WATER MONITORING IN WATERSHEDS

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WORLD AGROFORESTRY CENTRE

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FOREWORD

Indonesia has millions of hectare of degraded land and watersheds that need rehabilitation. One of the ways to recover degraded watersheds is through tree-planting campaigns. In addition, it is also necessary to enhance existing policies related to 1) land use; and 2) degraded land and watershed management.

Newspapers and environmental NGOs always point to forest destruction and illegal logging as causes every time floods and landslides occur. The loss of forest cover is viewed as the only cause of the loss of watershed functions and communities inhabiting upstream areas are often accused of being the source of environmental destruction. But, if looked at more closely, many areas in Indonesia and Southeast Asia have natural beauty and yet maintain good watershed functions although they no longer have vast areas of natural forests. Well-maintained watershed functions are caused by well-managed river flows, especially when supported by social institutions that maintain a balance between individual and public interests. Today, people realize that by planting trees with economic value in their agricultural system they are also maintaining watershed functions at the same time because trees help stabilise hill slopes as well as prevent soil loss because of erosion and water flow.

A community's success in watershed management is affected by interconnecting factors, such as:.

- Human populations (and their cattle) and how they interact with each other, including their interaction with local governments. For example, whether they have traditional rules and whether the rules are still applied in daily life.
- Land-use systems or land-coverage types may take the form of natural forests, secondary forests, crops, trees with economic value, grasslands and embankments with plants for fodder, roads, pathways and settlements.
- Soil conditions, such as soil-density level, soil-coverage level by litter layer, soil organisms and plant rooting, which play a part in keeping soil structures from compaction.

- Topographic and geological aspects related to slope steepness, land movement, geological history, earthquakes and eruptions, and the balance between soil formation and erosion.
- Climate- and weather-related rainfall and seasonal patterns; daily sunlight cycle; rain intensity (heavy rain, light rain); river-flow pattern following the pattern of rocks and hills; meandering river course that causes soil sedimentation, which probably resulted from erosion and landslides and was considered as destructive in past times but has been transformed into fertile land over time.

Overcoming problems of landscape management requires integrated interdisciplinary cooperation such as socio-politic, conservation, forestry, spatial planning, geography and hydrology. Each of these disciplines should complement each other instead of standing on their own. An integrated effort is required to understand each discipline, knowledge and the perceptions of people and policy makers in addressing problems in landscape management. Open communication between everyone involved (researchers, community members and government policy makers) needs to be maintained and improved.

This book is our contribution toward better communication between people who have an interest in watershed management. It contains our experiences at the World Agroforestry Centre in diagnosing and monitoring problems with watershed management. The main topic is watershed hydrological functions, especially, 1) interaction between landscape and rainfall; and 2) landscape as water organisms' habitat, functioning as an indicator of water quality and pollution levels. The results of the observations are expected to inform negotiations to achieve better watershed management for the benefit of all. Issues related to watershed management are not only a matter of planting an amount of critical land with trees. Watershed management has different dimensions and each problem requires a different approach.

Watershed functions can be looked at in two ways: 1) supply aspects, which consist of river-water quantity (discharge), time, river-flow quality; and 2) demand aspects, which consist of availability of clean water and prevention of flood, landslides and mud puddles (Figure 1). Poor access to clean water is a main determinant in poverty and poor health. The problem of insufficient and untimely water supply for downstream communities can be dealt with using two approaches.

1) Technical approach, usually applied in the river body in the middle of a watershed through, among other means, increasing water flow to prevent flooding in critical areas; building dams or reservoirs as temporary water holders; and/or building pipelines or water catchments (ponds, water towers) to distribute drinking water from upstream to downstream consumers.
2) Land-use approach in upstream areas, that is, by designating forests as protected and/or managing land in view of buffered water delivery.

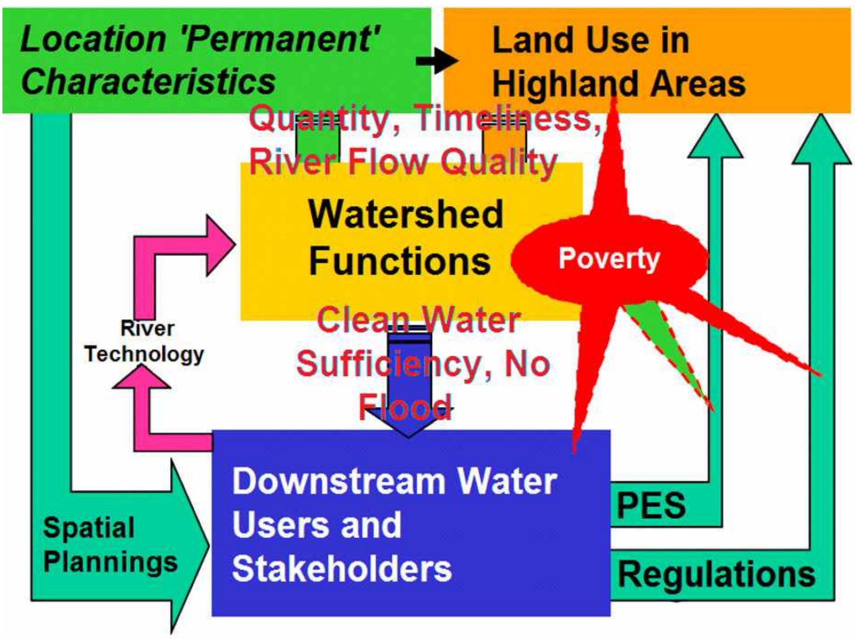

Figure 1. Reciprocal relations between 1) upstream areas that provide watershed functions in terms of quantity, time and quality of river water; and 2) area characteristics, both permanent (such as geology and topography) and non-permanent (such as land-use types and their impacts on downstream areas). (PES = Payments for Environmental Services)

Chapters in this book elaborate on how local communities and scientists together assess the 'weak points' of a landscape that greatly affect the circumstances of downstream areas (Chapter 1), how to monitor sediment in river water (Chapter 2), physical and chemical characteristics of river water (Chapter 3), and how to use water organisms to assess the quality of river water (Chapter 4). We also provide some examples of how to measure and monitor water flow using several quantitative indicators (Chapter 5). These indicators can be used as an index for assessing and comparing the patterns of relationship between river flow and rain as a basis for monitoring changes of hydrological functions at sub-watershed level.

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We would also like to extend our appreciation to Tikah Atikah, without whom this book would not be as pretty as it is.

I. Understanding watershed landscapes

1.1 What to consider when assessing a watershed landscape?

A landscape is a part of the Earth's surface resulting from geomorphologic processes, climate, vegetation and human land use, that interacts in the delivery of ecosystem services and that requires management systems above farm scale, but in reach of local human communities. It includes land, soil and land cover (vegetation). As a specific type of landscape of current interest, a watershed forms an inseparable integration of land and a river and its tributaries that run through it. Rivers and tributaries in a watershed have important functions: holding, storing and streaming water from rainfall and other sources, which is managed based on the laws of nature according to the conditions of the watershed. This process is known as the hydrological cycle (Figure 1.1).

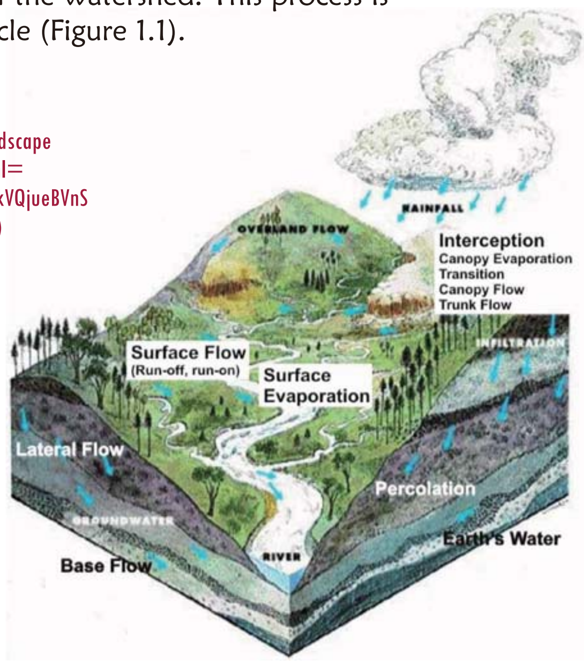

Figure 1.1 Hydrological cycle in a watershed landscape (adapted from http://www.google.com/imgres?hl=en&biw=1280&bih=640&tbm=isch&tbnid=HkVQjueBVnS_M:&imgrefurl=http://www.kaluyala.com/com)

Various problems, such as erosion, sedimentation, landslides and floods, occur in watersheds, in response to above-average rainfall. The level of the response is strongly influenced by a watershed's buffering characteristics.

The physical characteristics of a watershed are the basic variables that determine the hydrological processes, while the socio-economic and cultural aspects of society are variables that affect acceleration of changes in a watershed. Therefore, understanding the physical characteristics of a watershed—for example, terrain and geomorphology, flow pattern and temporary water storage—may be of help in identifying areas with high vulnerability to watershed problems, and in designing techniques on controlling them that are compatible with local conditions.

1.1.1 Terrain and Geomorphology

Geomorphology is the scientific study of landscape formation and structure, from large-scale to detailed examination of 'landforms' and their topographical patterns ('terrain'). Landforms and their terrain are formed as the result of structural processes (folds, fractures and uplifts), rock-weathering processes (geology), erosion, sedimentation and volcanism, producing the configurations of the Earth's that we know of as mountains, hills and plains. A more detailed introduction to the elements that make up terrain is necessary when learning about landscape characteristics, especially the characteristics that affect the potential for surface runoff, erosion, flood and landslides. Terrain elements—such as steepness, length, direction, configuration and uniformity of slopes—are very important to identify.

1.1.1.1 Slope steepness

Kslope steepness is the ratio of relative land steepness to a flat plane, which, in general, is expressed in percent or degree. The slope steepness is closely related to erosion level. The steeper the slope, the smaller the amount of rainwater that penetrates the ground. Consequently, the amount of surface runoff is greater.

Tabel 1.1 Classification of slope

No	Relief	Slope (%)
1	Flat	0-3
2	Undulating/gentle	3-8
3	Rolling/nearly flat	8-15
4	Hilly/slightly steep	15-30
5	Moderately steep	30-45
6	Steep	45-65
7	Very steep	>65

Source: Arsyad (2000)

1.1.1.2 Slope length
Slope length begins with the slope's starting point and ends at the particular point where runoff water enters a river or the point where the slope begins to change. The longer the slope length, the greater the runoff of surface water to the slope's end, thus, increasing the chance of erosion. The erosion level at a slope's end is greater than the erosion level at the slope's starting point. This is because of water flow accumulation, which gets bigger and faster when approaching the slope's end.

1.1.1.3 Slope configuration
Slopes can be convex or concave. A convex slope surface is likely to suffer from sheet erosion while a concave one is more susceptible to gully or groove erosion.

1.1.1.4 Slope uniformity
Slope steepness is not uniform, which means that at a given place the slope may be steeper and while at other places it may alternated with flat areas. Uniform slopes have higher erosion levels than non-uniform slopes.

1.1.1.5 Slope direction
The slope direction is that facing towards the wind, whether from the north, northeast, east, southeast, south, southwest, west or northwest. Generally, rain falls on the parts of a slope facing the wind and only a small portion of rain falls over the rear parts. The slope direction highly determines the amount of sunlight and rainfall that it receives. Some parts of a slope with direct and intensive sunlight tend to suffer from greater erosion than parts without direct sunlight.

1.2 Patterns of water flow and temporary water storage

Patterns of water flow and storage in a watershed are heavily influenced by soil characteristics, parent material (geology), watershed morphometry and land uses. These characteristics determine the amount of both flowing and stored rainwater, the flow velocity, and the water's travel time from the most distant to the outlet (concentration time), which becomes influential when floods (both flood inundation and flash floods) occur in the watershed.

1.2.1 Soil

Soil is a material resulting from rock weathering, the characteristics and distribution of which strongly determine the surface runoff (overland flow) and subsurface flow. Soil characteristics that are important to explore in watershed assessments are bulk density, texture, depth and soil horizon.

1.2.1.1 Soil Bulk Density

Soil bulk density (BD) is the ratio of soil mass and soil volume (gr/cm^3), including soil pore space volume. The BD, along with the soil texture and organic materials, determines the infiltration level of water. Higher BD values indicate more solid soil material. This means that water has greater difficulty passing through the soil. Soil BD is numerated as follows:

- Low: < 0.9
- Middle: 0.9-1.1
- High: > 1.1

1.2.1.2 Soil texture

Soil texture describes the composition of soil particles by size, consisting of (1) sand fraction (50 μm–2 mm); (2) silt (2–50 μm); and (3) clay (2 < μm), and the percentage of sand, silt and clay content for each texture grade is presented in Figure 1.2.

1.2.1.3 Soil depth

Soil depth or 'solum' (commonly in centimetre) is a measure of soil layer thickness from the surface to the soil parent material. The soil profile comprises horizons A and B. Its thickness affects water storage capacity, which generally can be classified into the following:

- Very shallow: < 20cm
- Shallow: 20 - 50cm
- Moderate: 50 - 75cm
- Deep: > 75 cm

1.2.1.1 Soil horizon

Soil horizons are a result of vertical soil formation. They are represented by the symbols A, B and C, while the soil layers are designated with symbols I, II, III and so on. Soil formation is a reflection of soil development as affected by climate, topography, parent material, vegetation and organism conditions as well as time. Horizon depth, both upper and lower parts, the existence of an impermeable soil layer and permeability are important characteristics. For certain soil types, some development obstacles are found, as indicated by the existence of an impermeable horizon that can block water infiltration.

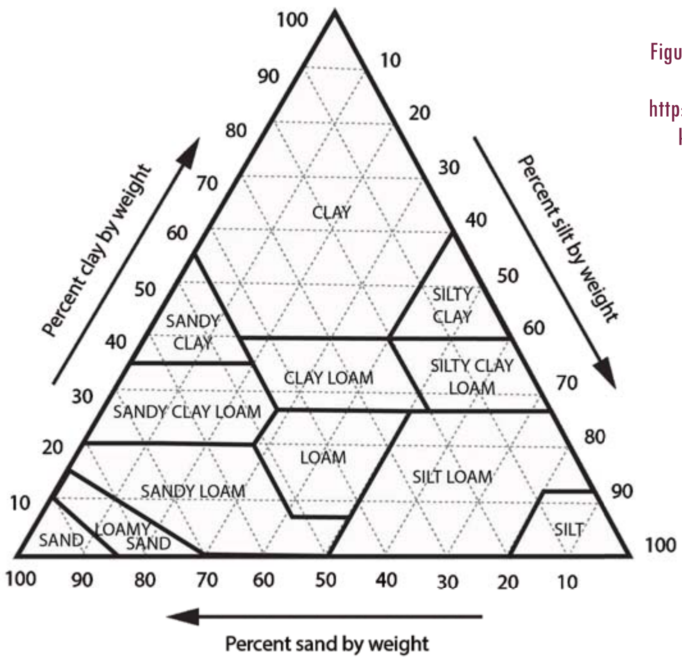

Figure 1.2 Texture triangle (Adapted from http://en.wikipedia.org/wiki/File:USDA_and_UK-ADAS_textural_triangle.jpg)

1.2.2 Soil parent material (geology)

In general, the type of soil parent material affects the form of the flow hydrograph. For example, watersheds with impermeable rock types (such as clay stone/shale or granites) generate a flow hydrograph characterized by high levels of peak discharge during relatively short concentration periods. On the other hand, watersheds with porous rock types (such as limestone) generate slightly sloping flow hydrographs with lower discharge peaks during relatively long concentration periods.

1.2.3 Land cover

The vegetation that constitutes land cover plays an important role in intercepting rainwater and water transpiration absorbed through the roots. Land with dense vegetation cover has the ability to absorb the kinetic energy of rainfall, so that splash erosion is minimized. In addition, it also minimizes the flow coefficient, thus, increasing the possibility of absorbing rainwater, especially in land with thick solum ('sponge effect'). The following are several land-use classes that need to be identified when analyzing hydrological problems:

- Percentage of agricultural vegetation
- Percentage of grass and pasture
- Percentage of forests
- Percentage of settlements and waterproof roads
- Percentage of grasslands and scattered trees
- Percentage of unoccupied land
- Percentage of wetlands and reservoirs

1.2.4 Watershed morphometry

Watershed morphometry is the quantitative measurement of watershed characteristics associated with the geomorphological aspects of a region. These characteristics are associated with the drainage of rainfall that covers the watershed. The parameters are: a) watershed area; b) watershed shape; c) stream network; d) flow density; e) flow pattern; and f) river steepness gradient.

1.2.4.1 Watershed area

A watershed is a gathering place of precipitation into a river system. A watershed's area can be estimated by measuring the area using a topographic map.

1.2.4.2 Watershed shape

The shape of a watershed affects the time it takes rainfall to reach the outlet. When the watershed shape is round, a shorter time is needed by rainfall to reach the outlet, then higher fluctuations of floods occur. But if the shape is oval, longer time is needed to reach the outlet, and there are lower fluctuations of floods. Quantitatively, watershed shape can be estimated using the ratio of longitudinal ('elongation ratio'/Re) and roundness ('circularity ratio'/Rc).

'Elongation ratio' is calculated using the following formula:

$$Re = 1.129 \left(\frac{A^{\frac{1}{2}}}{Lb} \right)$$

where:

Re = shape factor; A = watershed area (km^2); Lb = length of main river (km).

'Circularity ratio' is calculated using following formula:

$$Rc = \frac{4\pi A}{P^2}$$

where:

Rc = shape factor; A = watershed area (km^2); P = perimeter of watershed (km)

1.2.4.3 River network

A river's network can affect the amount of discharge by the tributaries. This parameter can be measured quantitatively from the branching ratio, which is a ratio between the number of river channels which belong to an order, with the order of one level above it. A higher branching ratio means that the river has many tributaries and the fluctuations of discharge that occur also increases.

'River order' is a river channel's branching position in a certain order in relation to the main river in a watershed. A greater order number indicates a wider area and longer river line. River order can be determined using the Horton, Strahler, Shreve and Scheidegger methods (Ranalli and Scheidegger 1968). However, in general, the Strahler method is easier to apply than the others. According to the Strahler method, the most upstream river line with no branch is classified as the first order (order 1); the meeting point between the first order with the same order is classified as the second order (order 2) and so on until the main river is marked by the greatest number of orders (Figure 1.3) .

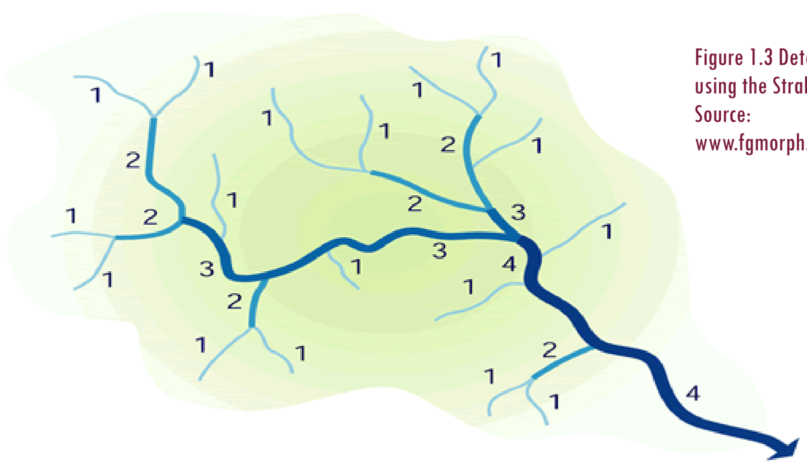

Figure 1.3 Determining river order using the Strahler method
Source: www.fgmorph.com/fg_4_8.php

The number of rivers that belong to an order can be determined from the river-branching index ('bifurcation ratio'), with the following equation:

$$Rb = \frac{N_u}{N_{u+1}}$$

The Rb calculation is usually performed in a sub-watershed or sub-sub-watershed unit. To obtain the Rb value from the overall watershed area, the branching level of River Weighted Average (Mean Weighted Bifurcation Ratio/WRb) is used, calculated using the following equation:

$$W_{Rb} = \frac{\sum Rb_{u/u+1}\left(N_u + N_{u+1}\right)}{\sum N_u}$$

where:

R_b = index of river branching level; N_u = number of river lines which belong to the (u)-order; N_{u+1} = number of river lines which belong to the (u + 1)-order

The result of the equation above indicates the following circumstances:

- $R_b < 3$: rapid increase of flood surface level, but slow decrease
- R_b 3–5: moderate increase and decrease of flood surface level
- $R_b > 5$: rapid increase of flood surface level, as well as decrease

1.2.4.4 River flow density

River flow density describes the capacity of surface water storage in catchments such as a lake, swamp and river that flows through a watershed. River flow density can be calculated using the ratio of the total length of a river's network and its watershed area. The higher the density of river flow, the more water can be accommodated in river bodies. River flow density is an index that indicates the number of tributaries within a watershed. The index can be obtained with the following equation.

$$D_d = \frac{L}{A}$$

where:

D_d = stream density index (km/km^2); L = total length, including the length of the river's tributaries (km). A = watershed area (km^2)

The river flow density index is classified as follows:

- D_d : < 0.25 (Low)
- D_d : 0.25–10 (Medium)
- D_d : 10–25 (High)
- D_d : > 25 (Very high)

Based on these indices, it is clear that the river density index is less in permeable geological conditions such as limestone (karst), but higher in high rainfall areas.

1.2.4.5 Flow pattern

River flow patterns indirectly indicate the characteristics of the parent material, such as permeability, geological structure and susceptibility to erosion. A parallel pattern is generally found in watersheds with fracture structure. The flow patterns in watersheds can be classified into the following.

- Dendritic: generally found in areas with homogenous rocks and wide distribution, for example, an area covered by extensive sediment deposits and located on a horizontal plane somewhere in lowlands. Braided streams with limestone rocks ('limestone') and clay stone ('shale') and solutional topography may have a dendritic flow pattern. On topography with homogenous slopes, the flow pattern formed is dendritic medium, while on small terraced topography, the flow pattern formed is smooth dendritic. Another form of dendritic pattern is a combination of rectangular dendritic, which is found in areas with metamorphic rocks with rounded peaks. This pattern has lines which are nearly parallel, deep and with smooth-to-medium texture. This form can be found in wet areas. In areas with metamorphic rocks the topography of which has paralleled peaks, a pattern might form of smooth rectangular dendritic, which occurs in dry areas. In igneous rock formations, located in areas with rounded hill topography and wet areas, the flow pattern formed is medium dendritic.
- Radial: usually found on slopes of volcanoes or areas with a dome-shaped topography.
- Rectangular: found in limestone areas.
- Trellis: usually found in areas with sediment layers in folded mountains.

* Combination of dendritic and trellis: found in parallel mountain belts, especially with folded structural rocks with fine to medium texture.

1.2.4.6 River gradient

The gradient of a river is the ratio between different elevations and the main river length. Gradient indicates river steepness: the greater the steepness then the higher the flow velocity. River gradient can be estimated with the following equation:

$$S_u = \frac{(h_{85} - h_{10})}{0{,}75Lb}$$

where:

S_u = gradient of the river;
h_{85} = elevation at the point as far as 85% of the watershed outlet;
h_{10} = elevation at the point as far as 10% of the watershed outlet;
Lb = length of main river.

1.2.5 Climate

Climate components that are the most influential to hydrological process are precipitation (especially rainfall) and evapotranspiration.

1.2.5.1 Precipitation

Precipitation is the process of water pouring from the atmosphere to the Earth's surface. The main source of precipitation in tropical areas is rainfall. Important elements in precipitation are rain amount as expressed in rainfall depth units (mm) and rainfall intensity as expressed in amount of rain per time unit. Rainfall intensity classifications are presented in tables 1.2 and 1.3.

Tabel 1.2 Clasification of rainfall intensity

Clasification	Rainfall intensity (mm/hour)
Low	< 6.25
Medium	6.25 - 12.5
Heavy	12.5 - 50.0
Very heavy	>50.0

Note: As in Kohnke and Bertrand 1959
Source: Arsyad (2000)

Tabel 1.3. Clasification of rainfall intensity

Clasification	Rainfall intensity (mm/hour)
Very low	0-5
Low	5-10
Medium	11-25
Bit heavy	26-50
Heavy	51-75
Very heavy	> 75

Source: Arsyad (2000)

1.2.5.2 Evapotranspiration

Evapotranspiration is a combination of evaporation and transpiration. Evaporation is the phenomenon whereby water changes into vapour and moves from the surface soil and water into the air. Evaporation from plants is called transpiration. Therefore, the evaporation of water from the surface soil, surface water and plants together is called evapotranspiration.

The following are the main factors that affect evapotranspiration.

1. Meteorological factors
    - solar radiation
    - air and surface temperature
    - humidity
    - wind
    - air pressure
2. Geographic factors
    - water quality (colour, salinity etc.)
    - waterbody depth
    - size and shape of water surface
3. Other factors
    - soil moisture content
    - characteristics of soil capillaries
    - depth of groundwater surface
    - soil colour
    - type, density and height of vegetation
    - water availability (rain, irrigation etc)

The amount of evapotranspiration can be estimated based on the result of evaporation pan measurement and lysimeter reading. However, direct measurement of evaporation and evapotranspiration from water or land surfaces has many obstacles. Therefore, some methods have been developed using data input that are predicted to be significantly influential to the evapotranspiration level. The level of evapotranspiration can also be estimated using Thornwaite, Blaney and Criddle, Penman-Monteith methods (Xu CY and Singh 2002) or soil moisture balance analysis.

1.3 Signs of slope instability

Landslides are a natural phenomenon. They are a transfer process of soil mass or slope-forming rocks in an oblique direction from their original position so that they part from the previously solid mass because of gravity, movement of which is translational and/or rotational (Figure 1.4). In brief, the process of how a landslide occurs is set out below.

- Water penetrates into the soil, then soil weight increases
- Water penetrates to the soil's impermeable layer, which in this case acts as a slip plane, then the ground becomes slippery and the soil above it moves downwards, following the slope line and finally out of the slope

Figure 1.4 Outcrops on slopes by landslide (Photo: ICRAF-Sumberjaya archives)

Generally, a landslide-prone area is an area having the following characteristics.

1 It has high steepness of slope (over 40%) and/or is in an earthquake-prone area.
2. It is an area where many water lines are encountered or has springs in fertile valleys by the rivers.
3. The slope is in the bend of a river as a result of erosion or abrasion by river flow (Figure 1.5).
4. Bending slope area, which is a transition area between a steep slope and slightly sloping area, which is usually occupied by settlements. Such a location is an accumulation zone for water that penetrates through from steeper parts of the slope. Therefore, a bending slope area is very sensitive to increases of porous water pressure, thus weakening the bond between soil particle grains and is likely to trigger a landslide.
5. Areas traversed by a structure/fault and commonly inhabited. This area is characterized by a valley with steep slopes (above 30%),

composed of cracked rocks in a dense form, and presence of springs in the valley. Cracks in rock structure may cause decreasing stability in the slope, so that rock falls/slips can occur if rainwater infiltrates into the crack or when a tremor occurs on the slopes.

6. Geology (rock type and characters, stratigraphy and weathering level). Types of rock/soil are, among others:
   - deep soils with advanced degree of weathering
   - high plasticity of soil as in soil with high clay content, especially 2:1 minerals, such as monmorillonite
   - layered sediment (permeable soil is above the impermeable one)
   - soil/rock coating in line with slope direction
   - soil from weathering is thick
   - high level of wetness (high rainfall)
   - intensive lateral erosion that causes abrasion in lower parts of the slope, which makes it steeper
7. Morphology or slope geometrical shape
   - intensive lateral and backward erosion causes intensive abrasion at the lower part of the slope, so that the slope gets steeper. the steeper the slope, the smaller its stability value
   - fracture heading out of the slope
8. Rainfall
   - areas with high average rainfall (above 2000 mm/year)
   - rainfall causes an increase of soil water content, resulting in rock strength decreasing and turning into a mechanical burden for the soil

Figure 1.5 River bank erosion due to steep land and milling the bend of the river
(Photo: ICRAF-Sumberjaya archives)

- high rainfall causes infiltrated water volume to increase so that the soil is more saturated and it saturates (and adds more weight to) the soil level above the slip plane

9. Human activities
   - interference with slope stability, for example, by cutting through the slope
   - constructing buildings without considering spatial layout of the area/village
   - interfering with land-cover vegetation so that it fails to absorb surface runoff, for example, 'over-cutting', looting or uncontrolled logging, which causes backward and lateral erosion
   - adding external mechanical loads, for example, reforesting an area too densely or leaving mature and big timbers unharvested

1.4 Indications of erosion and sedimentation

Erosion can be predicted based on field conditions, by considering the formation of erosion such as sheet, rill and gully erosion, as shown in Figure 1.6.

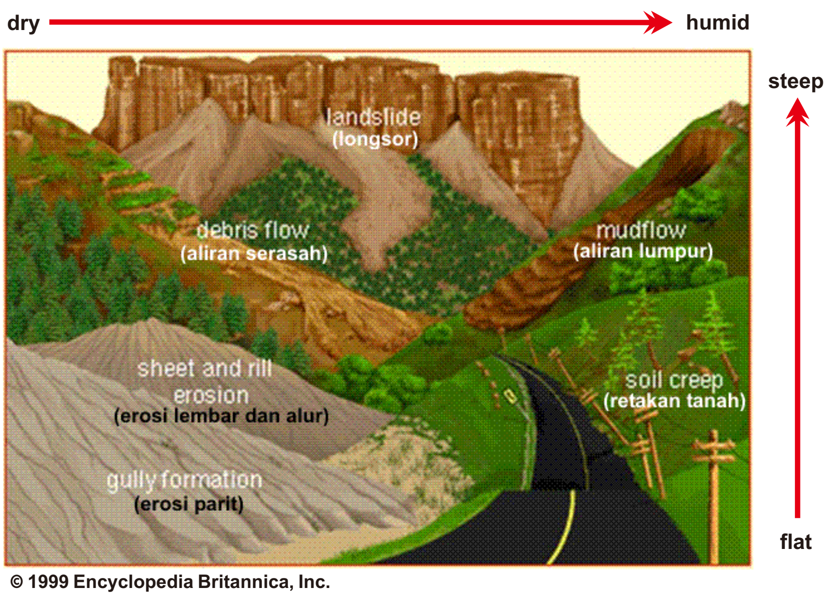

Figure 1.6. Types of erosion and landslides (Source: Encyclopaedia Britannica, 1999).

Another approach to estimating erosion is to pay attention to the changes in soil surface conditions. In general, soils which suffer from erosion are characterized by changes to the colour and consistency of the soil as well as the emergence of roots or rock layers on the surface (Figure 1.7).

Figure 1.7 Soil erosion is marked by changes in soil colour and hardness, also the emergence of the roots of plants above the ground's surface (Photo: ICRAF-Sumberjaya archives)

Tabel 1.4 Level of erosion hazard based on the amount of soil missing

Level of erosion hazard	Amount of lost soil surface layer
No erosion	0 %
Mild	< 25% top layer lost
Medium	25 - 75% top layer lost
Quite heavy	> 75% top layer lost and < 25% bottom layer lost
Heavy	> 25% bottom layer lost
Very heavy	Gully erosion

Source: Arsyad (2000)

1.4.1 Erosion process

The main factors influencing the occurrence of erosion are rainfall, soil characteristics, slope, vegetation and soil management.

1.4.1.1 Rainfall

The most influential aspect of rainfall in relation to erosion is its intensity. Increasing rainfall intensity results in potentially higher erosion. High intensity rainfall accelerates the process of weathering and transportation of soil aggregates. The destruction of soil aggregates can clog soil pores and later cause the soil to fail to absorb water, thus, increasing the amount of surface runoff.

The soil destruction process ('soil detachment') by rainfall is determined by the kinetic energy possessed by the rainfall. The heavier the rainfall, the higher its power of destruction will be.

1.4.1.2 Soil characteristics

Soil characteristics that need attention are those which affect the soil's sensitivity to erosion, such as texture, shape and its structural stability, as well as the infiltration capacity, soil permeability and organic material contents. In general, the relationship between soil characteristics and erosion can be described as follows.

1. Sandy-textured soil is not sensitive to erosion because the sizes of its particles are larger, which reduces the flow transportation ability (erodibility). Soils containing particles of smoother size (clay and dust) are easily transported by surface runoff, particularly when the runoff velocity is high. Therefore, the size of soil particles is influential in the sediment transportation process.
2. Stable-structured soils with rounded structure shape (granular, crumbly and rounded blob) are more resistant to erosion because they can absorb more water, thus, reducing the surface runoff's force.
3. Soils with high infiltration capacity have lower sensitivity to erosion than soils with low infiltration capacity.
4. Soils rich in organic materials are more resistant to erosion because the organic materials affect the aggregate stability level.

1.4.1.3 Slope

The erosion level is affected by the slope form. The steeper and longer a slope, the higher erosion level it suffers from. This is because of the increasing surface runoff speed, which in turn increases its transportation ability for destroyed soil particles.

1.4.1.4 Vegetation

Vegetation basically restricts rainwater from falling directly onto the soil surface. Consequently, it dulls the rainwater's destructive force. Vegetation can also obstruct surface runoff and increase the amount of infiltrated water. The most effective land use is forest, but dense grass vegetation can function as effectively as forest.

1.4.1.5 Soil management

Humans are the main causes of erosion. Land-use conversion from forests to agriculture and roadway infrastructure development, as shown in Figure 1.8, as well as settlements that ignore conservation principles, can accelerate environmental degradation because of erosion.

Figure 1.8 Footpath erosion (Photo: ICRAF-Sumberjaya archives)

2. Measurement of hydrological parameters

Water discharge and sediment are important components related to watershed problems such as erosion, sedimentation, floods and landslides. Therefore, it is necessary to measure water discharge and sediment as part of watershed monitoring.

2.1 River discharge

Discharge is the quantity of water flow in a water channel or a river per time unit. The common method to measure river discharge is the river profile ('cross-section') method. According to this method, the river discharge is the result of multiplication of the river profile by the river flow velocity.

$$Q = A.V$$

where:

Q = Discharge (m^3/sec); A = River profile (m^2); V = River flow velocity (m/sec)

The river profile can be measured using a metre tape and a wood or bamboo stick, while the flow velocity is measured using a 'current meter'.

2.1.2 Preparation before measuring water discharge

Before measuring, it is important to choose the best location because it affects the accuracy of the measurement.

The criteria to select an ideal location are:

- no whirlpool;
- flat river profile with no blocking of the river flow;
- centralized water flow that does not broaden when the water level rises; and
- a strong bridge, especially when measuring big rivers.

The necessary equipment is:

- stationery (notebook, ruler, pencil and marker);
- Timer (stopwatch);
- floating tools (tennis ball, bamboo with ballast attached);
- metre tape;

- threads or ropes;
- hammer and nails; and
- bamboo or wooden stick.

2.1.3 Water discharge measurement

Activities when measuring water discharge are: 1) determining the river profile; and 2) measuring the flow velocity.

2.1.3.1 Determining the river profile

The river profile—the geometrical form of the river channel—affects the velocity of the water flow, making it necessary to determine the river profile when measuring the water discharge of a river. The following steps are taken to determine the profile.

- Select a representative location for measuring water discharge.
- Measure the river's width (horizontal cross-section).
- Divide the river's width into 10–20 equal interval parts (Figure 2.1).
- Measure the river's depth at each interval using a stick.

As an illustration, the division of a river's width and depth can be seen in Figure 2.2.

Figure 2.1 River profile development: A) a bridge is an ideal locations to measure water discharge; B) measuring the depth of each interval; C) rope use; and D) a stick used as a measurement tool (Photo: ICRAF-Sumberjaya archives)

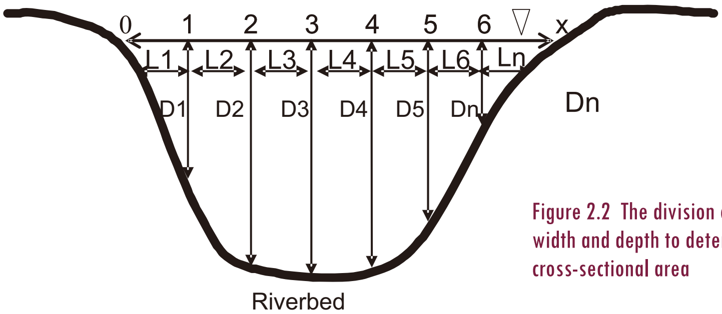

Figure 2.2 The division of a river's width and depth to determine the cross-sectional area

An example of measuring a river profile is shown in Figure 2.3.

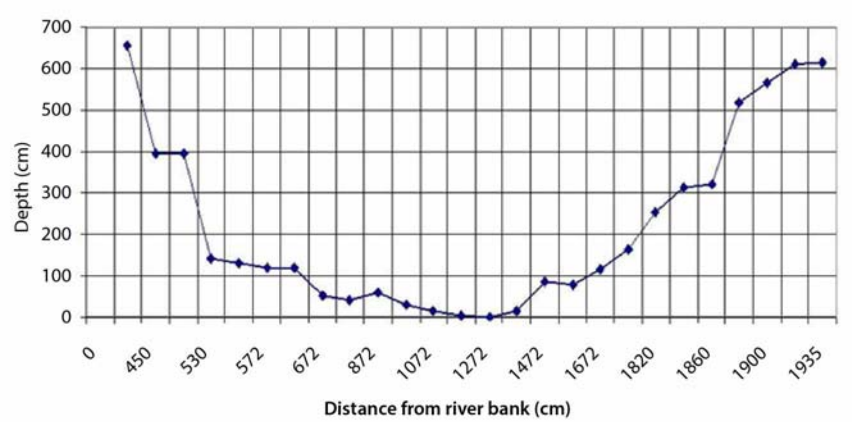

Figure 2.3 Example of river profile measurement

By measuring the river profile, information about the river's cross-sectional area can be obtained. The cross-sectional area (A) is the sum of all parts of the river's cross-section, where each part is obtained by multiplying the horizontal distance between intervals and the water depth, as formulated in the following equation:

$$A(m^2) = \sum_{n=1} \tfrac{1}{2} (D_n + D_{(n-1)})L_n$$

where:

A = Cross-sectional area (m^2); L = Width of horizontal cross-section (m); D = Depth (m)

Based on the example of a river profile in Figure 2.3, the cross-sectional area is 26.47 m^2 (Verbist et al. 2006).

2.1.3.2 Measuring flow velocity

River flow velocity at one cross-section is not always the same. The flow velocity is determined by the shape of the river flow, channel geometry and other factors. It is acquired from the average flow velocity in each part of the river section. Ideally, the average flow rate is measured using a 'flow probe' or 'current metre' (Figure 2.4). By using these tools, the rate at different river depths can be measured. However, if the tools are not available the flow velocity can be measured using the floating method.

Figure 2.4 An example of river profile and river flow velocity measurement using a flow probe. Photo: Maria Arweström

a. Measuring flow velocity with a floating object

Flow velocity measurement is performed by floating an object, for example, a tennis ball, on a specific track to a determined point. The process is performed by three persons: one as the floating object releaser at the starting point; one as the observer at the end point; and one as the time recorder. The steps of the measurement are as follows.

1. Select a measurement location on a relatively straight part of the river, without too many whirlpools. In the case of a relatively wide river, the ideal location for measurement would be under a bridge.
2. Determine the track with a specific distance on which the floating object has approximately 20 seconds to flow between the points.
3. Determine the river profile at the end point of the track.

4. Record the travel time from the release point to the end point.
5. Repeat the measurement at a minimum in three times.
6. Calculate the average speed.

Velocity is the result of the quotient between the lengths of the track and travel time. It can be represented with the equation:

$$V = \frac{L}{t}$$

where:

V = Velocity (m/sec); L = Length of track (m); t = Travel time (sec)

Because velocity obtained by this method is of the maximum speed, the number must be multiplied by a speed correction factor. The correction factor for a rough riverbed is 0.75, while for a smooth one it is 0.85, although the number used here is 0.65.

b. Flow velocity measurement using 'flow probe' or 'current metre'

Measuring flow velocity using this method may result in a sufficient flow velocity estimate. The principle of this method is to measure flow velocity at each measurement depth and at specific interval points using a current metre or flow probe.

The followings steps are taken to measure flow velocity.

1. Select a location for measurement on a relatively straight part of the river, without too many whirlpools. In case of a relatively wide river, the ideal location for measurement will be under a bridge.
2. Divide the horizontal cross-section of the river channel into 10–20 parts of equal intervals.
3. Measure the flow velocity according to the river's depth at each interval point.
4. Calculate the average flow velocity.

The depth of measurement and calculation of flow velocity can be determined using Table 2.1.

Tabel 2.1. Relation of depth of measurement and calculation of flow velocity

River depth (m)	Measurement depth	Average flow velocity
0-0.6	0.6 d	V=V0.6
0.6-3	0.2 d and 0.8 d	V=0.5(V0.2 + V0.8)
3-6	0.2 d, 0.6 d and 0.8 d	V=0.25(V0.2 + V0.6 + V0.8)
> 6	S, 0.2 d, 0.6 d, 0.8 d and B	V=0.1(V S+ 3V0.2+ 2V0.6+ 3V0.8+ Vb)

where:
d = depth of measurement; s = Surface; B = Riverbed; V = velocity (m/sec)

Water discharge is the total sum of the flow velocity at each cross-section. It can be expressed in the following equation:

$$Q = \sum_{n=1} \tfrac{1}{2} (D_n + D_{(n-1)}) L_n \overline{V}_n$$

where:
Q = Water discharge (m^3/sec); L = Length of interval (m); D = Depth (m); $\overline{V}$ = Average velocity at each point of the depth of measurement (m/sec)

2.1.4 Monitoring a river's discharge

Continuous monitoring of a river's discharge is required if conducting a long-term evaluation of a watershed. The method used for this purpose is the discharge rating curve method. This method is a line equation that connects water level with the amount of water discharged, so that the discharge can be predicted through the water level (Figure 2.5).

When performing long-term water discharge monitoring, follow these steps.

1. Select a relatively straight part of the river, with not too many whirlpools and which has a strong riverbed. The ideal location will be under a bridge or irrigation dam.
2. Rating curve should represent variations in the water surface.
3. Check the river profile at least once every six months.
4. Check the flow velocity at least once a year.

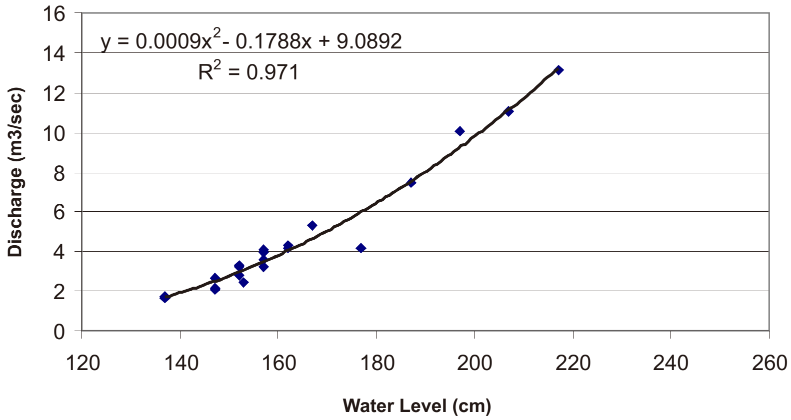

Figure 2.5 Rating curve used to estimate the amount of water discharge based on the water surface level in the Way Besai River

2.2 Measuring sediment load in a river

Sediment is residue material from erosion, which is carried by the river flow from upstream areas to settle in downstream areas. The upstream erosion process deteriorates soil fertility and sedimentation downstream often brings problems such as shallowing of the river and reservoirs. Therefore, the sediment flow or the sediment result is used as an indicator of a watershed's condition.

Sediment in the river can be divided into two types: 1) suspended load; and 2) bed load. The suspended load can be measured by taking samples of river water through the grab samples method (for a homogeneous river) or the depth integrated method (for a heterogeneous river). The bed load can be determined using the trap method.

Suspended load is carried further than bed load by river flow. In addition, the suspended load usually also contains other particles, such as nutrients or other material, that can contaminate the water. Therefore, the measurement of the suspended load is performed more frequently than the bed load.

Determining the amount of suspended load in a river can be carried out through the following steps.

1. Take samples of river water in fixed amounts, then dry them in an oven at 105 °C for 2 x 24 hours to obtain the dry residue to be weighed.

2. Sediment concentration in water samples can be measured from the dry weight. Furthermore, the amount of sediment can be determined from water discharge data.

Example:

If in a 500 ml water sample the dry residue is 5 g then the sediment concentration at the sampling site is 5 g/500 ml.

2.2.1 Sampling the suspended load

Sediment in a river is usually closely connected to water discharge. Therefore, water samples should be adjusted to the water discharge level. By way of illustration, Figure 2.6 shows the increase of water turbidity from 300 NTU to more than 1000 NTU during peak discharge. Thus, load sampling should be done simultaneously with measurement of discharge.

NTU (Nephelometric Turbidity Unit) is a measurement unit for water turbidity. The NTU value is obtained from measuring water turbidity with a turbidity meter (detailed in Chapter 3).

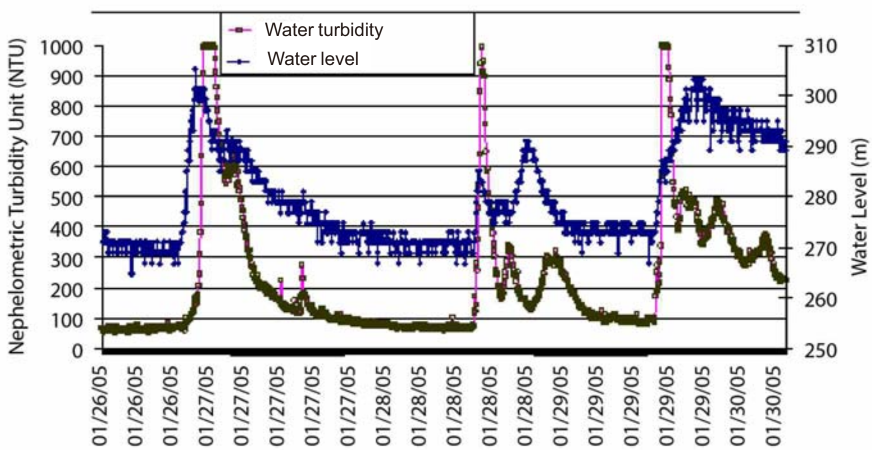

Figure 2.6 Water turbidity and water level Sumber: Verbist, B. (2006)

Tools needed to sample water are:

- scale stick;
- 1500 ml capacity plastic bottle with a 2 cm hole in the bottom (bottle top closed);
- plastic bags or bottles to store samples;
- rubber bands;
- stationery
- markers; and
- timer.

Steps for water sampling, as shown in Figure 2.7, are as follows.

1. Take 1 litre water sample from the middle part of the river using a bottle tied to a stick. Lower the bottle slowly from the surface to the riverbed. Record the water level height or measure the water discharge while taking the sediment sample.
2. Store water samples in plastic bags or bottles.
3. Label the samples with date, time and place at which they were taken.

Figure 2.7 Water sampling process (Photo: ICRAF-Sumberjaya archives)

Sediment quantity in the watershed can be estimated from the relationship curve between the discharge and sediment. The curve is generated from measuring the sediment against water-level variations in a stream. The accuracy is ensured after at least 30 replications of discharge fluctuations.

2.2.2 Determining sediment concentration

The presence of sediment in water can be detected by examining the water's turbidity. More turbidity means higher sediment concentration. Therefore, the sediment concentration can be estimated by measuring the turbidity levels.

A quick method for measuring water turbidity in the field is with a Secchi or black-and-white disc (Figure 2.8). A Secchi disc is designed to measure turbidity through estimating the limit of an observer's vision in water. More water turbidity means shallower eyesight limit.

Tools needed:

- Transparent tube 45 cm tall. The tube can be made by combining two 600 ml plastic bottles.
- Secchi disc, made of circular wood of 5 cm diameter, painted black and white, and attached to a 35 cm stick. Attach a metre tape measure to the stick (Figure 2.8).

How to read a Secchi disc:

- Pour the water sample into the tube until it reaches a height of 30 cm.
- Stir the water evenly.
- Slowly insert the Secchi disc into the tube and observe vertically until the black and white colour on the disc can no longer be distinguished.
- Note the depth of the disc (cm).

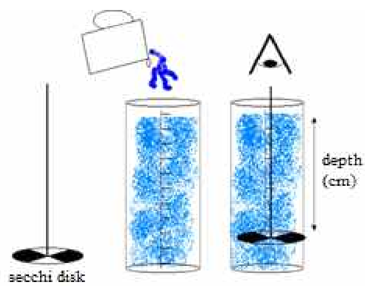

Figure 2.8 Secchi disc method is used to measure water turbidity

Hasil bacaan 'Secchi disc' dapat dikonversi menjadi konsentrasi sedimen (Gambar 2.9). Sebagai contoh, konsentrasi sedimen hasil pengukuran 'Secchi disc' yang dilakukan oleh ICRAF di Lampung Barat, dapat diduga dengan mempergunakan persamaan berikut (Verbist et al., 2006):

$$\text{Konsentrasi Sedimen (mg/l)} = (3357.6 * D^{-1.3844})$$

where:
D = Secchi disc depth (cm)

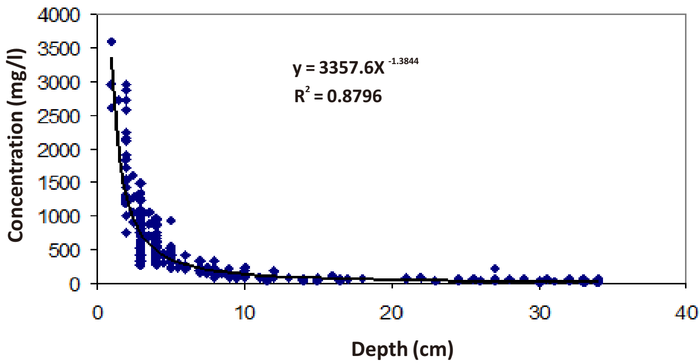

Figure 2.9 Conversion of Secchi disc depth reading to sediment concentration (mg/L)

Source: Verbist et al. (2006)

The observer's accuracy in reading the Secchi disc and the size of the particles dissolved in the water influence the precision of the sediment level measurement. The most accurate Secchi disc reading is obtained in the range 10–30 cm depth. At a depth of less than 10 cm, the result is less accurate because the water is too turbid (Figure 2.10).

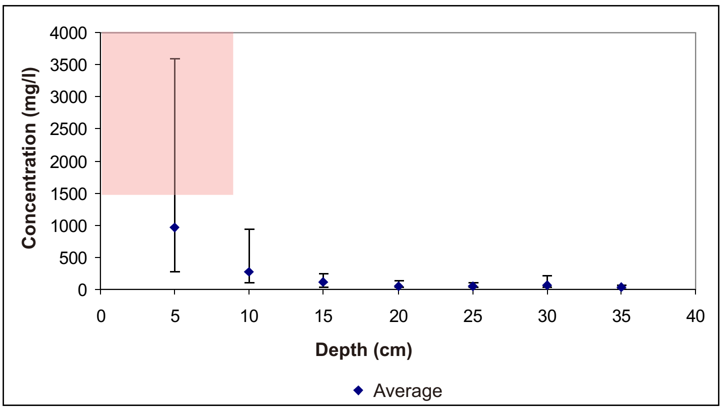

Figure 2.10. Accuracy of Secchi disc to measure water turbidity at various depths

In addition, measurement at a depth of less than 10 cm is also less accurate if the sediment concentration is more than 500 mg/L (Figure 2.11).

Geological conditions, riverbed material, and soil types affect the types of flowing sediment in a watershed. Therefore, when measuring water turbidity using a Secchi disc, you should ensure that 1) observations are calibrated to determine the observers' accuracy levels; 2) results are calibrated; and 3) sediment concentration is within a readable range.

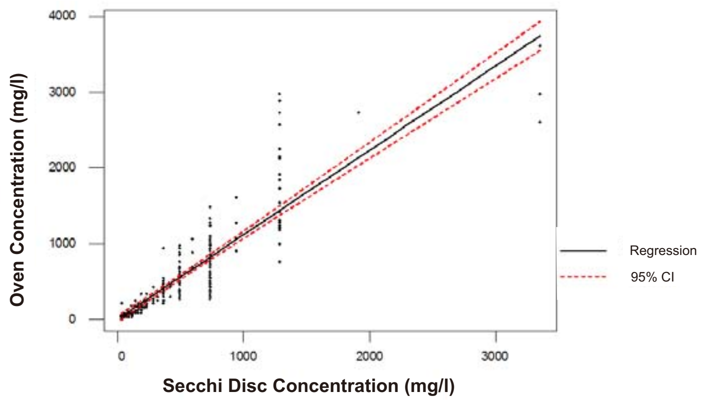

Figure 2.11 The greatest accuracy in Secchi disc measurement of turbidity is indicated by the narrow vertical range of the points in the graph below 500 ml concentration. After 500 ml concentration the points tend to spread, indicating low accuracy

The calibration of observers and sediment concentration can be done at the same time, following the steps below.

1. Collect samples of river water with different turbidity levels.
2. Read each sample using a Secchi disc.
3. Store 300 ml of sampled water in an aluminium bowl of known weight. Leave the sample for 24 hours and discard part of the water carefully.
4. Oven-dry the remaining sediment at 105 °C for 2 x 24 hours.
5. Weigh the dry material and calculate the sediment concentration by using this equation:

$$Concentration\ (g/l) = \frac{Sediment\ weight\ (g)}{Sample\ volume\ (l)}$$

6. Convert the results into a graph.

By calibrating the observers' accuracy the measurement result will also be more precise.

As mentioned earlier, observations will be less accurate if turbidity is above 500 mg/L or if the Secchi disc's colour can be distinguished at depths less than 10 cm. However, if during observation the Secchi disc can only be distinguished at depths less than 10 cm, it is better to dilute the water by adding clear water. Later, the sediment concentration should be adjusted for the dilution concentration.

Example:
The Secchi disc is distinguishable at a depth of less than 10 cm in 400 ml of water. To obtain a more accurate reading, the water should be diluted by adding 400 ml of clear water so the total is 800 ml. Take some of the water for observation. If the Secchi disc is still distinguishable at 15 cm depth after dilution, the actual depth would be 30 cm because the dilution concentration is twice that of the actual volume.

3. Chemical water quality monitoring

3.1 Introduction

Decreasing quality of a river's water occurs both in upstream and downstream areas. Conversion of forests to agriculture and settlements is the main factor that affects water quality through sedimentation, nutrient accumulation and pesticide residues.

Decreased water quality has an impact on human health and water biota. Nutrient accumulation in water accelerates the excessive growth of algae and some water plants, causing the deaths of various water organisms that are food sources for fish. Pesticides not only cause the deaths of water organisms, they also threaten human life because they stimulate various diseases. Sedimentation in rivers causes siltation, which in turn triggers floods.

3.2 The concept of water quality

Water quality refers to the suitability of water for specific purposes. The requirements of water quality are different according to the purpose. For example, water used for irrigation is of a different standard than water for human consumption. Water quality can be measured through physical, chemical and biological characteristics.

Classification and criteria of Indonesian water quality is regulated under the Government Regulation No. 82 Year 2001. Based on the regulation, water quality is classified into four as follows.

- Class I: used for drinking water and other consumption.
- Class II: used for water recreation, fisheries, animal husbandry and irrigation.
- Class III: used for fisheries, animal husbandry and irrigation.
- Class IV: used for irrigation only.

The criteria for water quality for each class is set based on quantification of physical, chemical, biological and radioactive conditions as listed in Appendix 1.

Most simply, water quality can be assessed by water colour and smell. However, some physical and chemical materials cannot be detected using only smell and colour, thus, a series of examinations should be carried out. Two kinds of water quality assessments are used: 1) physical-chemical; and 2) biological.

3.3 Physical water quality monitoring

Physical water quality monitoring can be done by measuring water variables such as temperature, sediment load, flow velocity, size of riverbed rock, turbidity, colour, scent, condition of canopy and types of vegetation by the river. Variables used in physical monitoring are supporting information in chemical and biological determination of water quality.

3.3.1 Physical variables characteristics

3.3.1.1 Temperature

1. Temperature is an important factor in biological and chemical process occurring in water, such as the breeding activities of organisms.
2. Temperature affects dissolved oxygen content in water, photosynthesis by water plants, and the metabolism rate of water organisms and their sensitivity to pollution, parasites and diseases. In warm water, dissolved oxygen is at lower levels than in cold. Therefore, measurement of dissolved oxygen should be done at the same place as temperature measurement.
3. Water temperature varies at each depth of river, lake or any waterbody.

3.3.1.2 Width, depth and river flow velocity

1. The river's width and depth affects the physical, chemical and biological characteristics of a river. A wide and shallow river gets more sunlight, thus, increasing water temperature.
2. Water velocity is also affected by the width and depth of a river. A deep and wide river has flow with higher velocity.

3.3.1.3 River surface coverage (canopy)

1. River surface coverage is a comparison between a vegetation-covered sample area and total sample area.

2. River canopy is an important factor in maintaining water quality because vegetation covering the river blocks direct sunlight from the river's surface, thus, keeping it cool and providing nutrition input from leaf litter falling from the plants.
3. Vegetation rooting beside the river can stabilize the riverbank and reduce erosion levels.

3.3.1.4 Size of riverbed rocks

1. The size of rocks in the riverbed affects water flow. Riverbeds which consist of mixed big and small rocks tend to have increased water turbulence, thus, also increasing the amount of dissolved oxygen.
2. Rock size also affects the types of organisms living in a river.

3.3.1.5 Rock size also affects the types of organisms living in a river.

1. Measuring turbidity means measuring materials dissolved in the water, such as mud, algae, detritus and other contaminants. When the water condition becomes turbid, the amount of sunlight that enters the water is reduced, causing the water plants to decrease their photosynthesis, which also reduces the oxygen supply generated by the plants. Dissolved materials absorb heat, which also reduces the dissolved oxygen in water.

3.3.1.6 Total dissolved materials

1. Measuring total dissolved materials is required for water quality assessment. Low concentration of dissolved materials hampers water organisms' growth owing to lack of nutrients. However, when too high, the concentration could lead to eutrophication or the death of water organisms.

3.3.2 Measurement procedure

All physical variables can be measured in the field. The procedure for measurement of each variable follows.

3.3.2.1 Temperature

Use a standard thermometer to measure water temperature (no need to use a special thermometer). The steps for temperature measurement are:

1. Record the air temperature before measuring the water temperature.
2. Put the thermometer in the water for 1–2 minutes.
3. The thermometer reading should be done while it is under water or as soon as it is drawn from the water.

4. Temperature measurement should be done at two different points (located 1 km from the original point or somewhere else, depending on the length of the river) so as to estimate the temperature differences in the river.

3.3.2.2 Width, depth and velocity of flow

Width, depth and velocity measurement have been discussed in Chapter 1: 1. Understanding watershed landscapes

3.3.2.3 Canopy cover

Canopy cover is measured in percentages. The steps to measure canopy cover follow.

1. Determine a sample plot of 400 m^2 ([1]) in the river. Plot width follows the width of the river and the length is adjusted so that the minimum total area will be 400 m^2.
2. Calculate the percentage of vegetation canopy covering the river in the sample plot.
3. Calculate the size of the sample plot and then compare it to the canopy cover percentage. A simple equation follows:

$$CC(\%) = \frac{AV}{AP} x100\%$$

where:

CC=canopy cover (%); AV = area covered with vegetation (m^2); AP = plot area (m^2)

4. Repeat the measurement at a minimum of three sample plots with different canopy density (low, medium and high).

3.3.2.4 Size of rocks in riverbed

As well as canopy cover measurement, riverbed rock assessment can be performed in the sample plot.

1. Calculate the riverbed area covered with rocks, sand and mud.
2. Compare each area to the sample plot area, multiply by 100%

[1] The plot size is adjusted using the standard method for canopy-cover measurement for vegetation surveys (Hairiah et al. 2011)

3.3.2.5 Turbidity

The following three methods can be used to measure turbidity.

1. Turbidity meter. Measurement by turbidity meter can be done in the field and the turbidity value is automatically converted to NTU (Nephlometer Turbidity Units)
2. Secchi disc. Measurement using a Secchi disc has been discussed in Chapter 2: Measurement of hydrological parameters.
3 Chemical method. This method must be done in a laboratory.

Of the three methods, the Secchi disc is the most practical in the field.

3.4 Chemical water monitoring

Variables observed in chemical water monitoring are

1. acidity (pH);
2. dissolved oxygen;
3. electrical conductivity;
4. nitrate;
5. nitrite;
6. ammoniac;
7. phosphate component;
8. bacteria; and
9. other chemical components according to the use of the water.

Most of the variables in chemical monitoring can only be revealed in a laboratory because they need advanced analysis.

Water quality measurement based on chemical variables has been a standard for water quality because:

- results from direct measurements can indicate pollutant materials that cause water quality degradation; and
- the result is quantitative and comparable to suggested threshold values, so that it can indicate the level of pollution.

However, there are disadvantages when using chemical variables measurement:

- high cost and must be done through laboratory work;
- the result is temporary because it represents only the time when the sample is collected, so that the measurement should be conducted repeatedly in time series;

- there is no standard in analysis technique yet, so that each laboratory may use a different method, which generates different results;
- no standard is set for the thresholds for tolerable pollutants; each country applies different thresholds.

3.4.1 Characteristics of chemical variables

3.4.1.1 pH

1. pH shows the level of acidity in water as shown by indicator paper (litmus paper) (Figure 3.1). The pH scale ranges 0–14 with the following classifications:
   - pH 7: neutral
   - pH <7: acid
   - pH >7: alkaline
2. The optimum condition for living organisms is pH 6.5–8.2; a too acid or too alkaline environment would be lethal.
3. pH may change during seasons, even during hours in a day.

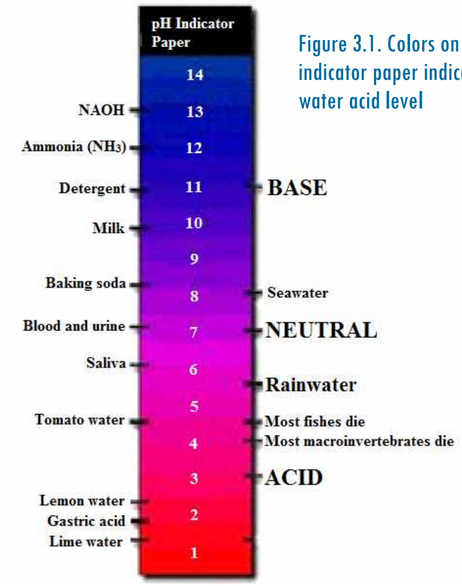

Figure 3.1. Colors on the indicator paper indicate water acid level

3.4.1.2 Alkalinity

1. Alkalinity measurement is performed to measure a river's ability in surviving pH change. In freshwater ecosystems, alkalinity values range 20–200 ppm.

3.4.1.3 Hardness

1. Hardness shows total concentration of cations in water, especially Calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{2+}) and manganese (Mn^{2+}). Too high concentration of such cations may cause problems to potable water.

Tabel 3.1. Impact of pH levels on aquatic life

pH Range	Impact on aquatic life
3.0 - 3.5	Very little possibility that fish can live in this water condition for hours. Only some invertebrates found living within this pH range.
3.5 - 4.0	Death to several fish species.
4.0 - 4.5	All fish species, most frogs and insects cannot survive conditions within this pH range.
4.5 - 5.0	Some insect species cannot live in conditions within this pH range and most fish eggs will not hatch.
5.0 - 5.5	Decomposer bacteria cannot live. Leaf and stem litter start to accumulate, thus, they interfere with chemical cycles. Planktons start to disappear and so do snails. Fungal colonies start to appear.
5.5 - 6.0	Generally, metal materials are trapped inside sediments and poison the water.
6.0 - 6.5	Freshwater shrimps do not live in this pH range. Unless there is a high content of free CO_2 in the water, this condition is harmful to fish.
6.5 - 8.2	Optimum range for most living organisms.
8.2 - 9.0	No direct harm to fish, but an indirect effect of this pH condition is chemical content changes in the water.
9.0 - 10.5	Endangers some fish species if occurs over a long period
10.5 - 11.0	For long periods, causes death to gurami and redfish species.
11.0 - 11.5	Death to all fish species.

3.4.1.4 Nitrate, nitrite and ammonia

1. Nitrate, nitrite and ammonia are forms of nitrogen elements in water.
2. They result from dissolved fertilizer, animal waste etc.
3. They function as nutrients or fertilizers for water plants.
4. High concentration in water increases water plants' growth and activities so that the oxygen content in water reduces and causes restricted growth, even death, of water organisms. Such a condition is known as eutrophication.
5. High content in drinking water is extremely dangerous to human babies because haemoglobin is bound by nitrate. Ingestion of high content causes a baby's blood to lack oxygen. Consequently, the baby becomes susceptible to the disease known as haemoglobinosis.

3.4.1.5 Phosphate

1. Phosphate is a form of phosphor elements in water.
2. Phosphate results from detergent waste, animal waste, dissolved fertilizer etc.
3. It functions as a nutrient to water plants and may trigger the eutrophication process.

3.4.1.6 Dissolved oxygen (DO)

1. DO is oxygen in water.
2. DO is generated from oxygen in open air and water plants' photosynthesis.
3. Highly needed for the life of water plants and animals.
4. Oxygen content in water is less than in open air.
5. Oxygen content in moving water is more than in stagnant water.
6. Oxygen content may differ from season to season, even hour to hour in a day; it changes according to temperature and altitude.
7. Lack of oxygen causes restricted growth in water plants and animals.

3.4.1.7 Biological oxygen demand (BOD)

1. BOD is the amount of oxygen used by microorganisms (bacteria) to decompose organic materials in water.
2. The amount depends on pH, temperature, type of microorganism and type of organic and inorganic materials in the water.
3. BOD sources are leaves and pieces of wood in stagnant water, dead plants or animals, animal waste etc.
4. The higher the BOD level, the faster the oxygen in the water expires, thus, having a negative impact on the growth of water organisms.

3.4.1.8 Coliform bacteria

1. Coliform bacteria live in animals' digestive canals and assist the digestion process
2. Coliform bacteria may be found in rivers through mammals and birds as intermediaries or in sewers.
3. Non-pathogenic.
4. Its presence in a river is an indicator that the river is contaminated with dirt that possibly contains pathogenic microbes. If the coliform content is > 200 colonies per 100 ml water, this indicates the possibility of pathogenic microorganisms in the water.

3.4.1.9 Electrical conductivity (EC)

1. The EC is water's ability to conduct electrical power.
2. EC shows that there are chemicals dissolved, such as sodium chloride (salt).
3. The EC may rise because of the existence of heavy metal ions transmitted by pollutant materials.

3.4.2 Measurement procedures

Generally, variables in water quality can only be chemically measured in laboratories, except for pH. But today, thanks to technological advances, it is possible to directly measure several variables using tester chemicals in the form of tablets, known as a 'water test kit'. But these materials are only available in certain places at a relatively high price.

Prior to conducting a test, the water should be sampled. Detailed steps for obtaining water samples are explained in Chapter 4.

The water sample will be chemically tested for several variables such as pH, nitrate, phosphate, DO, BOD and coliform bacteria. The tests can be performed using either a 'water test kit' or in a laboratory.

Testing using a 'water test kit' can be done according to instructions available with the kit.

Another way to carry out pH testing is by using litmus paper or other material specified for testing pH, as provided in chemical stores. How to measure pH using litmus paper follows.

1. Prepare the measuring cup/tube for testing; wash the tube and fill it up with the sample water.
2. Dip the litmus paper into the water and wait until the paper's colour changes. Compare the litmus paper to standard colours.
3. Note its pH according to the standard colours.

3.4.2.1 Coliform test

Escherichia coli (E. coli) is one type of coliform, consisting of around 700 sub-species that generally are not harmful. A coliform test cannot be performed directly at a sampling site because it takes several days and specialised equipment usually not available in the field. The test requires laboratory facilities, at least a field laboratory. Unlike pH, nitrate, phosphate, DO and BOD testing, the coliform test cannot be conducted with a 'water test kit'. In addition, the procedure is more complicated. The stages for coliform testing follow.

a. Tools and materials

- coliform test media, which usually are available at shops for laboratory tools
- petri dish
- refrigerator

- band tape
- paper labels
- styrofoam (used for storing the Petri dish)
- 5 watt lamp
- pipette of at least 5 mm length
- ice cubes
- incubator

b. Preparation
- prepare media for coliform test
- put the media into the refrigerator
- Remove bottle containing media from the refrigerator before sampling or one day before test to make sure that the media has reached room temperature
- Prepare the Petri dish and its cap using thick double-sided band tape so that they are hinged. The purpose is to easily open and close in order to prevent contamination by other bacteria
- Label the cap with date and sampling site
- Prepare the styrofoam with the 5 watt lamp as an incubator. Principally, the incubator is operated to achieve a suitable and stabilized temperature at which bacteria breeds (29–37 °C (85–99 °F)
- Prepare a sterilized pipette of at least 1 ml capacity and wrap tightly

c. Sampling
- Unwrap the pipette at the sampling site, starting from its handle
- Avoid touching the pipette with your hand or any other thing
- Take a 1 ml water sample using the pipette at 5–8 cm depth if the sampling site is a river or 5 ml if it is a well
- Do not insert your hand into the sampled water
- Put the water sample into a bottle containing media. Set the bottle and pipette at a tilted position to avoid spilling the water sample
- Close and slowly stir the bottle to mix the media and water sample
- Repeat three times
- Keep the media bottle filled and mixed with sampled water inside the storage containing ice cubes

d. Moving media mixed with water sample into the Petri dish
- Move the test media that was previously mixed with sampled water no longer than 2 hours after sampling

- Open the Petri dish sufficiently so the media in the bottle can be poured into it. Make sure the media does not touch the Petri dish or spread to the outer side
- Gently close the Petri dish and shake it with a circular movement
- Put the Petri dish on a flat surface, avoiding direct sunlight, and leave the media to harden for 30 minutes to 1 hour
- When the media is solid, turn the Petri dish upside-down so the water evaporated from the cap does not fall down
- Place it inside the incubator
- Store in the incubator for 24–48 hours at 29–37 °C (85–99 °F). The Petri dish should not be incubated more than 48 hours

e. Colony observation

- After incubating for 24–48 hours, count all colonies grown in the Petri dish. An E. coli colony has a dark blue to purple colour. Other coliform are pink to dark red. A light blue colour indicates enterobacteriaceae but not a coliform. An enterobacteriaceae colony could be from the salmonella and shigella group, which are pathogenic bacteria and should be recorded.
- Count the colonies visible to the naked eye; do not use a magnifying glass. No need to count colonies that appear as tiny dots.
- If the amount of E. coli exceeds 200, it should be recorded as too many.
- To see how many E. coli are contained in 100 ml, divide the number of E. coli in the Petri dish with the volume of the sampled water, then multiply by 100.

4. Biological water monitoring using macroinvertebrates

4.1 Biomonitoring concepts

Biomonitoring is biological water quality monitoring using water organisms as indicators (bio-indicators). The common bio-indicators in water assessment are:

- Plankton: a microorganism that floats in water
- Periphyton: algae, cyanobacteria, microbes and detritus living in water
- Microbenthos: microorganisms living in water or at the surface
- Macrobenthos: macroinvertebrates living in water or at the surface
- Macrophyton: water plants
- Nekton: fish

These groups are common in water monitoring because they reflect the physical and chemical changes in water during a certain period. However, there are some disadvantages to this method:

- It cannot identify the cause of changes
- Assessment results show ecological water quality but cannot indicate pathogens or other harmful organisms
- Can only be done by people who understand aquatic biology or have been trained accordingly, because this methodology requires taxonomical identification of the bio-indicators

For more accurate information on water quality, it is better to combine physical-chemical water monitoring with biomonitoring.

4.2 Why use macroinvertebrates?

Macroinvertebrates are invertebrate animals that can be seen with the naked eye. Water macroinvertebrates are biological components in water ecosystems that can indicate the state of the physical, chemical and biological conditions of a given water area, so they are used as indicators of river water. In addition, water macroinvertebrates have the following characteristics.

- They are sensitive to changes of water quality in their habitat, affecting their composition and abundance
- They are found in almost all aquatic habitats
- There are a large number of species and they give different responses to different stresses
- They have limited mobility, thus, their presence can be used as an indicator of local environmental conditions
- Their bodies accumulate toxic substances, thus, can be indicators of pollutants
- Easy to collect and to identify, at least to family level
- Easy to collect as samples, using only simple and low-cost tools, and do not affect other organisms

However, there are some concerns with biomonitoring using macroinvertebrates:

- They are strongly affected by seasons. Therefore, sampling activities should be done in each season
- Macroinvertebrates only respond to certain changes in their environmental conditions
- Physical and chemical conditions in a river, such as stream velocity, riverbed substrate, whirlpools and puddles, width, slope, vegetation cover on the river banks, nutrient composition and dissolved oxygen, may affect macroinvertebrates. Thus, it is necessary to sample at polluted locations as well as unpolluted ones, but with the same physical conditions, to be used as control
- Certain groups are difficult to identify to the species level

4.3 Sampling procedure

4.3.1 Preparation

4.3.1.1 Choosing sampling sites

The choice of sampling sites depends on the monitoring purpose. In this manual, the purpose of monitoring is to assess the impact of land-use changes on water quality. If the purpose is different, the choice of sampling site would need to be adjusted.

When choosing sampling sites the following points need to be taken into account.

a. Land-use system
   1. Choose sampling sites for all land-use systems that exist along the stream, for example, forests, shrubland, gardens and paddy fields
   2. Avoid sampling sites located in transitional land-use systems (for example, gardens that are in the process of becoming paddy fields or vice versa)
   3. Avoid sampling in drains
   4. Choose sampling sites 5 m distance from drains to avoid influences from drain water

Figure 4.1 Substrate types: stone (top); sand and clay (bottom)
Photo: Indra Suryadi

b. Substrate types, such as clay/loam, sand, gravel and stone (Figure 4.1)
   1. Take samples from any kind of substrate available
   2. In one sample plot, choose a site with homogenous substrate
   3. Avoid sampling sites which are located in transition between two substrate types

c. Flow velocity (fast flow and slow flow)
   - Choose sampling sites both in fast and slow flow
   - Choose sample plots in the same flow velocity
   - Avoid sampling sites which are located in transition between fast and slow flow

4.3.1.2 Supporting data

As mentioned above, biomonitoring using macroinvertebrates reflects the water condition at the sampling sites but it cannot be used to indicate factors changing the macroinvertebrate community. Therefore, it is necessary to gather supporting data, as follows.

- Physical and chemical variables, such as turbidity, pH, temperature, DO, nitrate composition, phosphate and conductivity
- Land-use systems during monitoring period
- History of land use
- Times of fertilizer and pesticide applications (if any), types of crops cultivated in surrounding areas, types of cattle (if any) and settlements or factories (if any)
- Other information, such as weather, fisheries activity, evidence of pollutants such as plastic, soap, unpleasant smells etc.

4.3.1.3 Tools and materials

a. Tools and materials for sampling at site

- plastic sacks to carry tools and samples from site
- 10 m length rope
- tweezers
- plastic bag with 1 kg capacity
- waterproof markers
- rubber bands
- name tags
- pencils
- GPS
- net (with mesh size of 500 µm, as seen in Figure 4.2)

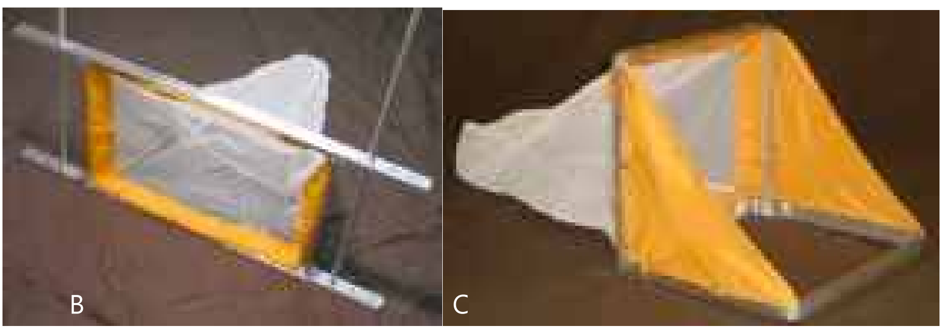

Figure 4.2 Nets for macroinvertebrate sampling: (A) drift net sampler for 'kick sampling'; (B) drift net sampler to be placed on riverbed; and (C) Surber sampler net. Photo: Andy Dedecker and Ans Mouton (A); www.pearce-environment.co.uk/acatalog/Pond_Eq... (B and C))

Types of net used for macroinvertebrate sampling are different according to riverbed substrate types. Based on riverbed substrate conditions, nets utilized can be classified into two:

- Driftnet sampler
  This net is used to take macroinvertebrate samples in rivers with muddy riverbeds and at sites with a low degree of slope
- Surber sampler net
  This net is used to take macroinvertebrate samples in rivers with riverbeds which are rocky and full of pebbles, and have a fast flow. The sampling is performed by placing the net on the riverbed. The area around the net frame should be mixed to get the macroinvertebrates swept and caught in the net. This can be repeated at least four times per sampling location

b. Tools and materials for sorting and identification

- trays
- filter (with mesh size of 500 μm)
- tweezers
- labels
- pencils
- preservative liquid (alcohol 70% or formalin 4%)
- plastic bottle
- binocular and monocular microscopes

4.3.2 Sampling

4.3.2.1 Setting up the sample plot

After determining the sampling site by taking into account various factors, such as land use, drain position, substrate types and river flow pattern, the next action is to set up the sample plot at each site. In the same local conditions, repeat at least three times: the more repeats, the better the result. Following are the stages in setting up a sample plot.

- Choose the location for the sample plot according to the monitoring purpose
- Lay the rope of 10 m along the bank, following the river (Figure 4.3)
- Measure the river's width

4.3.2.2 Water sampling

Before sampling macroinvertebrates, sample the water for physical and chemical variables. Later, the results of the physical and chemical tests are used as supporting/ complementary data.

Figure 4.3. Sample plot (Photo: Indra Suryadi)

a. Tools

- plastic bag with capacity of 1 kg
- rubber band
- permanent marker
- cooler box and ice packs or ice blocks

b. Water sampling

1. Take water samples before an observer enters the river at the sample plot in order to avoid turbidity and macroinvertebrate movement
2. Collect water samples in a plastic bag or other clean container. Make sure the sample volume is sufficient for analysis
3. Secure water samples with a rubber band
4. Store samples in a cooler box containing ice packs or ice blocks
5. Mark the samples (site, hour, date, month, year)
6. Conduct chemical testing in the field, such as for DO, temperature and pH

4.3.2.3 Macroinvertebrate sampling

Collect macroinvertebrates before anyone enters the river at the sample plot and always do so against the flow direction (start downstream and end upstream).

Based on the depth of river, sampling can be distinguished into: a) shallow river; and b) deep river.

a. Shallow river

Sampling in a shallow river is easier because samplers are able to enter the river body (Figure 4.4). The sampling procedure is as follows.

1. Take samples from the sampling plot
2. Mix the body and wall of the river by trampling and shaking it
3. Shake big rocks in the riverbed and twigs and roots that hang on the riverbanks
4. Place the net and store the water that flows with the substrate
5. In rocky substrate, place the net so it is easy to reach and take more samples
6. In sandy substrate, place the net a bit above the riverbed to prevent too much sand being collected
7. Put the samples from the net into plastic bags
8. Check for macroinvertebrates in the river wall, under rocks, twigs and roots in the river wall, and those that move on the water's surface
9. If there are any animals, such as fish or crabs captured, return them to the river. We only observe macroinvertebrates
10. Before releasing those animals into the river, make sure there are no macroinvertebrates attached to their bodies
11. Put the sampled water into a container (plastic or bottle)
12. Apply a label to the container indicating code, time and place of sampling (please do double coding to make sure the label is not washed out by water or mud)
13. Move diagonally from one bank to another in a zigzag pattern (Figure 4.5)
14. Finish sampling within five (5) minutes for each plot of 10 m

Figure 4.4 Sampling macroinvertebrates: (A) stirring up the river; (B) picking macroinvertebrates from a twig; and (C) rocks
Photo: Indra Suryadi

Figure 4.5 Sampling procedure
Photo: Indra Suryadi

b. Deep river

Sampling in a deep river is harder, especially collecting macroinvertebrates that are attached to the substrate, because it is not possible to enter the river body. This problem can be addressed by the following procedure.

1. Sample at shallower, reachable parts, for example, at the side of the river
   - Sampling procedure is the same as in a shallow river
2. Create artificial substrate
   - Prepare three nets and fill them with rocks (Figure 4.6 left)
3. Place the artificial substrate in the river (see Figure 4.6 right) and leave for 2–3 weeks in each sample plot. Remove the artificial substrate from the river when it is time for observation

Figure 4.6 Artificial substrate (left); Where to place artificial substrate in a river (right)
Photo: Andy Dedecker dan Ans Mouton

4. Slowly remove the rocks outside the net so the macroinvertebrates did not escape from the nets
5. Place the macroinvertebrates in a plastic container
6. Seal the container with a rubber band
7. Label the container with time, date and place of sampling

4.3.3 Sorting and identifying the samples

4.3.3.1 Sorting

Sorting is needed for easier identification of the macroinvertebrates.

1. Remove mud, twigs or rocks from the samples
2. Removal should be done immediately, no later than two days, to avoid injury to macroinvertebrates
3. Remove macroinvertebrates from the sample bag carefully
4. Place on a sieve
5. Pour some water to remove any mud
6. Remove the material left on the sieve
7. Place in plastic tray (Figure 4.7 top).
8. Add some water
9. Separate macroinvertebrates into different species (Figure 4.7 bottom)
10. Place in plastic bottles containing 70% alcohol
11. Count the number of each species found
12. Label with time, date and place of sampling

Figure 4.7 Macroinvertebrates before separation (left); macroinvertebrates after separation into species (right)
Photo: Indra Suryadi

4.3.3.2 Identification

After separation of each macroinvertebrate, the next step is identification.

1. Take the separated macroinvertebrates
2. Place on Petri dish
3. Observe and identify to family level, if possible, by matching to pictures in Appendix 3
4. Label with name, family, time, date and place of sampling

4.3.3.3 Data tabulation

Monitoring data is based on identification results and individuals found as well as physical and chemical supporting data (Table 4.1).

Tabel 4.1. Macroinvertebrate sampling sheet

Plot name: Location: Type of land use:	Observation date: Hour: Observer:
1. Biological monitoring	
Macroinvertebrates found	Number of individuals
2. Chemical monitoring	
pH: Dissolved oxygen:	Ammonia: Nitrate:
3. Physical monitoring	
Temperature (water surface): Temperature under water (depth >1 cm): Type of meander:	Percentage of canopy cover: Percentage of substrate:

4.4 Data analysis and water quality assessment

The last step in water quality monitoring is data analysis, which is conducted to obtain quantitative values or indices. A water quality index can be generated in several ways from easy to complicated calculation. The more complicated procedure provides a more accurate result.

4.4.1 Biotic Index at Secondary Education Level

Calculation using the Biotic Index at Secondary Education Level (BISEL (De Pauw 1999)) is based on the encountered frequency and number of taxon of the seven indicator macroinvertebrates listed in Table 4.2. An example of the BISEL is given in Box 1.

Table 4.2. Standard table of Biotic Index at Secondary Education Level

Macroinvertebrate group indicator (I)	Score (II)	Encountered Frequency (III)	Number of taxon (IV)				
			0–1	2–5	6–10	11–15	>16
Plecoptera (Heptagenidae)	1	>2	-	7	8	9	10
		1	5	6	7	8	9
Trichoptera cased	2	>2	-	6	7	8	9
		1	5	5	6	7	8
Ancylidae (Gastropoda), Ephemeroptera (except Ecdyonuridae)	3	>2	-	5	6	7	8
		1-2	3	4	5	6	7
Aphelencherius (Hemiptera),Odonata, Gammaridae (Crustacea: Amphipoda), Mollusca (except Sphaeriidae)	4	>1	3	4	5	6	7
Asellidae (Crustacea: Isopoda), Hirudinea, Sphaeridae (Mollusca), Hemiptera except Aphelecheirus	5	>1	2	3	4	5	-
Tubificidae, Chironomous thummi - plumosus	6	>1	1	2	3	-	-
(Chironomidae) Syrphidae-Eristalinae	7	>1	0	1	1	-	-

Sumber: Biotic Index Manual for Secondary School, University Gent, Belgium (1999)

Note:

- Column I: list of indicator macroinvertebrate, grouped based on sensitivity to pollutants

- Column II: number (score) showing sensitivity value of an indicator macroinvertebrate group during monitoring. The higher the score, the more insensitive
- Column III: frequency of group encountered during monitoring
- Column IV: contains the value of the biotic index of each indicator macroinvertebrate based on taxon encountered

Based on the BISEL standard table, water quality is classified into six classes as shown in Table 4.3.

Table 4.3 Water quality classification based on Biotic Index at Secondary Education Level

Class	Biotic Index	Color code	Pollution level
I	10–9	Blue	Lightly polluted or not polluted
II	8–7	Green	Fairly polluted
III	6–5	Yellow	Moderately polluted
IV	4–3	Orange	Highly polluted
V	2–1	Red	Heavily polluted
	0	Black	Biologically dead

Source: De Pauw 1999

4.4.2 Family Biotic Index

The Family Biotic Index (FBI) is a water quality index measurement developed by Hilsenhoff (1988) based on tolerance (toward environmental changes) value of each family. The example in Box 2 is calculated based on the following equation:

$$FBI = \frac{\sum (x_i * t_i)}{n}$$

where:

x_i = number of individuals found in each family
t_i = tolerance value of family
n = total individu found in each plot sample

Based on the FBI value, water quality is classified into seven classes as shown in Table 4.4.

Table 4.4 Water quality classification based on the Family Biotic Index

Family Biotic Index	Water quality	Pollution level
0.00–3.75	Excellent	Unpolluted with organic material
3.75–4.25	Very good	Lightly polluted with organic material
4.26–5.00	Good	Polluted with several organic materials
5.01–5.75	Fair	Fairly polluted
5.76–6.50	Fairly poor	Polluted
6.51–7.25	Poor	Very polluted
7.26–10.00	Very poor	Heavily polluted with organic materials

Source: Hilsenhoff 1998

An example of a water quality assessment using the FBI method is shown in Box 4.3. Both methods—BISEL and FBI—had been applied by ICRAF in Way Besai watershed, Sumberjaya, Lampung province, Indonesia.

Box 4.1.

Example of water quality assessment using the Biotic Index at Secondary Education Level

BBI assessment procedure:
- Identify taxon and count the number of individuals of each taxon in the same sample plot
- resent the results as in Table Box 4.1

Table Box 4.1 Result of macroinvertebrate sampling

Plot code: 1
Name of river: Way Petai
Geographical position: 0443642; 9442914
Date of sampling: 3 August 2005
Type of land use: forest

No.	Genus name	Family name	Number of individuals
1.	Coleoptera	Dryopidae	1
2.	Coleoptera	Haliplidae	1
3.	Coleoptera	Simuliidae	10
4.	Crustacea	Perlidae	17
5.	Diptera	Caenidae	3
6.	Diptera	Hydropsychidae	16
7.	Ephemeroptera	Psephenidae	8
8.	Hemiptera	Gerridae	2
9.	Hemiptera	Naucoridae	2
10.	Hemiptera	Veliidae	2
11.	Odonata	Lestidae	2
12.	Odonata	Cordulegastridae	2
13.	Plecoptera	Nemouridae	2
14.	Plecoptera	Palaemonidae	10
15.	Plecoptera	Heptageniidae	22
16.	Trichoptera	Limnephilidae	1
17.	Trichoptera	Hydroptilidae	2
18.	Trichoptera	Baetidae	23
Total taxon = 18			Total individual = 126

- Separate macroinvertebrate based on indicator group such in Table 4.2
- Put number in score column based on its group
- Count encountered frequency
- Count different taxon in each group
- Put biotic index value based on encountered frequency and taxon number such in Table 4.2

Table Box 4.1 BISEL values of indicator macroinvertebrates in sample plot

Indicator macroinvertebrate group	Score	Number of taxon	Frequency of encounter	Biotic Index value	Remarks
Plecoptera	1	3	>2	7	Three taxa of Plecoptera were found more than twice during observation. This means Plecoptera has an index value of 7
Trichoptera	2	3	>1	6	Three taxa of Trichoptera were found more than once during observation. This means Trichoptera has an index value of 6
Ephemeroptera	3	1	1	5	One Ephemeroptera taxin family was found once during observation. This means Ephemeroptera has an index value of 4
Odonata	4	2	>1	3	Two Odonata taxon were found more than once during observation. This means Odonata has an index value of 3
Hemiptera	5	3	>1	3	Three Hemiptera taxa were found more than once during observation. This means Hemiptera has an index value of 3
Turbificidae/Chiron omidae	6	-		-	Not found
Syrphidae	7	-		-	Not found

Table Box 4.2 shows that biotic index value from observation ranging from 3 to 7. A maximum value of 7 is taken. Based on Table 4.3, value 7 classified into class II which is fairly polluted. The conclusion of water condition at that particular sample plot is fairly polluted.

Box 4.2

Example of water quality assessment based on Family Biotic Index

FBI assessment procedure:

* Identify and count individuals of each taxon in one sample plot (Table Box 4.3)
* Write tolerance value of each taxon based on Hilsenhoff criteria (1998), as in Appendix 3
* Calculate FBI by summing total individuals multiplied by the tolerance value, divided by total individuals in one sample plot.

Table Box 4.3 Results of observation in sample plot and tolerance values

Plot code: 1
Name of river: Way Petai
Geographical position: 0443642; 9442914
Date of sampling: 3 August 2005
Type of land use: forest

Genus	Family	Number of individuals (x_i)	Tolerance value (t_i)	$x_i * t_i$
Coleoptera	Dryopidae	1	5	5
Coleoptera	Haliplidae	1	7	7
Coleoptera	Simuliidae	10	6	60
Crustacea	Perlidae	17	1	17
Diptera	Caenidae	3	7	21
Diptera	Hydropsychidae	16	4	64
Ephemeroptera	Psephenidae	8	4	32
Hemiptera	Gerridae	2	5	10
Hemiptera	Naucoridae	2	5	10
Hemiptera	Veliidae	2	6	12
Odonata	Lestidae	2	9	18
Odonata	Cordulegastridae	2	3	6
Plecoptera	Nemouridae	2	2	4
Plecoptera	Palaemonidae	10	4	40
Plecoptera	Heptageniidae	22	4	88
Trichoptera	Limnephilidae	1	4	4
Trichoptera	Hydroptilidae	2	4	8
Trichoptera	Baetidae	23	3	69
	Total	126		475

$$\text{FBI} = \frac{475}{126} = 3.77$$

FBI value from calculations in Table Box 4.3 is 3.77. Based on Table 4.4, this value is classified as 'very good' (Lightly polluted with organic material). Thus, it can be concluded that water quality at that particular plot is lightly polluted with organic material.

Note

In this method, the tolerance value of a macroinvertebrate family is one of the variables used. Different tolerance values are likely to occur in different areas. Therefore, it is necessary to develop tolerance values further to gain more accurate results. Since there is no other source, this manual uses water quality index measurement according to Hilsenhoff (1988), as listed in Appendix 3.

Both methods for assessing water quality—BISEL and FBI—show the same result: the water quality at the plot is lightly polluted.

Box 4.3

Example of water quality biomonitoring in Way Petai, Sumberjaya, Lampung province, Indonesia

Procedures:
Conversion of forests to shrubland, coffee gardens and rice fields in the Way Besai watershed, Sumberjaya, Lampung province, Indonesia, reduced water quality. Biomonitoring activities using macroinvertebrates were performed in the upstream part of the Way Petai River—one of the Way Besai tributaries—to assess the impact of the land-use conversion on water quality.

Six sample plots in forests, shrubland, coffee gardens and rice fields were established along the Way Petai River during the wet and dry seasons in 2005. The result of data observation and analysis based on the Family Biotic Index is shown in Figure Box 4.1.

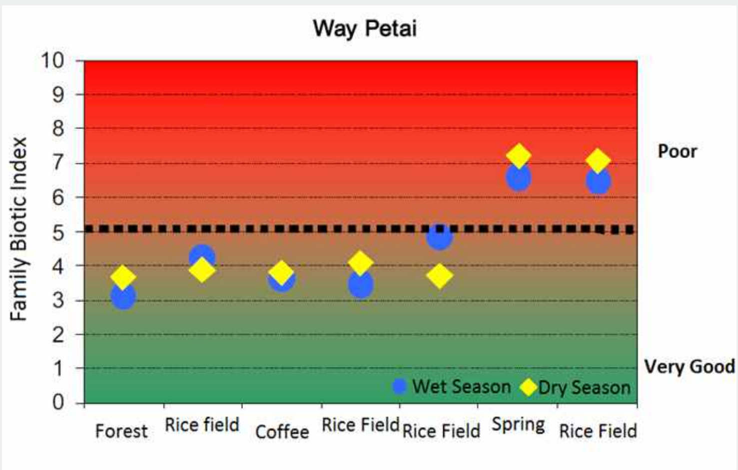

Figure Box 4.1 Water quality in upstream part of Way Besai River based on Family Biotic Index

Source: Andy Dedecker and Ans Mouton (dry season 2005 data); Indra Suryadi (wet season 2005 data)

Figure Box 4.1 shows that the quality of river water flowing through the forest is better than that in rice fields and coffee gardens. As for the spring, their water quality is classified as poor because of human activities utilizing water for washing and bathing. In addition, the spring was located near a traditional market and rice fields, so that market garbage and pesticide residues from the rice fields contaminated the river near the spring. The poor water quality around the spring affected the water quality in the rice fields that were located downstream from the spring. Water quality during wet seasons was nearly equal to dry seasons.

5. Quantitative indicators of watershed function

5.1 Why do we need indicators of watershed function?

Integrated watershed rehabilitation activities are costly and time consuming. Therefore, it is necessary to prioritize, which requires an objective quantitative indicator of watershed function. Through this indicator, quantitative and more empirical assessments of water quality and the hydrological response of the watershed to 'rehabilitation' can be carried out.

Up to the present, the ratio between maximum and minimum water discharge (Qmax/Qmin) is still being used as an indicator for watershed function, although it has some weaknesses, such as:

- Q_{max} and Q_{min} are two extreme values (highest and lowest) of water discharge data distribution. Statistically, these values are 'not good' because they have a wide 'confidence interval', especially if the two are set as a ratio. The data will not represent the actual condition if it is taken from several years of observation in watersheds that are relatively stable.
- When Q_{min} reaches zero, the ratio becomes undefined, which restricts the use of the ratio to permanent streams. Furthermore, in most system, the Q_{min} value reflects the longest period without rain, which will vary from year to year and be spatially influenced by rain variability without having any connection to the watershed's condition, whether directly or indirectly.
- Also Q_{max} is closely related to maximum rainfall, again without having any connection to the watershed's condition.
- Therefore, the ratio between Q_{max}/Q_{min} is a value which reflects rain variability. Thus, the Q_{max}/Q_{min} quantity has a high level of uncertainty and variation between years. In the end, there will be a tendency to select the data in order to have a 'realistic' Q_{max}/Q_{min} quantity, with some of the data series considered as 'outliers', that is, not representative. This causes the result of the Q_{max}/Q_{min} to become very subjective.
- The Q_{max}/Q_{min} ratio is very dependent on the climate where the watershed is located (such as duration and frequency of dry season/season change and extreme rainfall) and the position of the

river. Maximum discharge (on average) is equal to the watershed's area to the power of 0.7 (Rodriguez-Iturbe and Rinaldo 1998) and average water flow is equal to the watershed's area. As to the minimum discharge, zero flow, this ratio scale cannot be calculated, therefore, it is ignored. The geology of a watershed affects the dynamics of the flow rate. In a karst area, discharge is stable, so that it has relatively high Q_{min} value. The influence of land use and land cover (Q_{max}/Q_{min}) on a watershed tends to be small compared to climatic and geological influences, which are more permanent.

Despite all these flaws, the Qmax/Qmin at undefined measuring points is still used as a major argument in declaring watersheds eligible for investment in 'watershed rehabilitation' projects. The 'political hydrology' aspects of its use as a negotiation tool are probably more interesting than what it tells us about catchment behaviour and status.

The widespread use of the ratio indicates, however, that there is demand for a numerical indicator that is easy to grasp. Such an indicator would probably have to explicitly incorporate rainfall and its temporal variation to tease out the influences landscape and land cover have on watershed functions.

'Watershed functions' are here defined as the way landscapes determine quantity, timing and quality of river (or groundwater) flow, by the way they

1. transmit;
2. buffer;
3. gradually release the rainfall that is received;
4. modify water quality; and
5. maintain the integrity of the soil capital in the catchment area.

For these five 'criteria' we present quantitative indicators, applicable in assessments at different scales.

- W1: Water transmission (total water yield per unit rainfall)
- W2: Buffering (above-average river discharge per unit above-average rainfall)
- W3: Gradual release of stored water supporting dry-season flows
- W4: Maintaining water quality (relative to that of rainfall)
- W5: Stability of slopes, absence of landslides and balance of sedimentation and erosion.

Each of the above factors depends on the interaction between actual rainfall, permanent determinants in the landscape (W_p) and features under direct human influence (W_h), as indicated in Table 5.1.

Table 5.1 Defining watershed function separate from rainfall and jointly determining the feature of river discharge = rainfall * (W_p + W_h)

River flow aspect	Rainfall aspect	W		
		Watershed function	W_p, permanent determinants in the landscape	W_h, determinants influenced by humans
Total water yield	Mean rainfall	Water transmission (total water yield per unit rainfall)	Solar radiation, advective flow of wet or dry air, geology substrate and a aquifers	Fraction of ever-green and deciduous vegetation; fraction of bare soil; water extractions
Peak flow (flooding risk)	Space-time patterns of rainfall	Buffering (above-average discharge per unit above-average rainfall)	Landforms, slope, soil depth	Changes in surface soil properties, modified infiltration; changes in 'channelling' and rapid drainage
Dry-season flow	Seasonal rainfall	Gradual release of stored water	Landforms, geological substrate	Infiltration and (lack of) vegetation access to stored water
Water quality (including sediment load, suitability as drinking water)	Space-time patterns of rainfall	Maintain water quality (relative to rainfall)	Riverbed, alluvial deposits, soil stabilization by natural vegetation, presence of nutrients and pollutants in the soil profile	Changes in soil cover modifying erosion and filter functions; point sources of metal, organic pollutants, pesticides, nutrients; changes in riparian buffer vegetation; changes in nutrient balance; changes in water balance modifying salty groundwater movement
Changes in the riverbed	Peak rainfall events	Stability of slopes and absence of landslides	Slope, mechanical properties of soil profile	Infiltration; anchoring of topsoil to subsoil through live or still intact tree roots; road incisions in slopes

Simple descriptions of Wp and Wh elements that have roles in various watershed functions shows that the five functions do not always give the same response to a change of land use/land cover. These indicators' values also vary, depending on climate, landscape geology conditions, and changes in the drainage system caused by channel formation (paths, roads), implementation of technology for temporary water storage and soil characteristics of the river body/sediment as a result of interaction between the river and land cover. We provide those indicators as a 'toolbox'. It is necessary to carry out further research to determine the exact tool to use in certain situations.

5.2 Transmission function

5.2.1 Water balance at the plot level

Rain that falls in one location can reach the atmosphere or lake/sea through one of the following five ways (Figure 5.1).

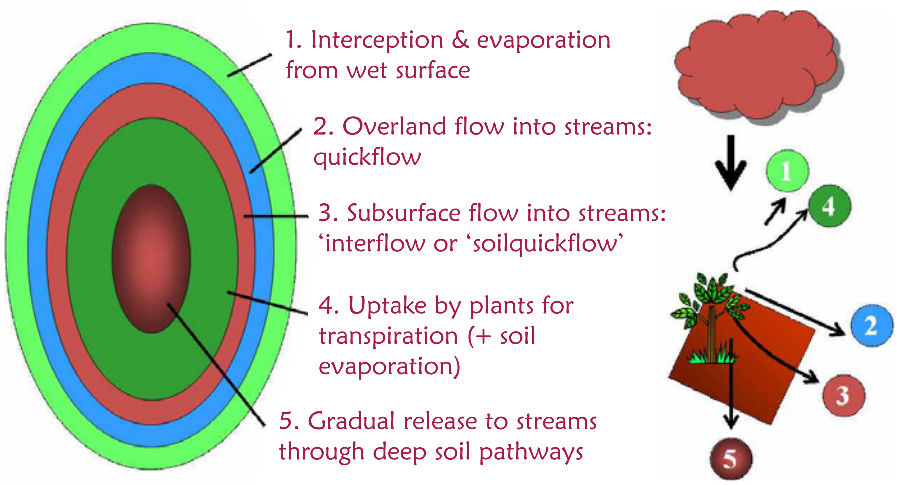

Figure 5.1. What happen to water drops that fall in a location?

There are five paths that raindrops can go through: two of them take them back to the atmosphere (evaporation from plant canopy that intercepts rainfall; and evapotranspiration from beneath the ground) and three others take them to a river network at different rates: surface or 'quick' flow, quick underground or 'sub–surface' flow and groundwater slowly released or 'low flow'.

In a simplified representation of hillslope hydrology, we can distinguish three pathways for water to reach the river: directly by overland flow (often within an hour of rainfall, depending on distances involved), through the surface layers of soil ('interflow' or 'soilquickflow' (with a typical time constant of 1 day) or via (deep) groundwater flows (with a time constant of weeks or months) (Figure 5.2).

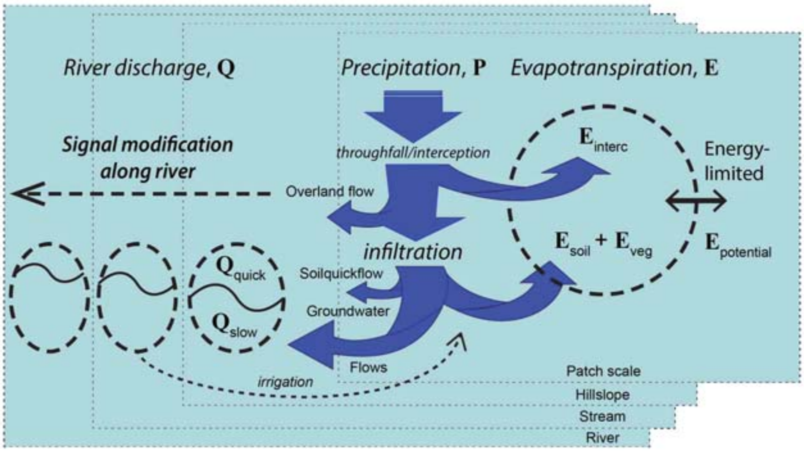

Figure 5.2 Flowchart of Precipitation (P), Evapotranspiration (E) and River Discharge (Q) at various spatial scales

Land use can affect the proportions of these different flow types through:

- soil compaction affecting, especially, the macroporosity of a soil (the difference between 'saturation' and 'field capacity', or the volume of water that will typically drain from the soil in a 24-hour period, as used in the definition of field capacity); the bulk density of a soil has a quantitative relation to macroporosity; pedotransfer functions that account for the effects of soil texture and soil organic matter on a 'reference' bulk density are available; soil compaction is not easily reversible.
- surface compaction, often linked to direct exposure of a mineral soil surface to sun and rainfall after removal or destruction of the litter layer; soil crusting can be easily reversible, by combined effects of soil cover and soil biota.

If soil compaction is the primary 'degradation' process, the effects are likely to be small during the early parts of the rainy season because there still is storage capacity in the soil. Later in the season, when the soil is close to saturation, the difference in temporary storage capacity will be noticeable, and 'interflow' shifts to 'overland flow', with sharper peaks in the hydrograph as a result.

If surface compaction is the primary issue (and there are more reversible types of degradation), then high runoff can be expected at any part of the rainy season, without differentiation.

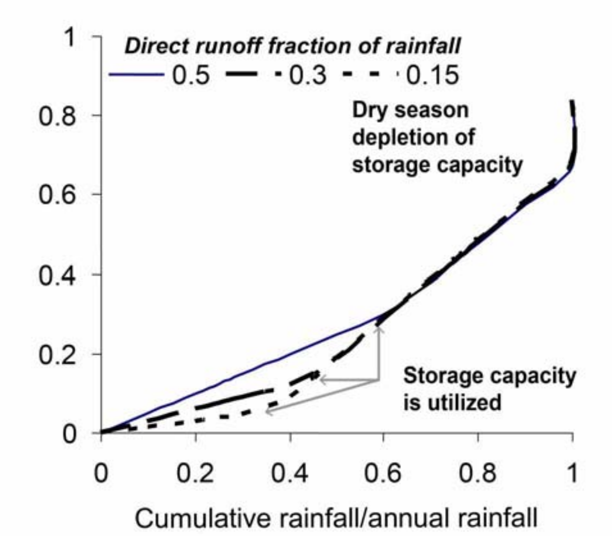

Figure 5.3 Examples of the relationship between rainfall and river flow (both expressed in cumulative form during a hydrological year (from start to end of the rains)), for different conditions of surface infiltration

The graphic of cumulative river flow and cumulative rainfall provides a picture of the influence of seasons on the river flow pattern in a watershed, particularly in terms of water storage and slow release of the water. A graph based on the ratio of cumulative data like this can still be used even if the available rainfall data do not represent spatial variability, which is usually high. If unrepresentative rainfall data is analyzed daily it will not able to show the relation between peak rainfall and peak river flow. By using cumulative data, however, the weakness can be tackled.

Based on ICRAF's experience in analyzing the seasonal patterns of river flow in several watersheds, we obtained a new indicator, which is relative cumulative discharge at 25% condition and 75% of cumulative rainfall, calculated for a one-year period. This ratio can be used as an indicator of the main cause of quick flow: is it related to soil surface conditions or is it because of a limited ability to store water underground? If 'quick flow' happens because of soil surface conditions then a 'land rehabilitation' project by planting trees has a chance of succeeding and effectively repairing the hydrological functions of the watershed. Success can be achieved with a note that the addition of water used by the planted trees (transpiration) should be balanced with additional rainfall infiltration in order to provide a positive influence (addition) to the amount of basic flow. If quick flow happens from saturation of soil in watershed and a lack of water storage capacity then a 'land rehabilitation' project will not have much influence even if it is able to provide conditions for soil/land cover.

Annual rainfall in the first and second quarter in Figure 5.4 is obviously different from the third and fourth quarters. The graph shows that rainfall makes the biggest contribution to river flow in the third quarter (lasting about one month). This pattern shows the condition of lack of water (first quarter), the process of water filling/storage (second quarter) and an increase of quick flow in the third quarter when soil condition almost reaches its field capacity.

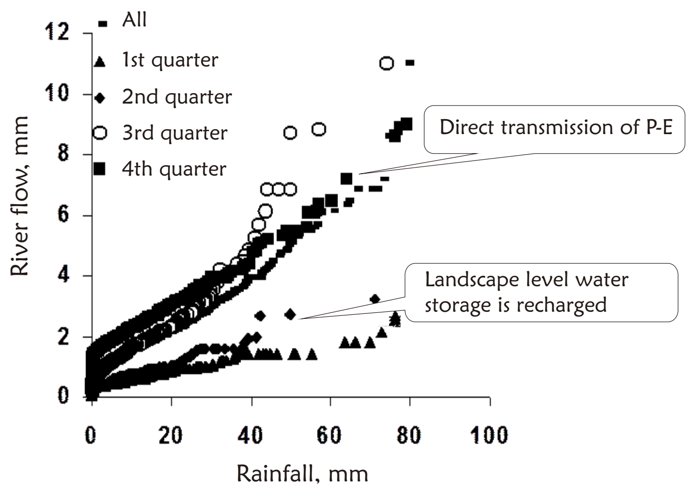

Figure 5.4. The relationship between rainfall and river flow for one year in Mae Chaem, North Thailand. Each line describes a 3-month period: 1 January–4 June; 5 June–27 July; 28 July–1 September; 2 September–31 December

5.3 Buffering

The condensation process changes water vapour to water. When the temperature in the atmosphere decreases, water vapour condenses on little particles of dust in the air, which then gather to become clouds and then rain. Water can change again, becoming vapour through evaporation. The opposite of the condensation, evaporation requires a temperature increase. The Sun's radiation increases the water temperature so the surface of water molecules have strong energy to release the molecular band and, when released, become invisible water vapour.

From the two processes, we can conclude that the change of water's form is highly related with the energy balance on Earth. The Sun's radiation heats the Earth's surface and causes differences in air pressure. Those parts of the Earth that receive the most energy—the tropics—have lower air pressure. Air moves from places that have high pressure to places that have low pressure. Therefore, there is a big flow of air in the tropics. This condition explains the basics of climate distribution in the tropics and sub-tropics.

Evaporation from a wet surface to the almost saturated air can happen in plant tissue, controlled by the closing and opening of stomata (little holes on the surface of a plant's stem and leaves). The term 'evapotranspiration' is used to describe water evaporation from a wet surface followed by the 'transpiration' process, which is water evaporation from plant tissue.

Other characteristics of water are easy to understand, such as flows from higher places to lower places, and follow the law of mass balance: the amount of water that goes into a system is equal to the amount of water that goes out. Note that calculation is done during the period when 'water storage inside the ground' is zero.

This mass balance law does not apply when water storage component is close to saturated. In this condition, the amount of water flow that goes out of the sub-system can be different from the amount of water flow that goes in. Usually, water flow that goes out will be slower and more equally distributed than the flow that goes in. The system's ability to change the variation of water flow at different times can be defined as its 'buffering' function. A landscape that has vegetation can change the temporary pattern of rainfall that goes in, in the sense that water that goes out in the form of surface flow and sub- surface flow will be different from the amount of precipitation that goes in. In total, the amount of water in the system will be the same as the amount of precipitation minus evaporation[2]. Precipitation in the form of rain will be able to be partially supported by the soil, so the condition of the watershed is over the storage capacity and the amount of water buffered is zero. This balance implies that peak flow decreases, and low flow relatively increases compared to the water discharge that goes in.

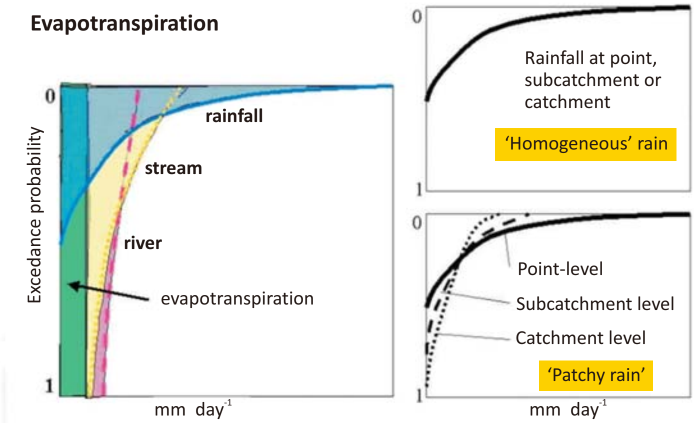

Figure 5.5. Comparison between the possibilities of excessive rainfall, evapotranspiration, tributary and river discharge (left side of tributary and river discharge curve is equal to the left side of rainfall curve minus the left side of evapotranspiration curve if the change of water storage can be ignored); the shape of the rainfall curve at the observation point, tributary and river show an increase in 'buffering'; figure on the right shows the degree of dependency from 'uneven distribution' of rainfall, amount of water that goes in per day can change from single observation point in upper part of sub-watershed and watershed that forms 'support' is shown in the picture on the left

Based on common perceptions, a watershed's buffering function is highly related with the existence of 'forest', although, most water will be stored in the ground and not in tree vegetation. The type of land cover that is able to increase quick absorption of rain by the soil contributes to a landscape's buffering function, in the context of the decrease of the proportion of surface flow compared to the amount of rainfall. Physical structures that are able to store water on the surface, such as rice fields, can also decrease surface flow relative to rainfall. Basically, a rice field's ability is equal to forest in terms of its ability to support water temporarily. To compare more precisely, whether it is a rice field, forest, or other water 'buffering' system, we need to have indicators that can quantitatively measure the buffering function. These indicators will be able to provide a deeper understanding of the factors that could increase or decrease the 'buffering' function.

[2] Unless precipitation is in the form of snow and keeps piling up so that water will be stored in solid form. In this case, the amount of water formed when the snow melts might be smaller compared to the amount of earlier precipitation.

A quantitative indicator of buffering can be utilized for the dynamics of a watershed's buffering ability and its relation to vegetation, land and rainfall (or 'precipitation', including snow). This indicator can be based on direct comparison between input and output discharge patterns from time to time at various spatial scales. This comparison can be based on a single event (as is commonly done in hydrology when river discharge is measured and compared with the rainfall at the time) or based on event distribution frequency, for example, annual river flow pattern compared to annual rainfall pattern.

In one year time, the water balance can be described in an equation as follows:

$$P = Q + E + \Delta S = \Sigma\, p_i = \Sigma\, q_i + \Sigma\, e_i + \Sigma\, \Delta s_i \qquad (5.1)$$

where:

P dan p_i = total annual precipitation and precipitation at i-time, in litre per m^2 or mm
Q dan q_i = total annual river discharge or river discharge at i-time, in litre per m^2 or mm
E dan e_i = total annual evapotranspiration or evapotranspiration at i-time, in litre per m^2 or mm
ΔS dan ΔS_i = change (plus or minus) of total annual storage capacity or change (plus or minus) in storage capacity at i-time, in litre per m^2 or mm.

For all terms in the water balance, we can subtract their mean and then split the total into a positive (exceeding average) and negative (below average) set, with equal absolute value for the two sums.

$$\begin{aligned}
\sum\left(p_i - \frac{P}{n}\right| > 0\Big) &= -\sum\left(p_i - \frac{P}{n}\right| < 0\Big)\\
\sum\left(q_i - \frac{Q}{n}\right| > 0\Big) &= -\sum\left(q_i - \frac{Q}{n}\right| < 0\Big)\\
\sum\left(e_i - \frac{E}{n}\right| > 0\Big) &= -\sum\left(e_i - \frac{E}{n}\right| < 0\Big)\\
\sum\left(\Delta s_i - \Delta S\right| > 0\Big) &= -\sum\left(\Delta s_i - \Delta S\right| < 0\Big)
\end{aligned} \qquad (5.2)$$

where:

P dan p_i = total annual precipitation and precipitation at i-time, in litre per m^2 or mm
Q dan q_i = total annual river discharge or river discharge at i-time, in litre per m^2 or mm
E dan e_i = total annual evapotranspiration or evapotranspiration at i-time, in litre per m^2 or mm
ΔS dan ΔS_i = change (plus or minus) of total annual storage capacity or change (plus or minus) in storage capacity at i-time, in litre per m^2 or mm.

Through a mathematic manipulative process from equation 5.1 we obtain the following equation:

$$\sum\left(q_i - \frac{Q}{n}\bigg| > 0\right) + \sum\left(e_i - \frac{E}{n}\bigg| > 0\right) + \sum\left(\Delta s_i - \frac{\Delta S}{n}\bigg| > 0\right) = \sum\left(p_i - \frac{P}{n}\bigg| > 0\right) \qquad (5.3)$$

From the equation above we can define six new indicators, three of which are related to the buffering function:

$$U_q = \frac{\sum\left(q_i - \frac{Q}{n}\Big| > 0\right)}{\sum\left(p_i - \frac{P}{n}\Big| > 0\right)}$$

U_q = inequality indicator between relative discharge to rainfall

$$U_e = \frac{\sum\left(e_i - \frac{E}{n}\Big| > 0\right)}{\sum\left(p_i - \frac{P}{n}\Big| > 0\right)}$$

U_e = inequality indicator between relative evapotranspiration to rainfall

$$U_{\Delta s} = \frac{\sum\left(\Delta s_i - \frac{\Delta S}{n}\Big| > 0\right)}{\sum\left(p_i - \frac{P}{n}\Big| > 0\right)}$$

$U_{\Delta s}$ = inequality indicator between relative change in water storage to rainfall

$B_q = 1 - U_q$ B_q = indicator of river flow support relative to precipitation

$B_e = 1 - U_e$ B_e = indicator of evapotranspiration flow support relative to precipitation

$B_{\Delta s} = 1 - U_{\Delta s}$ $B_{\Delta s}$ = indicator of change in water storage ability in watershed support relative to precipitation

And the final equation is:

$$B_q = U_e + U_{\Delta s} \qquad (5.4)$$

Equation 5.4. shows that a river flow's buffering function relative to rainfall can be increased by increasing 'uneven distribution' of evapotranspiration (for example, by planting vegetation that is only actively transpiring in rainy seasons) or by increasing the water storage ability that fluctuates depending on a watershed's daily condition. What's important for a buffering function is not the total storage capacity in a watershed but the ability to respond to daily rainfall fluctuations. Usually the value of Ue will be small, because plants are well able to find and use water that is stored underground to maintain their constant daily evapotranspiration rate (the number is approximate to 'potential' rate in the condition where a leafy canopy is fully closed). Therefore, the buffering function of river flow is highly dependent on the change in the watershed's[3] water storage ability each day.

The above example uses daily data to calculate pi, qi, ei, and si and the indicator produced applies to that time scale. The same indicator can be calculate for different time scales, for example, hours, weeks, months or years, therefore, obtaining a series of buffering indicators. Furthermore, we can review the relationship between these indicators on a temporary scale. The review related with scale is not a small thing and requires clarity of the time scale used in calculating the buffering indicator.

In a watershed, water can be stored temporarily in several locations, with different total capacities and discharge rates. Overall, the river flow buffering function depends on the characteristics of rainfall, soil, vegetation and water storage system in the surface (or sub-surface), whether it is natural or manufactured (Table 5.2.).

[3] High rainfall at the end of a wet season tends to cause floods in the downstream areas because dam authorities usually want dams to be filled by water for supply during dry season. Reducing the risk of flooding means decreasing a dam's water storage capacity to below maximum. Watershed authorities need to establish clear regulations related to the pros and cons of this policy.

Table 5.2 Components of water balance and temporary storage in a watershed that play a role in river discharge support relative to rainfall in various space and time scales

The process of 'supporting' contributions to river flow relative to rainfall	Effect on flow timing relative to rainfall at various scales						
	Effect on annual discharge	Indicative time scale	Patch (m²), Field (ha)	Hill slope (km²)	Stream / sub-catchment (10 km²)	River/ catchment (100–1000 km²)	Basin (1000–10,000 km²)
Spatial asynchrony of rainfall	–	Day/month	–, –	0	+	++	+++
Canopy interception: storage => evaporation	++	Day	++, +	+	+	+	+
Canopy interception: delayed throughfall	_	<hour	+, 0	–	–	–	–
Infiltration to soil: recharge to field capacity, compensating preceding plant water uptake	+++	Day/week	++, ++	++	++	++	++
Surface water storage in local depressions	–	Hour/day	+, +	0	–	–	–
Interflow to stream via topsoil	–	Hour	0, +	+	0	–	–
Interflow to stream via subsoil	–	Hour/day	0, +	++	+	0	–
Flow towards stream via groundwater	–	Day/week	0, +	++	++	+	0
Flow restriction in stream	–	Day/week	0, 0	0	+	+	0
Stream associated wetlands	–	Day/week	0, 0	0	++	+	+
Bank overflow temporary water storage	–	Day/week	0, 0	0	++	++	+
Small reservoir for local irrigation	–	Week/month	0, 0	+	+	+	+
Large reservoir	+	Month	0, 0	0	0	+	+
Inter annual storage reservoir	+	Year	0, 0	0	0	0	+
Summary per group:							
Vegetation	++	Day	++, +	+	+	+	+
Soil management	–	Hour/day	0, +	++	+	0	–
Engineering	–	Week/month	0, 0	+	++	++	++
Climate property	–	Day/month	-, -	0	+	++	+++

Based on ICRAF's experience in conducting watershed function assessment in various locations, temporary indication shows that vegetation (including trees) has a big influence on the storage function at plot or field scale, land management at hillslope scale, construction at sub-watershed scale and climate at watershed scale.

5.4 The function of gradual water release

Water flow during a dry season, or basic flow, is highly desired by water stakeholders and users in downstream areas because the flow stabilizes transportation and water supply. To show the stability of river flow, we can plot today and yesterday's water discharge, which is known as plot persistence (Figure 5.6). This plot can be used to predict how much water will discharge today based on the discharge of the day before. Without rain, river flow will surely decrease. A good condition for river water users is if the decrease happens gradually.

In general, a plot will show a spread pattern with the bottom triangle almost empty. One line through the point (0,0) and covering all points above it, reflects the minimum discharge prediction. How the minimum ratio increases if the outliers one by one ($N_{outliers}$) is taken away, stated the river flow stability fraction (q_p), which is described in $100*(1 – N_{outliers}/N_{total})$ percent from total number of days (Equation 5.6).

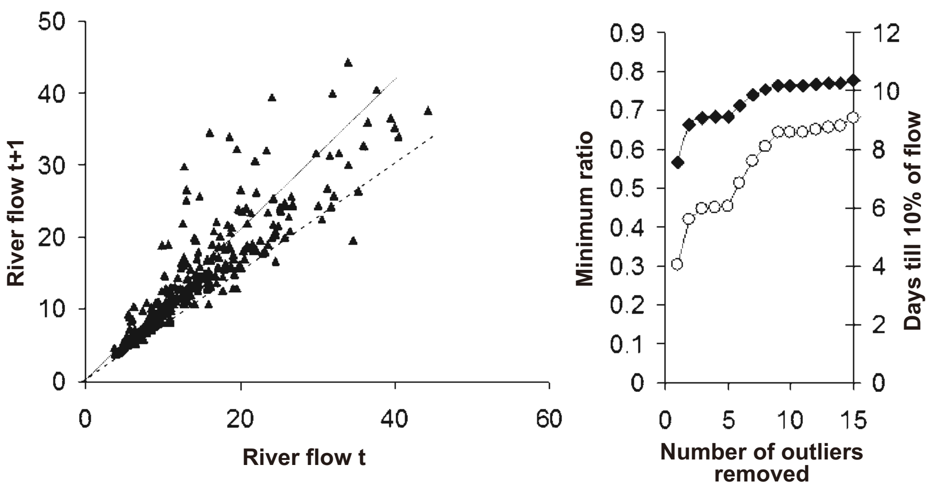

Figure 5.6 Water flow at sample plots in a tributary compared to river flow the day before; the slope of the lower regression line (after excluding 'outliers') shows the minimum ratio of 'flow stability'

Flow stability can also be stated in the number of days needed until river flow reaches the level of Y% from current flow:

$N_{daystoY\%} = (\log (Y) / \log (100)) / q_p$

By observing and checking the graph of the flow's stability, we can be aware of 'fracture' or missing flow at certain points. The example in Figure 5.6 shows a relatively stable river flow.

The existence of 'outliers' in a river flow stability graph may reflect an error in the measurement, although such a condition could actually occur and could be explained by hydrology. If some of the water flow in the river happens because of surface flow before the soil reaches its saturation point, then water flow the next day will decrease. However, if the surface flow happens when soil reaches its saturation point, then water flow the next day will remain high. Thus, the high frequency of outliers could be interpreted as an indicator of the existence of 'quick flow' (big flood) and land degradation.

5.5 Maintaining water quality

When discussing watershed functions related to water quality, what are often hot topics are erosion and sedimentation of soil particles. Ecologically, damage to water quality is mainly related to pollution, such as nutrients, pesticides and other organic materials that reduce oxygen availability in the water, as explained in Chapter 3.

Elements that could pollute water, among others, are nutrients; heavy metals such as mercury (Hg), that is usually used in gold mining, and arsenic (As) that occurs in soil, dissolves in groundwater and then moves to other water sources; organic materials that can be dissolved in water; and active biological materials (for example, pesticides, drugs). To know whether or not pollutants exist in water flow requires special measurements and detailed investigations of the types and sources of the pollution. Preventing pollution is far better that dealing with it after it has occurred. However, decision makers usually need solid evidence before they fully understand the risks of pollution. To be able to physically see pollution usually requires considerable time and very much depends on rainfall, hydrological conditions and how robust is the natural 'filter' in a watershed. Unfortunately, once river pollution can be seen clearly, it will take a much longer time to handle.

5.6 Maintaining good soil conditions

Soils in old forests are often used as a reference in assessing whether land is degraded or not. Soil degradation involves the loss of organic materials, a decrease of nutrients, changes in soil biota and food chains in the ground, soil compaction and changes in water retention. Change of soil retention is related to the soil's capacity to absorb water during rain, release of the water after rain until it reaches 'field capacity' and maintenance of the water at an appropriate pressure for plants to absorb (Figure 5.7).

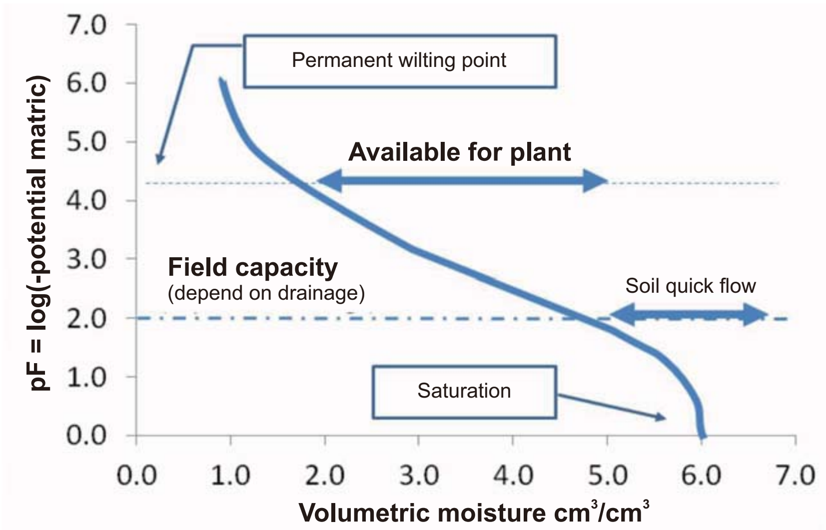

Figure 5.7 Ground water retention curve, which explains three main indicators of soil condition: 1) total water content when saturated; 2) the amount held 1 day after heavy rain (field capacity); and 3) permanent wilt point. Soil compaction will influence soil condition when approaching saturation point

The influence of soil compaction varies depending on soil type but in general it can be estimated by connecting actual bulk density (mass per volume unit) with a 'reference' value that can be calculated based on the soil's texture (sand, dust, clay and organic material content of the soil), as conducted by Wösten et al. (1998) for most data on soil agriculture. By using a calculation approach like this, it is possible to estimate that most topsoil in natural forest has around 70% content density from that of the reference value, while for soil that experienced heavy compaction, the content density can reach 1.3 times that of the reference value.

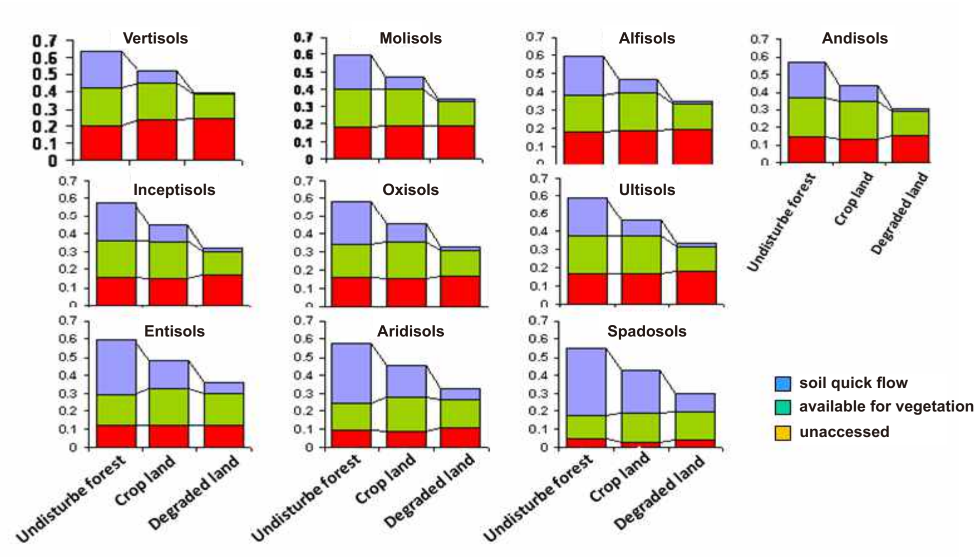

Figure 5.8 Upper limit of soil compaction influence on the water retention curve, estimated using pedotransfer function from Wösten et al. (1998), based on soil data in the tropics (Suprayogo et al. 2003), assuming that the soil in natural forests has a mass volume 0.7 times that of agricultural soils, while the mass volume of degraded soil increases up to 1.3 times

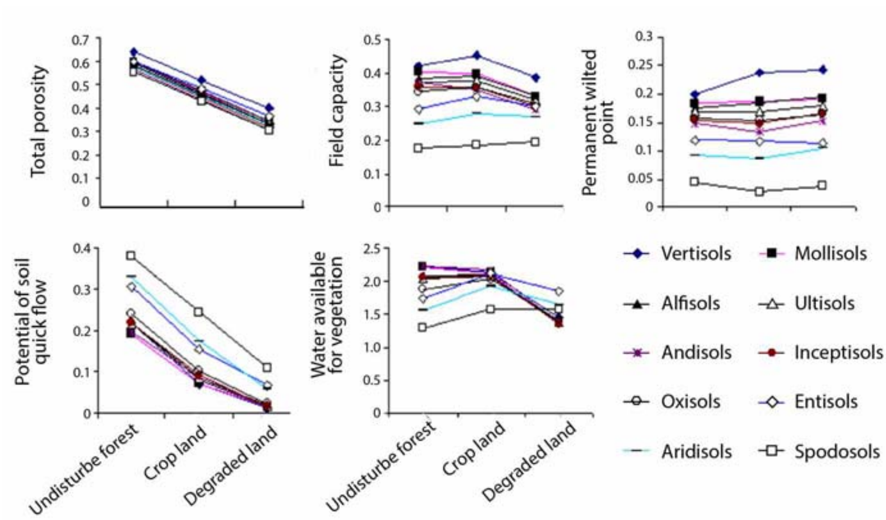

Figure 5.9 Upper limit of soil compaction influence on the water retention curve, estimated using pedotransfer function from Wösten et al. (1998) based on soil data in the tropics (Suprayogo et al. 2003), assuming that the soil in natural forests has a mass volume 0.7 times that of agricultural soils, while the mass volume of degraded soil increases up to 1.3 times and has an influence on different soil groups

Based on the data of 10 soil groups compiled by Suprayogo et al. (2003), on average, the change from 'forest' to 'agricultural land that has been managed for a long period of time' will have 0.136 cm3 cm-3 decrease of water storage capacity, equal to the ability of topsoil with 20 cm deep to store 25 mm of rainwater. When rain occurs the following day, the soil will still be able to store water since at that time water has flowed to the river or been stored in underground layers if the soil has not yet been saturated. If the agricultural land becomes 'degraded land' there will be another 0.081 cm3 cm-3 decrease in storage capacity (equal to the ability to absorb 15 mm of rainwater). The loss of storage capacity at this point might cause 'surface runoff', which can trigger floods and erosion.

The impact of land degradation on the loss of available water for plants is relatively small compared to the impact on the loss of water storage capacity related to surface runoff. Moreover, the change from forest to agricultural land could increase water availability for plants by as much as 0.01 cm3 cm-3, while further soil compaction will cause a loss of 0.055 cm3 cm-3 of water availability for plants. Therefore, the impact of soil compaction because of, say, pathway formation will have a far bigger influence on the increase of water flow (surface runoff, sub-surface flow and low flow) compared to water availability for plants. Other negative impacts of soil compaction is the disturbance of plants' roots aeration and soil porosity of around 0.1 in field capacity, which is considered as the threshold value, particularly for food plants.

Soil compaction can happen quickly, particularly because of tracks from bulldozers, cars, animals and humans, especially under wet soil conditions, such as is experienced in wet seasons. Without land cover, the release of soft soil particles can have the same influence as soil compaction. The recovery process, formation of macroporosity, is slow and highly dependent on worms and other 'developer' organisms' activities and tree root decomposition. If the soil is already very compacted, the recovery process might take tens of years or even a century. Land processing by reversing the soil does not satisfactorily substitute for the biological soil structure formation process: the influence is short term and can also damage the biological structure of the soil, which worsens the condition because it has to be continually repeated. Nevertheless, other land-processing strategies, such as making planting holes or breaking the dry soil layer, can be the beginning of the biological land recovery process.

Physical degradation of soil can form a 'crusting' layer on the land's surface that will decrease the potential surface infiltration rate. In areas with a dry climate, this condition will trigger surface flow although the soil condition is far from saturated.

Thus, the ability to diagnose the main factors that cause land degradation in a watershed is very important, since it is related with the time needed for the recovery process. To avoid soil compaction in areas that have conditions like that of 'natural forest' is far more effective than rehabilitating degraded places. However, in conditions where there is damage on the surface, land rehabilitation with mulch added to the surface can quickly return the soil condition.

5.6.1 Measurement

Soil physics books generally explain how to measure a soil's volume weight but rarely explain how the data should be interpreted. Volume weight is highly related to soil texture and its organic material contents (organic material contents also depend on the soil structure), so to be able to correctly interpret the compaction process we need to have a reference value from soil that has the same structure.

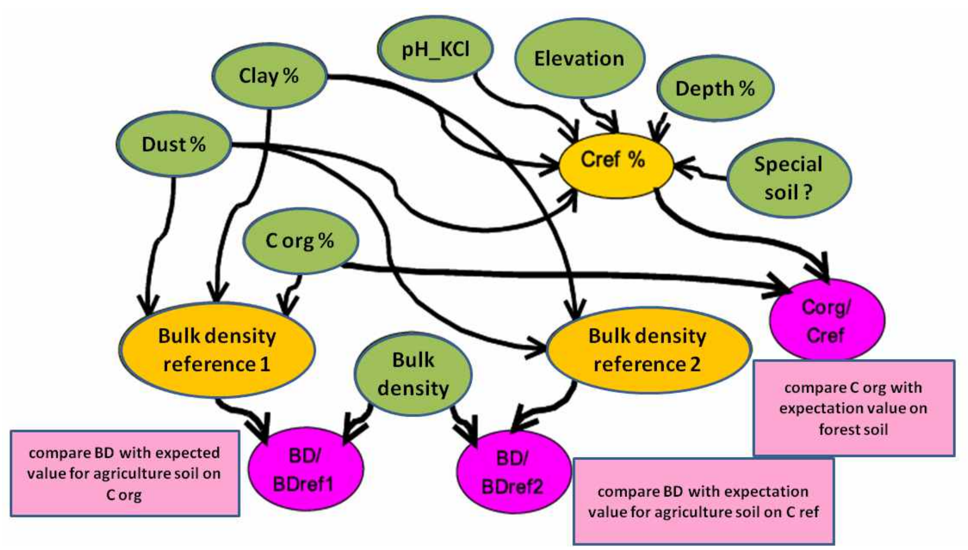

Figure 5.10 Flowchart on calculation according to various measurement of land parameter to obtain 'reference value' on substance density and content of soil organic materials that can be used as comparative values to soil sample

Note: BD is 'bulk' or volume density; BDref1 is reference volume density 1 which was calculated based on Corg field data and BDref2 is reference volume density 2 which was calculated based on Cref where Cref is Corg reference from estimation based on the soil's structure.

5.6.2 Physical degradation and rehabilitation process modelling

There are many good and fairly accurate models for water, nutrient and soil carbon balance and the important processes within. However, there are not many models available to understand soil structure dynamics, damage and recovery. There are many unknown processes related to soil structure dynamics, thus, leading to less accurate water balance assessments. The Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model uses the field assessment BDref value as a minimum value or the worst a soil can be when the structure is damaged and there is no macropore development activity by earthworms (and other soil development organisms). Earthworms revitalize soil structure by eating litter, mulch and delicate roots; and tree roots will turn into macropores as they are decomposed. Conceptually, this model (Figure 5.10) shows that the parts of a tree that play a role in 'land rehabilitation' are litter, delicate roots and roots. It is not easy to understand further the process of soil recovery by mulch because mulch lies on the soil surface and, depending on its size and weight, is easily blown away by the wind or carried away by water. This can lead to differences in soil structure even though the soils exist on the same plot of land. Soil with mulch will have a high infiltration rate while an area with less or no mulch will probably harden and develop a crust layer owing to high surface flow. Detail study of the types of litter (based on tree species) to know its 'movement' tendency is required to understand how litter affects soil recovery.

In large-scale semi-arid areas, the transported litter is often seen in tiger-like stripe pattern, a phenomenon known as the 'tiger bush effect'. In this condition, the degraded zone functions as a 'water receiver', which will be stored and used by vegetation. 'Land rehabilitation' can help change the pattern and size of the tiger bush effect so that it becomes more effective, though it will not eliminate it entirely.

Figure 5.11 Rehabilitation and degradation zones in a coffee system in Sumberjaya, Lampung province, Indonesia at different scales: plot scale (left); and landscape scale (right). At plot scale, litter moves toward an accumulation point and at landscape scale it forms erosion patterns and alternate accumulation on hill slopes. Rice fields in valleys are important 'filters'
(Foto: Meine van Noordwijk)

5.6.2.1 Basic principles of restoring degraded land: new findings

- Soil management, the objective of which is to increase infiltration, is an important step in avoiding the soil degradation cycle of surface runoff–erosion. Infiltration zones can reduce erosion's negative impacts on the plots below and provide positive feedback to vegetation growth in an infiltration zone by supporting soil structure recovery and increasing infiltration. Examples of soil management that supports infiltration are rock terraces (such as in the Sahel, Africa and Nusa Tenggara, Indonesia), planting holes for trees (although this can be done at an early stage of reforestation activity, it is commonly considered as an activity related to soil structure recovery) and making natural vegetative strips, which is a common practice in the Philippines and Indonesia.
- Using forest land as the basic reference, soil compaction in the beginning has a stronger effect toward 'lateral flow', which affects 'watershed function' more than soil productivity in particular areas. Maintaining forest land will reduce degradation and this effort can be more effective than degraded land rehabilitation. Unfortunately, government policy related to the environment and rewards for environmental services schemes have been found to have difficulties in solving problems by 'avoiding destruction'. Meanwhile, 'rehabilitation' efforts are more prominent.
- Increase in soil organic material has little direct effect on water availability for plants, however, it has strong indirect effects through soil structure, depending on the soil texture and rainfall regime.
- The most important part of a 'forest', in relation to soil and water flow, is its role as litter producer and transformer of dead root systems, providing support for soil biota that maintain soil structure. Half-open land-use systems with trees (agroforestry) have a similar function and also provide better livelihoods and incomes for communities.
- For assessment and monitoring purposes, new models and models that provide 'internal control' in the form of reference values for soil carbon and weight can be used to address problems based on variation of soil characteristics and its relation to the 'lateral flow' process across spatial scales.

5.7 Quantitative indicators of watershed hydrology

Table 5.3 Criteria and indicators related to quantity and river discharge periodic cycle

Criteria	Indicator	Dimension	Diversity
1. Transmit water	1.1 Total water yield (discharge) per unit rainfall $TWY = \frac{\Sigma Q}{(A * \Sigma P)} = 1 - \left(\frac{\Sigma E}{\Sigma P}\right) - \left(\frac{\Sigma \Delta_s}{\Sigma P}\right)$ Q = river discharge P = rainfall A = area E = evapotranspiration	[-]	a) Accumulation over specified length of observation period b) Mean of annually calculated value
	1.2 Seasonal pattern of discharge in relation to cumulative rainfall	Graph Q_{cum} vs P_{cum}	
2. Buffer peak rain event (avoiding flood damage)	2.1 Buffering indicator for above-average flow given above-average rain event $BI = \frac{\left(P_{abAvg} - \left(\frac{Q_{abAvg}}{A}\right)\right)}{P_{abAvg}} = 1 - \frac{Q_{abAvg}}{(AP_{abAvg})}$ where: $P_{abAvg} = \sum \max(P - P_{mean}, 0)$ $Q_{abAvg} = \sum \max(Q - Q_{mean}, 0)$	[-]	a) Maximum during specified length of observation period b) Mean of annually calculated value of maximum or mean (shift from calendar to hydrologic year?)
	2.2 Relative buffering indicator, adjusted for relative water yield $RBI = 1 - \left(\frac{P_{mean}}{Q_{mean}}\right) * \left(\frac{Q_{abAvg}}{P_{abAvg}}\right)$	[-]	
	2.3 Buffering peak event $1 - Max \frac{(daily\_Q - Q_{mean})}{(A * Max(daily\_P - P_{mean}))}$	[-]	
	2.4 Highest monthly river discharge total relative to mean monthly rainfall	[-]	
	2.5 Fraction of total river discharge derived from overland flow (same day as rain event)	[-]	
	2.6 Fraction of total river discharge derived from soil quick flow (1 day after rain event)		
	2.7 Scaling factor X in relationship of Qmax in contributing area A: $Q_{max} = A^X$ (default assumption: X=0.7)		
3. Release gradually (maintaining low flow)	3.1 Fraction of discharge derived from slow low (> 1 day after rain event) $\frac{\Sigma Q_{slow}}{(\Sigma Q)} = \frac{(\Sigma P_{infiltr} - \Sigma ES + V)}{\Sigma Q}$ where: $P_{infiltr}$ = amount of rain infiltrated ES+V = evaporation of soil surface and plant's transpiration	[-]	
	3.2 Lowest monthly river discharge total relative to mean monthly rainfall	[-]	

	3.3 Flow persistency: lower envelope of Q(t) vs Q (t-1) graph (after discarding of n% 'outliers')	[-]
4. Maintaining soil and reducing sediment	4.1 Standard time of sediment concentration	
	4.2 Sediment concentration relative to flow related transport capacity	
	4.3 Seasonal pattern in sediment concentration	
	4.4 Fraction of land with effective contact cover (for example, at start and halfway through the rains)	
	4.5 Fraction of sediment in overland flows intercepted in land-based filter	
	4.6 Fraction of river sediment flows intercepted in 'trap dam'	
	4.7 Flow-adjusted sum of sediment transport/ area size	
	4.8 Sediment delivery ratio (net sediment loss per unit area measured at catchment scale divided by that measured at plot scale)	

5.8. Discussion

Watershed functions are very important for governments and policy makers, especially those people directly working with damage to hydrological functions and the effect on humans, infrastructure and economies. The type and scale of watershed impact on humans is very much affected by land-cover change, infrastructure development such as dams and irrigation channels that can change drainage systems and temporary water storage at landscape levels, and the location of settlements (Figure 5.12)

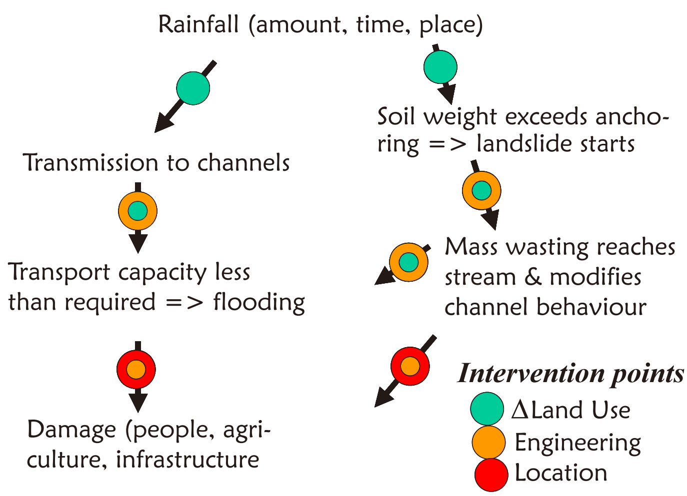

Figure 5.9 Causality relation of rainfall with possible impact on humans. Stages involve changes of land cover and land use, technology affecting drainage and water storage systems in the landscape and location of human activity such as settlement

The causes of droughts and floods can be classified into three levels: 1) direct (proximate); 2) indirect (intermediate); and 3) basic (ultimate). The most basic cause is the absence of flood prevention procedures in downstream areas, which is probably caused by the inability of area managers to predict water discharge caused by human activity, which leads to disaster. Direct cause usually takes the form of a rainfall period that exceeds expectations (causing floods) or falls below expectations (causing drought). Indirect cause relates to a watershed's ability to capture rainfall and flow it to a river and how different types of land cover and land use change the watershed's hydrological function. The combination of these three factors commonly contributes to floods and droughts. By only considering one factor of the three that lead to disaster means understating or over-simplifying the problem. A common weakness of watershed management is that hydrological functions are only viewed in relation to the upstream–downstream relationship and tend to ignore the importance of the 'transmission zone' between upstream and downstream. For example, a change in a river's body can greatly affect the river's hydrological behavior and land-use changes in the transmission zone can have the same impact as land-use changes in the upstream watershed (Figure 5.13).

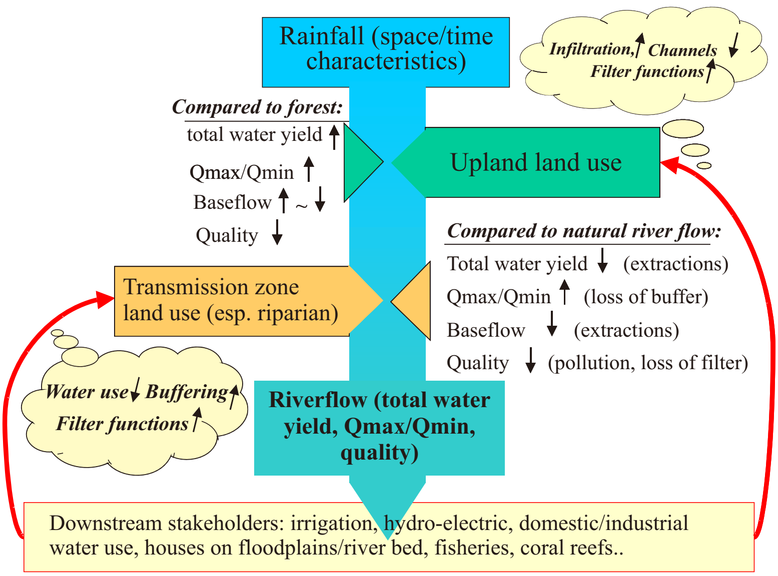

Figure 5.13. The relationship between rainfall and watershed functions in upstream areas and stakeholder in downstream areas is influenced by 'transmission zone' changes, for example, water use (for irrigation, for instance) can change total water discharge and changes in riverbank vegetation can affect flow characteristics and water quality

In conclusion, policy that relates to watershed functions needs to combine the following three components:

- Reducing the type and timing of human presence and economic activities in sensitive locations (flood, landslide);
- Engineering interventions that modify water transport and storage capacity; and
- Maintaining and restoring 'watershed function' in the main source areas of the river.

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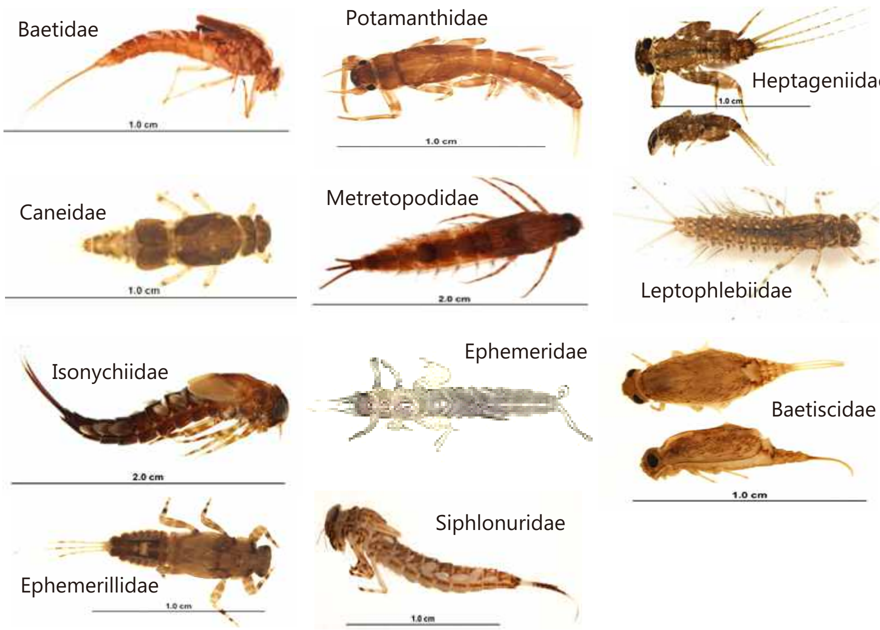
Appendix 1. Water quality criteria for Indonesia according to Government Regulation No. 82 Year 2001

Parameter	Unit	Class				Remark
		I	II	III	IV	
PHYSICAL						
Temperature	°C	Deviation 3	Deviation 3	Deviation 3	Deviation 3	Deviation from naturall
Dissolved residues	mg/litre	1000	1000	1000	2000	
Suspended residues	mg/litre	50	50	400	400	≤ 5000 for conventional drinking water processing
ANORGANIC CHEMICALS						
pH		6-9	6-9	6-9	5-9	If naturally beyond the interval, then determined according to natural condition
BOD	mg/litre	2	3	6	12	
COD	mg/litre	10	25	50	100	
DO	mg/litre	6	4	3	0	Minimum threshold
Total PO_4 as P	mg/litre	0.2	0.2	1	5	
No_3 as N	mg/litre	10	10	20	20	
NH_3 -N	mg/litre	0.5	Not required			In fisheries, the content of free ammonia for sensitive fish is ≤0.02 mg/litre
Arsenic	mg/litre	0.05	1	1	1	
Cobalt	mg/litre	0.2	0.2	0.2	0.2	
Barium	mg/litre	1	Not required			
Boron	mg/litre	1	1	1	1	
Selenium	mg/litre	0.01	0.05	0.05	0.05	
Cadmium	mg/litre	0.01	0.01	0.01	0.01	
Chrom (VI)	mg/litre	0.05	0.05	0.05	0.1	
Copper	mg/litre	0.02	0.02	0.02	0.2	Cu ≤ 1 mg/litre for conventional drinking water processing
Iron	mg/litre	0.3	Not required			Fe ≤ 5 mg/litre for conventional drinking water processing
Lead	mg/litre	0.03	0.03	0.03	1	Pb ≤ 0.1 mg/litre for conventional drinking water processing
Manganese	mg/litre	1	not required			
Mercury	mg/litre	0.001	0.002	0.002	0.005	
Zinc	mg/litre	0.05	0.05	0.05	2	Zn ≤ 5 mg/litre for conventional drinking water processingZn

Parameter	Unit	Class				Remark
		I	II	III	IV	
Chloride	mg/litre	1	not required			
Cyanide	mg/litre	0.02	0.02	0.02	not required	
Fluoride	mg/litre	0.5	1.5	1.5	not required	
No_2 as N	mg/litre	0.06	0.06	0.06	not required	NO2-N ≤ 1 mg/litre for conventional drinking water processing
Sulphate	mg/litre	400	not required			
Free chlorine	mg/litre	0.03	0.03	0.03	not required	Not required for raw water of drinking water
Sulfur as H_2S	mg/litre	0.002	0.002	0.002	not required	
MICROBIOLOGY						
Fecal coliform	Number/ 100 ml	100	1000	2000	2000	≤ 2000/100 ml for conventional drinking water processing
Total coliform	Number/ 100 ml	1000	5000	10000	10000	≤ 10000/100 ml for conventional drinking water processing
RADIOACTIVITY						
Gross-A	Bequerel/ litre	0.1	0.1	0.1	0.1	
Gross-B	Bequerel/ litre	1	1	1	1	
ORGANIC CHEMICALS						
Oil and fat	µg/litre	1000	1000	1000	not required	
Detergent as Methylene Blue active substance	µg/litre	200	200	200	not required	
Phenol compound	µg/litre	1	1	1	not required	
BHC	µg/litre	210	210	210	not required	
Aldrin/Dieldrin	µg/litre	17	not required			
Chlordane	µg/litre	3	not required			
DDT	µg/litre	2	2	2	2	
Heptachlor and Heptachlore epoxide	µg/litre	18	not required			
Lindane	µg/litre	56	not required			
Methoxyctor	µg/litre	35	not required			
Endrin	µg/litre	1	4	4	not required	
Toxaphan	µg/litre	5	not required			

Appendix 2. Illustrations of macroinvertebrate families

EPHEMEROPTERA



CRUSTACEA

Gammaridae
Sumber: www.forskning.no/.../1163760359.2/artikkel_print

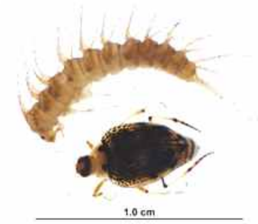
Asellidae
Sumber: nathistoc.bio.uci.edu/.../water%20slater.htm

Hirudinea
Sumber: www.lakecountyohio.org/soil/monitoring_inform...

COLEOPTERA

Elmidae

Haliplidae



Dytiscidae

Elmidae

Gyrinidae

Hydroptilidae

Hydroptilidae

Dryophilidae

MEGALOPTERA

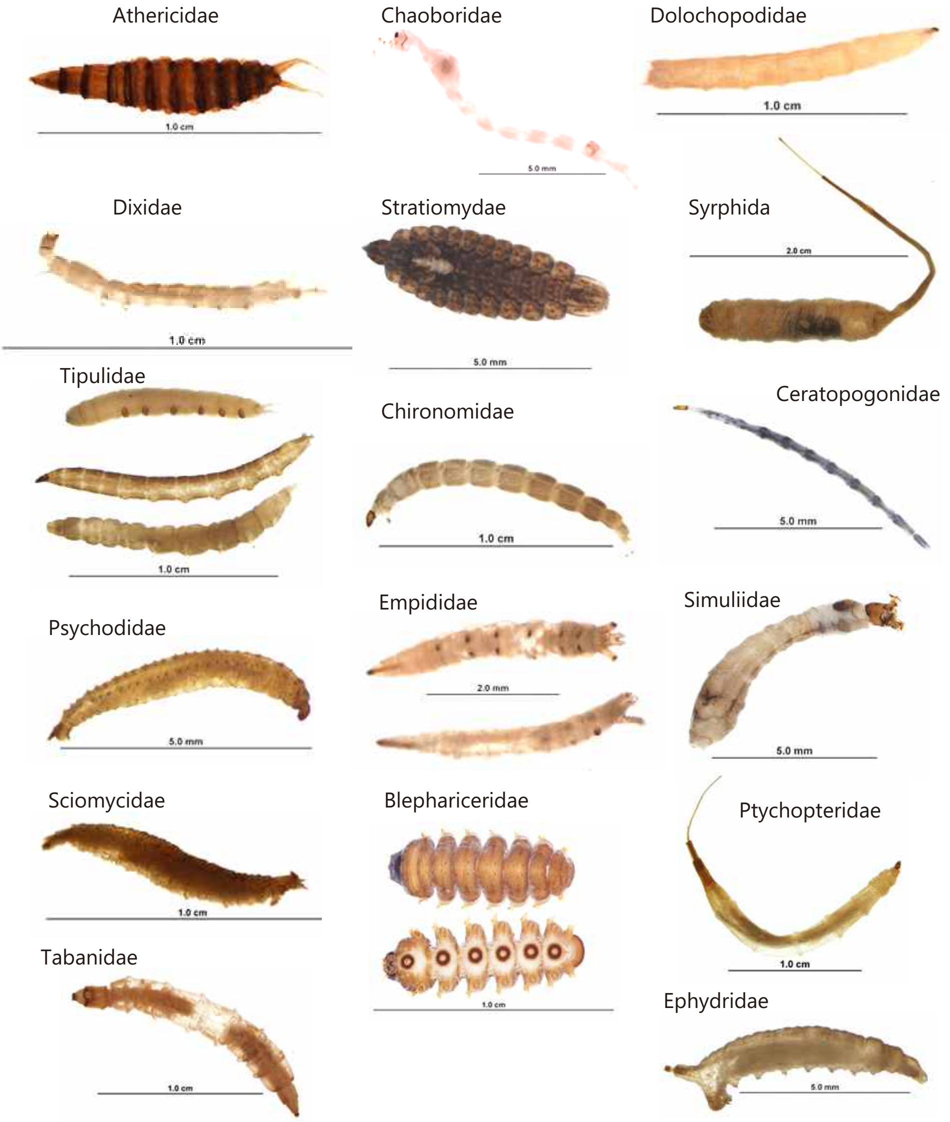
Corydalidae

Sialidae

LEPIDOPTERA

Pyralidae

DIPTERA


Athericidae
Chaoboridae
Dolochopodidae
Dixidae
Stratiomydae
Syrphida
Tipulidae
Chironomidae
Ceratopogonidae
Psychodidae
Empididae
Simuliidae
Sciomycidae
Blephariceridae
Ptychopteridae
Tabanidae
Ephydridae

TRICHOPTERA

Brachycentridae

Molanidae

Odontoceridae

Psychomyiidae

Hydropsychidae

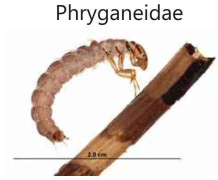
Hydroptilidae

Leptoceridae

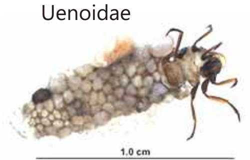
Sericostomatidae

Limnephilidae

Phryganeidae



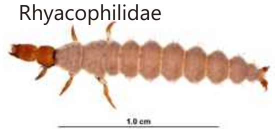
Uenoidae



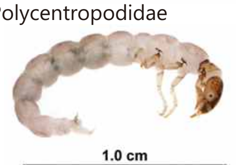
Philipotamidae

Helichopsychidae

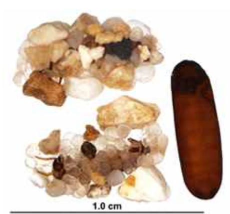
Rhyacophilidae



Polycentropodidae



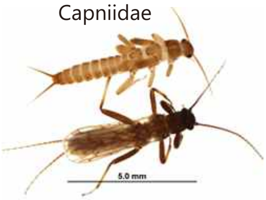
Glossosmatidae



Lepidostomatidae

PLECOPTERA

Capniidae

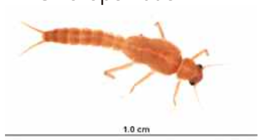


Perliodidae

Taeniopterygidae

Pteronarcyidae

Chloroperlidae



Nemouridae

Perlidae

Leuctridae

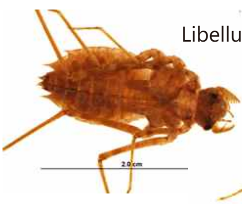
ODONATA

Aeshnidae

Coenagrionidae

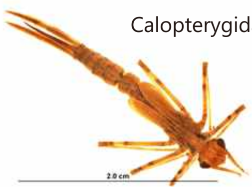
Cordulegastridae

Libellulidae



Gomphidae

Lestidae



Calopterygidae

MOLLUSCA

Ancylidae

Physidae

Lymnaeidae

Planorbidae

Valvatidae

Viviparidae

Pleuroceridae

Hydrobiidae

Bithyniidae

Sphaeriidae

Source:
www.manandmollusc.net/
.../Musculium-lacustre.gif

Turbellaria

Source:
www.cdb.riken.jp/jp/
04_news/img/
planarian300.jpg

Oligochaeta

Source:
library.thinkquest.org/
.../images/earthworm.jpg

Tubificidae

Source:
www.fcps.edu/.../ecology/
aquatic_worm.htm

HEMIPTERA

Corixidae

Sumber:
i.pbase.com/t1/94/
339594/4/
60514931.IMG_4443.jpg

Gerridae

Source:
eny3005.ifas.ufl.edu/
lab1/Hemiptera/Gerrid_1.jpg

Hydrometridae

Source::
delta-intkey.com/britin/
images/bent0321.jpg

Aphelocheiridae

Source::
guillaume.doucet.free.fr/
photos/
HETEROPTERE/A...

Appendix 3. Tolerance value of various macroinvertebrate families

Source:Hilsenhoff 1988 in Bounchard 2004

Class/Ordo/Family	Tolerance value
Ordo Ephemeroptera:	
Baetidae	4
Baetiscidae	3
Caenidae	7
Ephemerilidae	1
Ephemeridae	4
Heptagenidae	4
Isonychiidae	2
Leptophlebiidae	2
Leptohyphidae	4
Metretopodidae	4
Polymitarcyidae	2
Potamanthidae	4
Siphlonuridae	7
Ordo Hemiptera:	
Belostomatidae	10
Corixidae	9
Naucoridae	5
Nepidae	8
Veliidae	6
Ordo Trichoptera:	
Brachycentridae	1
Calamoceratidae	3
Dipseudopsidae	5
Glossosomatidae	0
Goeridae	3
Helicopsychidae	3
Hydropsychidae	4
Hydroptilidae	4
Lepidostomatidae	1
Leptoceridae	4
Limnephilidae	4
Molannidae	6
Odontoceridae	0
Philopotamidae	3
Phrygaenidae	4
Polycentropodidae	6
Psychomyiidae	2
Rhyacophilidae	0
Sericostomatidae	3
Uenoidae	3
Ordo Polydesmida	6

Class/Ordo/Family	Tolerance value
Ordo Odonata:	
Aeshnidae	3
Calopterygidae	5
Coenagrionidae	9
Cordulegastridae	3
Corduliidae	2
Gomphidae	1
Lestidae	9
Libellulidae	7
Macromiidae	2
Ordo Plecoptera:	
Capniidae	1
Chloroperlidae	1
Leuctridae	0
Nemouridae	2
Peltoperlidae	0
Perlidae	1
Perlodidae	2
Pteronarcyidae	0
Taeniopterygidae	2
Ordo Lepidoptera:	
Arctiidae	5
Nepticulidae	5
Pyralidae	5
Ordo Coleoptera:	
Curculionidae	5
Dryopidae	5
Dytiscidae	5
Elmidae	5
Gyrinidae	4
Haliplidae	7
Hydrophilidae	5
Psephenidae	4
Ptilodactylidae	3
Scirtidae	7
Ordo Megaloptera:	
Corydalidae	0
Sialidae	4

Class/Ordo/Family	Tolerance value
Ordo Isopoda	8
Ordo Diptera:	
Anthomyiidae	6
Atheceridae	2
Blephariceridae	0
Ceratopogonidae	6
Chaoboridae	8
Chironomidae (red)	8
Chironomidae (pale/pink)	6
Culicidae	8
Dolichopodidae	4
Dixidae	1
Empididae	6
Ephydridae	6
Muscidae	6
Psychodidae	10
Ptychopteridae	7
Scathophagidae	6
Sciomyzidae	6
Simuliidae	6
Stratiomyidae	8
Syrphidae	10
Tabanidae	6
Tanyderidae	3
Tipulidae	3
Ordo Amphipoda:	
Gammaridae	4
Hyalellidae	8
Ordo Cumacea	5
Ordo Decapoda	6
Ordo Cladocera	8
Nematoda	5
Hydracarina	4
Palaenomidae	4
Cambaridae	6

Class/Ordo/Family	Tolerance value
Ordo Acariformes	
Arrenuridae	6
Lebertiidae	6
Atractideidae	6
Mideopsidae	6
Tyrellidae	6
Limnesidae	6
Limnocharidae	6
Sperchonidae	6
Unionicolidae	6
Klas Bivalvia	8
Corbiculidae	6
Dreisseniidae	8
Sphaeriidae	6
Pisidiidae	8
Klas Gastropoda:	
Physidae	8
Lymnaeidae	6
Planorbidae	7
Ancylidae	6
Viviparidae	6
Pleuroceridae	6
Bithyniidae	8
Hydrobiidae	6
Valvatidae	8
Klas Turbellaria	4
Platyhelminthidae	4
Klas Hirudinea	10
Glossiphoniidae	6-8
Colembola	10

Note:
0-3: Low tolerance (very sensitive to environmental conditions)
4-6: Medium tolerance
7-10: High tolerance (resistant to environmental conditions)

World Agroforestry Centre

RUPES
REWARDS FOR, USE OF AND SHARED INVESTMENT IN PRO-POOR ENVIRONMENTAL SERVICES

VLIR Vlaamse Interuniversitaire Raad
UOS University Development Co-operation

Newspapers and environmental NGOs always point to forest destruction and illegal logging as causes every time floods and landslides occur. The loss of forest cover is viewed as the only cause of the loss of watershed functions and communities inhabiting upstream areas are often accused of being the source of environmental destruction. But, if looked at more closely, many areas in Indonesia and Southeast Asia have natural beauty and yet maintain good watershed functions although they no longer have vast areas of natural forests. Well-maintained watershed functions are caused by well-managed river flows, especially when supported by social institutions that maintain a balance between individual and public interests. Today, people realize that by planting trees with economic value in their agricultural system they are also maintaining watershed functions at the same time because trees help stabilise hill slopes as well as prevent soil loss because of erosion and water flow.