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Assessing Hydrological Situation of Talau Watershed, Belu Regency, East Nusa Tenggara

Betha Lusiana, Rudy Widodo, Elok Mulyoutami, Dudy Adi Nugroho and Meine van Noordwijk

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Abstract

This report presents results of a ‘rapid appraisal’ of the hydrological situation in Talau Watershed, Belu District in East Nusa Tenggara (Indonesia). The main objective of this study was to assess the hydrological situation of Talau watershed, to provide information on what and where the payment for watershed services could be focused.

Talau also has a very dry climate, with average annual precipitation of around 1600 mm/year. Around 95% of the rainfall falls within 4 months of rainy season, causing the rest of the year in a dry condition. Due to this condition, the dominant land cover classes in Talau watershed are grassland.

Water springs are the main source of water for people in the area. The main focus of this study is in Lahurus, where the water spring is currently used by the local people for household consumption and agricultural irrigation, as well as by the public water company (PDAM) for drinking water in another watershed.

Local knowledge surveys to local community and policy makers as stakeholders in Talau watershed revealed that their main hydrological concerns are:

1. Sensitivity to climate variability and imbalance of demand and supply of water in dry periods, which leads to:
    a. Concerns over low flows and water shortage in dry season, shortfalls at intake of drinking water supply;
    b. Lack of landscape scale water storage, with ‘overflow’ conditions in the second part of the rainy season, and shortfalls in the dry season
2. Soil erosion that could add further degradation to the landscape

Both local community and policy makers of Talau believe that good land management could improve soil conditions and it is important to reduce further degradation of the watershed. They suggested that activities such as planting trees and developing infiltration pits could help in reducing the hydrological problems they are facing.

From the limited information available on river flow, the overall pattern of Talau river flow can be described in three phases: the early part of the rainy season when the soil and landscape storage capacity for water is recharged, the second part of the rainy season when a larger proportion of the current rainfall is transmitted to the river, and the dry season when river (and spring) flow depends on the gradual release of stored water. Our analysis of hydrological data confirms with our assessment on Talau watershed function (using modeling approach), where we explored how the year-to-year variation in rainfall translates to variations in hydrological behaviour. The buffering capacity of the Talau watershed is less in years with high rainfall and consequently high total water discharge. A similar situation occurred for ground water discharge. River flow in the Talau watershed is strongly seasonal; the risks of flash floods is

especially high in the second part of the rainy season when the storage capacity of the landscape is saturated and strong rainfall is passed on to the river without much buffering.

The landscape water balance both in Talau watershed and Lahurus sub-catchment shows strong seasonal differences. Annual potential evapotranspiration (1430 mm) is just slightly lower than the average total annual rainfall (1634 mm), but the actual evapotranspiration (estimates to be 613 mm) is much lower than the potential evapotranspiration, due to the strong seasonality of rainfall and limited storage capacity of water in the soils. From an eco-hydrological perspective, it is likely that planting more trees in the area, as currently suggested by local people and policy makers, will not substantially increase low flow, but even risks compromising it.

Further analysis on the relationships between land use and hydrology revealed similar result as above rough water balance calculation. Converting non-productive land (defined as grassland and bush/shrubs land class) into agroforestry systems or forest does not change the annual low flow. Nevertheless, adding tree into the landscape reduced surface runoff and increased soil quick flow. This result implied that rainfall will not reach the river as soon as it occurred, increased watershed buffering capacity and consequently flash flood can be avoided. Assuming that runoff is highly correlated with soil erosion, reduction in surface runoff also suggested reduction of soil erosion and therefore improved water quality.

At this stage the evidence for a reward scheme that uses real outcomes (some measure of actual low flows) as basis for conditional rewards is relatively weak for addressing problems in water quantity, even though potential 'buyers' and 'sellers' might both believe that planting trees will solve the problem of water scarcity during the dry season. Further awareness campaign and discussions to reconcile the perspectives will be required. In particular, addressing the issue on what types of intervention will be needed and what are their plausible effects, to ensure that the subsequent negotiations on PES mechanisms will succeed. However, analysis so far suggested that rewards/payment schemes could be based on reduction of soil erosion. Further evidence on actual sediment loads of streams and field measurements of erosion is needed for verification. Development of a reliable monitoring system for rainfall, river flow and water quality is needed if one wants the payments for watershed services to become outcome based.

Water harvesting techniques in the area could actually help in increasing supplies of water during dry season. Besides the fact that harvested water could be of direct benefit to local community use, it is in fact will be of benefit to PDAM water users as well. Additional water supplies from harvested water could partially release pressure from water use from the Lahurus spring, thus possibility of additional water for PDAM.

Implementation of water harvesting techniques, particularly by using 'embung' (a semi-constructed pond), should synergize with effort in reducing soil erosion. Since harvesting water by embung will be optimal if soil erosion in the area can be suppressed.

Based on the current existing evidence, future development of reward mechanisms in the area could link to activities such as (i) water harvesting i.e. developing 'embung', a semi-constructed ponds to harvest water during wet season, (ii) soil management to avoid further soil degradation (run-off, soil erosion, fertility loss) i.e. terracing, developing infiltration pits in tree-based systems, and (iii) planting trees to increase soil cover and reducing further soil degradation.

Further activities on good water management, particularly in areas (yet to be identified) where currently surface runoff exceeds 30% of rainfall, would also be of benefits as increasing infiltration (through tree planting) will have high possibility to increase low flow and recharge water springs.

Keywords

environmental services assessment, environmental services reward mechanisms, hydrological modeling, Indonesia, local knowledge, watershed function

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Contents

Acronyms

WWF:	World Wild Fund
DANIDA:	Danish International Development Agency
IIED:	International Institute for Economic and Development
RUPES:	Rewarding the Upland Poor for the Environmental Services they provided
BAPPEDA:	Badan Perencanaan dan Pembangunan Daerah (Regional Planning and Development Bureau)
RTRWP:	Rencana Tata Ruang Wilayah Propinsi (Spatial Planning for Provincial Area)
PDAM:	Perusahaan Daerah Air Minum (Public Drinking Water Company)
RHA:	Rapid Hydrological Appraisal
CIFOR:	Center for International Forestry Research
WCMC:	Water Conservation Monitoring Centre
BAKOSURTANAL:	Badan Koordinasi Survei dan Pemetaan Nasional (National Coordinating Agency for Surveys and Mapping)
BMG:	Badan Meteorologi dan Geofisika (Meteorological and Geophysical Agency)
KIMPRASWIL:	Pemukiman dan Prasarana Wilayah (Settlement and Regional Infrastructure Agency)

Introduction

Talau Watershed as potential site for reward mechanism

Increasing degradation of watersheds has led to awareness of services that a watershed can provide and recognition of the need to maintain these functions. It is known that land use can significantly affect watershed functions such as water quality, water flow, erosion control and sedimentation in downstream areas. However, those who own or manage upper watershed land often have little incentive to maintain these services because the benefits occur downstream and because they do not receive compensation for providing them.

The increased awareness of the importance of maintaining watershed functions has triggered various form of initiatives to protect watershed including providing incentives for people in upper watershed areas to protect watershed functions. Landells Mills and Porras (2002) identified 61 initiatives on reward mechanism associated with maintaining watershed functions, mostly with goals to maintain dry season flows, to protect water quality and to control sedimentation. Reward mechanism is seen as a more direct approach in watershed conservation approach and it explicitly recognized the need to bridge the interests of landowners and outside beneficiaries through compensation payments.

Geographically, Belu Regency lies at 124° - 126° East and 9° - 10° South. It is located in the eastern part of East Nusa Tenggara, strategically positioned in the border of Timor Leste. To the north of Belu is Ombai Strait and to the south is Timor Sea. Two regencies, Timor Tengah Utara and Timor Tengah Selatan, lie in the west border of Belu.

Belu has an area of 2445 km2 with population of around 39000 people. In 2004, the regency was divided into 12 districts with 12 urban sub-districts and 154 rural sub-districts. The natural vegetation in Belu comprise of dry tropical forest, dominated by savannah vegetation such as *Corypha utan*, *Acacia leucophloea*, *Casuarina sp*. and *Eucalyptus alba*.

Belu, with its tropical climate, has two main seasons: dry and wet. The dry season normally occurs for 8 months during February to October, while the wet season is 4 months in November to January. The average total yearly rainfall in Belu is low, around 1500 mm year-1. This is influenced by the geographical position of Belu which is closer to Australia than the Asian continent. With this climatic condition, availability of water during dry season is an issue.

Figure 1. The location of Belu Regency with Atambua as its capital.

Indonesia National Human Development report (2004) stated that in 2002, 42.4 % of population in Belu is without access to clean water. Detailed data from 2001 suggested that only 8% of Belu population used water from Public Water Company (Perusahaan Daerah Air Minum = PDAM), mostly by people living in and around Atambua, the capital of Belu. Availability of continuous supply of clean drinking water is crucial for Belu.

Currently, the source of water for PDAM is located in the upland areas of Belu, in Talau Watershed. The current situation in Belu is an opportunity to develop reward mechanism, specifically in Talau Watershed areas. The local people who are living in the surrounding water springs in Talau watershed are the potential sellers in providing service to maintain the water supply and the local government (in this case PDAM) is the potential buyer.

Reward mechanism could also potentially address poverty issue in Belu, Nusa Tenggara. The province of East Nusa Tenggara has the third lowest Human Development Index (HDI) among 30 provinces in Indonesia (Indonesia National Human Development Report, 2004). Within the province, Belu was ranked 7 (out of 14 regencies including Kupang as the capital of East Nusa Tenggara), or 318 (out of 340 regencies in Indonesia). The low HDI scores of East Nusa Tenggara and Belu reflect the livelihood situation of Belu.

Why Hydrological Assessment in Talau Watershed, Belu

As a consequence of landscape variability and site-specific characteristics of watershed functions, it is important that we conduct a general approach to monitor and assess the biophysical condition of a watershed, prior to developing reward mechanism. The hydrological assessment is crucial and it needs to be conducted independently and transparently. Otherwise, the development of reward mechanisms could be based on myths or general beliefs about land use and water relationship that lead to inappropriate solutions (Kaimowitz, 2001).

RUPES[1] proposed seven necessary stages in the development of reward mechanisms (Jeanes, *et al.*, 2006): (1) Scoping, (2) Awareness, (3) Identifying Partners, (4) Negotiations, (5) Action Plans, (6) Environmental Services Rewards: Support for Actions and (7) Monitoring. Hydrological condition assessment encompasses the first three stages that need to be conducted at the beginning of reward mechanisms development.

Van Noordwijk *et al.* (2006, 2007) developed criteria and indicators of ‘equitable compensation and reward’ mechanisms: realistic, voluntary, conditional and pro-poor (Table 1). The current report is focused on step I, the appraisal of ‘realistic’ relations between land use and environmental services that are of sufficient value to become the basis for reward mechanisms. Step I also requires appraisal of the degree of ‘awareness’ and ‘shared understanding’ between stakeholders, so there is necessarily interaction with activities in step II, which should run in parallel, jointly preparing for a negotiation phase.

1 RUPES (Rewarding the Upland Poor for the Environmental Services they provide) is a program for developing reward mechanisms in upland poor Asia. Its goal is to enhance the livelihoods and reduce poverty of the upland poor while supporting environmental conservation at local and global levels. See http://www.worldagroforestrycentre.org/sea/networks/rupes

The main objective of the hydrological study is to assess the hydrological situation of Talau Watershed from the perspective of multiple stakeholders (local ecological knowledge, policymakers knowledge and ecohydrology) to assess 'whether there is a case to be made', as first step to appraisal of 'the business case', and to provide information on what parts of the area and which environmental service functions are most interesting for further exploration and development of payments for watershed service mechanisms.

Table 1. Steps in the process of developing equitable environmental service reward (payment) mechanisms that are based on a "business case" with identified buyers, sellers and intermediaries

I. Knowledge to knowledge (K to K):	II. Actor to actor (A to A)
Scoping the knowledge systems: is there a realistic case for cause-effect relations between upland land use and downstream effects (avoided degradation and/or rehabilitation), and is there enough awareness and shared understanding of these issues among major stakeholder (RUPES step 1+2)	***a. Mandatory*** protection of environmental services, spatially explicit and general restrictions on land use. b. Options for ***voluntary*** agreements: Exploring stakeholder positions, preferences, scenarios for the future and preferences; what are their likely negotiation positions. c. Comparison of willingness to engage on the buyer side, willingness to engage on the seller side and availability of trusted intermediary – jointly defining '***the business case***' d. Differences in wealth and power between stakeholders, exploration of what '***equitability***' implies in the local context.
III. Negotiations: (K+K ⇔ A+A) leading to (K to A) link	
Focus on conditionality (quid pro quo) of the agreements, the criteria for success and mechanisms for learning and step-wise improvement	
IV. Implementation and monitoring	

Specifically the objectives are:

- To identify the major forms of land cover/land use in the watershed,
- To identify the core hydrological issues and problem according to major stakeholders (including scientists),
- To identify which part of the watershed contributes the most to core problems and possible solutions,
- To estimate the water balance of the watershed, how it is affected by land use change and how it is related to the core problems identified,
- To suggest and rank options to deal with the hydrological issues, as a potential basis for payment/reward schemes.

Methodology

Hydrological appraisal methods

The hydrological condition of Talau Watershed was assessed using 'Rapid Hydrological Appraisal (RHA)' approach[2] (Jeanes, 2006). This approach was developed to provide a rapid, inexpensive and integrated tool to assess hydrological functions of a certain watershed. It was also developed to identify the gaps in understanding between three types of knowledge on watershed function: local people, policy makers and scientific knowledge. If there are no major gaps, then we can focus on the conditionality of reward mechanism. If there are gaps, then we need to address those first.

The most important aspect of RHA approach is that it can provide clarity concerning criteria and indicators of hydrological function and thus provide clarity on: (i) how the watershed function is provided, (ii) who can be responsible for providing this service, (ii) how it is being impacted upon at present, and (iv) how rewards can be channeled to effectively enhance or at least maintain the function.

The assessment was based on the following activities:

i. Spatial analysis of Talau Watershed based on LANDSAT imageries, available maps and digital data to obtain land cover information for watershed modeling purpose
ii. Collection and review of existing relevant information on Talau Watershed, including climate, river flow data and land cover maps
iii. Exploration of local ecological knowledge from the stakeholders of Talau Watershed (local community and policy makers) on hydrological functions, water movement and consequences of land use options on the landscape
iv. Analysis of existing hydrological data
v. Estimating the water balance and water use in Talau Watershed using GenRiver[3] model.
vi. Scenario analyses of plausible land cover changes and their likely impacts on key performance indicators with the GenRiver model

Land cover/land cover change analysis

Land cover maps were obtained through two approaches: (i) in-house spatial analysis on LANDSAT imagery and (ii) collecting existing maps developed by other institutions. In the first approach we conducted image classification based on medium resolution image. As we were only able to acquire one year image (1999), we used the resulting land classification to describe the land cover situation in that particular year (1999) as well as for model parameterization. In the second

2 Rapid Hydrological Appraisal (RHA) was developed by ICRAF to assess hydrological functions of a watershed and the impacts of land use change on key functions. ICRAF has also developed Rapid Carbon Stocks Appraisal (RaCSA) and Rapid (Agro)Biodiversity Appraisal (RaBA). These are three basic tools that can be used to assess environmental services of a given area. For more information see http://www.worldagroforestrycentre.org/sea/networks/rupes

3 GenRiver is a generic river flow model developed by ICRAF. For more information, see http://www.worldagroforestrycentre.org/sea/products/models

approach, we used existing land cover maps to understand historical land cover changes in the area.

Image classification was conducted using object-based classification approach. In this study we used one scene of LANDSAT-TM acquired in 1999. Table 2 shows the description of Landsat images used in this study and other additional data.

Accuracy assessment was conducted to the classified image with the aim to provide quantitative estimation on the quality of information from land cover map by comparing sample locations on the land cover map with reference data taken during field trip. We used Kappa methods in Arc View.

Training samples for image classification were obtained during field survey in September 2006 and a total of eight land cover classes were identified:

Table 2. Description of data used in land classification of Belu

Sensor/ Platform	Description of Data
Landsat 7 ETM	Scene ID: 110-66 Acquisition date: 8 September 1999. Spatial resolution: 30 m. Cloud cover: 1%. Sun elevation: 57.21
GPS data	GPS data for training sample, obtained in November 2006 (dry season)
Topographic map	Scale: 1 : 25 000 Source: BAKOSURTANAL, 2002 Used as reference in image classification
Tata Guna Kesepakatan Hutan (TGHK) map	Scale: 1 : 100 000 Source: Dinas Kehutanan Belu

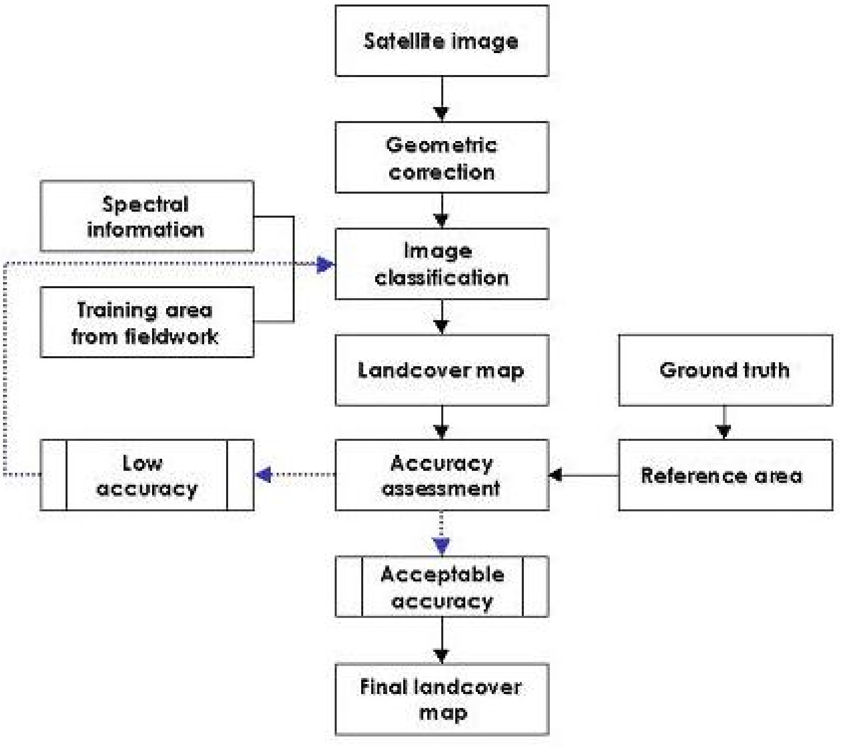


Figure 2. Flow chart of land cover analysis from Landsat image conducted in Rapid Hydrological Appraisal study in Talau watershed (Source: Jeanes, *et al*., 2004).

Forest, refers to area with tree vegetation of high density

Agroforestry (tree based systems), refers to a mixed systems (trees and crops) managed by farmers. Included in this category is a home garden and smallholder timber-based system (*Paraserianthes falcataria*)

Crop land is defined as an area cultivated with annual crops or non-woody vegetation.

Shrubs are characterized by an area covered by mostly low woody-herbs combined with grass. These areas usually correspond to abandoned land where farmer have left their land unmanaged for various reasons. Shrub may represent degraded land.

Grassland refers to an area dominated by *Imperata* grass. In some areas, the physical appearance of grass is almost similar to shrub. The major difference is that most of the vegetation cover is usually non-woody herbs

Rice field refers to inundated rice field include irrigated or non-irrigated rice field. These areas usually appear in light blue using visible-NIR-MIR bands combination.

Water body, an area that is inundated or flowed with water, such as lake or stream.

Settlement represents an area used as human residential area, including main road and village.

Delineation of watershed and its sub-catchments

To delineate watershed area in Belu, we used DEM data from SRTM (Shuttle Radar Topography Mission), obtained from http://srtm.csi.cgiar.org//. Table lists the descriptions of STRM data used in this study.

Table 3. Description of STRM-DEM data used in delineation of Talau watershed

Product	Data File	Centre point	Year
STRM 90 m DEM	strm_61_14	Latitude 7.50 S Longitude 122.50 E	2004
STRM 90 m DEM	strm_62_14	Latitude 7.50 S Longitude 127.50 E	2004

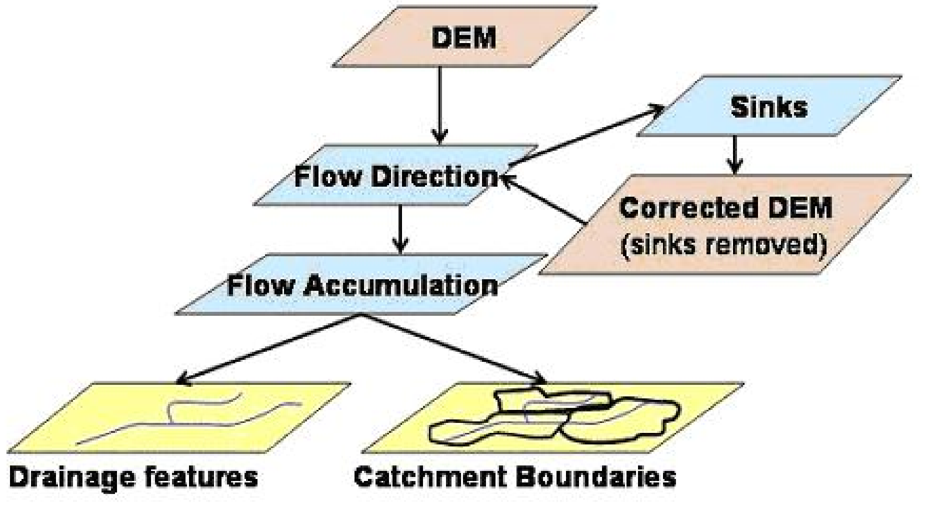


Figure 3. General work flow of hydrological features extraction in ArcView Hydro Module (Source, Jeanes, *et al*., 2004).

Notes:

Flow Direction: each cell is assigned a value denoting the direction of the flow based on the height differences of its neighbouring pixels

Sink: cells identified as having no outlet, being the lowest in height compared to its neighbouring cells

Flow Accumulation: each cell is assigned a value of accumulated number of cells contributing their flow to that cell

Knowledge surveys and stakeholder analysis

The objectives of these surveys are to explore the local people and policy makers' perspectives and concerns on hydrological issues in Belu Regency, particularly in Talau watershed. Perspectives from urban water users were also explored.

Local people are the actual land manager that work and interact with watershed landscape on day to day basis. Policy makers at regency and provincial level are people that have been given a mandate to control and manage the watershed areas. The policies they create will have strong influence on the future condition of a watershed. Thus, both local and policy makers views on watershed hydrological condition are very vital in this overall study.

The local knowledge surveys were carried out in Lahurus (Lasiolat) and Tasifeto Timur in September 2006 and January 2007, while the policy makers knowledge surveys was carried out in Atambua and Kupang (the capital of East Nusa Tenggara) in September 2006. The methods used in the survey are adapted from Knowledge Based Systems developed by Dixon *et al*. (2001)[4].

Stakeholder identification and analysis were conducted at regency level and provincial level, between staffs of CARE International Atambua Office, local informant, members of Forum DAS Kupang[5] and interviews with local government institutions. Stakeholders were identified based on their interest and institutional position. These institutions were interviewed to gain their view on land cover change, hydrological issues and watershed services of Talau watershed.

Climatic, geology and hydrological data of Talau watershed

Up to date data on rainfall and river flow in Talau watershed is very scarce. There were no continuous monitoring program for water quality or quantity in Talau watershed, thus there are no continuous water quality or quantity data available. Some data on climate and river flow exists but were only measured at a given location and time, therefore has only limited use to reveal spatial or temporal trends.

The quality of the data that we have managed to acquire were also 'not exceptionally good', in a sense that it required cleaning up prior to direct use. The steps in data clean up will be clearly shown in this report.

Table 4. List of data on climate, geology and river flow of Talau watershed.

Data	Type	Year	Source
Climate	Daily rainfall, weather station: Tasifeto Timur-Wedomu	1989-2002	CARE - Atambua
	Monthly rainfall weather station: Sukabitek-Atambua	1978-1995	Mining Agency Atambua
	Monthly temperature, weather station: Sukabitek-Atambua	1978-1993	Mining Agency Atambua
Soil and Geology	Soil map, scale: 1:250000	-	CARE Atambua
	Geological map, scale: 1:250000	-	CARE Atambua
Hydrology	Daily river flow, station: Motabuik	1991-1994	Water Resource Research Centre – Bandung

Estimating the landscape water balance of Talau watershed

To estimate the landscape water balance, we used modeling approach using GenRiver model (Farida and van Noordwijk, 2004, van Noordwik *et al*, 2003), a generic model of land use and river flow. GenRiver is a distributed process-based model that simulates river flow. It was

[4] More information on local knowledge is also available at Sinclair, FL (1998).

5 Forum DAS is a forum of concerned individuals, organizations or institutions on watershed management and rehabilitation issues. Forum DAS was established by WWF Kupang and BP DAS on NTT province.

developed for data-scarce situations and is based on empirical equations. The model can be used to explore the basic changes of river flow characteristics across spatial scales – from patch level, sub-catchment to catchment. GenRiver is a simple river flow model that aims to simulate changes in river flow due to land use change.

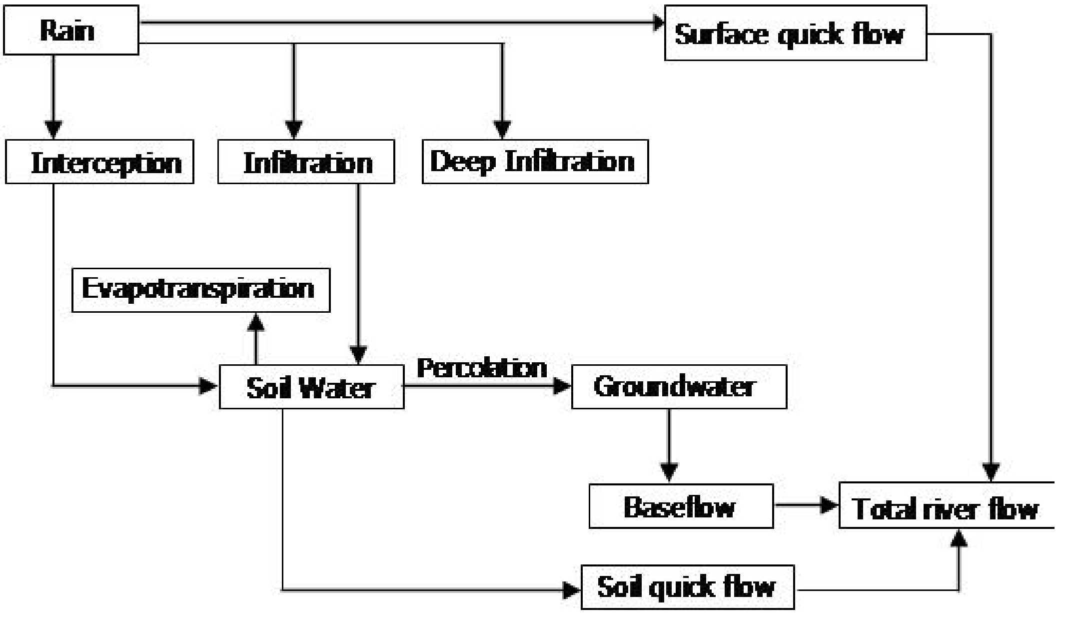


Figure 4. Diagram flow of hydrological processes in GenRiver

The core of the model is a patch level daily water balance, driven by local rainfall and modified by the land cover and soil properties of the patch. The patch can contribute to three types of stream flow: surface-quick flow on the day of the rainfall event, soil-quick flow on the next day and base flow (simulated as the gradual release of groundwater).

The modeling activity was carried out using the following steps:

i. Data preparation

ii. Processing spatial information resulting from spatial analysis. The activity conducted in this step includes producing hydrological features data such as sub-catchment boundary, drainage, routing distance (distance of streams within sub-catchment to main river), soil characteristics

iii. Model parameterization.

iv. Model calibration using existing data

v. Scenario development

vi. Model simulation with plausible land use change scenarios to understand the impact of land use change on sub-catchment water balance.

Analysis on Indicators of Watershed Functions: water quantity and water quality

The assessment of hydrological situation in Talau watershed is established mostly on criteria and indicators of water transmission (total water yield per unit rainfall), buffering capacity (relationship of peak river flow and peak rainfall, linked to flooding risk) and gradual release of (ground) water in the dry season, based on recharge in the rainy season (Table 5). These indicators all relate the flows of water to the preceding rainfall – and by doing so; allow the analysis of the relatively small land use effects, superimposed on substantial year-to-year variation in rainfall.

As there is a shortage of reliable data on river flow, we first calibrated and validated a water balance model for the area, and then used this for further exploration of scenarios. As no data continuous data on sedimentation or erosion exist, we will assess the risk to erosion through level of runoff. This is with an underlying assumption that high run-off would lead to high risk of erosion.

Analysis of relationship between land cover and water balance

To understand the impact of land cover on landscape water balance and river flow, we will use modeling approach to simulate land cover change scenarios. The scenarios will be based on the results of both local knowledge surveys and policy makers' surveys. The simulation study will focus on (i) Talau watershed and ((ii) Lahurus sub-catchment, because (i) Lahurus is the location of water spring that is the source of water for Public Water/PDAM, thus a relevant site for PES development and (ii) Talau watershed is an ideal location for scaling up the current project.

Table 5. Criteria and indicators of watershed hydrological functions that relevant to downstream stakeholders (Van Noordwijk, *et al*., 2004)

Criteria	Indicator	Quantitative Indicator		Site characteristics	Relevant for
Water transmission	Total water yield (discharge) per unit rainfall (TWY)	$TWY = \frac{Q}{A \times P}$,	Q = annual river flow, A = total watershed area P = annual precipitation	Annual rainfall (mm.year^{-1})	Downstream water users
Buffering peak rain event	Buffering indicator for peak flows given peak rain events (BI)	$BI = 1 - \frac{Q_{abs\_Avg}}{A \times P_{abs\_Avg}}$, where $P_{abs\_Avg} = \sum \max(P - P_{mean}, 0)$ $Q_{abs\_Avg} = \sum \max(Q - Q_{mean}, 0)$		Geomorphology	Communities living along the river and in flood plains
	Relative buffering indicator, adjusted for relative water yield (RBI)	$RBI = 1 - \left(\frac{P_{mean}}{Q_{mean}} \times \frac{Q_{abs\_Avg}}{P_{abs\_Avg}} \right)$			
	Buffering peak event (BPE)	$BPE = 1 - \frac{\max(Daily\_Q - Q_{mean})}{A \times \max(Daily\_P - P_{mean})}$			
	Fraction of total river discharge derived from surface quick flow (run off)	Direct output from model			
	Fraction of total river discharge derived from soil quick flow	Direct output from model			
Gradual water release (water availability during dry season)	Lowest of monthly river discharge totals relative to mean monthly rainfall			Soil type and characteristics	Communities who do not own water harvesting/ storing systems (lake, *embung*)
	Fraction of discharge derived from slow flow (> 1 day after rain event)	Direct output from model			

Note: Q (mm.day^{-1}) = {[(**m^3.sec^{-1}**) x24 hourx3600 sec.hour^{-1}]/ [**A (km^2)** x10^6 m^2.km-^{2})]}x10^3 (mm..m^{-1})

Land use/cover analysis of Talau watershed

The study site

Talau watershed has an area of 720 km2, encompassing Indonesia and Timor Leste. The upstream of Talau is located in Indonesia, with an area of 562 km2 covering 78% of the watershed or covers 23% of Belu Regency and falls under five districts: Lamaknen, Tasifeto Barat, Tasifeto Timur, Lasiolat and Atambua - the capital of Belu (based on districts classification in 2004). Rivers from Talau watershed drain to Ombai Strait in Timor Leste. Overall, the length of rivers in this watershed ranges between 7 – 55 km. For the purpose land use classification and simulation study, Timor Leste area will be included.

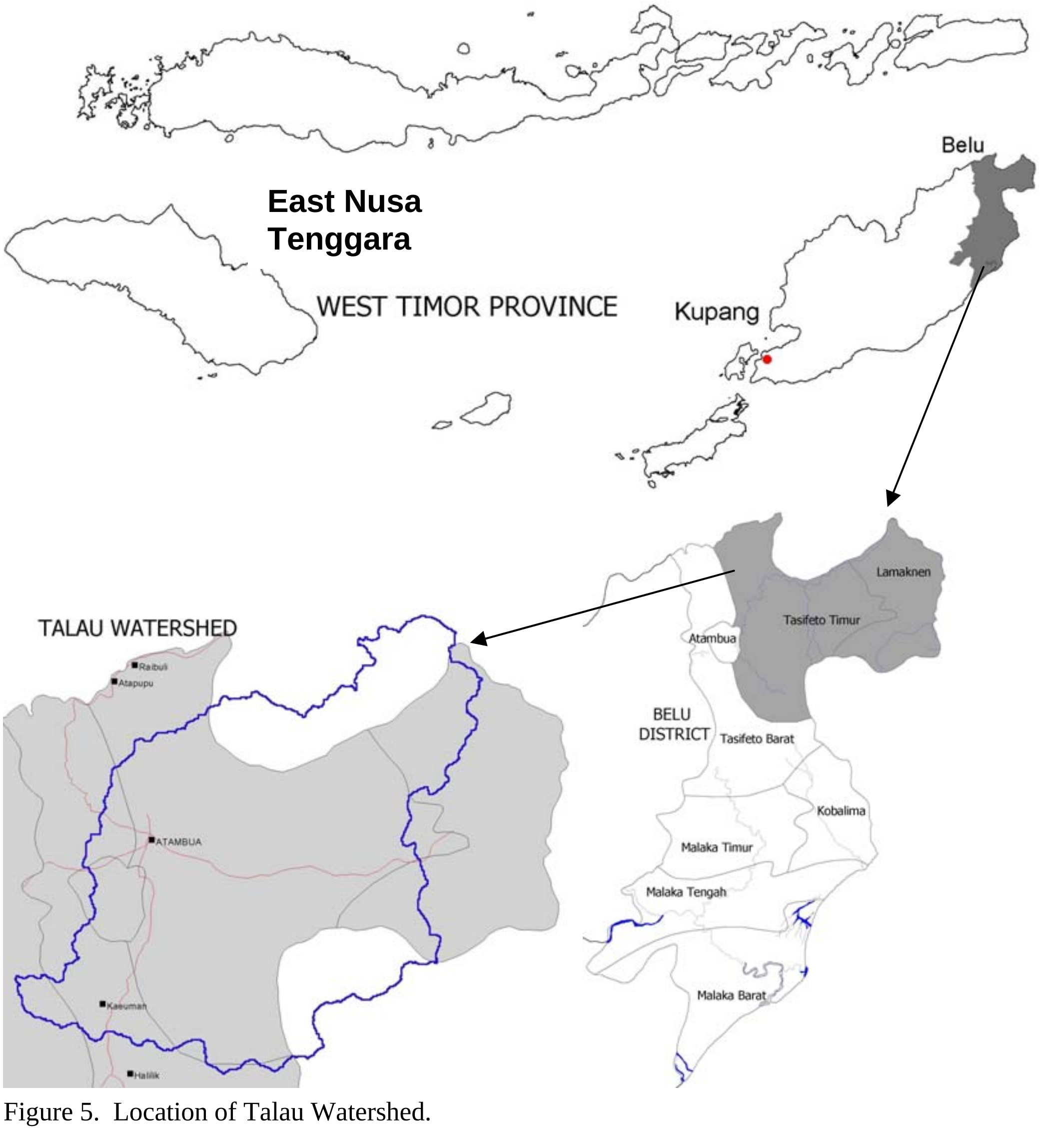


Figure 5. Location of Talau Watershed.

Land use/cover change analysis

The result of land cover classification analysis on 1999 Landsat image are presented in Table 6 and Figure 6. The land cover map has an overall pixel accuracy of 76% (see Appendix 1).

Table 6. Area of Belu in 1999 under various land cover

Land cover Class	Total Area in km^2 (Proportion in %)		Area in Indonesia - km^2 (Proportion in %)	
Forest	5.9	(0.1)	4.4	(0.1)
Agroforestry	47.2	(6.6)	37.6	(6.7)
Crop land	25.1	(3.5)	19.2	(3.4)
Bush	33.0	(4.6)	23.6	(4.2)
Grassland	473.0	(65.7)	365.9	(65.0)
Rice field	111.2	(15.4)	92.8	(16.5)
Water body	1.0	(0.1)	0.6	(0.1)
Settlement	23.7	(3.3)	18.6	(3.3)
Total	720.0		562.6	

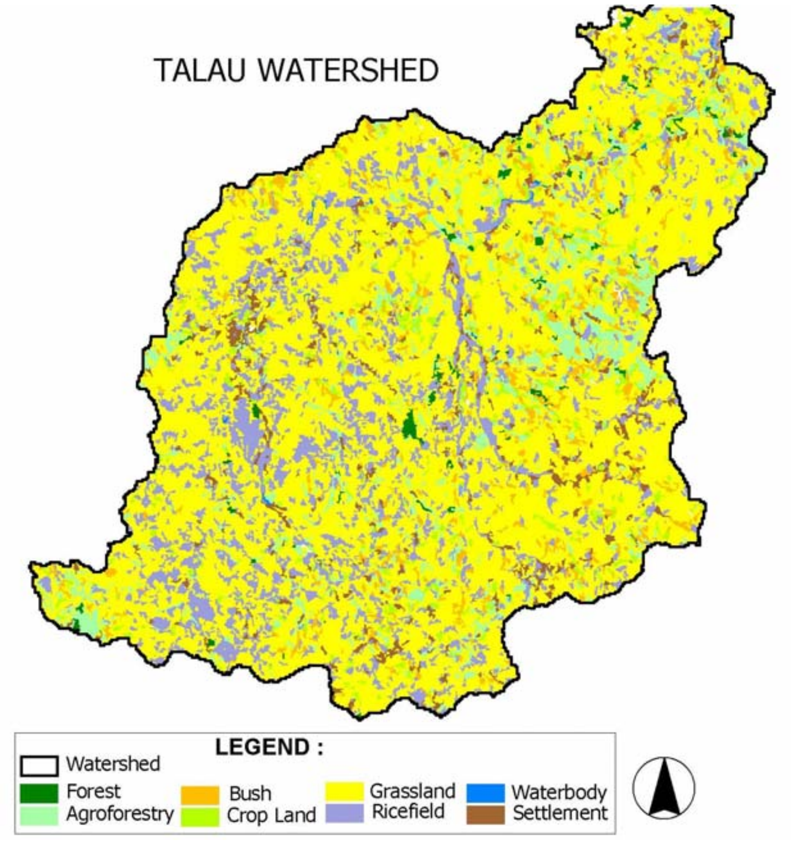


Figure 6. Land cover map of Talau Watershed based on classified image of Landsat in 1999.

Grassland

Rice field

Forest

Settlement

Cropland

Agroforestry

Water body

Figure 7. Example of land use systems found in Talau Watershed

In 1999, the main land use systems in Talau watershed is grassland, covering around 66% of the area. The dry climate of the area and its main soil formation of limestone, do not allow other vegetation besides grass to grow well in this region (Figure 8). In addition to that, shifting cultivation system that is practiced by local farmers, are leaving land to fallow during dry season. Part of these grassland areas are used by farmers as pasture land for their livestock.

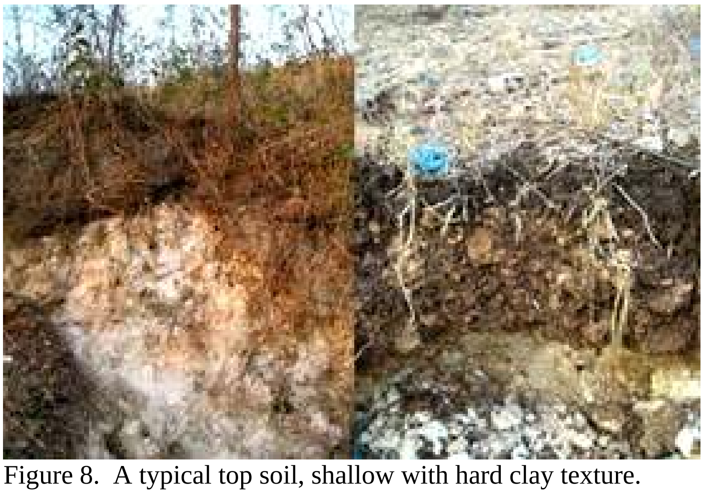


Figure 8. A typical top soil, shallow with hard clay texture.

Only around 1% of the area is covered with forest, mainly found around water springs. Cultivated land covers around 25% the watershed with 7% of agroforestry systems, 3% of cropland (upland crops) and 15 % of rice field.

Land use systems in Lasiolat and Tasifeto Timur districts are dominated by dry land areas. Farmers still practiced slash and burn and shifting cultivation and plant upland rice, maize, beans and vegetables in their systems. Trees such as mango, jackfruit, coconut, cashew nut, candle nut, kapok, orange, and betel nut are planted extensively around water springs with low input.

An important land use systems in this area is *mamar* systems (Figure 9), which is forest/tree systems around water springs. The local people believed *mamar* is important in protecting and regulating water flows from the springs. Thus, *mamar* systems are protected areas. However, some economic plants are harvested, such as sirih (*Piper betle*) and pinang (*Areca catechu*)[6]. Fruit trees such as mango, jackfruit, coconut, cashew nut, candle nut, kapok (*Ceiba petandra*), orange, and betel nut are also allowed to be planted around water springs.

[6] Pinang and sirih are used locally for chewing.

Figure 9. Forest and agroforests around water spring as 'sacred grove' or ***mamar***. This area is communal land and becomes conservation area prohibited to changes.

In terms of the hydrological study, there are two important sub-catchments in Talau, Lahurus and Motabuik. The Lahurus sub-catchment, is the location of Lahurus water springs that provides water for the surrounding community as well as to Public Water Service (PDAM) of Atambua. Motabuik sub-catchment is the top most upper catchment (Figure 11). It also is the area where data on river flow is available. The size of Lahurus and Motabuik catchments are approximately 14 km^2 and 103 km^2 respectively (Table 7).

The Motabuik sub-catchment has similar land cover pattern as the overall Talau watershed. Lahurus, however it has slightly higher forest cover, possibly due to the existing well maintained water spring.

Figure 10. Lahurus water spring, the source of Public Water Service (PDAM) of Atambua

Table 7. Area of Lahurus and Motabuik sub-catchment in 1999 under various land cover.

Land cover Class	Area in km2 (Proportion in %)			
	Lahurus		Motabuik	
Forest	0.37	(3)	0.65	(0.6)
Agroforestry	2.6	(18)	6.1	(6)
Crop land	1.1	(8)	2	(2)
Bush/shrubs	0.9	(6)	1.8	(1.7)
Grassland	8.3	(58)	66	(64)
Rice field	1	(6)	24.3	(24)
Total	14.3		102.6	

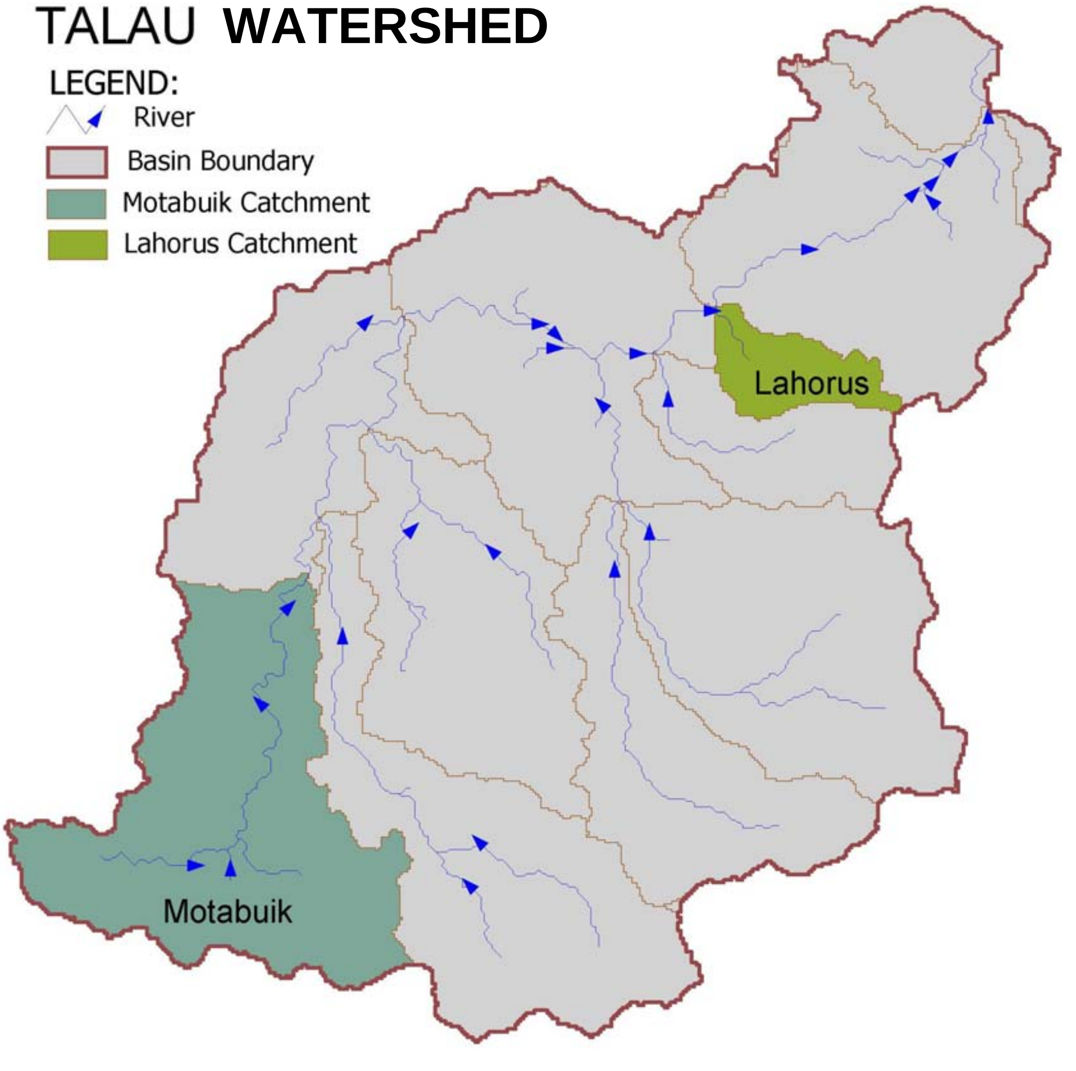


Figure 11. Map of ten sub-catchments in Talau Watershed. Lahurus is located in the lower part of the watershed while Motabuik is in the upper watershed.

Land cover change

To obtain a general understanding of the land cover changes in area, we compared existing maps of 1987, 1999 and 2004. Only information of land cover from the Indonesia part of the catchment is available. It should be noted that the land cover class (legend) of 1987 map differs from the maps of 1999 and 2004. Thus direct comparisons can only be conducted between maps of 1999 and 2004. The land cover map of 1989 was used to obtain understanding of the forest situation at that time. Table 8 presented the size of each land cover class and the maps are shown in Figure 12.

In 1987, forest covered roughly 15% of Talau watershed. This decreased to 1% in 1999 and stabilized for the next 5 years. During 1999 – 2004 periods, the main land cover is shrubs and grass covering more than 50% of the area. Within similar period, dry land agriculture area has significantly increased by 250%, mostly in the area close to Atambua (capital of Belu Regency). The sharp difference in agricultural conversion rate in the western part of the catchment is probably linked to differences in soil fertility, as it matches boundaries in the soil map.

Table 8. Land cover map of Talau in 1987, 1999, and 2004

(a) Land cover map of Talau in 1987[1]

Land cover class	Area (km)	%
Lowland evergreen broadleaf rain forest	27	5
Semi-evergreen moist broadleaf forest	37	7
Lower montane forest	15	3
Non-forest	466	85
Total	545	100

(b) Land cover map of Talau in 1999 and 2004

Land cover class	1999[2]		2004[2]	
	km	%	km	%
Forest	7	1	8	1
Tree based systems	28	4	31	4
Grass and shrub	392	55	401	56
Rice field	14	2	14	2
Agriculture (dry land)	87	12	215	30
Others	22	3	23	3
No data (cloud etc.)	169	24	27	4
Total	719	100	719	100

Note:

[1] Data from World Conservation Monitoring Centre (WCMC), http://www.wcmc.org.uk. Scale: 1: 1000000

[2] Data from Agency of Soil and Land Survey (BAKOSURTANAL) Scale: 1: 250000

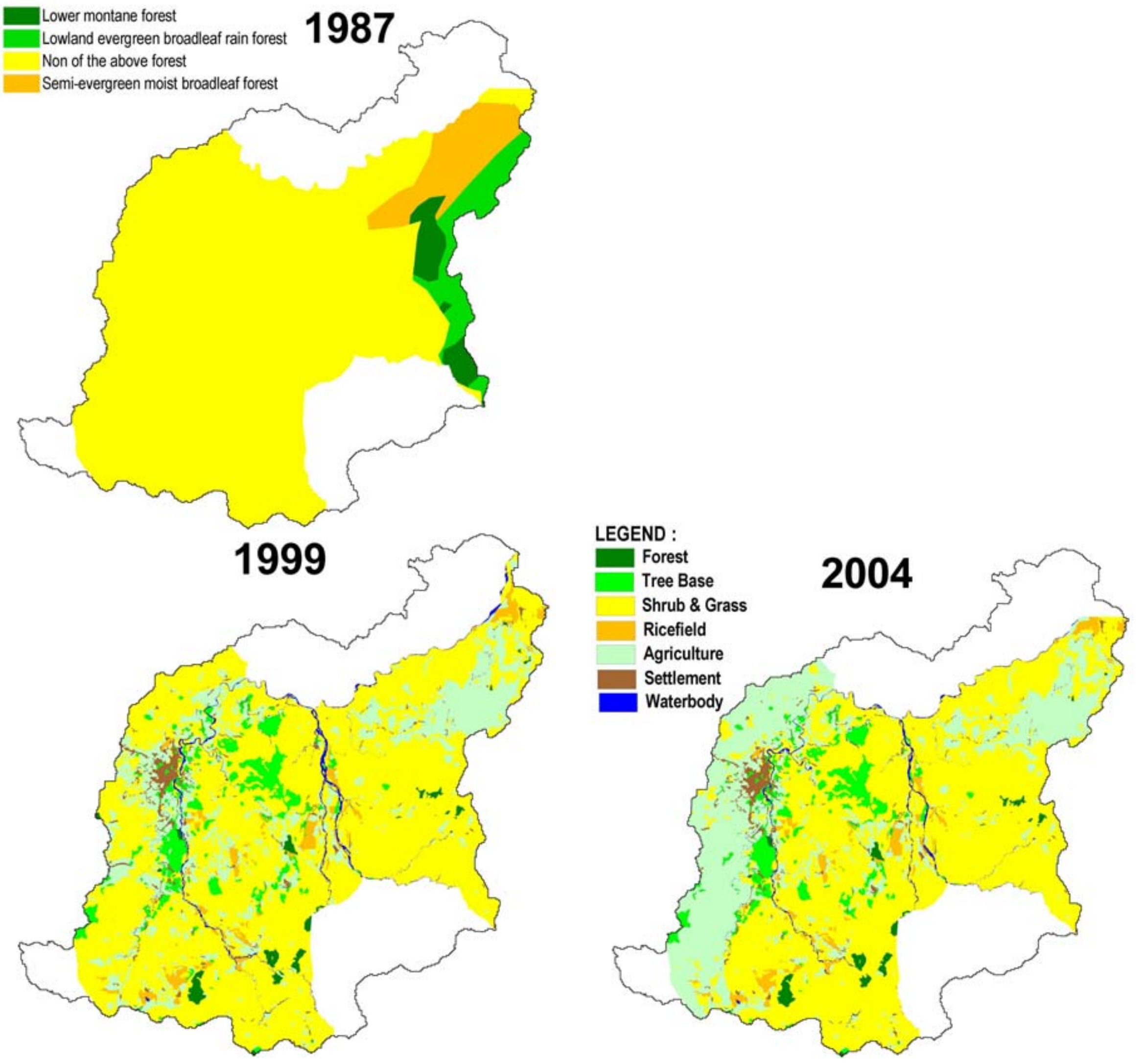


Figure 12. Land cover maps of Talau watershed in 1989, 1999 and 2004.

What are the main hydrological problems in Talau watershed? local community and policy makers' perspectives

Local Community Perspectives and Knowledge

People and Customary Law

The dominant ethnic groups in Belu Regency are Tetun (Belu), Dawan (Attoin Metto), Bunak (Marae) and Kemak. These main ethnic groups can be further divided into smaller groups or sub-groups. In Lahurus site (Lasiolat district), Leoklaren is the dominant sub-group followed by Astalin and Leowes. In Tasifeto Timur district, Kemak and Tetun are dominant, followed by Leowes and Maumetan.

Ethnicity greatly influences day-to-day life. The ethnic groups define the customary law applied in the regions that control the management and use of natural resources. In the customary law within Belu, there are three strata of law: (i) *Kneter*/*Neter* - way of life, (ii) *Ktaek*/*Taek* – norms and (iii) *Ukun badu* – laws that states the taboos and restrictions. Interactions between people and nature are based on *Badu* that sets the rules on how to manage natural resources. According to *badu*, natural resources (soil, water, big rocks, big trees, mountain, etc) are considered sacred and have owner. All activities that relates to sacred forms must be preceded with ceremony to show respect and to request consent. Sacred lands usually belong to communal and governed by all ethnic groups member.

Water springs are treated as 'sacred groves' and are usually owned and controlled by a sub-ethnic group (clan). The clan has the right to regulate spring water use and protection. Forest around the water springs (*mamar* systems; Sumu, 2003) is protected from access by livestock and no wood harvesting is allowed. However, people who belong to the clan are allowed to use some economic plants such as sirih (*Piper betle*) and pinang (*Areca catechu*). In the past, only people of the clan were allowed to use water from springs. People from other clans need to ask permission and will be penalized if they refuse to comply. However, recently customary law no longer has strong hold. This has triggered conflicts over water use.

Land use patterns

Availability of water or access to water strongly influences settlement pattern and the systems that farmers managed (Figure 13). For example paddy rice and vegetables are planted if the farmers have good access to high quantity of water, which occurs in areas close to water springs or have good irrigation systems such as *embung* (small reservoir).

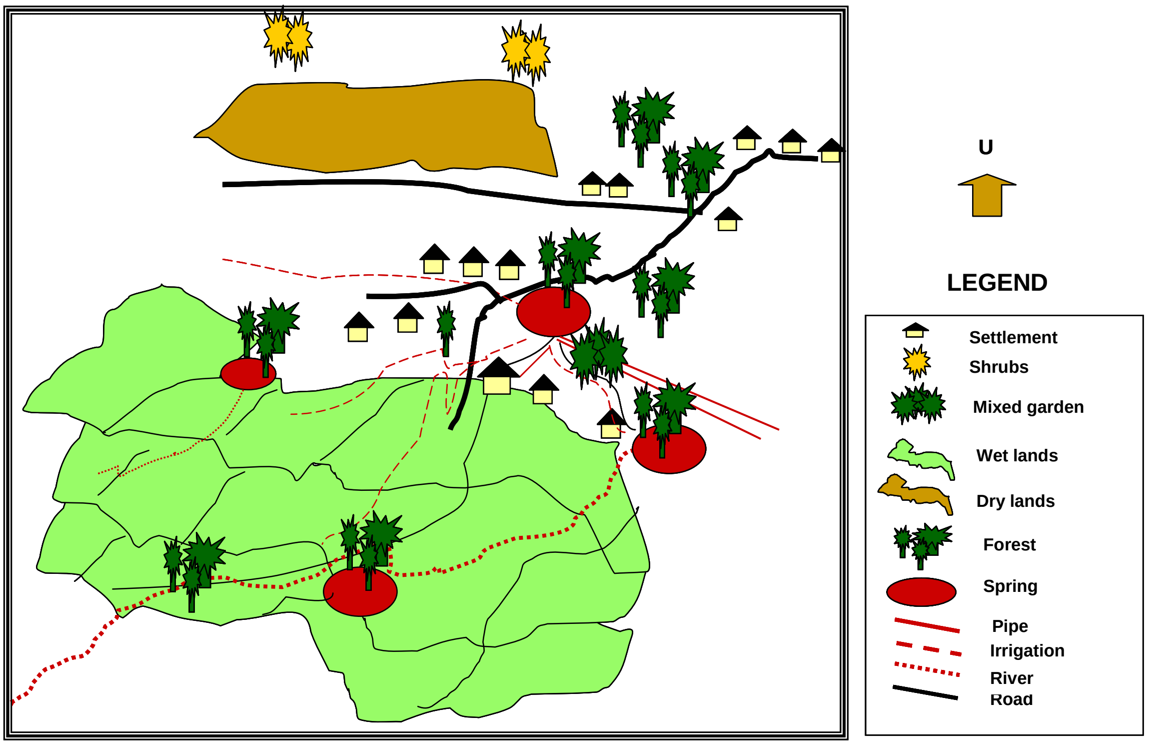
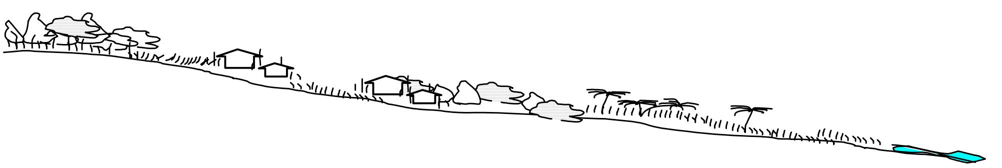


Figure 13. Settlement pattern in Lasiolat and Tasifeto Timur districts (Source: observation and interview during LEK survey, September 2006 and January 2007)



Landuse	Forest	Grassland	Settlement area	Horticulture plot	*Mamar*	Kebun	Paddy field	Fishpond
Source of water	-	-	Spring Digging well Pipe	-	Spring	-	Simple irrigation	Simple irrigation
Vegeta-tion	Banyan (Ficus) Syzigium sp. *(jambu air hutan)*	Grassland (alang-alang)	Grasses	Maize, longbean	Banyan (Ficus) Syzigium sp. *(jambu air hutan)* Palm, bamboo	Rice, onion, *Sallaca*, Pinang Sirih	Rice	
Topo-graphy	Undulating steep slopes	Undulatin g steep slopes	Hilly	Flat terrain	Hilly	Flat terrain	Flat terrain	Flat terrain
Land Tenure	Not clear status	Private/ communal	Private	Private	Customary Forest	Private	Private	Private
Animal		Livestock such cow, goat, etc	Livestock, dog, chicken, cat	Livestock, dog, chicken, cat	Livestock	-	Rat	Red nila

Note: *Mamar*: agroforesty systems around the springs

Figure 14. Land uses pattern in Lasiolat and Tasifeto Timur. (Source: observation, transect walk and interview)

Local knowledge

Local knowledge of people in Tasifeto Timur and Lasiolat on their landscape and climate is in principal similar. Their knowledge on ecological processes is mainly based on experience not ethnicity per se.

(a) Season and climate

Local knowledge on season and climate is tightly linked to knowledge on planting calendar. Rain season is very short (only three – four months) and dry season is longer (8 months). This knowledge influences local people choice of plants to grow.

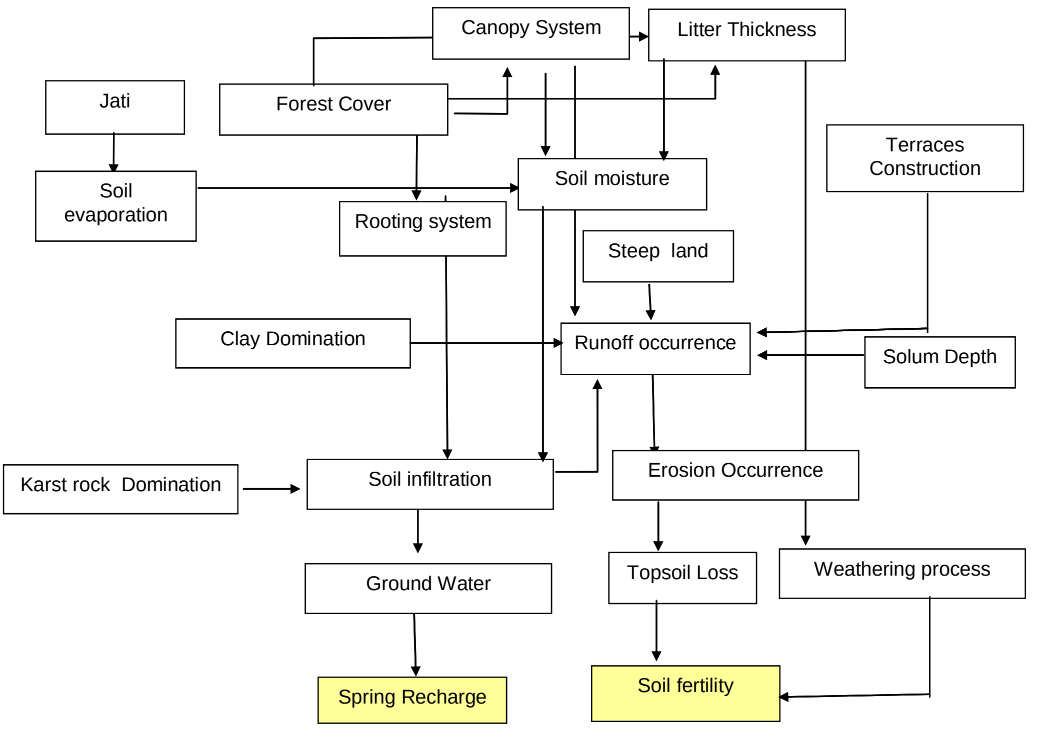


Figure 15. Local ecological knowledge on landscape in Lasiolat and Tasifeto Timur (Source: LEK Survey)

(b) Forest, trees and spring

Local people believe that forest has an important role as ground water provider, regulator, and also as source of livelihood. Forest is associated with the existence of water springs. Tree density and tree species are significantly link with ground water availability. Trees function as rainwater holder, groundwater keeper and preventing erosion. Below is a list of farmers' knowledge relationship between trees and water.

Decreasing of forest area make ground water flow also decreasing

Trees canopy helps to prevent the soil erosion because of raindrops falling directly to the soil

Trees canopy helps to hold the rainwater, absorb rainwater, and flow to the ground

Trees roots will hold the water on the soil as water provider

Leaf litter can protect the humidity of soil

Leaf litter helps the water absorption to the soil

Local people also have a well-articulated understanding on the relationship between vegetation, soil and water availability. According to them, plants that are suitable in water spring area are species that has deep roots, that it can hold water on the ground, such as betel nut, mahogany and candlenut. Local people said that teak is not a good plant to plant close to water springs, as it takes a lot of water but does not keep water on roots or stem and instead releasing water into the air.

Type of vegetation that have water keeper value nearby the spring are kelapa hutan, jambu air hutan, beringin, mahoni (mahogany), johar, mangga hitam, kelapa (coconut), pinang (betel nut) and kemiri (candlenut)

All those species mention above will have big influence to water flow on the spring if it is planted on the wider area.

Jati or teak leaf release water into the air

The amounts of water absorb by jati (teak) is much, but jati release much water into the air, so jati make the soil is dry.

Jati cannot be planted near other economic plants because it is highly competitive with other plants in absorbing water.

Kayu putih absorb water and release the water into the air easily.

Water conservation value of Kayu putih is low.

Fibrous root can prevent the soil from erosion or landslide

Fibrous root can keep the water and hold on the root.

Aiwe or kayu air has a fibrous root type

Kelapa have a fibrous root type

Mahogany have a fibrous root type

Farmers believed that the land must be fallowed for about three years after being cultivated. To make their land fertile again, they plant turi (*Sesbania grandiflora*) or during fallow period because they believe that lamtoro and turi can make soil fertility increase. After several years they can use the land to grow rice or other crops with the high yield. In addition, lamtoro (*Leucena leucocephala*) and turi can be used as fodder.

Figure 16. Candle nut (left), Teak (middle) and Mahogany (right) have different effects water spring protection

(c) Soil type

Local knowledge on soil depth, the role of stones and soil fertility becomes the basis for land management techniques. Farmers planted different trees and practiced different soil management depending on soil type.

Local people aware that cultivating the land continuously can cause land to be highly eroded and may caused landslide. This happens on steep areas with very light vegetation cover. Farmers with support from extensionist and local NGOs had built stone terraces to avoid soil erosion (Figure 18).

Table 9. Soil classification based on farmers' knowledge

Soil type	Rai Mutin	Rai Meak	Rai Metan
Common name	Tanah putih (white soil)	Tanah merah (red soil)	Tanah hitam (black soil)
Colour	White	Brown, Reddish Gray	Brownish Black
Texture	Dry, compact	Dry, quasi compact	Humid, loose
Fertilizer	Fertilizer need is high Dolomite need is high	Fertilizer need is high	Fertilizer is not necessary
Vegetation	Sirih and labu jepang (*Sechtum edule*)	Groundnut, cashew nut	Maize and sweet potato
Location	Lakaan mountain, hills	Upland field	Paddy field

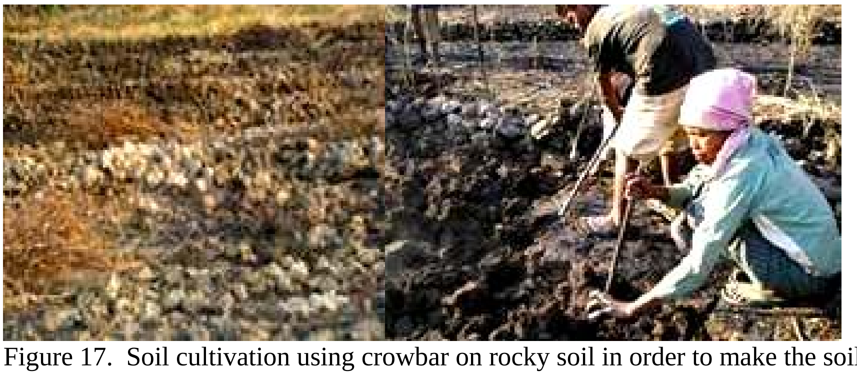


Figure 17. Soil cultivation using crowbar on rocky soil in order to make the soil loose.


Figure 18. Soil erosion and stone terracing

Hydrological issues

The common hydrological issue in both districts is scarcity of water, which are caused by problems in (i) access to water and (ii) water distribution (particularly for irrigation).

Access to water is strongly linked to the landscape position of the village itself (Table10A and 10B). There are basically two types of villages: (i) good access and (ii) limited access to water. Villages that have good access to water are normally located in the valley and within a short distance to water springs, for example Fatulotu, Baudaok and Lakanmau. Villages that have limited access to water are usually positioned in the slope of a hill, such as Maneikun and Lasiolat. These villages are depending on other villages (water springs in other villages) for water. Thus, for these villages availability of infrastructures such as water pipes or small reservoirs (*embung*) is very crucial. Problem of water allocation can occur in both types of villages. Table 11 presented listed local people perspectives on hydrological problems, what factors causing the problems and how to solve those problems. A more detailed assessment on landscape physical characteristics in Tasifeto Timur is presented in Table 12.

Table 10. Community access to water.

A. In Lasiolat district

Village	Water springs	Location of spring	Drinking Pipes	Access to drinking water	Access to irrigation
Fatulotu	5	Hill	Yes	Easy	Easy
Lakanmau	8	Hill	Yes	Easy	Easy
Baudaok	6	Hill	Partially	Easy	Easy
Maneikun	1	Valley	Yes	Difficult	Difficult
Lasiolat	3	Valley	Yes	Difficult	Difficult
Dualasi	2	Valley	Yes	Difficult	Difficult
Railulun	3	Valley	Yes	Difficult	Difficult

B. In Tasifeto Timur district.

Category	Low access to water	High access to water with sufficient amount	High access to water with abundant amount
Village	Manleten, Sarabau, Fatubaa, Bauho, Sadi	Tulakadi, Silawan, Baudaok, Tialai	Halimodok, Dafala, Takirin, Umaklaran
Water source	Pipe, river, digging well	Spring, digging well, pump, river	Spring, digging well, pipe, river

Source: LEK Survey (RHA Team, September 2006 and January 2007)

Conflicts over water use have arisen in some parts of areas, mainly due to distribution of water to other areas outside the surrounding village. For example, the use of water from Lahurus springs by PDAM for drinking water in Belu was also seen by local people as the cause of water scarcity. An earthquake in 1995 has also caused changes in quantity and quality of water flow for a period of time.

Soil erosion and low fertility of soil are considered to be caused by slope, soil type, and high intensity of rainfall and reduction of land cover. Wild foraging also believed to cause land cover loss and soil structures became loose and highly eroded. Erosion and landslide problems also occur along the riverbank, causing flooding in riparian zone and affecting cropland along the river.

People around water spring believed they need to protect the spring from drying. There are no significant sign of that it will occur, however people believe it will happen one day. Thus, they intend to keep the land around the spring forested. They also believed that reforestation in open land, river banks, water spring area can help improve water recharge.

Table 11. Hydrological and water management problem faced by local people based on their typology and explanations

	People with good access to water		People with poor access to water	
Location	Valley		Hilly area	
Gender	Men	Women	Men	Women
Problems	Soil erosion Decreasing water flow Uneven water distribution	Decreasing river flow Low fertility of soil around water springs	Poor access to water Soil erosion	Poor access to water Soil erosion River flooding
Cause of problem	Slash and burn Wild forage system Reduction of forest cover surrounding water springs Too much water allocated to PDAM	Soil characteristics Rain intensity Extreme weather	No water source nearby – need large effort to get water Soil characteristics and types of stone	
What can they do?	Adoption of customary law: communal land for conservation and water conservation zones		Adoption of customary law: communal land for conservation and water conservation zones	
	Conservation practices on upland field and paddy field Regreening in degraded land Application of agroforestry systems in dry upland systems		Conservation practices on upland field and paddy field Regreening in degraded land Application of agroforestry systems in dry upland systems Find alternative water sources with external support	

Source: observation and interview during LEK Survey (September, 2006 and January, 2007)

Table 12. Landscape physical characteristics in Tasifeto Timur

	Manleten	Sarabau	Tialai	Dafala	Tulakadi	Silawan
Topography	Undulating					
Steepness	Medium – steep	Medium – steep	Flat – steep	Medium – steep	Flat – steep	Steep
Water source	Well, water spring in other village, rainwater, and river	Spring, river and rainwater	Spring, well and river	Spring	Spring, well and river	Spring, well and river
Land use	Forest, Mixed garden, plantation, upland field (ladang), rainfed paddy field and settlement area	Forest (dominated by Kayu putih, jati, cemara), mixed garden, upland field (ladang), rainfed paddy field, bushes and settlement area	Forest (dominated by Kayu putih, cendana, cemara), mixed garden, Plantation, upland field, rainfed paddy field, bushes and settlement area	Forest (dominated by Kayu putih), cemara, Plantation, mixed garden, irrigated paddy field, upland field (ladang), bushes and settlement area	Jati (teak), mixed garden, upland field (ladang), rainfed paddy field, bushes and settlement area	Forest, jati (teak), mixed garden, upland field (ladang), rice field, bushes, and settlement area
Hydrological problems	Water scarcity during dry season					Erosion
	Water turbidity on rainy season Disease: diarrhea and itchy	Disease: diarrhea and itchy	Meandering	Decreasing water flow during dry season Uneven distribution of water	Low quality of water	
Causing factors	Logging, slash and burn	Logging, land conversion, slash and burn	Logging, land conversion, weather, river condition	Weather, land conversion	Logging, slash and burn	Logging, weather

Source: observation and interview during LEK Survey (September, 2006 and January, 2007)

Public and Policy makers perception and knowledge

Stakeholder identification and analysis

Stakeholder analysis was conducted at regency level and provincial level, between staffs of CARE International Atambua Office, local informant, members of Forum DAS Kupang[7] and interviews with local government institutions. Stakeholders were identified based on their interest and institutional position. At provincial level, we particularly explored their view on environmental service and rewards for environmental service.

(a) Stakeholder at regency level

Local institutions on watershed management in Belu Regency can be categorized into three group based on their role and interactions with community: (i) a group of institutions that has direct interaction with local people, (ii) a group of institutions that has indirect interaction with local people and (iii) a group consisting of policy makers institution.

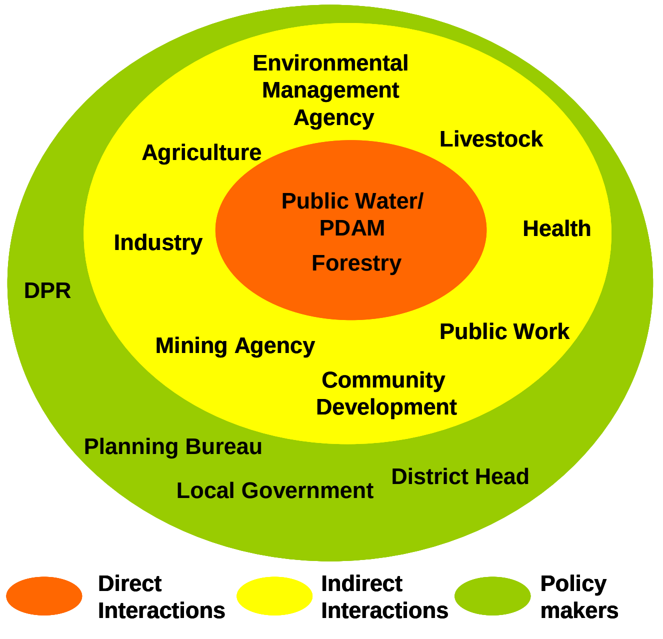


Figure 19. Stakeholder analysis based on interest and role

Source: discussion series with CARE International Atambua Office and other stakeholder, 2006

The first group consists of technical institutions that have role in managing and exploration of water source, such as PDAM and Forestry Agency. The second group is those that have no direct role in watershed management, but they are involved in short term program on watershed management led by other institutions. The institutions included in this group are Mining Agency, Bapedalda (Environmental Impact Management Agency), Peternakan (Livestock Services Agency), Public Works Agency, BPMD (Badan Pengembangan Masyarakat Desa/Local

Community Development), Health Agency, Industrial Agency and Farming Agency. The third groups are policy makers and decision maker on area development such as DPRD, Pemda and also Bappeda.

In Belu, government institutions that have strong influence on watershed management are PDAM, Forestry Agency and Local Government (PEMDA). PDAM is responsible in managing water sources for public water supply. Forestry Agency role is in managing conservation areas and also their rehabilitation. Local government at regency, district and sub-district level also have important role in coordinating and regulating the management of watershed at local level.

(b) Stakeholder at provincial level

Similar exercise was conducted at provincial level to understand the role and interest of various provincial institutions in watershed management (Table 13).

Table 13. Stakeholder interest and role in watershed management

Stakeholder	Role on watershed management	Watershed function position in stakeholder interest	Stakeholder role in watershed management	Score
Watershed management centre (BP DAS)	Controller and Supporter	3	5	8
Regional Development Planning Agency (Bappeda)	Policy maker Controller	3	5	8
Forestry agency	Organizer, Controller, Policy maker	3	5	8
Settlement and Regional Infrastructure Agency (Kimpraswil)	Controller, Policy maker, support	3	4	7
Environmental Impact Management Agency (Bapedalda)	Controller, Support	3	4	7
Watershed forum (FORUM DAS)	Support	4	5	9

Note: 1= not important, 2 = less important, 3 = moderately important, 4 = important, 5 = very important.

Source: Interview and discussion with some member of Forum DAS Kupang

[7] Forum DAS is a forum of concerned individuals, organizations or institutions on watershed management and rehabilitation issues. Forum DAS was established by WWF Kupang and BP DAS on NTT province.

(c) Water users

PDAM users in Atambua use water from the Lahurus spring. The water is mainly used for household consumption and few small industries. PDAM users are satisfied with the current service in the rainy season. Most Atambua household also own a system for water harvesting for usage in dry periods.

Perception and knowledge

(a) Regency Level

Table 15 summarize the various perception and knowledge of regency level policy makers on hydrological issues in Belu.

The level of water spring flow in Lahurus is also a concern for most stakeholders. In 1983 – 1988 the average spring flow of Lahurus is estimated at 104 l/second. During rainy season, this could increase up to 140 l/second. In 2005, during dry season the estimated spring flow is at 42 l/second (*pers. comm.* Seksi Sumber Daya Air Dinas Kimpraswil Kabupaten Belu).

Table 14. Predicted population density and water requirement in Belu

Years	Population	Water Requirement (liter/day)
1994	68186	4.602.555
2000	77146	5.207.355
2005	87283	5.891.603
2010	98752	6.665.750

Note: assumed water requirement 67.5 l/day/person (Arismunandar dan Ruhijat, 1995)

(b) Provincial Level

All stakeholders agreed that the main hydrological problem in East Nusa Tenggara is land degradation due geomorphology (geology, soil, and topography) of Timor island that is very prone to soil erosion. This condition is worsened with the condition of land which is dominantly covered by grasses and bushes. Steep topography, soil characteristics, extreme weather between dry and rainy season and high intensity of rainfall during rainy season caused continuous problem of erosion, flood, and drought. Report on level of erosion in Belu stated that around 77% of Belu area is considered very heavily eroded, 19% heavily eroded and only 2.5% of the area is considered lightly eroded (Direktorat Jenderal Rehabilitasi Lahan dan Perhutanan Sosial, Departemen Kehutanan, 2004). In Tasifeto Timur district (the location of Talau watershed); it estimated that erosion occurred in 37% of the area (BAPPEDA, 2005)

Anthropogenic activities such as over logging, fire, over mining without reclamation practice and farming activities with low or zero conservation practice, also add to the problem. Wild foraging is also claimed to cause the structure of soil become loose and easily eroded.

All stakeholders also considered the influence of disharmony within and between various relevant government institutions has made the situation worse. In many institutions, the approach in tackling the hydrological issues is always towards ‘structured’ or ‘bottom-up’ approach. All agreed that both ‘structured’ and ‘non-structured’ approaches must be take into account to identify natural resource management problems and needs and formulate opportunities to manage water resources and improve water use efficiency. Indeed, integrated watershed management is necessary and required involvement by all stakeholders. Involvement of local community in the overall efforts is crucial.

Water pollution is also a concern for Department of Settlement and Regional Infrastructure (Dinas Pemukiman dan Prasarana Wilayah - Kimpraswil). They indicated that the river has become waste disposal for community as well as industry. Water quality monitoring conducted in July – Augusts 2005 showed that none of the river in urban area fell under first or second grade in terms of water quality. The report also stated that only three rivers fall in the third grade, Bawono, and Wolowona river (Laporan Pemantauan Kualitas Air Sungai di 10 Kabupaten/Kota pada 11 sungai yang melintasi kota, 2005).

Environmental Management Agency (Bapedalda) also has similar concern. They attributed the pollution in river and water sources to the following reason:

- bad management in water sources area
- bad sewage system from industrial sectors
- pesticide, herbicide, and fertilizer contamination from farming activity
- farming activity without conservation techniques
- bad sewage system in settlement area (e.g. no septic tank use caused e-coli contamination)

Table 15 and Table 16 summarize proposed activities by regency and provincial level policy makers in resolving hydrological problems in Belu.

Table 15. Hydrological problems in the perspectives of regency level policy makers

Hydrological problems	Causing factors	Relevant activities to address problems	Whose perspectives?
Drought in dry season Floods and landslides in rainy season	Extreme weather	Good land management	Regional Development Planning Agency (Bappeda)
Reduction of springs and river flow	Slash and burn, wild foraging		
Water use conflicts	Differences in boundary of customary land and state land		
Scarcity of water during dry season	Reduction of forest area for refugee settlement (from Timor Leste)	Spatial planning for settlement, forest, land and water conservation area Planting Mahogany in conservation area and around water springs Water use and sewage management systems downstream (settlement, trading, industrial area) and improving community participation and collaboration between relevant institutions	Environmental Impact Agency (Bappedalda)
Degraded land		Rehabilitation of critical land and conserving protected areas, i.e. GNRHL[8] program in collaboration with Watershed Management Agency (BPDAS) and supported construction of *chek dam* and small reservoir (embung)	Forest Agency (Dinas Kehutanan)
Sufficient availability of water	-	Capacity building for the farmers on knowledge on land suitability and land conservation technology Good irrigation systems	Agricultural Agency (Dinas Pertanian)
Erosion Landslide Reduction of water flow	Land steepness and soil type causing low infiltration and high runoff during intense rainfall. Conversion of land to agricultural land or settlement	Land conservation technology. Forest rehabilitation, riverbank and river protection Constructing small water reservoir (embung)	Public Work (Dinas Pekerjaan Umum)
Water scarcity Water distribution	Low rainfall and reduction of land cover, population increase (T. Leste refugee)	LIPI (Research and Science agency) and Mining agency conducted water study and forest resource management through inter cropping (tumpang sari) technique and litter, good inter-sectoral collaboration	BPMD and Mining Agency

[8] GNRHL = Gerakan Nasional Rehabilitasi Hutan dan Lahan is a national program to rehabilitate degraded forest and land.

Table 16. Hydrological problems and activities to solve the problem suggested by policy makers

Problems	Cause of problem	What can we do?	Who will be involved?
Water flow reduction	Climate, rain intensity Soil structure	Land management and the vegetation base on soil structure, considering the climate and applying of conservation technique Introduction of conservation technology or agroforest system – empowerment	Local government (Village and sub district), Public works agency, BP DAS, Agricultural agency, PDAM, BPMD
	Reduction of forest cover due to logging and slash and burn Wild forage system	Replanting on critical and open land and also river bank zonary of production and conservation area Re-greening programme Customary and formal law enforcement	Local community, Bappeda, Forestry, Agricultural, and Veterinary agency, BP DAS
Uneven water distribution	Topography: some area have low access to water	Chek dam or embung, Irrigation, spatial plans, farmer empowerment and capacity building, customary law revitalization (spatial plans)	Bappeda, PDAM, Local government, Public works agency, Agricultural agency (irrigation), BPMD
Pollution	Community behavior	Regulation of water used and waste management through formal or customary law Community empowerment	Public works, Forestry agency, Economy sector, BPMD, Law agency., PDAM
Erosion and landslide	Soil structure Bad land management	Land management that considers plant suitability with soil, conservation practice, introduction of conservation technology or agroforest system	Agricultural agency, BP DAS, Forestry agency, BPMD, Bappeda, Local government
Erosion and riverbank collapse	Soil structure Flood	Riverbank rehabilitation, conservation practice along riverbank Law enforcement	PU, BPMD, Agricultural agency, Bappeda, Local government

(c) PDAM consumers

Water users expect continuous supply of water during dry periods. A few have water reservoir in their houses; however, it is not enough to carry on through the dry periods.

Table 17. Water users downstream and their expectation on quality of water

Group of PDAM customer	Water use	Expectation (based on priority scale)	Water problem	Water source	Willingness to pay
Household (low – medium level)	Daily consumption: cooking, drinking, bathing Irrigation	Quantity of water and continuity of water flows	Water quantity over dry periods Regulation of flows Water quality	PAM Well	Low
Household (medium – high level)	Daily consumption: cooking, drinking, bathing	Quantity of water and continuity of water flows Water quality	Declining levels of water quantity: pollution (E.coli and limestone) Water quantity over dry periods Regulation of flows	PAM Pump Well Private water company	Low to medium
Small industry	Industrial needs Household consumption	Quantity of water and continuity of water flows	Regulation of flow Water quantity over dry periods	PAM , Pump, private water company	Medium

Source: interview and observation (LEK Survey, 2006)

Most of PDAM consumer considered the current price is acceptable, considering the quality of service and the quantity and quality water provided. Nevertheless, some consumers considered the current price is too expensive and they would like PDAM to improve its service in particular on continuous of water during dry periods.

(d) PDAM as water provider

PDAM is aware of consumers’ criticism and has been continuously improving their service. PDAM indicates that the existing water flow from Lahurus can optimally reach 40 liter/second, but currently only reaching consumers at 14 liter/second. PDAM blamed leakage due to pipe damage or illegal tapping as the cause of this shortage. Sedimentation in water channels has also added to this problem. PDAM is also aware of the current ‘conflict’ that has arisen since they are tapping water from Lahurus spring. They are very cautious now in increasing the amount they take from Lahurus.

To improve its service, PDAM has conducted a series of extension programme with community involvement, establishing rural groups to monitoring water channels and constructing water pipes. So far, this programme has not worked well. Internally, PDAM is working in improving water distribution and management.

PDAM water project in Lahurus that was intended to start in 1998 but could only be realized in 2005 is a test case for PDAM in its effort to improve its service both to local community and consumers. PDAM indicated that currently Lahurus water spring is still ‘in trial run’. Nevertheless, it has already given PDAM profits. PDAM is planning to propose a program or mechanism that can allow direct payment or benefits to local community based on expected profits from PDAM consumers. PDAM plans to work with Bappeda as the planner, Kimpraswil in developing the infrastructures and Forestry Agency to help in conservation and monitoring the water source areas (forest controller). The mechanism can be through direct payment or Regional Income (PAD = Pendapatan Asli Daerah) with clear regulations and supported by formal that incorporates customary law.

Estimating landscape water balance of Talau Watershed

Climatic condition of Talau watershed

Based on a 14-year series of monthly rainfall (from 1978 – 1993, with data from 1982 missing) from Sukabitek weather station, the annual rainfall in Talau varied between 625 - 1838 mm.year-1 with an average of 1634 mm.year-1 (Figure 20). Talau has a very extreme weather condition. Rainy season commonly falls in November – April, where around 95% of the rainfall falls during this period. During dry season the total monthly rainfall is very low that is less than 50 $mm.month^{-1}$. The monthly average air temperature ranged from 23-27 ^{0}C. The estimated potential evapotranspiration is 1430 $mm.year^{-1}$ (Figure 21).

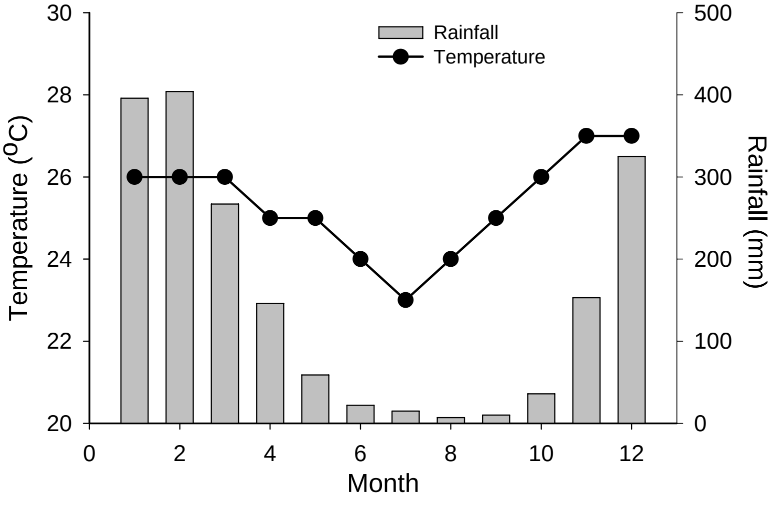


Figure 20. Average monthly rainfall and monthly temperature in Talau from 1978 – 1993 (Source: Sukabitek weather station).

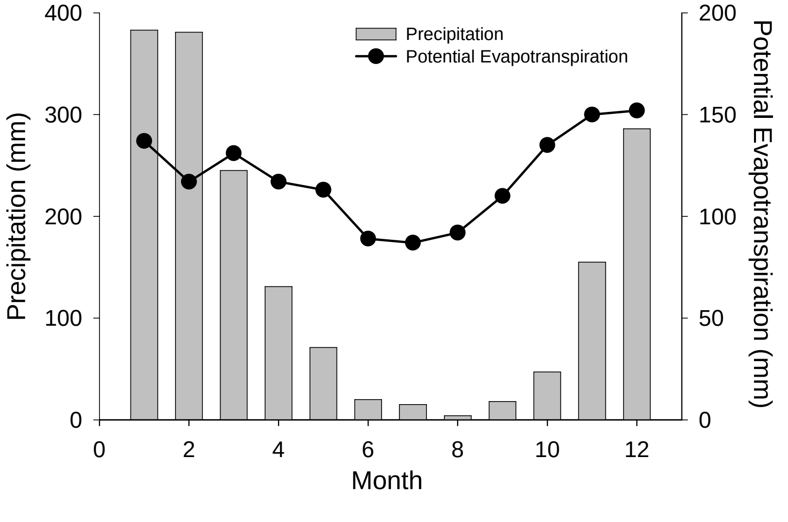


Figure 21. Average monthly rainfall and potential evapotranspiration estimates in Talau from 1978 – 1993. Monthly potential evapotranspiration were derived using Thornwaite methods.

River flow and rainfall pattern in Talau

Figure 22 presented daily rainfall and river flow of Talau River in 1991 – 1994. Prior to using this data further, we checked the consistency and 'sensibility' of the data by analyzing how the river flow response to the amount of rainfall. In normal conditions, the river flow pattern should match with rainfall pattern.

In the period of 1992 – 1993, the pattern of river flow does not seem to match the rainfall pattern. Low river flow corresponds with high intensity of rainfall and vice versa. It is very unlikely that a dry river corresponds to continuous rainfall as what had occurred in year 1992. Similar anomalies also plague the data for the 1993 period. We decided to only use the river flow data of 1994 for further analysis, as the quality of recording or data management was apparently below standard in the other period. A willingness by local stakeholders 'to already provide rainfall data for the coming three months' casts legitimate doubt on the quality of historical data.

The highest flow of 35 m^3/second (30 mm) occurred in February, corresponding to 85 mm of rainfall. The overall pattern is that Talau river flow can be described in three phases: (i) the early part of the rainy season when the soil and landscape storage capacity for water is recharged; (ii) the second part of the rainy season when a larger proportion of the current rainfall is transmitted to the river; and (iii) the dry season when river (and spring) flow depends on the gradual release of stored water.

The data suggest that the capacity of the Motabuik sub-catchment in buffering (or storing) rainfall is very low. Thus, river flow will quickly increase or decrease in response to variations in rainfall as depicted in Figure 23 and Figure 24.

The presence of 'phase II' suggests that the water storage capacity becomes fully used, and that limitations to infiltration due to topsoil degradation have not yet reached a critical level. As most of the storage occurs in the deeper layers of soil that are not directly affected by land cover change, the possibilities for enhancing storage are limited (but increasing surface water storage may be an option, see below). During the rainy season water can reach the river via essentially two pathways: overland and through the soil. The two pathways differ in timing (the first can lead to flash floods directly after rain, the second may have a 1-2 day time frame) and consequences for water quality (with the overland flow associated with erosion and sediment transport). Soil degradation tends to shift the pathway of water towards overland flow, before it substantially affects storage capacity and the capacity to recharge the subsoil water storage.

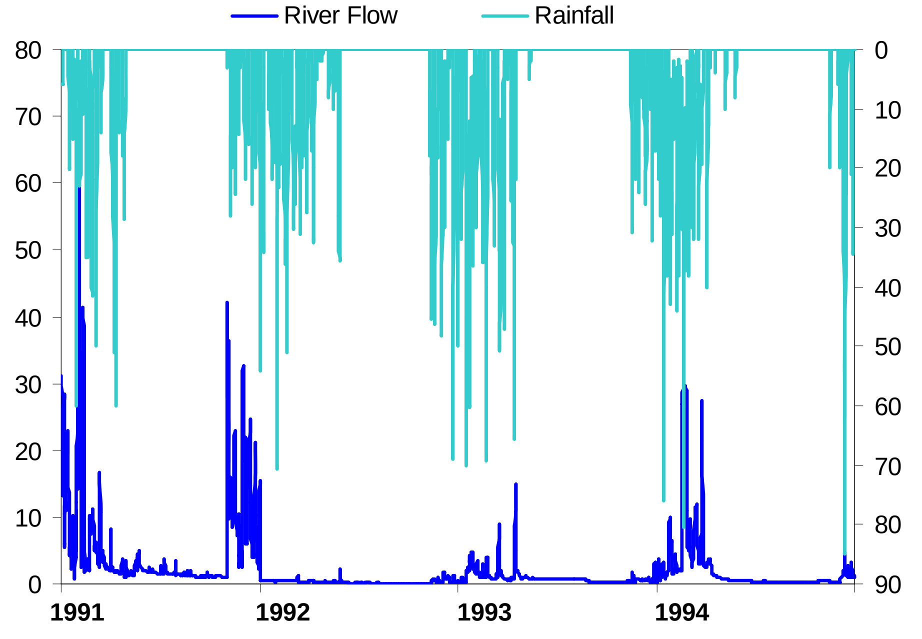


Figure 22. Daily rainfall and river flow pattern in Motabuik sub-catchment in 1990 – 1994

Figure 23. Example of river condition during dry season

Figure 24. Comparison of river flow during dry season – September 2006 (left) and rainy season – January 2007 (right). The land cover also dramatically changed.

Calibrating GenRiver model for the Talau condition

A modeling approach was used to estimate the water balance of Talau watershed. The first step was to parameterize and calibrate the model to simulate Talau conditions. See Appendix 2.

Simulation result showed that GenRiver model has able to capture the trend in river flow (Figure 25 and Figure 26). There is a similar trend of river flow between simulated result and actual data across the period of 1990-1994, particularly for rainfall of above 10 mm and below 70 mm of rainfall. The model was not able to capture the trend at peak rainfall and underestimated the quantity of river flow. Unfortunately, lack of data has made it difficult to further calibrate the model. Thus, we used the current model parameterization for land use scenario with caution that the model underestimate peak flows and overestimate low flows.

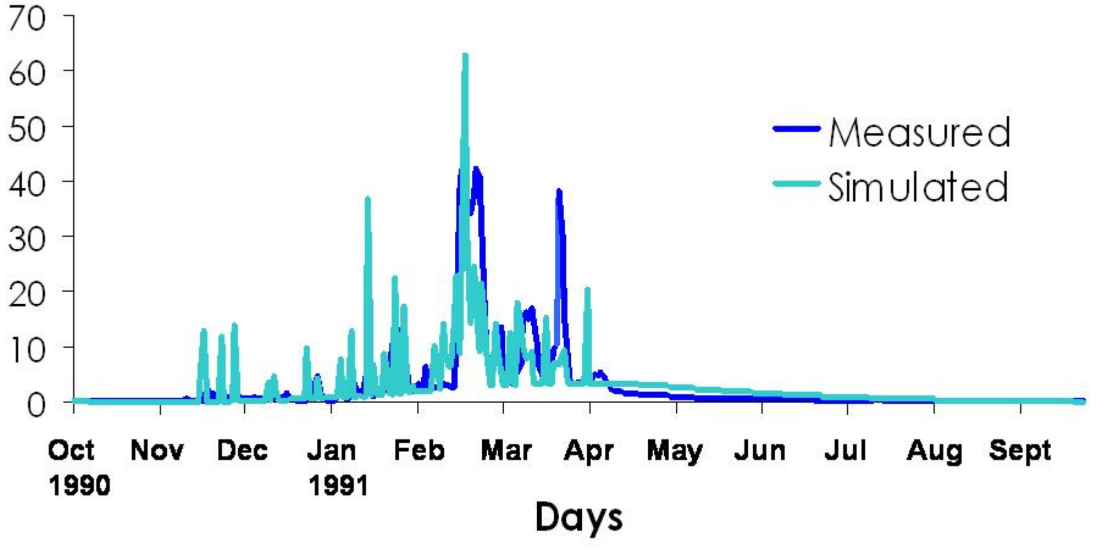


Figure 25. A hydrograph of Talau River in 1990 – 1991 in Motabuik sub-catchment: measured vs. simulated. Calibration result showed GenRiver model was able to capture the trend of Talau river flow.

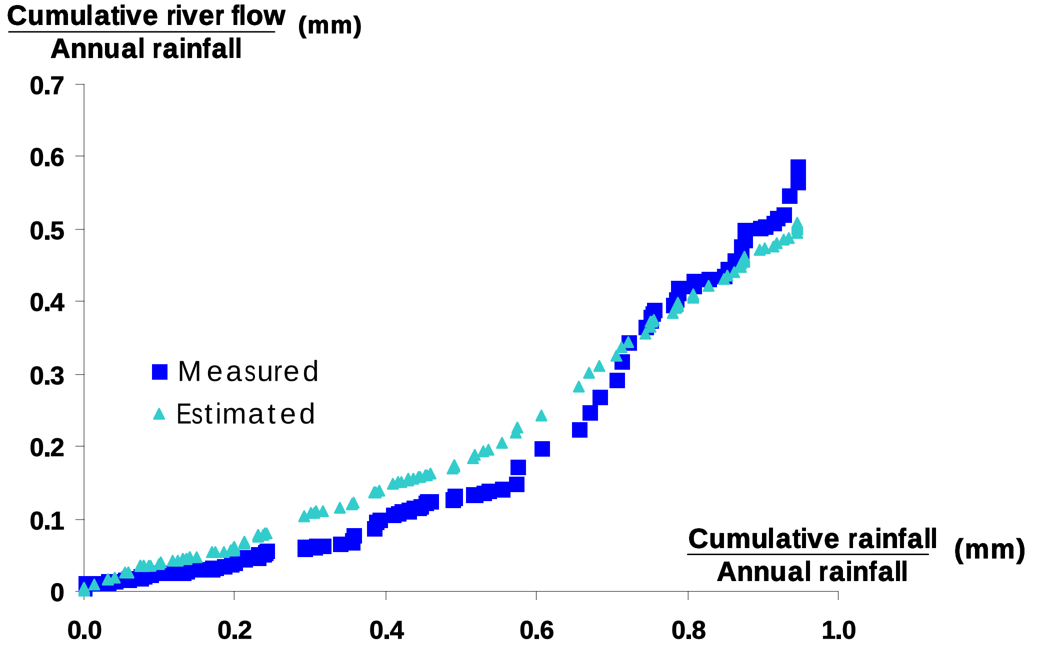


Figure 26. Plot of rainfall vs. river flow of Motabuik sub-catchment: measured vs. simulated. Simulated result underestimated peak flows and overestimated low flows.

Landscape water balance of Talau watershed

In this study, we estimated the water balance of Talau landscape and Lahurus sub-catchment, as the 'hot-spot' of this study.

Figure 27 presented the estimated water balance for Talau watershed and Lahurus sub-catchment. The water balances of both areas are more or less similar (Table 18). At annual rainfall of 1605 mm, around one third of the rainfall was evaporated and another one-third was captured by the soil and drained to the river as low flow. Run-off in the area is estimated to be around 22% of rainfall or for Lahurus sub-catchment this is equal to 98,000 m^3. Run-off is closely related to soil erosion (i.e. water quality problem in this project). The current percentage of run-off in the area, may suggest an erosion problem as indicated by local community and stakeholders.

Figure 28 shows the estimated water balance of Talau and Lahurus sub-catchment at rainy season and dry season. The model showed a clear differentiation between dry and rainy season. During the rainy season, the soil filled up its storage capacity with water for further use during dry season. Therefore, the water balance has a positive storage term during the rainy season and a negative storage during dry season (Table 19). The size of the water storage is estimated to be about 300 mm, or 20% of mean annual rainfall.

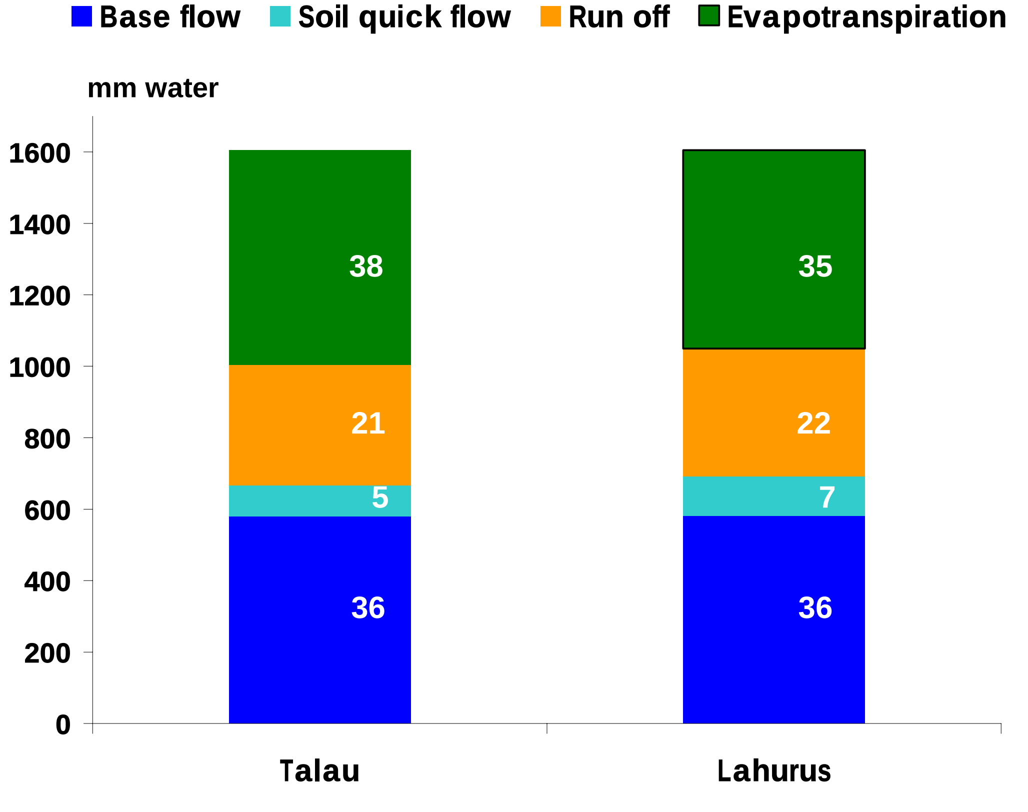


Figure 27. Estimated annual water balance of Talau watershed and Lahurus sub-catchment, value in bar refer to percentage (out of total rainfall)

Table 18. Water balance of Talau watershed and Lahurus sub-catchment, in percentage of rainfall negative storage means water shortage

		Talau			Lahurus		
		Annual	Rainy Season	Dry Season	Annual	Rainy Season	Dry Season
Total Rainfall (mm)		1634					
Evapotranspiration (%)		38	30	8	35	29	5
River Flow	Run off (%)	21	20	1	22	21	1
	Soil quick flow (%)	5	5	0	7	7	0
	Base flow (%)	36	23	16	36	24	10
Storage (%)			16	-19		13	-11

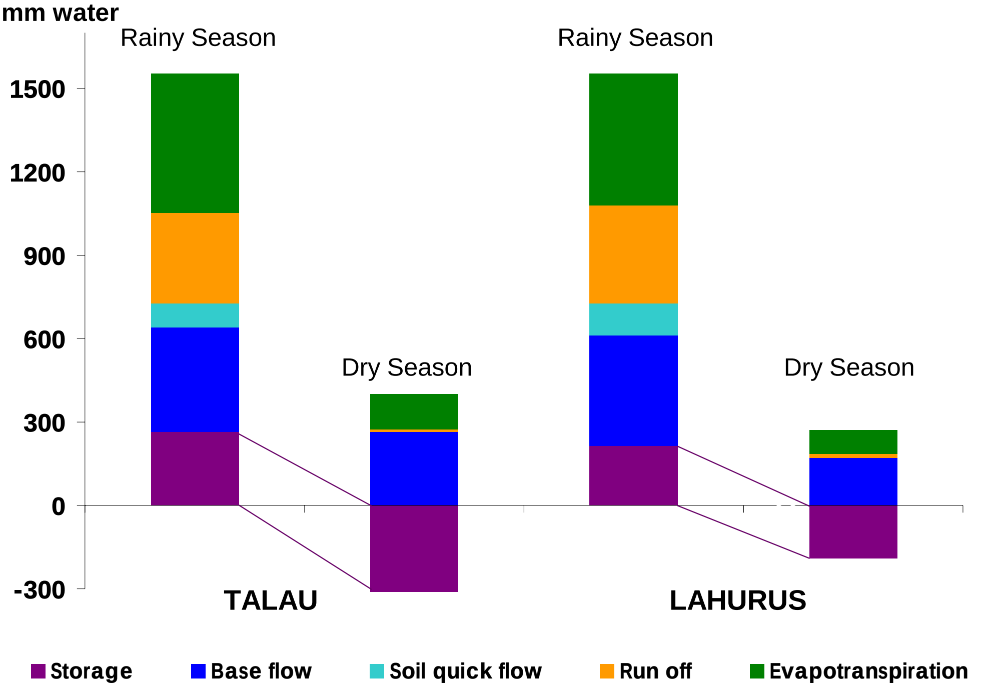


Figure 28. Estimated annual water balance of Talau watershed and Lahurus sub-catchment during rainy season and dry season.

In this analysis it still is the total storage capacity of the landscape that determines the volume of water that can flow in the dry season. In the second half of the rainy season there is an ‘overflow’ situation (increase in river flow per unit rainfall), which suggests that storage is maximized. If this analysis is correct, in the current situation the relationship between land cover and dry season flows of water is still weak and that only upon further degradation we can expect to get to a situation where storage capacity cannot be fully used because of infiltration problems.

Hydrological condition of Talau watershed

With the model we explored how the year-to-year variation in rainfall translates to variations in hydrological behaviour, with potential co-variation among the indicators of watershed function. The buffering capacity of the Talau watershed is less in years with high rainfall and consequently high total water discharge (Figure 29). A similar co-variation also occurred for ground water discharge. River flow in the Talau watershed is strongly seasonal; the risks of flash floods is especially high in the second part of the rainy season when the storage capacity of the landscape is saturated and strong rainfall is passed on to the river without much buffering.

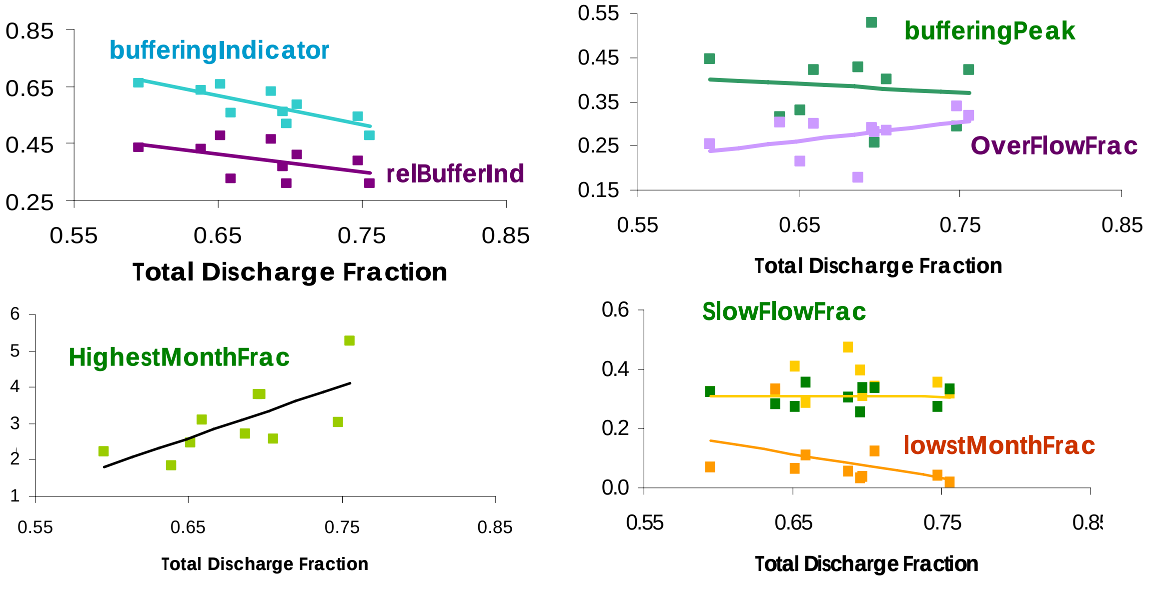


Figure 29. Indicators of watershed function of Talau watershed, expressed in relationship with the total discharge fraction (which is positively correlated with annual rainfall), over a 10 year period

The relationship of land use and hydrology in Talau watershed

Land use scenarios

Based on local knowledge and policy makers knowledge surveys, the main hydrological issues that emerge are (i) water scarcity during dry season and (ii) soil erosion due to land degradation. Most stakeholders (local, regency and provincial level) considered that reduction of forest cover area, shifting cultivation and slash and burn practices contributes to water scarcity problem. All stakeholders unanimously agreed that increasing tree cover over the landscape will increase water flow and resolve water scarcity problem.

Based on the above observation, we developed the following land use scenarios:

i. Converting non-productive land (grassland and bush-shrubs land classes) into forest.

ii. Converting non-productive land into agroforestry/tree based systems.

iii. Converting non-productive land into crop systems (well managed).

Impact of land cover change on water balance

Conversion of non-productive land to agroforestry systems or forest reduced annual run-off by 43% to 64% for agroforestry systems and 78% to 90% for forest (Figure 30 and Table 19). This situation also implied also a reduction in erosion. There is a slight increase in soil quick flow, from 1 – 7% of total rainfall when non-productive lands are converted to agroforestry systems or forest. The shift of run-off into soil quick flow suggested that rainfall reached the river more gradually (longer than 1 day). Thus, the increase of tree cover in the landscape can prevent flash flood from occurring. The increase of tree cover however did not change the amount of low flow during dry season. The stability of low flow is comparatively a ‘good’ situation, considering that the evapotranspiration had actually increased with more trees in the landscape.

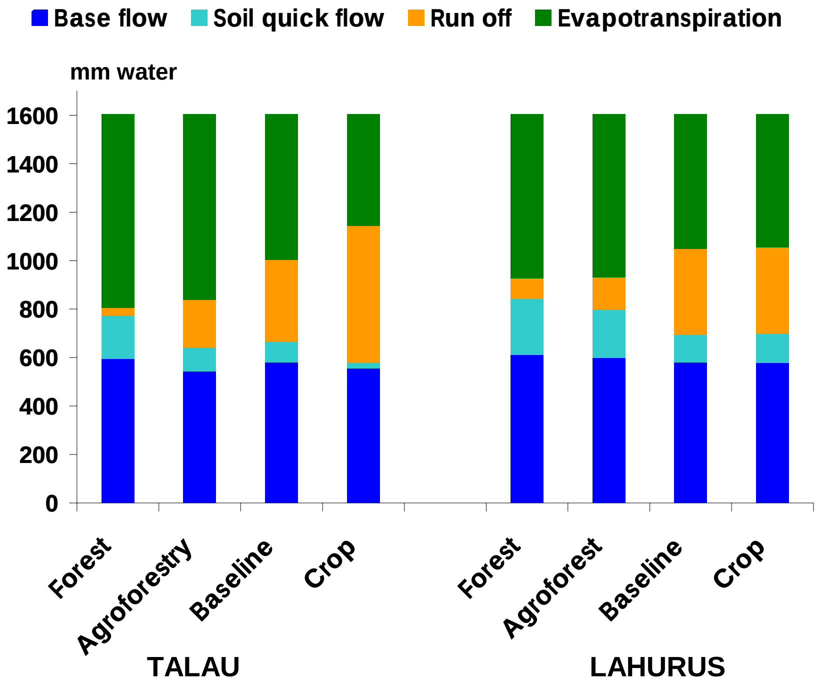


Figure 30. Water balance of Talau watershed and Lahurus sub-catchment at baseline condition and when non-productive land (shrubs and grass land class) converted to forest, agroforestry systems or well managed crop systems.

Table 19. Water balance of Talau watershed and Lahurus sub-catchment at baseline condition and when non-productive land (shrubs and grass land class) converted to forest, agroforestry systems or well managed crop systems. The water balance component is estimated as percentage of rainfall

		Talau				Lahurus			
		Forest	Agro-forestry	Base-line	Crop	Forest	Agro-forestry	Base-line	Crop
Total Rainfall		1634							
Evapo-transpiration		50	48	37	29	42	42	35	34
River Flow	Run off	2	12	21	35	5	8	22	22
	Soil quick flow	11	6	5	2	14	12	7	8
	Base flow	37	34	36	35	38	37	36	36

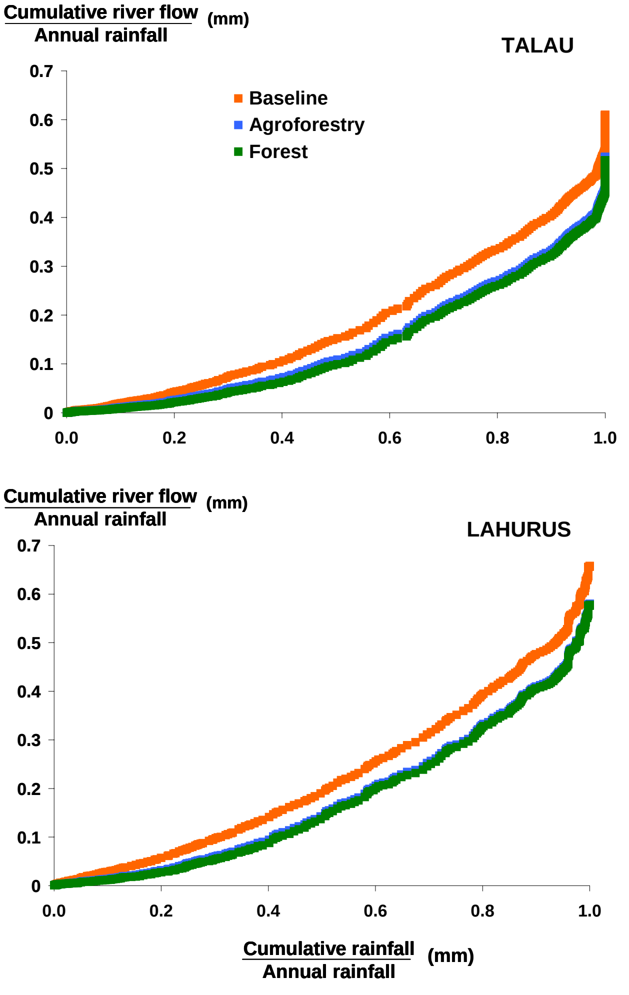


Figure 31. Plot of cumulative river flow versus cumulative rainfall as proportion of annual rainflow of Talau watershed and Lahurus sub-catchment at baseline condition and when non-productive land (shrubs and grass land class) converted to forest, agroforestry systems or well managed crop systems.

The plots of cumulative river-flow versus cumulative rainfall show an approximately proportional effect of more trees in the landscape on reduced river flow. However, no qualitative shifts occurred: the change in slope (low river flow per unit rainfall early on, higher ratios later on) stays the same, as does the last 'tail' end which represents dry season river/groundwater flow.

Impact of land cover change on water shed function

Changes in watershed function due to land cover change are summarized in Table . Comparison of watershed condition after increasing tree cover with the baseline condition showed that in general the changes in watershed condition that had occurred were still within the variation of baseline condition. Significant change occurred in overland flow fraction (run-off fraction) in Talau watershed.

This result, again suggested that adding tree in the landscape could have impact in improving soil erosion problem in the area through reduction in run-off.

Table 20. Changes in watershed function as percentage of baseline condition, compared with range of in baseline condition (also as percentage of mean in baseline condition). Figures in bold refers to significant changes

		Talau			Lahurus		
		(Range of Baseline)/ (Average baseline)	Average/ Average baseline		(Range of Baseline)/ (Average baseline	Average/ Average baseline	
			Agro-forestry	Forest		Agro-forestry	Forest
Water transmission - TotDischargeFrac		(74 - 112)	86	84	(86 - 113)	88	88
Water-shed Buffering Indicator	BufferingIndic	(85 - 122)	107	107	(80 - 114)	110	110
	RelBuffering-Indic	(82 - 120)	93	89	(76 - 118)	106	107
	BufferingPeak	(87 - 106)	102	103	(59 - 136)	118	121
	HighestMonth-Frac	(68 - 158)	103	106	(63 - 173)	107	109
	OverlandFlow-Frac	(79 - 123)	**53**	**22**	(58 - 129)	38	25
	SoilQflowFrac	(6 - 168)	131	200	(0 - 226)	167	194
Gradual Water Release	SlowFlowFrac1	(75 - 111)	98	102	(82 - 135)	104	106
	SlowFlowFrac2	(90 - 109)	81	86	(81 - 119)	100	104
	LowestMonth-Frac	(60 - 131)	82	76	(21 - 409)	80	79

Conclusion

Can we develop reward mechanisms in the area? A hydrological perspective The current study site, Lahurus sub-catchment in Talau watershed, Belu – East Nusa Tenggara provides an interesting case towards the 'traditional' view of upstream vs. downstream in environmental services reward mechanisms. Lahurus sub-catchment is located downstream of Talau watershed and it has water springs that has become the source of drinking water for Atambua residence. Meanwhile, Atambua is located in the upper part of Talau watershed. We need to see upstream – downstream as a functional rather than purely geographical relationship.

There is a potential for establishing environmental services reward mechanism in Lahurus. In this case, the service provider in this study is Lahurus community and the beneficiaries are the Local Public Water (PDAM) and PDAM consumers in Atambua. Current expectation from PDAM and PDAM consumers is Lahurus community could protect the water springs and carried out activities that could maintain water supply throughout the year and if possible increase the current low flow during dry season. The expectation of increasing low flow in dry season is in fact also the expectation of local community in Lahurus as they also use the water springs for their own needs.

Result from scenario analysis suggested that adding trees into the landscape of Lahurus or Talau in general would not be able to address the problem of low flow during dry season in the area. Changing the landscape through reforestation of agroforestation will not substantially increase water flow in the dry season, because there does not seem to be a critical problem (as yet) on infiltration that would prevent the storage capacity to be fully recharged in the wet season. Consequently, it will be difficult to develop a reward mechanisms in this area based on 'conditionality' at the level of outcomes. However, avoiding further degradation may well be a reasonable basis for engagement, as the current soil condition are considered to be fragile and potentially seal and reduce infiltration rates.

On the other hand, reforestation and agroforestation could potentially address soil erosion problem as result from scenario analysis suggested that additional trees would reduce runoff. If we can safely assume that runoff could lead to soil erosion, rewards/payment mechanisms could be based on water quality issue. However, further evidence based on actual field surface runoff and soil erosion would be required.

Water harvesting techniques in the area could actually help in increasing supplies of water during dry season. Besides the fact that harvested water could be of direct benefit to local community use, it is in fact will be of benefit to PDAM and PDAM water users as well. Additional water supplies from harvested water could partially release pressure from water use from the Lahurus spring, thus possibility of additional water for PDAM.

Implementation of water harvesting techniques, particularly by using '*embung*' (a semi-constructed pond), should synergize with effort in reducing soil erosion. Since harvesting water by *embung* will be optimal if soil erosion in the area can be suppressed.

Thus, to be able to meet the objectives of 'Equitable Payment for Watershed Services' of watershed conservation as well as poverty reduction, future developments of reward mechanisms in the area could be link with activities as described in the following sections.

Environmental services rewards: potential scheme

Construction of water harvesting infrastructures

Water harvesting refers to an activity of capturing and storing during rainy season, for later use in dry season. The water can be used for plant irrigation and household uses. In East and West Nusa Tenggara, the water is commonly contained in a semi-constructed pond called '*embung*'. In some parts of East Nusa Tenggara, an *embung* can be 30 – 60 Megaliter (30,000 – 60,000 m^3) in size that can sufficiently hold water for the need of 100 household in nine months (Naiola, 2007). An *embung* of this size is normally built using bulldozer. A smaller size *embung*, 150 – 500 m^3 will usually be built close to an agriculture plot for drainage. A 0.5 ha-plot will require an embung of the size approximately 10 x 5 x 3 = 150 m^3 (Purnomo, 1994).

According to Agus (2004) and Purnomo (1994), *embung*' is preferably built in a concave area within a micro-catchment[9]. Soil should not be to porous, clay texture is preferable, so that water will not be loss through percolation. For soil with high porosity, the bottom of *embung* will need to be covered with plastic or cement. Land with slope in a range of 8 – 30% will be able to efficiently capture water (through run off). A higher slope will cause erosion and *embung* will fill up quickly with sedimentation. *Embung* should be built not far from settlement of agriculture plots.

Based on baseline landscape water balance of Lahurus, around 20% of annual rainfall can be harvested. Thus, Lahurus catchment can potentially harvest water around 4,000 Megaliter (4 million m^3), equivalent to 135 ha of *embung* with 3-m depth. This is still a rough estimate that has not take into account soil texture, slope and distance to settlements or agriculture plots.

Planting trees in non-productive areas

Trees are planted in non-productive land with the objectives to reduce soil erosion as well as to provide local people with direct benefits from the tree systems. The direct benefits can be in form of timber, fruits, firewood and/or forage. Another potential direct benefit could be in form of 'payments' obtained from ES buyers for reducing soil erosion. The indirect benefits are in form of soil conservation, as trees can help maintaining soil fertility. The activities can be in form of reforestation or agroforestation. It is pertinent that the trees planted will actually be of benefit to the people and will not add further environmental/hydrological problems. Thus, the following criteria should be used when choosing tree species for planting:

- Trees that can grow well with minimal water condition (rainfall less that 1500 mm year-1). Deciduous tree, that shed its leaves during dry periods, fit well in this category.

[9] A micro-catchment has an area of 500 – 700 ha with hills as natural boundary. It collects water and drains it to one point through small drainage systems (Agus, 2004).

- Trees that can provide 'good' litter fall, for soil cover as well as soil fertility[10]. See Appendix 3.
- Trees with slow decomposing litter fall are good for soil cover, such as mahogany (*Swietenia macrophylla*), candlenut (*Aleurites moluccana*), durian (*Durio zibethinus*), jackfruit (*Artocarpus integra*), and mango (*Mangifera indica*). While trees with fast decomposition are good for soil fertility, such as lamtoro (*Leucena leucocephala*), dadap (*Erythrina*). See Appendix 3
- Trees that can give direct benefits in form of firewood, forage, fruits or timber.
- Indigenous species or exotic species that already known to local farmers. These trees would have a better chance to survive (see Appendix 4 and Appendix 5)

Based on the above criteria, the tree species that could grow well in Talau watershed are mahogany (*Swietenia macrophylla), Syzigium sp*, cashew nut (*Anacardiumi)*, candlenut (*Aleurites moluccana*), *Gliricidia sepium*, *Sesbania grandiflora* and *Leucena leucocephala*. A system of the above combination would be able to address the various important aspect of livelihood enhancement.

In Lahurus sub-catchment, there are 8.3 km^2 (55% of total area) and 1 km^2 (66%) of grassland and fallow (included undulating hilly areas). These areas are potential for reforestation and agroforestation. Obviously, part of these areas could actually be pasture or abandon agriculture plots. Thus, further detail ground assessment would be required.

It is also important to note the length of time for tree cover to take effect. In general, it will take about 3 – 5 years for tree cover to have an effect on soil surface recovery. For an agroforestry system to function well, it may take about 10 years. Meanwhile, it will take more than 30 years for forest to have an effect on deeper soil restoration.

Enriching tree species in *mamar* systems

In this activity, other tree species are planted in *mamar* systems with the objectives to protect the water springs condition (by reducing surface runoff) and provide benefit to the surrounding farmers. Tree species that are planted should have similar criteria as above be with the exception that the trees should not the types that livestock prefer to avoid having livestock getting close to the water springs area.

Trees that could fit in this category are mahogany (*Swietenia macrophylla)*, *Syzigium sp*, cashew (*Anacardium*), candlenut (*Aleurites moluccana*), jackfruit (*Artocarpus integra*), mango (*Mangifera indica*) and their combination.

Land and soil management

This activity has the objectives of reducing soil degradation by preventing soil erosion and increasing infiltration. Examples of activities are (i) terracing and (ii) establishing infiltration

[10] Hairiah, *et al.* (2004) described the role of litter fall in maintaining watershed functions by keeping the top soil covered and increasing soil porosity.

pits (rorak) in existing dry land plots. Increasing infiltration will potentially increase low flow during dry season.

The way forward

Watershed and water resource management is multi-stakeholder and multi-perspective. In Belu, although it has implemented multi-sector management approach to manage its natural resources, it is still lack of coordination and has weak link to local community. This view is acknowledged by most of the stakeholders involved. Therefore, developing environmental services reward mechanism will require concerted and strong effort from all stakeholders.

Future development of environmental services reward mechanisms need to focus on strengthening the local community capacity to negotiate with the various levels of government institutions, particularly in their effort to gain recognition on existing customary law in managing natural resources. Existing customary institutions in Belu are quite strong and influential; inevitably adoption of existing customary law on natural resource management could be the potential entrance for developing reward mechanism.

Appendix 1. Accuracy table from image classification analysis of Landsat-TM for Talau watershed.

Land use class	Accuracy (%)
Forest	67
Agroforestry	61
Crop land	98
Bush	80
Grassland	98
Rice field	83
Water body	98
Settlement	83
Total	76

Appendix 2. Steps in parameterize GenRiver model to simulate Talau watershed condition

Catchment Boundary and River length

To simulate Talau watershed, we divided the whole catchment into 10 sub-catchments. Table Appendix 2.1 listed the spatial characteristics of the ten-sub-catchments.

Table Appendix 2.1. Spatial characteristics of 10 sub-catchments in Talau watershed

Catchment	Outlet		Centroid		Catchment Area	River Length
	X_coord	Y_coord	X_coord	Y_coord	(km2)	(km)
1	731599	9005558	727361	9001435	86.5	7.20
2	722218	8998976	716892	8996655	93.2	21.19
Lahurus	722263	8998976	725459	8997022	14.3	18.43
4	720102	8997375	723980	8994635	28.0	24.58
5	718975	8992267	724853	8987165	87.6	37.84
6	718883	8992267	719074	8985355	60.4	33.45
7	711545	8998665	708777	8994856	64.2	36.18
8	710333	8994801	713869	8988010	71.7	45.74
9	708623	8991769	711139	8982772	88.0	50.87
Motabuik	708247	8989836	704867	8982667	102.6	54.89

Geology

Soil in Talau consist of rock formation from silt, coral, phyllite, quartzite, skiz, alluvium sand and sandy marly shale with irregular substances (*bobonaro*). According to survey conducted around Atambua, the groundwater surface is at 11.2-11.25 m, percolation rate within the soil is in a range of 1.15×10^{-6} to $2.8.10^{-7}$ $m^2.day^{-1}$, while water flows through aquifer surface is at a rate of $5 \times 10^{-6} - 1 \times 10^{-7}$ $m^2.day^{-1}$ (Arismunandar and Ruchijat S, 1995).

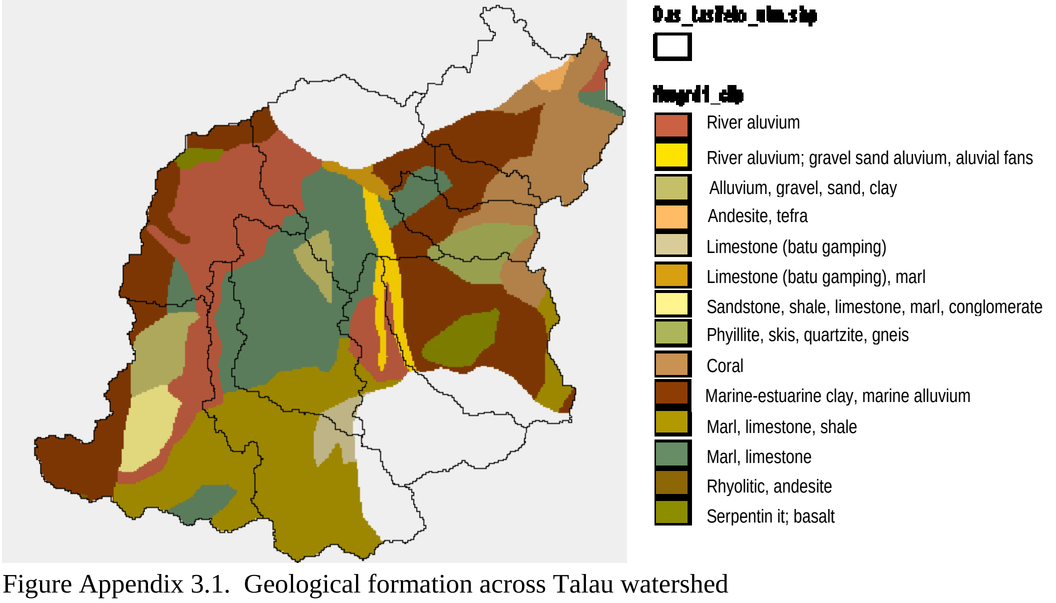
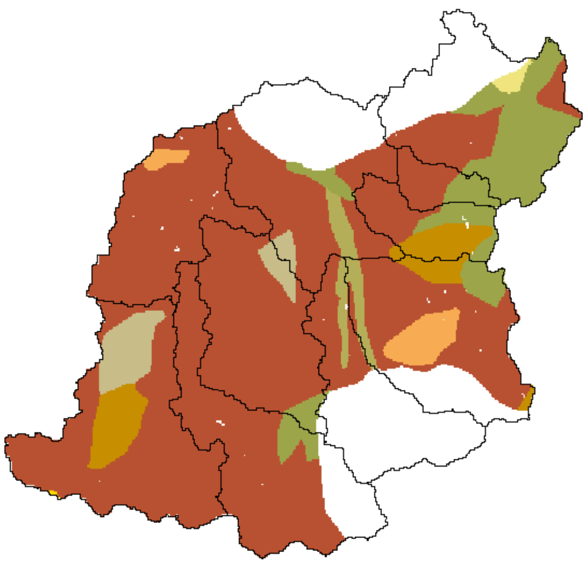


Figure Appendix 3.1. Geological formation across Talau watershed

Soils

There are 8 types of soil across Talau watershed with average soil depth of 90 cm and top soil depth of approximately 20 cm. The dominant soil type is Inceptisol characterized with its deep top soil and solum and moderate texture (silt). Based on this data and Suprayogo (2003), we derived estimates of relevant soil types across each sub-catchment and its relevant depth (Table Appendix 3.2.).



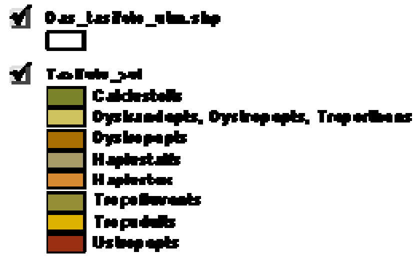


Figure Appendix 3.2. Distribution of soil types in Talau watershed.

Table Appendix 2.2. Soil parameters of Talau as input for GenRiver, based on existing soil maps and Suprayogo (2003).

A. Distribution of soils in each sub-catchment (in proportion)

Sub-catchment	Alfisols	Andisols	Entisols	Inceptisols	Mollisols	Oxisols
A	0.00	0.04	0.00	0.36	0.60	0.00
B	0.04	0.00	0.07	0.82	0.06	0.00
Lahurus	0.00	0.00	0.00	0.67	0.33	0.00
D	0.00	0.00	0.00	0.73	0.27	0.00
E	0.00	0.00	0.06	0.71	0.08	0.14
F	0.00	0.00	0.19	0.79	0.01	0.00
G	0.00	0.00	0.00	0.96	0.00	0.04
H	0.05	0.00	0.00	0.91	0.04	0.00
I	0.00	0.00	0.00	0.93	0.07	0.00
Motabuik	0.13	0.00	0.00	0.87	0.00	0.00

B. Soil depth of each soil types

Soil Type	Solum Depth (cm)	TopSoil Depth (cm)
Alfisols	150	10
Andisols	150	15
Entisols	90	5
Inceptisols	150	10
Mollisols	170	15
Oxisols	250	5

Land cover

Based on secondary data associated with existing land cover in Talau, we derived the following parameters for GenRiver input: (i) BD/BDRef (soil porosity indicator) (ii) Potential Interception, (iii) Relative Drought Threshold and (iv) Multiplier on Daily Evapotranspiration (Table Appendix 3.3.).

Table Appendix 2.3. GenRiver inputs associated with land cover/land use

A. Parameters as a constant

Land cover type	BD/BDref	Potential Interception (mm day-1)	Relative Drought Threshold
Agroforest	0.95	3	0.55
Imperata	1.05	1.5	0.6
Forest	0.85	4	0.5
Agriculture	1	1	0.7
Settlement	1.3	0.05	0.9
Water Body	0	1	0
Rice field	1.1	1	0.8
Shrubs	1	2.5	0.55

B. Monthly multiplier to evapotranspiration

Land cover type	Multiplier of Daily Potential Evapotranspiration											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agroforest	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Imperata	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Forest	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Agriculture	0.6	0.3	0.3	0.6	0.6	0.6	0.1	0.1	0.4	0.4	0.6	0.6
Settlement	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Water Body	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Rice field	1	1	1	1	1	0.6	0.2	0.2	0.2	0.2	1	1
Shrubs	1	1	1	1	1	1	1	1	1	1	1	1

Appendix 3. Farmers' perspectives on decomposition rate of various tree species, compared with chemical measurement on their leaves
(Source: Hairiah K, et al., 2004).

Local name	Scientific name	Decomposition rate (Farmers' perception)	C	N	L	P	Ratio		
			%	%	%	%	C/N	L/N	P/N
Lamtoro	*Leucaena leucocephala*	Fast	42.1	3	13	1.94	14	4.3	0.6
Jengkol	*Pithecellobium jiringa*	Medium	49.8	3.5	35	2.4	14	10	0.7
Kayu hujan	*Gliricidia sepium*	Fast	52.9	3.2	32	1.12	17	10	0.4
Jati Thailand (Bangkok teak)	*Tectona grandis*	Unknown	38.7	1.47	22.1	5.7	26	15	3.9
Mahoni (mahogany)	*Swietenia mahogany*	Slow	36.1	1.79	19.7	34.6	20	11	19.3
Ramayana tree	*Cassia spectabilis*	Unknown	41.3	3.35	20.2	6.5	12	6	1.9
Kayu afrika (umbrella tree)	*Maesopsis eminii*	Medium	36.8	4.03	14.2	4.9	9	3.5	1.2
Jati putih (white teak)	*Gmelina arborea*	Unknown	45	2.8	28	1.1	16	10	0.4
Mangga (mango)	*Mangifera indica*	Slow	36	2.2	20	3.1	20	10	1.4
Rambutan	*Nephelium lappaceum*	Slow	56.2	2	20	2.4	28	10	1.2
Alpukat (avocado)	*Persea americana*	Medium	40.4	1.58	14.7	34.7	26	9.3	22
Durian	*Durio zibethinus*	Slow	35.3	1.75	25.3	2.3	20	14.5	1.3
Nangka (jackfruit)	*Artocarpus heterophyllus*	Slow	45	3.2	32	0.63	14	10	0.2
Gandaria	*Boea macrophylla*	Unknown	48.9	2.8	28	3.3	17	10	1.2
Belinjo	*Gnetum gnemon*	Slow	42.1	2.36	7.3	6.5	18	3.1	2.8
Kemiri (candlenut)	*Aleurites moluccana*	Slow	36.2	2.15	18.3	5.7	17	8.5	2.7

Appendix 4. Tree species commonly found planted by farmers in Lahurus, Belu – East Nusa Tenggara
(based on observations during local knowledge surveys and livelihood surveys)

Tree species		Harvested products	Systems	Ecological value (Local knowledge)	Practiced tree spacing*	Economic value
English name	Scientific name					
Banyan		-	Mamar	Storing water	Irregular	-
Candlenut	*Aleurites moluccana*	Timber, fruit	Agrosilvopastural, mamar		50 trees/ha	Commercial, own consumption
Cashew	*Anacardium occidentale*	Fruits	Agrosilvopastural	-	200 tree/ha	
Coconut	*Cocos nucifera*	Fruit, wood, leaves	Agrosilvopastural, mamar	Storing water	50 trees/ha	
Coffee		Fruits		-	500 trees/ha	
Gmelina	*Gmelina arborea*	Timber, seeds	Agrosilvopastural, forest or agroforestry systems	-	330 tree/ha	Commercial
Jambu air hutan	Syzigium sp.	Timber, fruits	Mamar	Storing water	Irregular	-
Johar	*Cassia ciamea*		Mamar		Irregular	-
Kaliandra	Calliandra sp.	Fodder	Agrosilvopastural, forest, SIlvopastural	-	Irregular	Commercial, own consumption
Kayu air (Ai we)		Timber	Mamar	Storing water	Irregular	-
Lamtoro	*Lucaena leuchocephala*	Fodder, firewood and timber	Agrosilvopastural, forest, silvopastural, fallow systems, mamar	Litterfall could increase soil fertility	Irregular	Commercial, own consumption

Tree species		Harvested products	Systems	Ecological value (Local knowledge)	Practiced tree spacing*	Economic value
English name	Scientific name					
Mahoni	*Swietenia macrophylla*	Timber, seeds	Agrosilvopastural, silvopastural, forest, mamar	Storing water	330 trees/ha	Commercial, own consumption
Mangga	*Mangifera indica*	Timber, fruit	Agrosilvopastural, mamar	Storing water	20 – 40 tree/ha	Commercial, own consumption
Mangga hitam		Timber, fruit	Mamar	Storing water	Irregular	-
Orange	Citrus sp.	Timber, fruits	Agrosilvopastural, mamar	-	200 tree/ha	Commercial, own consumption
Pinang /beetle nut	*Areca catechu*	Fodder, firewood and timber, medicinal and chewing gum	Agrosilvopastural, mamar	Storing water	50 – 100 trees/ha*	Commercial, own consumption
Pisang/ banana	Musa sp.	Fruit, wood, leaves	Agrosilvopastural, mamar, fallow systems	-	200 trees/ha	Commercial, own consumption
Sandalwood	*Santalum album*	Timber, seeds	Agrosilvopastoral	-	330 tree/ha	Commercial, own consumption
Sengon	*Paraserianthes falcataria*	Fruit, wood	Agrosilvopastural, forest	Protecting commercial trees	20 trees/ha	Commercial, own consumption
Sirih		Fruit, leaves for medicine	Agrosilvopastural, mamar	-	50 – 100 trees/ha	Commercial, own consumption
Teak	*Tectona grandis*	Timber, seeds	Forest	Negative impact to water storage; uses too much water and makes soil dry	330 tree/ha	Commercial, own consumption

Tree species		Harvested products	Systems	Ecological value (Local knowledge)	Practiced tree spacing*	Economic value
English name	Scientific name					
Turi	*Sesbania grandiflora*	Fodder, firewood, timber, human consumption.	Agrosilvopastural, mamar, forest, fallow systems	Litterfall could increase soil fertility	100 – 200 trees/ha	Commercial, own consumption
Wild coconut		Fruit, wood, leaves	Agrosilvopastural, mamar	Storing water	Irregular	-

Appendix 5. Agroforestry systems commonly found in East Nusa Tenggara

(Source: Roshetko *et al*, 2002)

Systems	Land requirement	Direct and indirect products	Plot size (ha)	Issues	Potential activity
Agro-silvopastoral	Applicable in all soil/land condition	Crop yield, fruits, timber, firewood, fodder, mulch, manure, and livestock. Improving micro climate, wind and fire break, preventing erosion, seed banks.	0.5 – 1	Lack of knowledge to choose appropriate tree species and integrating these species.	Technical training on tree planting. Farmers cross visit.
Communal forest	Applicable in all soil/land condition	Timber, fodder, firewood, mulch, fruits. Improving micro climate, wind and fire break, preventing erosion, seed banks.	0,5 – 1	Lack of knowledge to choose appropriate tree species and integrating these species.	Technical training on tree planting. Farmers cross visit.
Silvo-pastoral	Required vast area of land	Livestock, fodder, mulch, firewood	above 10	Low fodder quality and low quantity of fodder in dry season, causing livestock susceptible to diseases	Developing tree species with high quality fodder
Fallow systems	Applicable in all soil/land condition	Crop yield, fodder, livestock, firewood, manure and mulch	0.25 – 0.5 A farmer can own 3-7 plots	Slash and bun systems Not yet integrated with trees	Training in managing tree systems
Amarasi systems (agri-silviculture)	Required vast area of land	Crop yield, fodder, livestock, firewood, manure and mulch	0.25 – 0.5 A farmer can own 3-7 plots	Slash and bun systems Not yet integrated with trees	Training in managing tree systems
Mamar (traditional agrosilvopastoral)	Area around water springs	Fruits, sirih, beetle nut, fodder, firewood, timber	0.1 – 1	Lack of tree management and selective tree species	Training in planting trees

Appendix 6. Monthly Rainfall (mm)

Recorded at Sukabitek Weather Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Des	Total
1978	115	387	98	64	178	27	65	9	1	28	56	172	1198
1979	70	105	151	16	152	5	2	0	0	1	14	112	625
1980	242	230	36	50	13	3	0	0	0	76	60	205	912
1981	237	105	115	0	60	0	28	1	13	2	251	249	1060
1982	119	151	152	49	14	0	0	0	0	0	26	252	763
1983	112	341	99	196	38	32	0	0	0	42	72	92	1025
1984	294	243	202	115	53	0	3	0	39	1	25	203	1178
1985	163	176	152	163	30	43	7	0	3	76	104	186	1103
1986	304	208	261	120	1	19	39	0	16	124	109	93	1293
1987	344	236	205	18	32	17	8	0	0	0	90	180	1129
1988	311	120	326	46	4	1	2	0	5	27	369	292	1503
1989	117	109	236	283	83	19	15	10	1	23	40	83	1021
1990	164	101	66	149	71	0	0	0	0	0	17	208	776
1991	133	351	34	91	0	0	8	0	1	0	184	194	996
1992	235	95	118	33	40	3	11	0	6	0	127	187	855
1993	265	155	119	193	16	41	6	1	5	15	42	102	958
1994	337	238	129	58	15	0	0	0	0	0	66	260	1103
1995	283	157	367	173	14	72	6	3	0	13	84	424	1597
Average	213	195	159	101	45	16	11	1	5	24	96	194	1061
Max	344	387	367	283	178	72	65	10	39	124	369	424	1597
Min	70	95	34	0	0	0	0	0	0	0	14	83	625

Appendix 7. Monthly Temperature (^{0}C)

Recorded at Sukabitek Weather Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978	26.1	25.5	25.8	24.8	25.5	23.5	23.5	23.5	24.1	25.5	27.1	26.4
1979	26.2	26.2	25.5	24.9	25.9	24.1		23.5	24.8	26.7	27.5	27.4
1980	26.3	25.5	26.2	25.9	25.2	24.1	23.4	24.1	24.2	25.9	27.0	26.7
1981	25.6	25.4	25.3	25.5	25.5	23.9	24.3	23.7	25.7	26.3	27.0	26.0
1982	25.8		25.4	25.1	24.1	23.1	21.6	23.2	23.8	24.6	26.6	27.1
1984	26.0	25.6	25.7	25.4	24.5	23.7	22.2	23.1	25.4	26.1	27.7	26.7
1985	26.5	26.2	26.0	25.3	24.8	23.8	24.2	24.1	24.8	25.8	27.0	26.8
1986	25.8	25.8	25.7	25.5	24.0	24.6	23.7	23.4	24.5	26.2	26.7	26.6
1987	25.8	25.3	25.4	25.2	25.4	24.0	23.1	23.9	24.0	26.3	27.7	26.4
1988	26.2	26.0	26.6	25.1	25.3	22.6	23.9	24.6	25.7	27.2	26.9	25.7
1989	26.1	25.8	25.2	25.5	24.4	23.9	23.6	23.2	24.8	26.6	27.2	27.0
1990	26.0	26.1	25.9	26.0	25.1	22.7	23.1	22.8	23.7	25.8	28.0	26.9
1991	26.3	25.6	27.9	25.4	24.0	22.9	22.5	23.5	24.7	25.6	27.1	26.9
1992	26.1	26.3	25.8	27.6	27.6				28.8			
1993		24.2		25.0	24.9	24.3	23.3	23.5	24.9	26.1	27.4	27.1
Average	26.1	25.7	25.9	25.5	25.1	23.7	23.3	23.6	24.9	26.1	27.2	26.7
Max	26.5	26.3	27.9	27.6	27.6	24.6	24.3	24.6	28.8	27.2	28.0	27.4
Min	25.6	24.2	25.2	24.8	24.0	22.6	21.6	22.8	23.7	24.6	26.6	25.7

Appendix 8. Monthly Rainfall (mm)

Recorded at Tasifeto Timur Weather Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1989	207	349	261	249	152	124	70	20	50	15	211	222	1930
1990	296	291	152	156	98	2	20				15	457	1487
1991	216	351	97	267		2	20				146	166	1265
1992	254	340	303	89	95						245	391	1717
1993	478	274	329	197	7						117	198	1600
1994	367	515	307	67	18						20	308	1602
1995	487	308	513	201	53	52				70	330	381	2395
1996	257					14				5	101	441	818
1997	320	701	71	37							178	264	1571
1998	207	279	298	101	105	48	80		52	139	370	211	1890
1999	558	388	205	300		60				108	256	200	2075
2000	395	253	238	97						10	78	88	1159
2001	348	285	365	65						22	229	235	1549
2002	524	118										388	1030
2003	382	630	75										1087
Average	353	363	247	152	75	43	48	20	51	53	177	282	1545
Max	558	701	513	300	152	124	80	20	52	139	370	457	2395
Min	207	118	71	37	7	2	20	20	50	5	15	88	818

Appendix 9. Monthly River flow (mm)

Recorded at Motabuik River Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	375.16	395.19	140.01	66.16	70.05	53.36	54.95	43.23	35.10	35.38	448.05	369.94
1992	12.39	11.70	10.43	10.51	10.93	3.66	3.76	3.28	2.27	1.88	9.05	21.51
1993	57.24	50.64	39.19	47.75	24.44	18.95	19.58	17.93	7.58	7.83	14.16	22.37
1994	78.87	304.51	224.29	56.13	20.08	13.63	10.96	10.27	10.49	11.01	11.15	45.12

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Glossary

Base flow: the part of stream flow that is attributable to slow release of groundwater to the stream and not related to current or recent rainfall.

Buffering capacity is the ability of a system to reduce the impact of external variation on internal properties, e.g. reducing the variation in stream flow relative to variation ion rainfall

Buffering indicator is derived from the ratio of above-average stream flow and above-average rainfall

Buffering for peak events is the 'buffer' function demonstrated at peak rainfall events

Evapotranspiration: The combined processes of evaporation from soil surfaces, open water or water films attached to plants and transpiration from living plants.

Flash floods: floods caused by heavy or excessive rainfall in a short period of time, generally under 6 hours, leading to stream flow and water levels that rise and fall quite rapidly

Gradual water release: gradual release of (ground) water in the dry season

Ground water discharge: is the release of groundwater to streams or subsurface flows

Low flow: flow through a watercourse after prolonged absence of rainfall

(Bank) overflow: flow of water outside of the regular river bed during conditions where recent inflow minus outflow has exceeded the storage capacity

Peak flows: maximum flows through a watercourse

Percolation: the downward movement of water through the openings in soil or rock

Precipitation: water that falls to earth in the form of rain, snow, hail, or sleet.

Relative buffering indicator: the 'buffer' function adjusted for relative annual water yield

River flow: the flow of water in the river channel

Run off or surface quick flow: streamflow that derived from rainfall by overland flow and that occurs quickly in response to precipitation events

Soil quick flow: streamflow that occurs shortly (e.g. 1 day) after a rain event but that passed though the soil for at least part of the pathway

Storage capacity: The total amount of water that can be stored in a reservoir before overflow occurs

Streamflow: Water flowing in the stream channel. The term is often used interchangeably with discharge.

Surface runoff or Surface-quick flow or run off: streamflow that derived from rainfall by overland flow and that occurs quickly in response to precipitation events

Total discharge fraction: Total water yield (discharge) per unit rainfall, usually on an annual basis

Water balance: The comparison over a certain time period (e.g. month or year) of inflow of water (precipitation) and outflows by evapotranspiration, streamflow and subsurface flows

Water quality: The chemical, physical, and biological characteristics of water with respect to its suitability for a particular use.

Water storage: The volume of water that can be (temporarily) withheld from evapotranspiration, streamflow or subsurface flows, either above ground in lakes, rivers, and other waterways or below ground as ground water

Water transmission: The functions of a watershed to transmit incoming precipitation to streamflow

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Who we are

The World Agroforestry Centre is the international leader in the science and practice of integrating 'working trees' on small farms and in rural landscapes. We have invigorated the ancient practice of growing trees on farms, using innovative science for development to transform lives and landscapes.

Our vision

Our Vision is an 'Agroforestry Transformation' in the developing world resulting in a massive increase in the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, income, health, shelter and energy and a regenerated environment.

Our mission

Our mission is to advance the science and practice of agroforestry to help realize an 'Agroforestry Transformation' throughout the developing world.

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