Technical Assistance
HYDROLOGY PROJECT

World Bank & Government of The Netherlands funded

Training module # WQ - 26

Basic Ecology Concepts

New Delhi, October 1999

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DHV Consultants BV & DELFT HYDRAULICS

with
HALCROW, TAHAL, CES, ORG & JPS

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1. Module context

This module introduces the basic ecology concepts with particular reference to aquatic ecosystems. Modules in which prior training is required to complete this module successfully and other available, related modules in this category are listed in the table below.

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

No.	Module title	Code	Objectives
1.	Basic water quality concepts	**WQ - 01**	• Discuss the common water quality parameters • List important water quality issues
2	Understanding biochemical oxygen demand test[a]	**WQ - 15**	• Understand the significance and theory of BOD measurement
3	Oxygen balance in Surface Waters[a]	**WQ - 25**	• Explain the importance of oxygen in water • Identify the main processes of oxygen addition and depletion in surface waters

a – prerequisite

2. Module profile

Title	:	Basic Ecology Concepts
Target group	:	HIS function(s): Q2, Q3, Q5, Q6, Q7, Q8
Duration	:	1 session of 60 min
Objectives	:	After the training the participants will be able to: • Explain how energy flows through an aquatic ecosystem • Explain how nutrients are cycled in the environment • explain the causes and problems of eutrophication
Key concepts	:	• Ecosystems • Energy flow and nutrient cycling • Eutrophication
Training methods	:	Lecture and open discussion
Training tools required	:	OHS, Board, flipchart
Handouts	:	As provided in this module
Further reading and references	:	Concepts of Ecology, Edward J. Kormondy, Prentice - Hall International, Inc., Englewood Cliffs.

3. Session plan

No	Activities	Time	Tools
1	***Preparations***		
2	***Introduction***: • Introduce the subject of ecology • Define commonly used terms using the example of a pond ecosystem	10 min	OHS
3	***Energy flow***: • List energy requirements of living beings in general and the possible sources. • Discuss solar energy input and the generalised concept of energy flow in ecosystems	15min	OHS Board
4	***Nutrient recycling*** • Define nutrients • Present the nitrogen and phosphorus cycles • Discuss the various forms of nitrogen and phosphorus and their relation to water quality	10 min	OHS
5	***Eutrophication***: • Explain eutropication and its causes and the concept of the limiting nutrient • Discuss the water quality problems associated with eutrophication • Discuss the pollution problems associated with plant nutrients in water	10 min	OHS
6	***Wrap up and evaluation***	15 min	Additional hand out

4. Overhead/flipchart master

OHS format guidelines

Type of text	Style	Setting
Headings:	OHS-Title	Arial 30-36, with bottom border line (not: underline)
Text:	OHS-lev1 OHS-lev2	Arial 24-26, maximum two levels
Case:		Sentence case. Avoid full text in UPPERCASE.
Italics:		Use occasionally and in a consistent way
Listings:	OHS-lev1 OHS-lev1-Numbered	Big bullets. Numbers for definite series of steps. Avoid roman numbers and letters.
Colours:		None, as these get lost in photocopying and some colours do not reproduce at all.
Formulas/Equations	OHS-Equation	Use of a table will ease horizontal alignment over more lines (columns) Use equation editor for advanced formatting only

Basic ecology concepts

- A pond ecosystem
- Generalised energy flow
- Nutrient cycling
- Eutrophication

A pond ecosystem (1)

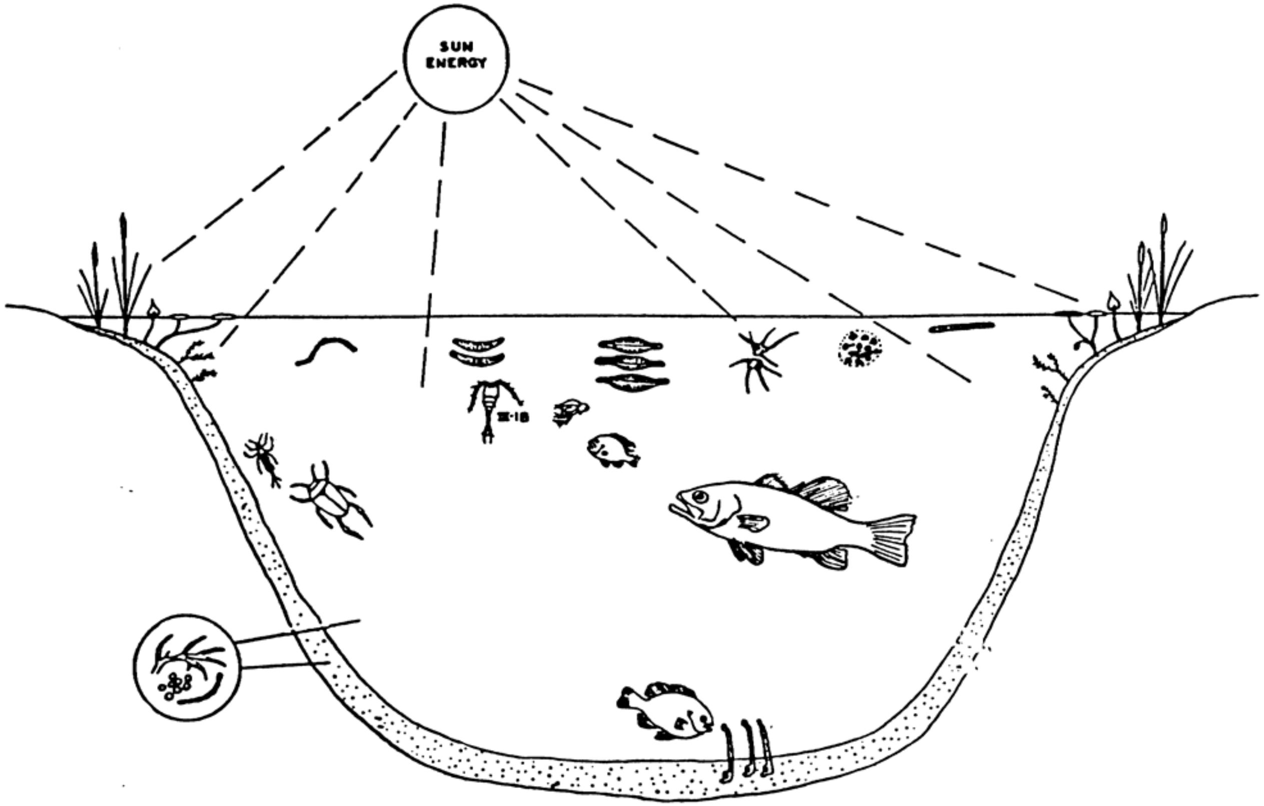

Figure 1 Diagram of a pond ecosystem

A pond ecosystem (2)

- Abiotic components
  - *gases, dissolved compounds, physical environment*
- Biotic components
  - *populations, community*
- Trophic levels
  - *autotrophs (producers), herbivores, carnivores, decomposers*
- Food chain and web

Solar insolation

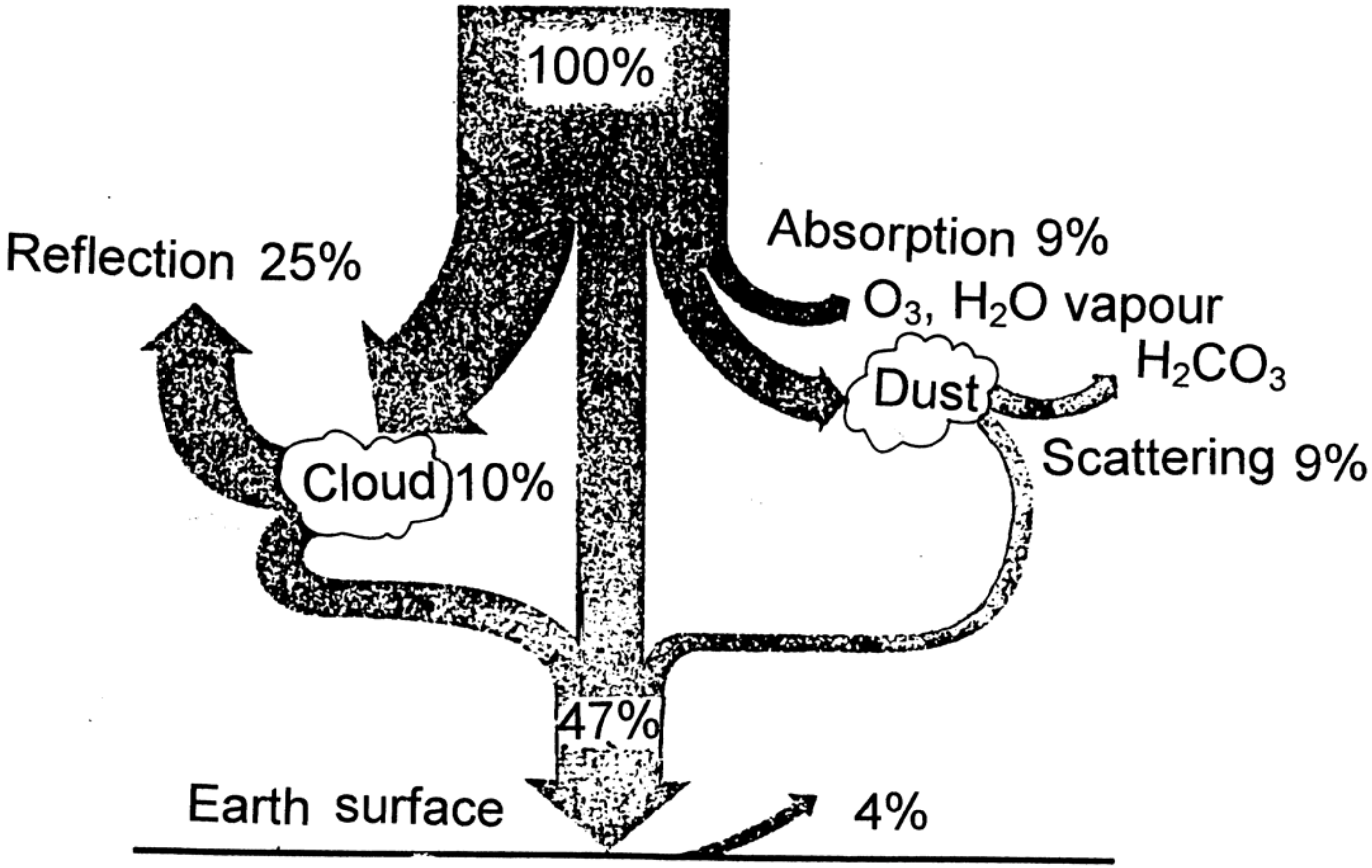

Figure 2 Solar insolation

Energy flow (1)

- Producers

1,300,000 cal + 106CO_2 + 90H_2O + 16NO_3 + mineral elements

equals

$C_{106}H_{180}O_{46}N_{16}P$(+185g other minerals) + 154O_2 + 1,287,000 cal dispersed

  - *1-6% energy is utilised, 25 - 50% expended in respiration*

- Heterotrophs
  - *net herbivore and carnivore production 10 - 15% of available food*

Energy flow (2)

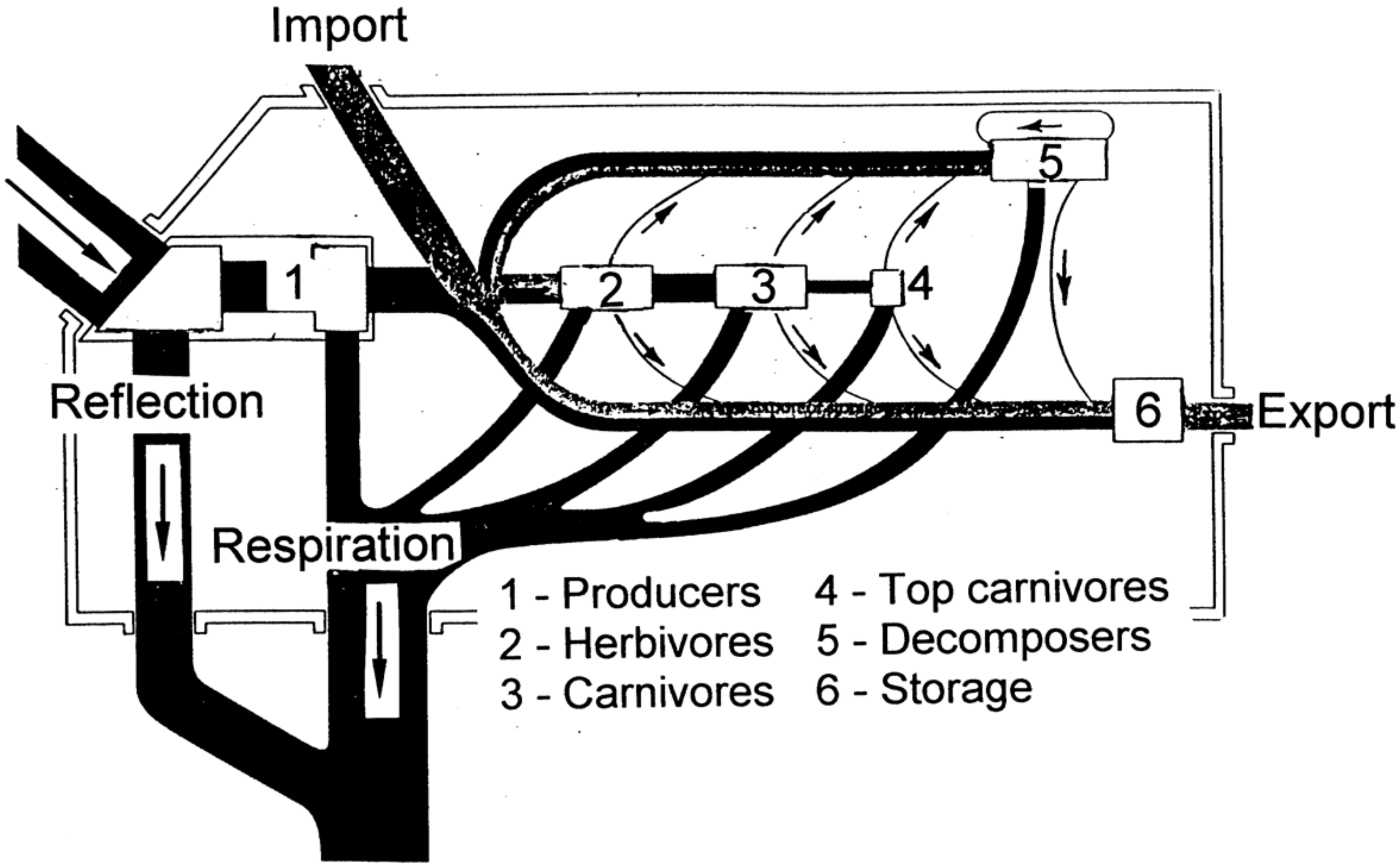

Figure 3 Energy flow diagram

Nutrients

- Macronutrients
  - *C, O, H, N,P > 1% of biomass*
  - *S, Cl, K, Na, Ca, Mg, Fe, Cu < 1% of biomass*
- Micronutrients
  - *about 20 elements such as Al, Co, I, Mn, Ni, Zn, etc.*
- Productivity depends on availability of nutrients
  - *solution, living organisms, cellular debris & mud*
- Macronutrients N or P may be limiting

Recycling of nutrients

- Nutrient quantity is limited
- Recycled by different populations during their life processes
- Physical processes modify availability

Nitrogen cycle

- Fixation of atmospheric nitrogen, N_2
  - *electrical discharge, chemical production, biological fixation*
- NO_3 → plants → animals → death & wastes
- Waste org. N → decomposers → NH_3
- NH_3 → nitrifiers → NO_2 & NO_3
- NO_2 & NO_3 → denitrifiers → N_2

Phosphorus cycle

- Soluble o-P from soils in meagre quantity
- Rock phosphate ⟶ soluble o-P
- Soluble o-P ⟶ plants ⟶ animals
- Plant & animal waste ⟶ decomposers ⟶ soluble o-P
- May be lost due to inaccessible deposits

Eutrophication (1)

- Ability to support life
  - *oligotrophic, mesotrophic, eutrophic*
  - *excessive fertilisation* → *explosive growth of algae*
- Effects on water quality
  - *aesthetic, growth of rooted plants*
  - *large diurnal variation in DO and pH affects fish life*
  - *decomposition of dead algal mass, anaerobic conditions*
  - *problems in water filtration, odours, toxic algae*

Eutrophication (2)

- Measurement of eutrophication
  - *counts of phytoplanktons, cell volume, chlorophyll conc.*
- Limiting nutrient
  - *P, N can be fixed by blue-green algae*
  - *addition of wastes*
- Water quality monitoring
  - *time of sampling*
  - *interpretation of water quality data*

5. Evaluation sheets

6. Handout

Basic ecology concepts

- A pond ecosystem
- Generalised energy flow
- Nutrient cycling
- Eutrophication

A pond ecosystem

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- Fixation of atmospheric nitrogen, N_2
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- Waste org. N $\rightarrow$ decomposers $\rightarrow NH_3$
- $NH_3 \rightarrow$ nitrifiers $\rightarrow NO_2$ & NO_3
- NO_2 & $NO_3 \rightarrow$ denitrifiers $\rightarrow N_2$

Phosphorus cycle

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Add copy of Main text in chapter 8, for all participants.

7. Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

Questions

1. A stream feeding a lake has an average flow of $500m^3/d$ and a phosphate concentration of 10 mg/L. The water leaving the lake has a concentration of 8 mg/L.

a. How much phosphate is retained in the lake every year?

b. Where does this phosphate go?

c. Would you expect the average phosphate concentration in water to be higher near the surface or bottom?

2. Match the items in List A with the terms in List B

List A	List B
1. Zooplankton	( ) Energy source
2. Detritus	( ) Nutrient
3. Photosysthesis	( ) Herbivore
4. Sun	( ) Waste
5. Abiotic	( ) Energy capture
6. Phosphorus	( ) Water

Questions and Answers

1. A stream feeding a lake has an average flow of 500m^3/d and a phosphate concentration of 10 mg/L. The water leaving the lake has a concentration of 8 mg/L.

a. How much phosphate is retained in the lake every year?

Phosphate retained/d = 10g/m^3 x 500 m^3/d - 8g/m^3 x 500 m^3/d = 1000g/d
Phosphate retained/year = 1000g/d x 365 d/year x 1kg/1000g = 365kg/year

b. Where does this phosphate go?

- taken up by phytoplankton and shoreline rooted plants.

c. Would you expect the average phosphate concentration in water to be higher near the surface or bottom?

- near bottom where the decomposers would be decomposing the waste deposits.

2. Match the items in List A with the terms in List B

List A	List B
1. Zooplankton	(4) Energy source
2. Detritus	(6) Nutrient
3. Photosysthesis	(1) Herbivore
4. Sun	(2) Waste
5. Abiotic	(3) Energy capture
6. Phosphorus	(5) Water

8. Main text

Contents

Basic Ecology Concepts

1. Introduction

Plants and animals in their physical environment make up an *ecosystem*. The study of such ecosystem is *ecology*. In an ecosystem, the living organisms (the *biotic* component) interact among themselves and with their non-living environment (the *abiotic* component) and maintain the ecosystem.

The present module describes the basic ecology concepts with particular reference to aquatic ecosystems and the effect of discharge of nutrients into water bodies, which influences an existing ecological regime.

It should be remembered that although we may draw line around a specific ecosystem in order to be able to study it more fully (e.g., a stretch of a stream or a lake) and in so doing assume that the system is totally self-contained, this obviously is not true. One of the tenets of ecology is that everything is connected with everything else.

2. A Pond Ecosystem

The best way to understand the concepts of ecology is to study an actual ecosystem. Figure 1 shows a pond ecosystem.

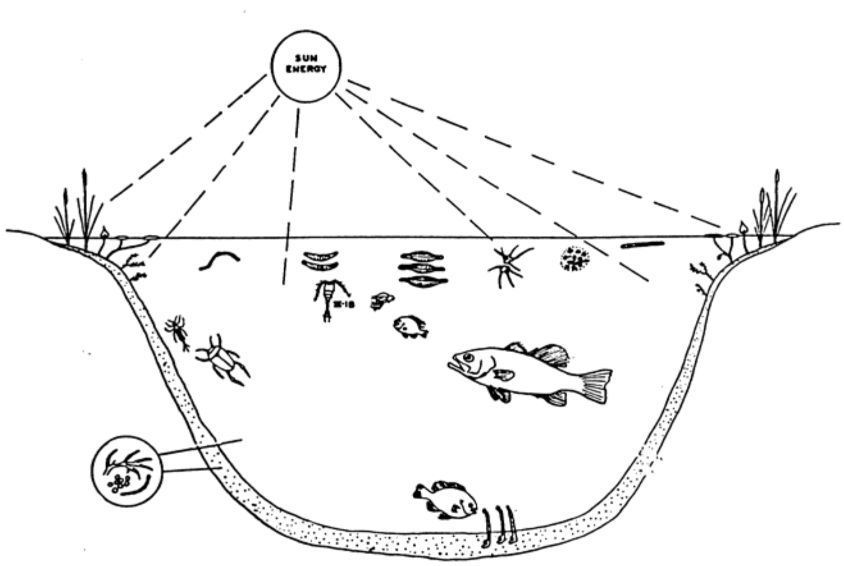

Figure 1 Diagram of a pond ecosystem

A number of abiotic substances present in the pond can be listed, such as, water, carbon dioxide, oxygen, calcium, nitrogen and phosphorus salts, amino acids, humic acid, etc. Each substance exists in a unique dynamic equlibrium. Oxygen in solution depends on the rate of photosynthesis, its partial pressure in the atmosphere, temperature, etc. A small portion of the vital nutrients is in solution and is immediately available to organisms, but a much larger portion is held in reserve in particulate matter (especially in the bottom sediments), as well as in the organisms themselves.

The biotic *community* consists of different *populations* (groups of organisms of one kind) which exist and interact with each other and their abiotic environment maintaining the ecological balance. The community can be described on the basis of various functional relationships.

The p*roducers* take energy from the sun, nutrients such as nitrogen and phosphorus from the water, and through the process of photosynthesis produce high energy chemical compounds of their cellular mass. These organisms are often referred to as being in the first *trophic* (nourishment) level and are called *autotrophs* (self-nourishing). In the pond, these can be rooted or large floating plants and minute floating plants, usually algae, called *phytoplankton.*

A second group of organisms are the primary *consumers* who use some of this energy by consuming the high energy molecules of the protoplasm of the producers. These organisms are in the second trophic level and are also called *herbivores.* To this group belong the *zooplankton* and the *benthos*. There are also secondary consumers (*carnivores*) such as predaceous insects, and fish who feed on the primary consumers and belong to the third trophic level. There can be organisms belonging to higher trophic levels as well who may feed on the organisms of the immediate lower or other lower trophic levels.

The third group of organisms, the *decomposers* or the decay organisms, feed on the animal wastes and dead plants and animals, and in so doing convert the organic molecules to stable inorganic compounds. The nutrients are thus released for reuse. Aquatic bacteria, flagellates and fungii, belong to this group. They are especially abundant in the mud water interface. The decomposers may be helped in their reactions by the detritus feeding animals who carry out the initial breakdown of the complex molecules.

In summary, the life processes in an ecosystem are driven by a continuous input of solar radiation. Various groups of organisms sustain each other in their life processes forming a *food chain* or *food web*. While the energy flow in ecosystems is uni-directional, there is a pool of nutrients which are recycled.

3. Energy Flow in Ecosystems

As stated earlier, the sun is the primary source of energy in all ecosystems. Figure 2 illustrates the transfer of solar radiation to the earth's surface. Clouds, dust, ozone layer and moisture modify the input both qualitatively and quantitatively. Half or more of this flux is depleted as it passes through the troposphere. Radiant energy absorbed in the troposphere is also reradiated in the far infrared portion of the spectrum, which heats the lower air, the soil and water. The visible light component of direct radiation, blue and red portion of the spectrum, drives the photosynthetic machinery.

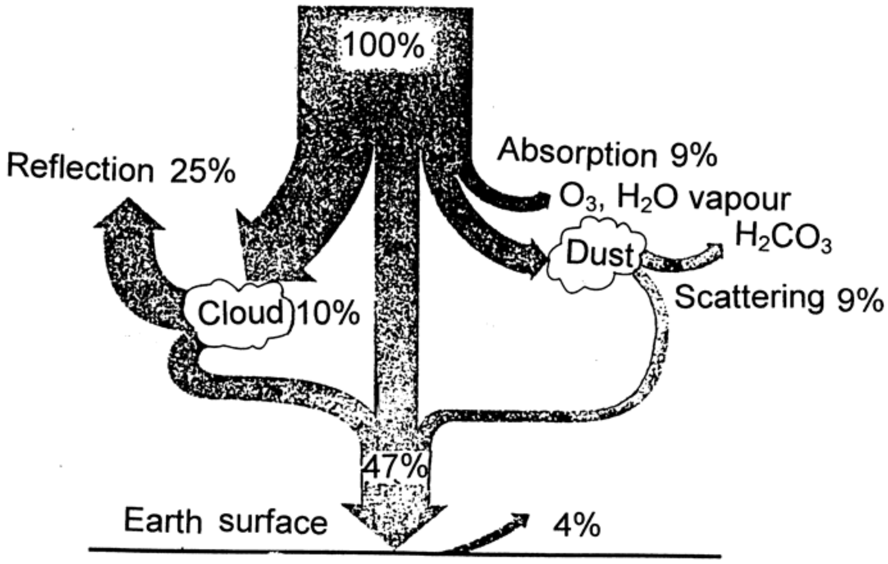

Figure 2 Solar insolation

The solar flux is measured in units of cal/cm^2.d or Langleys. Depending on the latitude and the season, about 150 - 250 cal/cm^2.d are received at the earth surface in the tropical regions.

A generalised concept of energy flow through an ecosystem, such as a pond, is shown schematically in Figure 3.

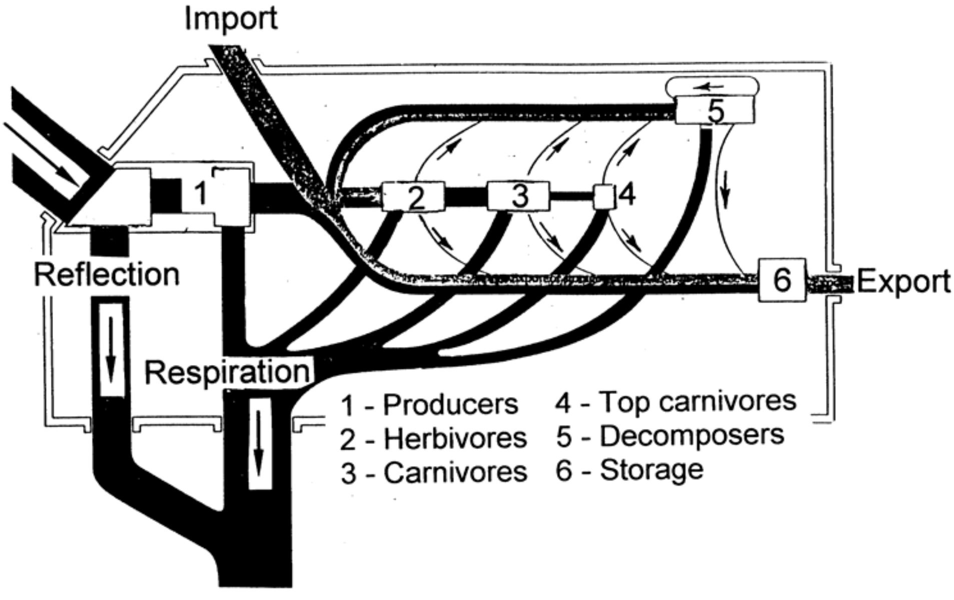

Figure 3 Energy flow diagram

- The producers incorporate about 1 - 6% of the total incident energy through the process of photosynthesis, in the form of chemical bond energy of the complex molecules of their protoplasm.

$$1{,}300{,}000\ \text{Cal} + 106CO_2 + 90H_2O + 16\ NO_3 + 1PO_4 + \text{mineral elements}$$
$$\text{equals}$$
$$C_{106}H_{180}O_{46}N_{16}P(+185\text{g other minerals}) + 154O_2 + 1{,}287{,}000\ \text{Cal dispersed}$$

- About 25 - 50% of this energy is expended by the producers themselves through respiration for sustenance of their energy requiring metabolic reactions.
- A part of the producer biomass is also lost through death and the remainder is available to the herbivores at the second trophic level.
- At the second trophic level, the net herbivore production after taking into account respiration, death and excretion, is about 10% of the net plant production.
- Similarly at the third trophic level, the net carnivore production is about 15% of the net herbivore production.

It is to be emphasised that the percentages given above will change from one ecosystem to another and from time to time for the same system. These should be taken only as indicative of the order of magnitude.

Figure 3 also shows import and export of energy in the form of organic matter from and to other ecosystems. The magnitude of this channel would depend on the extent of isolation of the ecosystem from the other systems.

4. Recycling of nutrients

Life is dependent not only on the energy but also on the availability of some 20 chemical elements. Those elements needed in relatively large amounts are generally referred to as *macronutrients*, each constituting 0.2 percent or more of dry organic matter. *Micronutrients* are those elements needed in smaller or trace amounts.

Macronutrients: Macronutrients may be considered in two groups: (1) those that constitute more than 1 percent each of the dry weight - C, O, H, N and P: and (2) those that constitute 0.2 to 1 percent of the dry weight - S, Cl, K, Na, Ca, Mg, Fe, and Cu.

The first group of macronutrients are mostly required as building blocks of protoplasm. The second group plays a variety of roles at the functional level of the complex biological system. To name a few: S as basic constituent of proteins; K is involved in formation of sugars; Ca, a major component of cell walls, is also involved in maintaining acid base balance and contraction of muscle; Mg is critical to the structure of chlorophyll and energy transfer and Fe is required in electron transfer.

Micronutients: About 20 elements have been identified as micronutrients, for example, aluminium, boron, cobolt, iodine, manganese, nickel, selenium, tin zinc, etc. The list continues to grow and more elements are being identified essential to life processes. In general, it can be stated that many of the micronutrients play key roles in enzymatic activity.

The productivity of an ecosystem depends on the availability of the nutrients and solar radiation. The requirement of the organisms for the second group of the macronutrients and the micronutrients is usually so small in aquatic ecosystems that it is served by concentrations present in the environment of the organisms. However, often the productivity is limited due to the non-availability of the first group of macronutrients, particularly nitrogen and phosphorus. This section will describe the availability of these two nutrients in greater detail. In addition to acting as plant nutrients (food), these elements and many of their compounds are important in terms of the quality of water in the environment.

Nitrogen and its compounds: An understanding of the chemistry and biochemistry of nitrogen is a very important factor in the management of water quality. As an aid to this understanding, Figure 4 shows a simplified representation of the nitrogen cycle in nature. Many of the interactions shown in the diagram also apply in the aquatic environment as discussed below.

Nitrogen in the air is converted to ammonia through biolgical fixation, electrical discharge or chemical processes of fertiliser production.

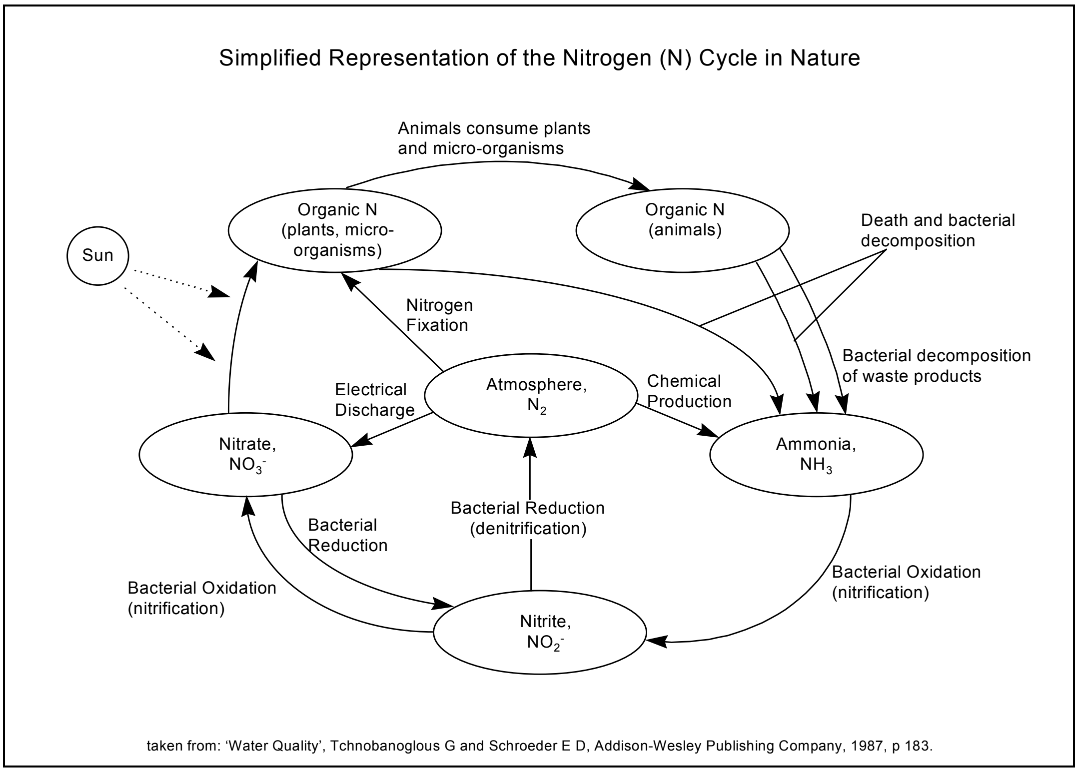

Figure 4: Simplified representation of the nitrogen cycle in nature

Water, which has been subject to pollution from organic waste materials, including sewage, often contains ammonia, either as free gas (NH_3) dissolved in water or as an ionic species (NH_4^+). The proportion of free gas to ionic ammonia depends upon the pH of the water.

Ammonia in water can be problematic in two ways. Firstly, the free (un-ionised) form of the gas is toxic to fish in very low concentrations (approximately 0.2mg/L can cause death in some species). Secondly, as can be seen from Figure 4, ammonia in the aquatic environment is normally oxidised by bacteria to nitrite (NO_2^-) and then nitrate (NO_3^-) in a process known as 'nitrification'. This process consumes dissolved oxygen in the water which can lead to distress or death for aquatic life if sufficient oxygen is lost.

Normally, the concentration of nitrite in water is low in comparison to the concentrations of ammonia and nitrate. This is because the rate of reaction of the oxidation of ammonia to nitrite is relatively slow in comparison to the rate of the nitrite to nitrate reaction. Thus, almost as soon as nitrite is produced it is oxidised to nitrate. Elevated concentrations of nitrite in water are normally associated with industrial discharges containing large quantities of the ion.

High concentrations of nitrate can also cause concern in the aquatic environment for two principal reasons. The first is that nitrate is an important factor in the eutrophication of surface waters (see below). The second reason is that they have been associated with methaemoglobinaemia (blue baby disease) in human infants. High nitrate concentrations often make river waters and groundwater unsuitable for extraction for potable supply without expensive treatment, therefore.

Plants convert nitrate to organic forms of nitrogen, which are taken up by animals, including humans, when they feed on vegetation. Organic nitrogen compounds are then excreted by animals or are released to the environment when animals die. Bacterial decomposition of waste products or the bodies of dead plants and animals produces ammonia. Nitrates are also reduced by denitrifying bacteria into nitrogen gas so completing the nitrogen cycle as seen in Figure 4.

Phosphorus and its compounds: A simplified phosphorus cycle is shown in Figure 5. Phosphorus may be added to the ecosystem through overland flow and lost to marine deposits through export of bones.

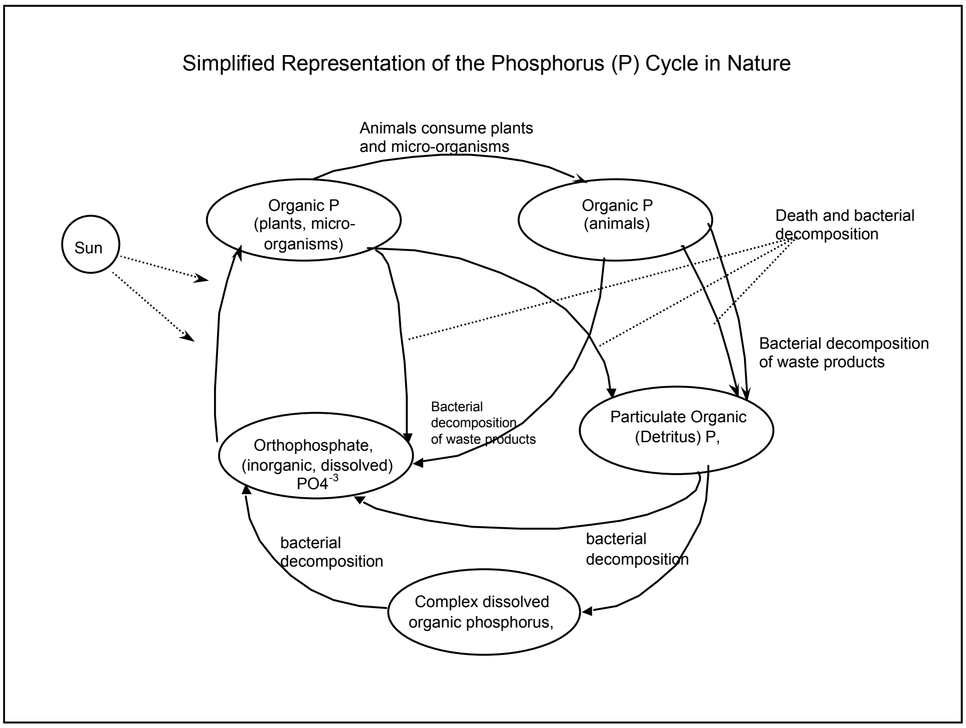

Figure 5: Simplified representation of the phosphorus cycle in nature

Total phosphorus is composed of 2 principal components:

- Organic phosphorus (primarily particulate) and
- Inorganic phosphorus (primarily dissolved orthophosphate)

The inorganic phosphorus form consists primarily of dissolved reactive phosphorus, (orthophosphate) that is available for plant growth. Orthophosphate (H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}) is the only form of phosphorus which can be used by most living things, and it is converted to organic phosphorus by plants. Herbivores and other animals in the food chain use organic phosphorus for their growth.

When plants and animals die, organic phosphorus is converted back to inorganic dissolved orthophosphate by bacterial decomposition. This occurs directly, or via an intermediate step in which first detritus is formed, and then the detritus is decomposed to orthophosphate.

In this way, phosphorus in the environment switches between its organic and inorganic forms due to the action of bacteria in much the same way as nitrogen does.

5. Eutrophication

Natural waters may be classified, according to their ability to support life, as oligotrophic, mesotrophic and eutrophic.

Oligotrophic waters contain low concentrations of essential nutrients such as nitrogen and phosphorus, and life forms are present in only small numbers. Natural processes of growth, death and decay as well as input of nutrients from runoff result in a gradual increase in nutrient concentrations, and the waters become increasingly productive. The terms mesotrophic and eutrophic are used to describe these progressive states.

Mesotrophic waters are characterized by the abundance and diversity of life forms at all trophic levels. Eutrophic waters characteristically have fewer species present, but the concentration of algae is particularly high. While the process of eutrophication can be a natural one, in most eutrophic water bodies, it is human impact, such as discharge of municipal and industrial wastes and agricultural runoff, that has caused the condition by the input of excessive amounts of nutrients.

If sufficient concentrations of nutrients are present, there is sometimes an unnatural, explosive growth of algae or other aquatic plants in water bodies. Eutrophication is the excessive growth of aquatic plants, both attached and planktonic. Once this abnormal mass of algae/plants die, they tend to sink to the bottom of the water, where their cells are decomposed by bacteria which leads to reduction in the dissolved oxygen in the water (in severe cases to zero concentration). Waters which are eutrophic can appear to be thick and green, or have rotted, stinking mats of decaying plants. High nutrient inputs to water, and the increased growth of aquatic plants (eutrophication) have several consequences regarding water quality:

- Aesthetic and recreational interferences – algal mats, decaying algal clumps, odors, and discoloration may occur.
- Large diurnal variations in dissolved oxygen (DO) can result in low levels of DO at night. This in turn can lead to the death of fish species
- Phytoplankton and other plants settle to the bottom of the water system and create a sediment oxygen demand which results in low values of DO in the deeper waters of lakes and rivers.
- Large diatoms (phytoplankton that require silica) and filamentous algae can cause clogging in water treatment plant filters.

- Extensive growth of rooted aquatic macrophytes (larger plant forms) can interfere with navigation, aeration and channel carrying capacity.
- Toxic algae have sometimes been associated with eutrophication in coastal regions and have been implicated in the occurrence of ‘red tide’ which causes paralytic shellfish poisoning.

The level of eutrophication due to excessive amounts of phytoplankton can be measured using several criteria:

- Counts (numbers/ml) of specific phytoplankton species. This requires a considerable effort by trained specialists in phytoplankton identification, thus is difficult to measure.
- Cell volume ($\mu m^3/\mu l$) of species. This measure requires an extensive analytical and data reduction effort.
- Chlorophyll-a concentrations ($\mu g/l$). Chlorophyll a is a measure of the gross level of phytoplankton, and is easily obtained without extensive effort in the laboratory. This has become the most common measure used in eutrophication studies. However, chlorophyll does not provide information on species levels nor does it permit grouping into classes of phytoplankton.

As discussed above, the presence of both nitrogen and phosphate are necessary for eutrophication to occur. However, because the concentration of phosphate is almost always lower than that of nitrogen, the growth of algae and the onset of eutrophication is usually controlled by the amount of phosphorus present in the water. If this is the case the concentration of phosphorus is said to be ‘limiting’. Further, nitrogen can be fixed from the air by certain species of algae.

Another consequence of eutrophication is that it induces wide daily variations in the dissolved oxygen concentration. This is due to the fact that algae are net producers of oxygen via photosynthesis during daylight hours but net consumers of oxygen through respiration during darkness. The oxygen concentration in the water is therefore very high during the day and low at night. This daily cycle can also be observed in the pH of the water body which also varies widely. This variation is due to the fact that algae consume acidic carbon dioxide gas during the day and release it at night.

Such wide variations in the chemical parameters of a eutrophic water body can lead to significant implications for the health and use of the water. Fish for example can become stressed if ammoniacal nitrogen is present in the water because as pH increases more toxic free ammonia (NH_3 gas) is produced. Further, excessive algal growth can cause problems with treatment of the water if it is to be used as a drinking water source.

Care needs to be taken when monitoring surface waters that are thought to be eutrophic. This is because, the existence of daily cycles of pH, carbon dioxide and dissolved oxygen can give a false impression of the health of the stream if the time of day of sampling is not taken into account when analysing the data collected.