likely to receive community approval where the protocols of emplaced clan authorities are consulted and respected.

Common property regimes and customary tenures are found widely throughout the area and are probably well recognized at local levels even if their formal status remains unauthorised or sanctioned by the present national government. One of the consequences of the continuing existence of customary tenures and claims is that there is likely to be comparatively little ‘free’ or empty land available, nor extensive areas attributed to state ownership (Tetum: rai estado).

Figure 5.2: Woodlands burning in Laclo catchment
Normative customary practices and their attendant cultural institutions persist with varying degrees of vitality within the catchment. Each of the three main representative ethnolinguistic groups (Galolien, Idate and Mambai) have their own local sets of protocols and conventions. Some of these institutions have implications for land/ coastal management. For example, Manatuto respondents report the use of traditional tidal (stone) fishtraps (*hatu metian*) which are the common property of particular groups and managed through customary gathering arrangements. All groups report the existence of customary seasonal prohibitions on harvesting or utilization of designated resource areas. This institution, known in Tetum as *tara bandu* (to raise a prohibition) or local language equivalents, represent indigenous institutions to manage common property resources. The injunctions can include prohibitions on timber cutting, wild food harvesting, theft or cultural burning for certain periods of time. Transgressing these proscriptions usually results in fines and other sanctions for the perpetrators. These practices are widely reported but there has been very little research into the scope and persistence of these local management systems either within the catchment or more widely across Timor Leste (see for example McWilliam 2001, 2003). A further area for prospective research is the extent to which periodic cultural burning of the woodlands and savanna as part of seasonal hunting practices is undertaken within the Laclo catchment. Certainly the practice of ‘fire stick’ hunting is reported for the Kairui speaking area in the hinterland of Laleia to the east of the Laclo. Periodic burning of the savanna grasslands is also practiced to encourage the growth of green vegetation for livestock and other fauna.

### 6.0 Summary of Key Findings

The major findings of this study of the Laclo catchment are:

1. The catchment community is unified in the view that deforestation was severe during the Indonesian period causing major gully erosion and downstream sedimentation of the rivers. There is less consensus about the role of swidden agriculture in adding sediments to the rivers.

2. The scientific analysis of the catchment shows that most sediment is coming from gullies, river bank erosion, and the few landslides in the catchment. It has also shown that the rivers are becoming shallower and wider, removing floodplains and the land uses on them, including paddy. Also, the natural erosion rate is very high, and the carbon exported to the ocean is as a consequence mainly derived from rocks and so is not readily biologically available.

3. The scientific analysis of dry season river water at the Laclo mouth and of seawater at Metinaro shows that there is no evidence of human pollution in measured
concentrations of ammonium, nitrite+nitrate, phosphate, and carbon dioxide. Potential sources of pollution are fertilizer, human waste, and animal waste.

4. The scientific analysis of the coastal zone shows that almost all of the sediment and nutrients are transported to the deep ocean across a very narrow continental shelf. As a result, mud in which mangroves grow on the nearby coast is not derived from the rivers but rather is derived from the ocean. Also, nutrients for the inshore foodweb that supports fish are derived both from the ocean and by release from sediments deposited on the shelf and upper continental slope. The major conclusion is that fish productivity in the vicinity of the mouth of the Laclo River has little dependence (if any) upon river-derived materials. Upper catchment land use is therefore not significant as an impact on marine productivity.

5. The major socio-economic drivers of change have been:
   5.1. Deforestation during the Indonesian period for commercial gain;
   5.2. Termination of chemical fertilizer use after Independence presumably because of cost;
   5.3. Major disruption of traditional management regimes and population distributions during the Indonesian period, with some return to pre-Indonesian patterns since Independence.
   5.4. Significant population increase by both birth rate increase and the return of refugees, particularly in the uplands where, as a consequence, agriculture and livestock grazing must have increased both in area and intensity.
   5.5. Some unwillingness on the part of many catchment residents to accept government administrative arrangements makes government-imposed management difficult to implement.
   5.6. Most of the residents of the Laclo catchment belong to smallholder farmer households with little disposable income and very limited ability or motivation to engage in land rehabilitation without significant external resources of funds and assistance.
   5.7. To sustain households, goat grazing is widespread within the catchment which, along with burning to promote fresh grass for livestock and to facilitate hunting, reduces the capacity of an already depleted vegetation to resist highly erosive rainfall.
   5.8. Customary land management practices exist to some degree along with traditional patterns of social organisation and relation.
   5.9. Any attempts at major government-sponsored catchment management initiatives (eg major reforestation) must begin by taking the customary practices of the local people seriously.
7.0 Next Phases

Two projects are proposed: a second pilot investigation, in the Caraulun catchment and a three year project.

![Figure 7.1: Laclo and Caraulun catchments](image)

**Figure 7.1: Laclo and Caraulun catchments**

**A second pilot study – the Caraulun River Catchment.**

Before fully designing a three year work program, it is essential that a pilot study of the Caraulun River catchment is performed. The export of sediments, nutrients and carbon from the Caraulun catchment is likely to have an impact on the productivity of the nearby coastal areas, unlike in the Laclo case. The reasons for believing this are: the continental shelf off the Caraulun mouth is wide and gently sloping, unlike off the Laclo, providing ample opportunity for bacterially – moderated release of nutrients from deposited sediments; deltas
on the south coast, and at the mouth of the Caraulun in particular, show that riverine materials do not all leave the coast to be deposited in the deep ocean, thereby creating habitat for mangroves which are important as sources of food and protection for various fish species; and wide floodplains and swamps provide habitat for freshwater fish breeding. Because of the substantial differences in coastal topography and demography it is not possible to extrapolate results from the Laclo to the Caraulun.

Given that marine productivity is likely to be affected by materials derived from the Caraulun catchment, the sources, rates of transport, and concentrations of sediments, nutrients, and carbon need to be known. Also, the history of land use and its impacts in the uplands need to be determined, particularly given the growing concentration of rural populations in the uplands and the significant areas of arable dryland under food crop cultivation. All of this information should be gathered in the context of the views of the local people, distilled, as in the Laclo catchment, by means of community consultations.

The investigation of the Caraulun catchment would include the following components:

1. Community consultations to distill local views and concerns within the context of land-use induced material transport within and from the catchment, and coastal impacts and productivity.

2. A preliminary study of current social and economic drivers of change based on existing documentation and selected settlement surveys

3. Some of the main components of a sediment and possibly a nutrient budget for the catchment, including:
   - estimates of mean annual yields to the coast of sediment, nutrients and carbon
   - sources of suspended sediment, particulate nutrients, and carbon
   - rates of accumulation in the delta and mangroves, and sources of materials deposited in the mangrove swamps
   - whether or not the floodplains are sinks or sources of sediments etc.

4. Estimates of coastal productivity, status of nutrients and carbon in mangrove soils, extent and health of mangrove forests, possible role for seagrass in fish productivity.

5. Management implications and planning considerations.

6. Field and Office training of MAFF staff.

This project will ideally be performed over the coming dry season (2006) and next wet season (2006/2007). This second pilot study will take 12 months and will include full development of a three year plan. Indicative cost is $(US)50,000.

**A Three Year Plan**
The full three year plan cannot be completed until the Caraulun project is at least well underway. It is believed that the link between catchment exports and coastal productivity is strong on the south coast by comparison with the north coast, but this hypothesis needs to be tested before fully designing the larger project.

However, the following components are likely in the three year plan:

1. Socio-economic surveys, case studies, and planning in the Laclo and Caraulun catchment, involving:
   - identifying cultural boundaries and customary political jurisdictions to design effective catchment management regimes.
   - case studies at three locations in each catchment to identify cultural, socio-economic and land use practices and trends, with budgets of materials, energy and cash coming from forests and non-forest land uses.
   - participatory planning and training involving local people and government staff, focussed on strengthening and broadening customary practices in the context of specific interventions such as reforestation and land conservation.

2. Complete budgets for sediment, nutrients and carbon in the Laclo and Caraulun catchments, including:
   - measured river fluxes involving local people doing sampling and MAFF the laboratory analysis, taking account of the ongoing sampling by NORAD.
   - isotopic determinations of sources of sediment, nitrogen, and carbon
   - dynamics of floodplains as either sinks or sources
   - timing of downstream changes in relation to land cover changes in the uplands.

3. Marine productivity estimates, including:
   - fish surveys inshore near the Laclo and Carulun rivers, both of extant populations and what is caught
   - estimates of productivity of seagrasses and mangroves, and the significance of this for fish productivity.

4. Catchment Management Plans, including:
   - participatory involvement of local people and MAFF staff (see #1 above)
   - integration with JICA work in the Laclo catchment
   - review of land and water resource development proposals and potential impacts in both catchments.
   - advice from specialists in ecosystem restoration of seasonally dry tropical areas.
   - review of international literature on the effects of reforestation on upland erosion, downstream river channel sedimentation, and coastal impacts.
   - a management plan for the Caraulun catchment and, in conjunction with JICA and NORAD, for the Laclo catchment.
5. **Project Management Training**

During the current study few resources have been available for training. During the proposed three year study of the LaClo and Caraulun catchments, more complete and formal training of government activity managers is envisaged. MAFF staff (and others) would be provided with a week long short course in Dili focussed on catchment processes, marine productivity, and management that is socially robust. This training could be offered each year to act as a refresher course and to include new people each time. The design and timing of the training will be informed and coordinated with other land management programs undertaken through MAFF. Consideration should also be given to formal postgraduate training for MAFF staff.

It is anticipated that MAFF staff will play a key role in planning and implementation of the proposed investigations. Wherever possible, MAFF staff should provide leadership. It is also envisaged that community representatives will participate in sampling programs, as they will have continuous access to sampling sites in adverse weather conditions. Training in sampling and storage of samples will be provided.
8.0 References


## 9.0 List of Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Country</th>
</tr>
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<tbody>
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