The movement of water in the landscape occurs through soil. Soil has varying capacity to absorb the water depending on its physical properties and the vegetation cover which again depends on the land use type. When precipitation occurs at a rate that is equal to or greater than the rate of soil infiltration, the excess water flows under the influence of gravity as runoff towards the stream (Diwan and Arora, 1995). In the present riverine system, the soil was sandy in texture (Table 5.1), which is commonly too loose and lacks the capacity to absorb and hold sufficient moisture and nutrient and is very susceptible to the loss of nutrient due to leaching (Bouwman, 1990a). Agren and Bossatta (1998) reported that leaching indicates high soil N availability and N saturation, a condition when the N availability exceeds the nutritional demand of plants and microorganisms. In this context, it may be mentioned that with heavy rainfall there was loss of the excess nitrates and phosphates particularly when the vegetation cover was not well established (Toky and Ramakrishnan, 1981; Mishra and Ramakrishnan, 1983a) as in case of the watersheds of Pachin and Dikrong (where canopy cover in the river bank was less; Table 3.1) that got accumulated in the lowland areas of river bed and river line with runoff water and thus ultimately lead to a hike in the nutrient concentration of the river water in the low-lying areas. In this context, it may be mentioned that a certain amount of erosion and sedimentation occur naturally which is also important for the aquatic system as they supply nutrient to the aquatic communities (Kordel et al., 1997; Brils, 2004) and complete control of sedimentation and erosion would lead to starvation of the aquatic communities and hence can lead to stream instability (Kordel et al., 1997). The detritivores of streams
and the sediment communities of slow-flowing rivers depend upon the organic matter for most of their energy (Moss, 1998). In the riverine ecosystem, three major components of organic matter can be identified: the refractory allochthonous material, the relatively labile autochthonous contribution and the anthropogenic input into the river (Kordel et al., 1997). Input of organic matter into the riverine ecosystem can be attributed to patterns of sediment erosion and land use (Hopkinson and Vallino, 1995). The main difference between natural organic input and gross organic pollution are that the former tends to be large packets, such as leaves, with a low surface to volume ratio, or is relatively refractory when finely divided, while the latter is usually soluble or finely divided and very labile. Organically polluted water rapidly becomes deoxygenated (Moss, 1998). In this context, it may be mentioned that in river Pare the organic input was mainly in the form of leaves, dead twigs etc. while in Pachin and Dikrong the organic input mainly comprised of soluble matters which came mainly from the human inhabited areas in the from of sewage. Roots of riparian vegetation in particular may impede stream bank erosion by water, thus decreasing sediment inputs to streams and rivers. Nevertheless, species and community response to disturbance are related not only to the severity and frequency (Grime, 1977) but also the nature of disturbance (Pandey and Singh, 1985), the resource requirement of the individual species (Armesto and Pickett, 1985) and the vegetation type (Shackleton et al., 1994). Thus, the vegetation plays an important role on the soil and nutrient transfer processes in riparian zones and ultimately in the river system.

Vegetation cover counteracts the runoff mechanisms in several ways, viz. increasing soil moisture, increasing seepage, increasing percolation, retaining maximum amount of water etc. (Pande, 1991). Riparian systems are now recognized as being integral and important components of watershed (Books et al., 1998). In this
regard, it may be mentioned that greatest diversity of riparian vegetation was found along the river bed of Pare at Sagalee and least in the river bed of Dikrong at Karsinghsa, followed by Pachin at Barapani thereby revealing least disturbed state in Pare at Sagalee and greater disturbance in river beds of Pachin at Barapani and Dikrong at Karsinghsa (Table 9.9). Because riparian region contains plant biomass, it is often assumed that plant uptake contributes substantially to their ability to affect water quality (Jhonston et al., 2001) and the rate of change of biomass i.e. productivity may be a product of disturbance (Lisa and Poul, 1996) as well as an index of fertility of an ecosystem (Odum, 1971). In this context, it may be mentioned that both the biomass and productivity of above and below-ground components of riparian vegetation along the river system of Dikrong was greater in Pare, followed by Dikrong and it was least in Pachin (Figure 10.4), thereby reflecting relatively better state in the riparian zone of Pare and the unhealthy condition existing along the riparian region in Pachin. In this context, it may be mentioned that in river Pachin, the nutrient concentration in the water was higher (Table 4.1) that showed a greater amount of draining out of nutrients from the river bank of Pachin which, otherwise would have been transferred to the biomass of the riparian vegetation thereby indicating the scarcity of the riparian vegetation along river Pachin. Nevertheless, it is expected that the wetland vegetation could absorb the excess nutrients instead of flushing it into the river and thus contributing to the nutrient conservation against runoff and leaching losses to the river water.

Soil microorganisms comprise the living portion of the soil (Wright and Coleman, 2000). Ecosystem functions that lead directly to soil nutrient transformations and pollutant neutralization, and indirectly to plant community composition, are dependent upon the soil microbial community (Atlas and Bartha,
The microbial biomass is the qualitative indicators of soil fertility and the changes in the microbial biomass can be used to predict the effect of ecosystem perturbations (Jenkinson and Powlson, 1976; Jenkinson, 1988; Diaz-Ravina et al., 1988; Hernot and Robertson, 1994). In this context, it may be mentioned that the microbial biomass C in the river bank of Pare at Sagalee and Kheel and Pachin at Barapani (Table 6.2) was comparable with the range for Vance et al. (1987) (61-2000 µg g⁻¹), but in the river bank of Dikrong (at Doimukh, Nirjuli and Karsinghsa) it did not fall within the range (32.03 -137.47µg g⁻¹) thereby indicating that the organic matter in the soil and sediment of Dikrong was less than the threshold limit (Table 5.2) which might be partly due to the coarse texture of the soil (Table 5.1) where natural addition of organic residue is generally low and partly due to the denudation of vegetation due to human habitation and grazing (Table 3.1) resulting in less accumulation of litters which is the primary source of nutrients for the microbes. In all the stations, microbial biomass nitrogen was more than the reported range by various authors for broad leaved deciduous and evergreen forest (Diaz-Ravina et al., 1988); coniferous forest (Martikinen and Palojarvi, 1990) and regrowing sub-tropical forest (Maithani et al., 1996) (Table 6.2) thereby showing the adequate nitrogen concentration in the soil of the study area (Table 5.2), whereas the microbial biomass phosphorous was much below the reported range (Table 6.2) for arable land, grassland and woodland soils (Brookes et al., 1984) thereby indicating that the availability of P in the soil was less than the threshold limit in the study area (Table 5.2).

In addition to the above information on the microbial biomass nutrient in the catchment area, the various results of the physico-chemical properties of water of the river system of Dikrong showed that the river water at Pachin was relatively more...
enriched followed by Dikrong and Pare (Table 4.1). The nutrients in the catchment area which were left after being absorbed into the soil, sediment, microbes and vegetation in the river bank and river bed ultimately find the way to the river line thereby increasing the nutrient concentration of sediment (Table 5.2) and water (Table 4.1) of the river system. The results on the microbial biomass nutrients along the riverine system of Dikrong (Table 6.2) again indicated that the rate of nutrient input along the river bank was highest in Pachin at Barapani where there was excess input of sewage, household wastes, piggeries and faecal matters. In the river bank of Pare at Sagalee and Kheel, the rate of disturbance was very less and the source of nutrient for the microbes was mainly the vegetation though a slight amount of animal source was prevalent at Kheel. In the river bank of Dikrong though there was human habitation and the related biotic disturbances the physico-chemical properties of water was satisfactory except during monsoon thereby indicating that rate of nutrient input in Dikrong was less than that in Pachin.

Biodiversity represents not only the organisms living in an area and the ecological processes necessary for their maintenance but includes the interactions between these two components which can be translated in the capacity of the ecosystem to support a number of living forms (Barbosa et al., 1997, 1999; Galdean and Staicu, 1997). Rivers, as very dynamic ecosystems, reflect the quality and health of the entire watershed since they receive not only organic matter (leaves, branches, fine detritus), which is very useful for the aquatic metabolism, but also a huge range of wastes, of which nutrients and pesticides from agriculture and effluents from industries are examples (Barbosa et al., 1999). Depending on the quality and quantity of these inputs, aquatic ecosystems may well use these allochthonous contributions to their advantage thus enhancing the existing biodiversity. In this context, the diversity
of the riparian vegetation, phytoplankton, zooplankton, periphyton and benthic macroinvertebrate communities was taken into account along the six stations under different land use systems in the river system of Dikrong.

Among the phytoplankton, there were a total of 43 taxa belonging to family Bacillariophyceae, Chlorophyceae, Cyanophyceae, Xanthophyceae and Euglenophyceae out of which Dikrong had a total of 26 taxa (Table 7.1). Among the periphyton, there were a total of 22 taxa belonging to family Chlorophyceae, Bacillariophyceae and Cyanophyceae out of which a total of 12 taxa were found in Dikrong (Table 7.2). Among the zooplankton, a total of 13 taxa belonging to class Branchiopoda, Copepoda, Protozoa, Rotifera and Arachnida were found in the study area out of which Dikrong had a total of 9 taxa (Table 7.3). Among the benthic macroinvertebrates, a total of 53 families belonging to order Ephemeroptera, Plecoptera, Trichoptera, Odonata, Hemiptera, Decapoda, Diptera, Coleoptera, Megaloptera, Gastropoda, Oligochaeta, Turbellaria and Rhabditida were found in the study area out of which Dikrong had a total of 32 families belonging to all the 13 orders (Table 8.1). Among the riparian vegetation, there was a total of 80 species of plants along the riparian zone of the river system of Dikrong belonging to 31 families out of which Dikrong had a total of 59 species belonging to 25 families (Table 9.1).

Various diversity indices were used in order to assess the diversity of the different communities in the river system of Dikrong along a disturbance gradient. The diversity indices of the riverine communities (Phyto- and zooplankton, periphyton and benthic macroinvertebrates) in the study area did not show any definite trend in relation to disturbance (Figures 7.12, 7.13, 7.14 and 8.6) whereas the diversity indices of the riparian vegetation (Table 9.9) showed definite patterns in relation to disturbance. In this context, it may be mentioned that diversity index is a synthetic
measurement of biological structure that incorporates two aspects, the number of taxa (richness) and the distribution in the number of individuals among taxa (evenness). Historically, many researchers have assumed that as ecosystem quality improves there is a corresponding increase in the number of species and a corresponding increase in diversity (Odum, 1971). Some researchers question the validity of that assumption, especially as it relates to the aquatic communities (Washington, 1984). Diversity indices originally were designed for terrestrial ecosystem by ecologist as a community structure tool which work well in the terrestrial environment. Wilhm and Dorris (1966) and Wilhm (1967) were the first to use a diversity index along a water quality scale to quantify the level of water pollution. Diversity indices worked well for their localized studies, but it was not intended to use widely.

The strategies of using allochthonous inputs are a normal function of the riverine ecosystem which can be assessed through the analysis of the functional component. In this regard, the phytoplanktonic productivity and chlorophyll $a$ concentration in periphytonic community was taken into consideration. The study showed that the net phytoplanktonic productivity was highest in river Pachin at Barapani (Table 7.10) where the nutrient concentration in the water was also very high and the least value was in river Dikrong at Karsinghsa where there was more siltation (Table 3.1). The chlorophyll $a$ concentration in the periphyton community was highest in river Pare at Sagalee where the water was most transparent with high flow rate and it was lowest in river Dikrong at Nirjuli where the water had low nutrient concentration with light limiting condition (Figure 7.17).

Studies by Lammert (1995), Lammert and Allan (1999) showed that local riparian land use was important in the stream ecosystem functions whereas a study by Roth et al. (1996) suggested that watershed-wide land use was most important for the
stream biotic integrity. The present study revealed the importance of both the local riparian land use as well as the watershed-wide land use in changing the physico-chemical and biological parameters of river water and sediment as well as a change in the diversity of the aquatic community. One of the important observations that was made from the present study, was that, the physico-chemical and microbial properties of the soil in the catchment and to some extent the sediment in the riparian region were completely depended on the local land use pattern but the qualitative study of the river water showed that it was not only dependent on the watershed characteristics of that particular region but also on the watersheds in the upstream area due to confluence of the river water as the river flows downstream.

It can be mentioned here that the total global water resource comprises 94% salt water (ocean and sea), 2% ice (polar ice caps and glaciers) and only 4% freshwater. Out of this total (4%) fresh water, only 1.5% is available in rivers, lakes, streams; etc. Understanding how lotic communities respond to combinations and gradients of physical disturbance and nutrient inputs is important for the practical management of the limited stream ecosystems, and to add to our knowledge of stream ecology. The present findings showed that conversion of land from forest to almost any other land use promotes overland flow of storm runoff; increases the timing, rate and magnitude of runoff; and increases sediment, organic matter, and inorganic nutrient export which is also corroborated by the finding of Hopkinson and Vallino (1995). It was seen that in the river bank of Pare in the least disturbed site of Sagalee, there was relatively more canopy cover with absence of human settlement which lead to more bank stability (Table 3.1) resulting in less nutrient leaching in the runoff water that flowed downstream as was also indicated by the less nutrient concentration in the river water in Pare at Sagalee. On the other hand, in the watershed area
underlying river Pachin, the disturbance intensity was highest because of unplanned urbanization and increased human habitation along the river bank with a very little canopy cover (Table 3.1) which resulted in an increased nutrient loss from the watershed that ultimately go down into the river as was also indicated by highest level of nutrient concentration into the river water of Pachin (at Barapani). In Dikrong which was in the intermediate state of disturbance in relation to human habitation and canopy cover (Table 3.1) there was also occurrence of nutrient loss due to runoff from the catchment area. Among the three stations of river Dikrong (Doimukh, Nirjuli and Karsinghsa), though the station at Karsinghsa had more nutrient concentration in the water as compared to the other two stations, there was not much variation in the physico-chemical properties amongst the three Dikrong subsections as was also shown by the results of ANOVA (Table 4.5), probably because of the fact that all the three stations are located within the same watershed area with more or less similar land use pattern. But when the physico-chemical properties of water for the six stations based on seasonal sampling were statistically analyzed using ANOVA it showed significant differences in some of the water properties (Table 4.4). The various results therefore, indicate that, the relationship between nutrient concentrations in the water and sediment and the communities of the phytoplankton, zooplankton, periphyton and benthic macroinvertebrates as well as the phytoplanktonic productivity and the chlorophyll a concentration in the periphyton community was mediated by landuse pattern as well hydrologic regime in the study area.

Over all, the results revealed that the water in river system of Dikrong was not polluted to that extent, except during monsoon when the water quality slightly dropped down due to input of several allochthonous materials in large quantity because of
greater runoff and leaching. However, a continuous monitoring for various parameters in the riverine ecosystem is warranted to avoid the risk of pollution because of rapid urbanization and increased traffic influx in order to maintain and enhance the diversity of the various riverine communities. The present study also showed that a watershed is an integrated unit and what is done in one part of the unit may have a major effect on others in terms of the water quality. Thus, restoration of ecosystem function in streams and rivers clearly requires to be looked beyond the banks, to the quality of the riparian and perhaps the entire landscape. Preventive or precautionary measures should be taken in hand before the problem starts and planning ahead is an important step toward success particularly in case of the riverine ecosystem that are diminishing in size and quality these days.

Based on the present research data and periodical site observations, the following measures are suggested and/or recommended for effective management of the river system of Dikrong.

- Establishment of river boards or river authorities with responsibilities for developing the entire basin or sub-basin.
- Sources of direct pollution such as defecation along the river bank and river bed should be immediately stopped and poor communities should be provided with at least low cost sanitation facilities.
- Dumping of municipal wastes and garbage should be restricted immediately and these can be converted to biogas and organic fertilizer through proper treatment plant for recycling of resources.
- There should be appreciation of the holistic concept of environment and interlocking, interdependent concept of ecosystem particularly by the industrialist, planners, decision makers, politicians and the common man. Here comes the role of environmental education through various formal and non-formal sectors.
• Integrated solutions should be found in the context of the whole river system and in close interaction with the stakeholders and the solutions need to respect natural processes and functioning through an environmental audit.

• To ensure active participation of the landless and other economically weaker sections in the management of the watershed, generation of alternative income, job opportunities in watershed management, suitable activities like management of common property resources both during and after the project should be entrusted to these groups to give them a sense of responsibility and belonging as well as provide them suitable economic incentives on a continuing basis. There should be a switch over from supply-driven to demand driven activities.

• Preservation of the riparian forest through maintenance of existing forest and restoration of forest in the impacted areas. Only a corridor of forest along the river may be needed. Either the biosphere reserve model or the community sanctuary model may be implemented so that development would be controlled within the riparian forest zone.

• Protection of the riparian region as it has the potential to absorb certain elements in runoff water and thereby buffer and protect the river from non-point source pollution besides it provides detritus input from litter fall which is recognized as an energy source driving food webs in the stream ecosystem. Riparian land use and management appear to be more important than upland land use in shaping instream physical habitat at local scales.

• Improvement of grazing lands by the introduction of grasses and legumes with good nutrition value and palatability so that there is no farther pressure on the riparian region which otherwise causes erosion of the soil into the riverine ecosystems due to trampling by livestock.

• Prevention of running of vehicles along the riparian zone of Dikrong.

• Promotion of three-tier cropping systems integrating tree species in contour trenches.

• Provision of runoff disposal through drop stairs and grassed waterways in the watershed.

• Land should be used in accordance with the ecology, capability and needs of the region and area.
• Mechanical conservation practices such as conservation terraces, strip cropping and counter cropping can be used to reduce slope length and steepness. Terraces can be combined with grass waterways as it can prevent erosion in the channel when water flows through it.

• Introduction of vegetative filter strips between the catchments and surface waters can be effective in reducing sediment and nutrient loads in runoff waters. As the nutrient poor coarse textured soil is incapable of sustaining healthy tree growth so there must be a cover of grasses and other herbaceous vegetation along the riparian region of the rivers. Native plant diversity (including genetic, species, and community diversity) should be maintained over time by retaining as much of the riparian area as possible in a natural vegetated, undisturbed condition.