Aquatic Ecosystems: Conservation, Restoration and Management

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INTRODUCTION

Aquatic ecosystems contribute to a large proportion of the planet's biotic productivity as about 30% of the world's primary productivity comes from plants living in the ocean. These ecosystems also include wetlands located at lake shores, river banks, the ocean shoreline, and any habitat where the soil or vegetation is submerged for some duration. When compared to terrestrial communities, aquatic communities are limited abiotically in several different ways (http://www.usgs.gov).

- Organisms in aquatic systems survive partial to total submergence. Water submergence has an effect on the availability of atmospheric oxygen, which is required for respiration, and solar radiation, which is needed in photosynthesis.
- Some organisms in aquatic systems have to deal with dissolved salts in their immediate environment. This condition has caused these forms of life to develop physiological adaptations to deal with this problem.
- Aquatic ecosystems are nutritionally limited by phosphorus and iron, rather than nitrogen and
- These are generally cooler than terrestrial systems which limit metabolic activity.

Global Scenario

The earth, two-thirds of which is covered by water, looks like a blue planet—the planet of water—from space (Clarke, 1994). The world's lakes and rivers are probably the planet's most important freshwater resources. But the amount of fresh water constitutes only 2.53% of the earth's water. On the earth's surface, fresh water is the habitat of a large number of species. These aquatic organisms and the ecosystem in which they live represent a substantial sector of the earth's biological diversity. The association of man and aquatic ecosystem is ancient. It is not surprising that the first sign of civilization is traced to wetland areas. The flood plains of the Indus, the Nile delta, and the Fertile Crescent of the Tigris and Euphrates rivers provided man with all his basic necessities. Water may be required for various purposes like drinking and personal hygiene, fisheries, agriculture, navigation, industrial production, hydropower generation, and recreational activities. The wide variety of wetlands, like marshes, swamps, bogs, peat land, open water bodies like lakes and rivers, mangroves, tidal marshes, and so forth, can be profitably used by humans for various needs and for environmental amelioration. Ever-increasing population and the consequent urbanization and industrialization have mounted serious environmental pressures on these ecosystems and have affected them to such an extent that their benefits have declined significantly.

It is interesting to know that there are nearly 14×10^8 cubic km of water on the planet, of which more than 97.5% is in the oceans, which covers 71% of the earth's surface. Wetlands are estimated to occupy nearly 6.4% of the earth's surface. Of those wetlands, nearly 30% is made up of bogs, 26% fens, 20% swamps, and 15% flood plains. Of the earth's fresh water, 69.6% is locked up in the continental ice, 30.1% in underground aquifers, and 0.26% in rivers and lakes. In particular, lakes are found to occupy less than 0.007% of world's fresh water (Clarke, 1994). This amount of water is found in lakes, rivers, reservoirs, and those underground sources that are shallow enough to be tapped at an affordable cost. Only this amount is regularly renewed by rain and snowfall, and is therefore available on a sustainable basis.

Indian Scenario

India by virtue of its geography, varied terrain, and climate is blessed with numerous rivers and streams that support a rich diversity of inland and coastal wetland habitats. Major river systems in the north are Ganga, Yamuna, and Brahmaputra (perennial rivers from the Himalayas) and in the south, Krishna, Godavari, and Cauvery (not perennial, as they are mainly rain-fed). The central part of India has the Narmada and the Tapti. The Indo-Gangetic floodplain is the largest wetland regime of India. Most of the natural wetlands of India are connected with the river systems. The lofty Himalayan mountain ranges in northern India accommodate several well-known lakes, especially the palaearctic lakes of Ladakh and the Vale of Kashmir, which are sources of major rivers. In the northeastern and eastern parts of the country are located the massive floodplains of Ganga and Brahmaputra along with the productive system of swamps, marshes, and oxbow lakes. Apart from this, there exists a number of man-made wetlands for various multipurpose projects. Examples are Harike Barrage at the confluence of the Beas and the Sutlej in Punjab, Bhakra Nangal Dam in Punjab and Himachal Pradesh, and the Cosi Barrage in Bihar-Nepal Border. India's climate ranges from the cold, arid Ladakh to the warm, arid Rajasthan, and India has over 7,500 km of coastline, major river systems, and mountains. Terrestrial ecosystems range from wet evergreen to deciduous forests in the Western ghats and north-east, scrub/plains in deccan plateau and gangetic plains amidst the mountain ranges.

There are 67,429 wetlands in India, covering about 4.1 million hectares. Out of these, 2,175 wetlands are natural, covering about 1.5 million hectares, and 65,254 wetlands are man-made, occupying about 2.6 million hectares.

According to Forest Survey of India, mangroves cover an additional 6,740 sq km. Their major concentrations are Sunderbans, and Andaman and Nicobar Islands, which hold 80% of the country's mangroves. The rest are in Orissa, Andhra Pradesh, Tamilnadu, Karnataka, Maharashtra, Gujarat, and Goa.

Wetlands have been drained and transformed due to anthropogenic activities, like unplanned urban and agricultural development, industries, road construction, impoundments, resource extraction, and dredge disposal, causing substantial economic and ecological losses in the long term. They occupy about 58.2 million hectares, of which 40.9 million hectares are under paddy cultivation. About 3.6 million hectares are suitable for fish culture. Approximately 2.9 million hectares are under capture fisheries (brackish and freshwater). Mangroves, estuaries, and backwaters occupy 0.4, 3.9, and 3.5 million hectares respectively. Man-made impoundments constitute 3 million hectares. Nearly 28,000 km are under rivers, including main tributaries and canals. Canal and irrigation channels constitute another 113,000 km (Rajinikanth, R. and Ramachandra, T.V., 2000).

Though accurate results on wetland loss in India are not available, the Wildlife Institute of India's survey reveals that 70-80% of individual fresh water marshes and lakes in the Gangetic flood plains have been lost in the last five decades. Indian mangrove areas have decreased by half from 700,000 ha in 1987 to 453,000 ha in 1995.

Karnataka Scenario of Aquatic Ecosystems

Karnataka state situated between 11° 31' and 18° 45' N latitude and 74° 12' and 78° 40' E longitude is endowed with numerous rivers, lakes, and streams, and has a coastline of about 320 km. Spatial extent of the state is 1,92,204 sq km (5.35% of the country's total geographical area) with a population of 52 million. Mean annual rainfall varies from 3,932 (Dakshina Kannada) to 140 mm (Bijapur). The wetlands of Karnataka are classified into inland and coastal categories, both natural and man-made. Natural inland wetlands include lakes, ox-bow lakes, and marshes/swamps; man-made inland wetlands include reservoirs and tanks. Natural coastal wetlands include estuaries, creeks, mudflats, mangroves, and marshes; while man-made coastal wetlands includes salt pans.. Wetlands cover about 2.72 million hectares, of which inland wetlands cover 2.54 million hectares, and coastal wetlands 0.18 million hectares. The area of 682 wetlands, scattered throughout the state of Karnataka, is about 2,718 sq km, of which seven are natural inland wetlands (581.25 ha), 615 are man-made inland wetlands (253,433.75 ha), 56 are natural coastal wetlands (16,643.75 ha) and four are man-made coastal wetlands (1,181.75 ha). Inland wetlands cover 93.43% (254,015 ha) of the total wetland area while coastal wetlands cover only 6.57 % (17,825.5 ha). Tanks (561) account for 79,088 ha; followed by reservoirs (53), which cover about 174,290 ha; lakes, which occupy about 438 ha; and mangroves, which account for 550 ha. Karnataka includes the basins of Krishna (58.9%), Cauvery (18.8%), Godavari (2.31%), North Pennar (3.62 %), South Pennar (1.96%), Palar (1.55%), and west flowing rivers (12.8%) with drainage of 191,770 sq km. (Rege et al., 1996).

The total water spread area during pre-monsoon is about 204,054 ha, and 246,643 ha in post-monsoon. Out of the total wetlands in the state, 71 have shown water spread less than 56.25 ha (Rege et al., 1996). Water-spread area of lakes/ponds in post-monsoon is about 437.50 ha, and 368.75 ha in pre-monsoon. Reservoirs have shown considerable variations from post-monsoon (167,268 ha) to pre-monsoon (138,684.25 ha). Tanks also vary from 46,975.25 ha (post-monsoon) to 60,912.25 ha (pre-monsoon). Coastal wetlands, under constant influence from the sea, have no variation in terms of water spread area in all seasons. Most of the tanks dry up during pre-monsoon.

Ancient human societies have traditionally recognised water resources in practical as well as symbolic ways. Failure by modern societies to deal with water as a finite resource is leading to unnecessary destruction of rivers, lakes and marshes that provide us with water. This failure in turn is threatening all options for the survival and security of plants, animals, humans, etc. There is an urgent need for

- *Restoring and conserving the actual source of water*—the water cycle and the natural ecosystems that support it—is the basis for sustainable water management;
- *Environmental degradation is preventing us from reaching goals* of good public health, food security, and better livelihoods world-wide;

- *Improving the human quality of life* can be achieved in ways that also maintain and enhance environmental quality;
- *Reducing greenhouse gases to avoid the dangerous effects of climate change* is an integral part of protecting freshwater resources and ecosystems.

AQUATIC ECOSYSTEMS: CATEGORIES

Aquatic ecosystems could be categorised as

1. Open Sea which occupies about 90% of the total surface area of the ocean, and contains about 10% of all marine plant and animal species.
2. Coastal Zone which is the area of the ocean where water depth is less than 200 metres. Within the coastal zone are several unique habitats, such as
   - Estuaries—the saline waters of the ocean meet with fresh water from streams and rivers and these habitats are very productive due to accumulation of nutrients from fresh water runoff.
   - Tidal marshes—common in temperate areas, and are dominated by sedges and grasses.
   - Mangroves—common in tropical areas and have tree species.
   - Coral reefs—supported by warm shallow tropical water and comparable with tropical forests in density of individuals, species diversity, and types of life-forms. Corals are tiny organisms that build a calcium carbonate chamber for a home. Over long periods of time, the continued building of these homes creates a large accumulation of coral skeletons (http://www.geog.ouc.bc.ca).
3. Lakes and Reservoirs: Lakes are natural features formed from the accumulation of fresh water in depressions. Sources for the water include precipitation, runoff, stream flow, and groundwater flows while reservoirs are bodies of fresh water that are artificially created by humans. Lakes are categorised according to their nutrient status as:
   - Eutropic: rich in nutrients – nitrogen and phosphorous. These have usually large populations of plankton and zooplankton, have less diverse populations of fish, and are often depleted of dissolved oxygen during periods of warm temperatures. Humans have altered the nutrient status of many lakes through the addition of nitrates, urea, and phosphates. This process results in physical, chemical and biological changes in the system.
   - Oligotrophic: these are nutrient poor, often crystal clear and have low biotic productivity.
4. Rivers and Streams: These are created by the accumulation of runoff and groundwater into low lying channels. These constitute important components of the hydrologic system and move water from areas where precipitation exceeds evapotranspiration to lakes and oceans.

5. Fresh Water Wetlands: These are terrestrial habitats that are partially submerged by fresh water and include habitats like marshes, swamps, ponds, etc. These habitats support many different species of fish, birds, and animals. Plants and animals present in wetlands are more than terrestrial habitats, thus making them highly productive environments. Wetlands function as *ecotones*, transitions between different habitats, and have characteristics of both aquatic and terrestrial ecosystems.

Wetlands have often been described as the kidneys of the landscape because of the role they play in water and chemical cycles. Wetlands filter out sediment and pollution from the surrounding environment so that the water they discharge to rivers and lakes is cleaner. In this manner, wetlands act as both a sink and source, storing and passing on vital resources to their local environment.

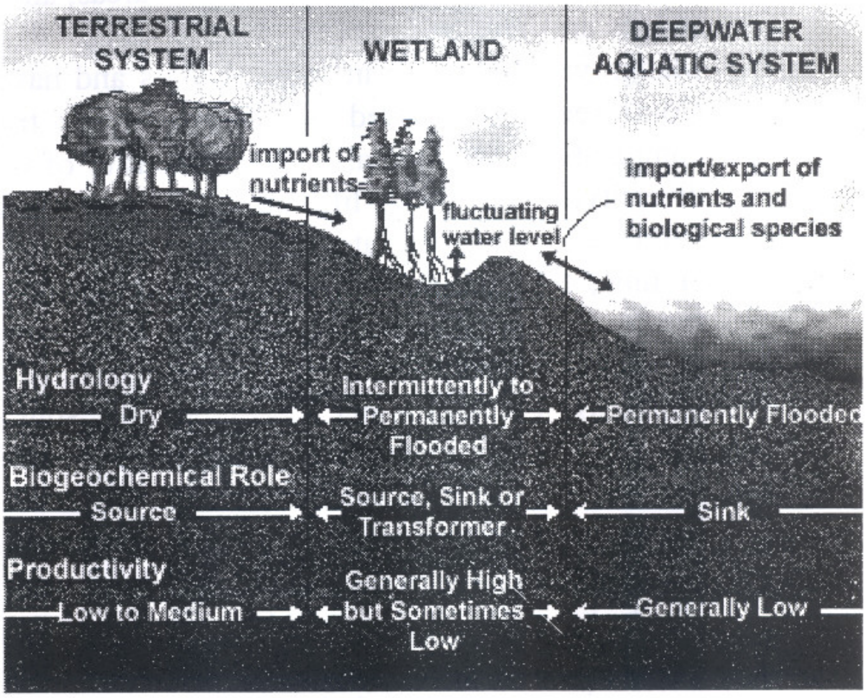

Fig. 1 Wetlands: Transition zone between aquatic and terrestrial ecosystems.

WATERSHED

River, pond, wetlands, lake or estuary is an ultimate destination of all water running downhill through an area of land, which is referred as watershed. A watershed is a catchment basin that is bound by topographic features, such as ridge tops and perform primary functions of the ecosystem (http://www.gdrc.org). It plays a critical role in the natural functioning of the ecosystem (Ahalya, N. and Ramachandra, T.V., 2002) such as:

- Hydrologically, watersheds integrate the surface water run-off of an entire drainage basin. It captures water from the atmosphere. Ideally, all moisture received from the atmosphere, whether in liquid or solid form, has the maximum opportunity to enter the ground where it falls. The water infiltrates the soil and percolates downward. Several factors affect the infiltration rate, including soil type, topography, climate, and vegetative cover. Percolation is also aided by the activity of burrowing animals, insects, and earthworms.
- It stores rainwater once it filters through the soil. Once the watershed's soils are saturated, water will either percolate deeper, or runoff the surface. This can result in freshwater aquifers and springs. The type and amount of vegetation, and the plant community structure, can greatly influence the storage capacity in any one watershed. The root mass associated with healthy vegetative cover keeps soil more permeable and allows the moisture to percolate deep into the soil for storage. Vegetation in the riparian zone affects both the quantity and quality of water moving through the soil.
- Finally, water moves through the soil to seeps and springs, and is ultimately released into streams, rivers, and the ocean. Slow release rates are preferable to rapid release rates, which result in short and severe peak instream flow. Storm events which generate large amounts of run-off can lead to flooding, soil erosion and siltation of streams.
- Ultimately, the moisture will return to the atmosphere by way of evaporation. The hydrologic cycle (the capture, storage, release, and eventual evaporation of water) forms the basis of watershed function. Economically, they play a critical role as sources of water, food, hydropower, recreational amenities, and transportation routes.
- Ecologically, watersheds constitute a critical link between land and sea; they provide habitat — within wetlands, rivers, and lakes — for 40 percent of the world's fish species, some of which migrate between marine and freshwater systems.
- Watersheds also provide habitat within the terrestrial ecosystems such as forests and grasslands for most terrestrial plant and animal species; and they provide a host of other ecosystem services — from water purification and retention to flood control to nutrient recycling and restoration of soil fertility — vital to human civilizations.

Hence, watershed should be managed as a single unit. Each small piece of the landscape has an important role in the overall health of the watershed. Paying attention primarily to the riparian zone, an area critical to a watershed's release function, will not make up for lack of attention to the watershed's uplands. They play an equally important role in the watershed, the capture and storage of moisture. It is seamless management of the entire watershed, and an understanding of the hydrologic process, that ensures watershed health.

Watershed-Based Approach to Resource Management

Each river system — from its headwaters to its mouth — is an integrated system and must be treated as such. The focus of water resource management is on wise and efficient use of water resources for such purposes as energy production, navigation, flood control, irrigation, and drinking water (Rajinikanth, R. and Ramachandra, T.V., 2001). It also places emphasis on improving ambient water quality. Watershed approach can provide benefits to individual citizens, the public sector, and the private sector. Individual citizens benefit when watershed protection improves the environment and the livability of an area. The watershed-wide participation of local citizens and organizations ensures that those who are most familiar with a watershed, its problems and possible solutions, play a major role in watershed stewardship. The private sector can benefit because the burden of water resource protection is distributed more equitably among pollution sources.

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from non-point and point sources as well as from habitat degradation. Watershed based planning and resource management is a strategy for more effective protection and restoration of aquatic ecosystems and for protection of human health. The watershed approach emphasizes all aspects of water quality, including chemical water quality (e.g., toxins and conventional pollutants), physical water quality (e.g., temperature, flow, and circulation), habitat quality (e.g., stream channel morphology, substrate composition, and riparian zone characteristics), and biological health and biodiversity (e.g., species abundance, diversity, and range).

To deal with non-point source pollution in an effective manner, a smaller and more comprehensive scale of analysis and management is required. While point source pollution control programmes encourage identifying isolated polluters, non-point source strategies recognize that small sources of pollution are widely dispersed on the landscape and that the cumulative impacts of these pollutants on water quality and habitat are great. A whole basin approach to protecting water quality has proved most effective because it recognizes connected sub-basins (Ahalya, N. and Ramachandra, T.V., 2002). This includes:

- Addressing issues of water quantity, protection of riparian areas, control of aquatic non-native species, and protection of water quality.
- Protecting the integrity of permanent and intermittent seeps, streams, rivers, wetlands, riparian areas, etc.
- Prioritising watersheds for protection and restoration and focus available resources on highest priorities. Also, identify subwatersheds in which to emphasize high water quality.
- Not implementing any timber management in riparian areas without proof that these activities actually increase coarse woody debris above natural

levels and the benefits outweigh the risks (sedimentation, oil and fuel runoff, etc).
- Conducting a comprehensive all seasons water quality monitoring.
- Eliminating commercial logging and unrestrained recreation in municipal watersheds.

Watershed Management Practices

Non-point source pollution poses a serious threat to the health of watersheds. It results from an accumulation of many small actions, and, although the individual impacts may seem minor, the combined cumulative effects are significant. Control measures and best management practices (BMPs) exist that can be utilized for improved watershed health (Kiran and Ramachandra, T.V., 1999). The effectiveness of the measures varies, depending on the specific pollutants addressed; the watershed hydrology and characteristics, such as soils, slopes, type of vegetative cover, and the nature and extent of area development; the waterbodies in the watershed; and the sources of the pollution. Effectiveness also depends on correct application of the control measure or practice. All types of land uses have the potential to create non-point source pollution. Most of this pollution results from changes and disturbances on the land. Some key sources include residential areas, agricultural activities and forest practices.

Residential problems stem from neighbourhoods containing typical single- or multi-family dwelling units. The problems arise from impervious surfaces that increase the flow and volume of runoff causing stream channel erosion and flooding, and from sedimentation from eroded lawns and gardens. Runoff can become contaminated by household chemicals such as fertilizers, pesticides and herbicides, paints, solvents, and street/auto contaminants like oil. The most effective control measures to address residential non-point source pollution include:

- public education
- use of vegetated swales and wetlands for contaminate filtration before runoff enters receiving streams
- sediment traps in stormwater systems
- stormwater retention (e.g. detached downspouts)
- landscape design for erosion control
- recycling and proper disposal of household chemicals and wastes
- proper maintenance of on-site septic systems to reduce nutrient loading
- combined sewer overflow management
- vegetative planting and riparian enhancement of neighbourhood streams
- street sweeping to reduce suspended solid loading and decrease heavy metals and phosphorus contamination to receiving streams
- planned development on steep slopes
- limited amount of impervious surface

- increased use of cluster developments
- utilization of erosion control ordinances, especially on construction sites.

Agricultural activities include land uses such as orchards, nurseries, crop production, feedlots, and grazing. Most non-point source pollution from agricultural practices comes from erosion or chemical contamination of receiving waters. The most effective control measures to address agriculture-related non-point source pollution include:

- riparian area protection and enhancement
- revised management practices for livestock grazing and manure handling.

Forestry practices generally lead to nonpoint source pollution problems of soil erosion and chemical contamination. The most effective control measures to address these problems include:

- technical assistance to landowners
- limits on road building and management
- use of erosion control standards
- chemical application controls (pesticides and herbicides)
- riparian area protection and enhancement.

This accentuates the need for healthier watersheds. Healthier watersheds would slow the runoff, increase percolation into underground aquifers, decrease siltation of waterways, and lengthen the flow period for the rivers.

Watershed management has worked for over a century in Tirunelvelli, where watershed recovered resulting in improved stream flow in less than five years when cattle grazing and fuelwood harvest were removed. The Palni Hills Conservation Council (PHCC) found that the watersheds of the Karavakurichi Reserve Forest improved in mere two years when fuelwood harvesters were given alternate employment in tree nurseries. Similar success stories are reported from dry arid districts like Ananthpur.

AQUATIC ECOSYSTEM: CONSERVATION STRATEGY

While rivers, lakes, and wetlands contain a mere 0.01% of the Earth's water, these ecosystems support a disproportionately large part of global biodiversity. Freshwater fishes alone account for approximately one quarter of all living vertebrate species and it is estimated that there are 44,000 scientifically named species of freshwater biota. Tallies of endangered species indicate that freshwater biodiversity is generally more threatened than terrestrial biodiversity. For example, of those species considered in the World Conservation Union's (IUCN) Red List for 2000, 20% of amphibians and 30% of fishes (mostly freshwater) were considered threatened. Freshwater biodiversity faces a broad range of threats. These include the direct impacts of dams, exotic species, overfishing, pollution, stream channelisation, water withdrawals, and diversions, as well as the indirect consequences of terrestrial activities such as logging, agriculture, industry, housing development, and mining (Prasad et al., 2002). Conservation strategies need to be evolved and implemented to protect freshwater biodiversity. The Aquatic Conservation Strategy focuses on conservation and maintaining the ecological health of watersheds and aquatic ecosystems so as to (Ramachandra, T.V. et al., 2002):

- Maintain and conserve the distribution, diversity, and complexity of watershed and landscape-scale features to ensure protection of the aquatic systems to which species, populations, and communities are uniquely adapted.
- Maintain and conserve spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include flood plains, wetlands, up slope areas and headwater tributaries. These linkages must provide chemically and physically unobstructed routes to areas critical for fulfilling life history requirements of aquatic and riparian-dependent species.
- Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.
- Maintain and preserve water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain in the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities.
- Maintain the sediment regime under which an aquatic ecosystem evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.
- Maintain in stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing (i.e., movement of woody debris through the aquatic system). The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.
- Maintain the timing, variability, and duration of flood plain inundation and water table elevation in meadows and wetlands.
- Maintain and conserve the species composition and structural diversity of plant communities in riparian zones and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration, and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.
- Maintain and conserve habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.
- Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding the various components, such as monitoring of water quality, socio-economic dependency, biodiversity, and other activities, as an

indispensable tool for formulating long term conservation strategies (Kiran & Ramachandra, 1999). This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programmes aimed at raising the levels of public awareness and comprehension of aquatic ecosystem restoration, goals, and methods. Actively participating schools and colleges in the vicinity of the waterbodies may value the opportunity to provide hands-on environmental education which could entail setting up laboratory facilities at the site. Regular monitoring of waterbodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

Watershed restoration should be an integral part of the conservation programme to aid recovery of habitat, riparian habitat, and water quality. The most important components of an aquatic restoration programme are control and prevention of pollution and sediment production, restoration of the condition of riparian vegetation, and restoration of in-stream habitat complexity (Ahalya, N. & Ramachandra, T.V., 2001).

RESTORATION OF AQUATIC ECOSYSTEMS

Due to various anthropogenic activities to cater the needs of growing population, the degradation of freshwater ecosystems by a variety of stressors has increased logarithmically. As a result, many aquatic ecosystems are in need of some drastic corrective measures/restoration. Restoration is the "return of an ecosystem to a close approximation of its condition prior to disturbance" or the reestablishment of predisturbance aquatic functions and related physical, chemical and biological characteristics (Gwin et al., 1999; Lewis, 1989; NRC, 1992; Race, M.S. & M.S. Fonseca, 1996). It is a holistic process not achieved through the isolated manipulation of individual elements. The objective is to emulate a natural, self-regulating system that is integrated ecologically with the landscape in which it occurs. Often, restoration requires one or more of the following processes: reconstruction of antecedent physical conditions, chemical adjustment of the soil and water; and biological manipulation, including the reintroduction of absent native flora and fauna (Zedler, J., 1996).

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values is to be considered. Coordination with the local people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area. In addition, partnership with all stakeholders can also add useful resources, ranging from finance and technical expertise to volunteer help with implementation and monitoring (Ramachandra T.V., 2001). Restoration principles are:

- *Preserve and protect aquatic resources:* Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems.
- *Restore ecological integrity:* Ecological integrity refers to the condition of an ecosystem — particularly the structure, composition, and natural processes of its biotic communities and physical environment.
- *Restore natural structure:* Many aquatic resources in need of restoration have problems that originated with harmful alteration of channel form or other physical characteristics, which in turn may have led to problems such as habitat degradation, changes in flow regimes, and siltation.
- *Restore natural function:* Structure and function are closely linked in river corridors, lakes, wetlands, estuaries and other aquatic resources. Reestablishing the appropriate natural structure can bring back beneficial functions.
- *Work within the watershed and broader landscape context:* Restoration requires a design based on the entire watershed, not just the part of the waterbody that may be the most degraded site. Activities throughout the watershed can have adverse effects on the aquatic resource that is being restored. By considering the watershed context in this case, restoration planners may be able to design a project for the desired benefits of restoration, while also withstanding or even helping to remediate the effects of adjacent land uses on runoff and non-point source pollution.
- *Understand the natural potential of the watershed:* Restoration planning should take into account any irreversible changes in the watershed that may affect the system being restored, and focus on restoring its remaining natural potential.
- *Address ongoing causes of degradation:* Identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible.
- *Develop clear, achievable, and measurable goals:* Goals direct implementation and provide the standards for measuring success. The chosen goals should be achievable ecologically, given the natural potential of the area, and socio-economically, given the available resources and the extent of community support for the project.
- *Focus on feasibility* taking into account scientific, financial, social and other considerations.
- *Anticipate future changes:* As the environment and our communities are both dynamic, many foreseeable ecological and societal changes can and should be factored into restoration design.
- *Involve the skills and insights of a multi-disciplinary team:* Universities, government agencies, and private organizations may be able to provide useful information and expertise to help ensure that restoration projects are based on well-balanced and thorough plans.
- *Design for self-sustainability:* Ensure the long-term viability of a restored area by minimizing the need for continuous maintenance of the site. In

addition to limiting the need for maintenance, designing for self-sustainability also involves favouring ecological integrity, as an ecosystem in good condition is more likely to have the ability to adapt to changes.

- *Use passive restoration, when appropriate:* Simply reducing or eliminating the sources of degradation and allowing recovery time will allow the site to naturally regenerate. For some rivers and streams, passive restoration can reestablish stable channels and floodplains, regrow riparian vegetation, and improve in-stream habitats without a specific restoration project. Passive restoration relies mainly on natural processes and it is still necessary to analyze the site's recovery needs and determine whether time and natural processes can meet them.
- *Restore native species and avoid non-native species:* Many invasive species outcompete natives because they are expert colonizers of disturbed areas and lack natural controls.
- *Use natural fixes and bioengineering techniques, where possible:* Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce living, functioning systems to prevent erosion, control sediment and other pollutants, and provide habitat. These techniques would be successful for erosion control and bank stabilisation, flood mitigation, and even water treatment.
- *Monitor and adapt where changes are necessary:* Monitoring before and during the project is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the project should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and can provide useful information for future restoration efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values should not be overlooked. The presence or absence of public support for a restoration project can be the difference between positive results and failure. Coordination with the people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area (Ramachandra, T.V. et al., 2002). Thus, a sustainable water system encompasses issues such as:

- Environment: watershed protection, ecosystem balance, waste-water and bio-solids.
- Community: sufficient and reliable water supply, participation in planning and recreational use to water.
- Economy: Evolution and diversification, sustainable and long-term growth.

Within this overall vision, water management system will require, among other steps, the following action to be taken:

- Through strategic partnerships among national agencies, provincial agencies and local/city departments.
- Developing alternate water sources—reclaimed/treated water, desalination, rainwater and water reuse.
- Implementing new technologies for water fees/metering, leak detection and water auditing systems.
- Engage the community through education, local and regional planning processes and outreach to cultural and community groups.
- Scientific investigations involving aquifer monitoring, coastal marine environment study, supply-demand forecasting and pollution prevention.

The principal components of water management system include:

- *Supply optimization*, including assessments of surface and groundwater supplies, water balances, wastewater reuse, and environmental impacts of distribution and use options.
- *Demand management*, including cost-recovery policies, water use efficiency technologies, and decentralized water management authority.
- *Equitable access* to water resources through participatory and transparent management, including support for effective water users association, involvement of marginalized groups, and consideration of gender issues.
- *Improved policy, regulatory and institutional frameworks*, such as the implementation of the polluter-pays principle, water quality norms and standards, and market-based regulatory mechanisms.
- *Intersectoral approach* to decision-making, and combining authority with responsibility for managing the water resource.

Water quality and quantity are becoming increasingly critical factors of socioeconomic development in many parts of the world. One of the milestones in managing international and transnational water resources and boundaries was the meeting and agreement on transboundary water management signed in Helsinki in 1966 (ILC Helsinki, 1966).

Helsinki rule evolved by the International Law Association in 1966 (see Annexure) are:

i) the geography of the basin including, in particular, the extent of the drainage area in the territory of each basin state;
ii) the hydrology of the basin including, in particular, the contribution of water by each basin state;
iii) the climate affecting the basin;
iv) the past utilization of the waters of the basin, including in particular, existing utilization;
v) the economic and social needs of each basin state;
vi) the population dependent on the waters of the basin of each state;

vii) the comparative costs of alternative means of satisfying the economic and social needs of each basin state;
viii) the availability of other resources;
ix) the avoidance of unnecessary waste in the utilization of the waters of the basin;
x) the practicability of compensation to one or more of the co-basin states as a means of adjusting conflicts among users; and
xi) the degree to which the needs of a basin state may be satisfied without causing substantial injury to a co-basin state.

POLICY OPTIONS

Burgeoning human populations coupled with agricultural and industrial developments increase the water requirements. As escalating need for food in dry climate areas increases the need for irrigation, water and water supply systems are increasingly becoming reasons for conflict. The development and implementation of a comprehensive forward-looking integrated water resources management scheme must include water law as an integral component. This is especially important in upstream/downstream situations where conflicts of water use are increasingly inevitable.

It is evident from recent water disputes/conflicts, that what has to be shared between those upstream and those downstream in a river basin is not the water currently going in the river (as suggested by the concerned authorities), but rather the rainfall over the river basin (which takes into account scarce rainfall period) and solutions should be based on sound economics, science, and enlightened and enhanced political commitment. In summary, policy:

1. Defines the legal entitlement to water and identifies the rights and obligations tied to water use and thus provides the prescriptive parameters for its development.
2. Provides the framework to ensure the ongoing integrity of the regime (i.e. monitoring, regulation, compliance, dispute avoidance and settlement).
3. Permits the rational modification of existing regimes (i.e. to meet changing needs).

Water development issues must be viewed in an overall context. In conflicts between upstream and downstream users, the scenario at all levels (national, regional and international) is much the same: the downstream user generally develops first and is keen to preserve into perpetuity these senior-in-time uses. The upstream user is thus placed in the unenviable situation of justifying the legitimacy of new uses, which almost certainly will adversely affect the existing uses downstream. Planning (the formulation of plans and policies) is an important and often indispensable means to support and improve operational management. Planning has six related functions, such as:

a) To assess the current situation (including the identification of conflicts and priorities), formulate visions, set goals and targets, and thus orient operational management.
b) To provide a framework for organising policy relevant research and public participation.
c) To increase the legitimacy, public acceptance of, or even support for operational management.
d) To facilitate the interaction and discussion among managers and stakeholders, offer a common point of reference (the plan or policy), and thus provide co-ordination. Planning should involve, in a systems framework, all phenomena, institutions and issues that affect the allocation and protection of inland waters. It should not result in negative effects on other natural resources and should consider linkages to plans for biodiversity management, coastal protection, ocean health, and human health and well being.
e) Planning should be focussed and coherent and be in proportion to the resources available for implementation. Planning should be rooted in the real problems to be solved and be realistic.
f) Planning systems should be evaluated to check whether they serve their purpose; planning systems should not be taken for granted; given the differences in problem situations and cultures, planning systems should reflect the local situation.

INTEGRATED AQUATIC ECOSYSTEM MANAGEMENT

Integrated aquatic ecosystem management requires proper study, sound understanding and effective management of water systems and their internal relations (groundwater, surface water and return water; quantity and quality; biotic components; upstream and downstream). The water systems should be studied and managed as part of the broader environment and in relation to socio-economic demands and potentials, acknowledging the political and cultural context. The water itself should be seen as a social, environmental, and economic resource, and each of these three aspects must be represented in the political discourse. This discourse should reflect the interests of local communities and people, their livelihoods and their aquatic environments. Users and managers at all levels must be allowed to have an input. The aim of integrated aquatic system management is to ensure the sustained multi-functional use of the system. The basic water needs of people and ecosystems should be fulfilled first. Essential ecological and physical processes should be protected. Moreover, the effects on the receiving water bodies (seas, lakes, deltas, coastal zones) should be paid full attention. The following points (Ramachandra, T.V. et al., 2002) need to be stressed as crucial for sustainable management:

- Should be applied at catchment level. The catchment is the smallest complete hydrological unit of analysis and management. Integrated catchment management (ICM), therefore, becomes the practical operating approach. Although this approach is obviously sound and finds wide acceptance, too narrow an interpretation should be avoided.

- Decentralisation should be pursued as much as possible in order to bring river basin management as close as possible to the individual citizens and facilitate local variation in response to differing local conditions and preferences. Decentralisation is also possible in case of tasks with a supra-local scope if the decentralised governments concerned co-operate (e.g. panchayaths in a river basin) or if they are supervised by a higher-level government body. The process should be transparent, phased and planned.
- It is critical to integrate water and environmental management. This principle is widely and strongly supported. Integrated aquatic ecosystem management can be strengthened through the integration of Environmental Impact Assessments (EIA's), water resources modeling and land use planning. It should also be understood that a catchment or watershed approach implies that water should be managed alongside the management of codependent natural resources, namely soil, forests, air and biota.
- Through a systems approach. A true systems approach recognizes the individual components as well as the linkages between them, and that a disturbance at one point in the system will be translated to other parts of the system. Sometimes the effect on another part of the system may be indirect, and may be damped out due to natural resilience and disturbance. Sometimes the effect will be direct, significant and may increase in degree as it moves through the system. While systems analysis is appropriate, analyses and models that are too complex to be translated into useful knowledge should be avoided.
- The only form of river basin management that directly affects the river basin and its users is operational management (the application of regulatory, economic and communicative policy instruments and concrete activities such as infrastructure management). Consequently, it should play a pivotal role in any river basin management strategy. Planning, policies, analytical tools and institutional systems play an essential role as deciders and facilitators. They can improve operational management, promote a basin-wide, intersectoral long-term approach, and in this way further the sustained multi-functional use of the basins concerned (Rajinikanth, R. & Ramachandra, T.V., 2001).
- Communicative instruments for operational management, such as voluntary agreements, can help to improve the implementation of river basin plans and policies, but they only work in relation to regulation and compliance mechanisms.
- Tradable water rights can be an important tool for river basin management, but they are only effective if a number of conditions are met:
  a) The basic water demands of citizens and ecosystems are safeguarded.
  b) The rights should be defined and agreed upon.

c) Utilisation of the rights should be physically possible.
d) Monopoly is to be prevented.

- Full participation by all stakeholders, including workers and the community. This will involve new institutional arrangements. There must be a high level of autonomy, but this must at the same time be associated with transparency and accountability for all decisions. Care should be taken to ensure that those participating in any catchment management structure do indeed represent a designated group or sector of society. It is also important to ensure that representatives provide feedback to the constituencies they represent. Integrated aquatic ecosystem management seeks to combine interests, priorities and disciplines as a multi-stakeholder planning and management process for natural resources within the catchment ecosystem, centered on water. Driven bottom-up by local needs and priorities, and top-down by regulatory responsibilities, it must be adaptive, evolving dynamically with changing conditions.
- Attention to social dimensions. This requires attention to, amongst other things, the use of social impact assessments, workplace indicators and other tools to ensure that the social dimension of a sustainable water policy is implemented. This will include the promotion of equitable access, enhanced role of women, and the employment and income implications of change.
- Capacity building. At many levels in the process—even at the governmental level—stakeholders lack the necessary knowledge and skills for full application of integrated aquatic ecosystem management. Community stakeholders may not be familiar with the concept of water resource management, catchment management, corporate governance, and their role in these. Capacity building categories include education and awareness raising about water; information resources for policy making; regulations and compliance; basic infrastructure; and market stability. Early and ongoing stakeholder collaboration and communication in capacity building is also important from the view point of "leveling the playing field" in anticipation of disputes that may arise. Filling strategic skills/capacity gaps supports integrated aquatic ecosystem management, facilitates dispute resolution, and builds practical understanding of the scope of sustainable natural resource development challenges and opportunities.
- The capacity of all institutions needs to be maintained and/or developed by means of short-term and long-term programmes (including postgraduate education and curricula development).
- Availability of information and the capacity to use it to make policy and predict responses. This implies, firstly, sufficient information on hydrological, bio-physical, economic, social and environmental characteristics of a catchment to allow informed policy choices to be made; and secondly, some ability to predict the most important responses of the catchment

system to factors such as effluent discharges, diffuse pollution, changes in agricultural or other land use practices and the building of water retaining structures. The latter hinges on the adequacy of scientific models. It is recognized that predicting ecosystem response to perturbation with reasonable confidence is severely taxing current scientific capabilities, stimulating ongoing research.

- Full-cost pricing complemented by targeted subsidies. This principle was strongly urged by the World Water Council at The Hague, the rationale being that users do not value water provided free or almost free and have no incentives to conserve water. Wide support for this principle was engendered, but also significant opposition from those who felt that the interests of the poor might not be sufficiently protected, even under an associated subsidy system, however well designed. Opposing views held that full-cost pricing, when applied in its narrowest sense, offends the principle that water is a public good, a human right, and not simply an economic good. Reiterating: The economic sustainability of water and sanitation services depends largely and appropriately on the recovery of costs through user fees or tariffs that are equitably assigned based on ability-to-pay. Under-served or unserved, marginalized users in many places already pay high financial costs of not having safe piped water, for example, because they are forced to pay for water trucked-in by suppliers. This water may be of dubious quality yet is expensive.
- Charges are effective and efficient means to finance aquatic ecosystem management (cost recovery) and reduce water use and pollution if the basic water needs of the poor are safeguarded, e.g. by means of block tariffs.
- Central government support through the creation and maintenance of an enabling environment. The role of central government in integrated catchment management should be one of leadership, aimed at facilitating and coordinating the development and transfer of skills, and assisting with the provision of technical advice and financial support, to local groups and individuals. Where specific areas of responsibility fall outside the mandate of a single government department, appropriate institutional arrangements are required to ensure effective inter-departmental collaboration.
- Traditional regimes and institutions should be recognised and integrated in aquatic ecosystem management. Adoption of the best existing technologies and practices—BMPs (best management practices).
- Reliable and sustained financing. In order to ensure successful implementation of integrated aquatic ecosystem management approaches, there should be a clear and long-term commitment from government to provide financial and human resources support. This is complemented by income from a healthy water and sanitation market, especially when local providers of goods and services that support the water sector are active players, and when there is active reinvestment in the sector.

- Equitable allocation of water resources. This implies improved decision-making, which is technically and scientifically informed, and can facilitate the resolution of conflicts over contentious issues. There are existing tools (e.g. multi-criteria analysis) to help decision-making in terms of balancing social, ecological and economic considerations. These should be tested and applied.
- The recognition of water as an economic good. The recognition of water as an economic good is central to achieving equitable allocation and sustainable usage. Water allocations should be optimized by benefit and cost, and aim to maximize water benefits to society per unit cost. For example, low value uses could be reallocated to higher value uses such as basic drinking water supplies, if water quality permits. Similarly, lower quality water can be allocated to agricultural or industrial use.
- There may be a distinct role for private entities (publicly or privately owned) in the provision of water services and water management. Private ownership of water infrastructure is a controversial issue that needs to be carefully explored.
- Strengthening the role of women in water management. A review by the World Bank of 121 water projects showed that ensuring women's participation in decision-making positively affects both project quality and sustainability (http://www.gdrc.org/uem/water).
- Floods not only cause suffering but also support life. Flood management should not be based solely on building dykes and dams. It needs to be based on strategies that use both structural and non-structural methods. The strategy should balance all interests involved and be based on an integrated assessment, of the environmental, economic and human costs and benefits of these alternatives, including their potential contribution to drought mitigation and including the possibilities that they offer for nature.
- The ultimate goal of pollution control is to close substance cycles and in this way prevent pollution. A mix of instruments for regulation and compliance can be used to move into this direction and solve urgent pollution problems: waste control, process and emission standards, and a water quality approach. The exact mix should reflect inter-alia the local management capacity and the availability of water quality data and other data (Ramachandra T.V. et al., 2001).
- Effective aquatic ecosystem management requires sound data, information and knowledge, including both data on surface and groundwater (quantity and quality) and social and economic data. Collection and processing of relevant data, easy accessibility and broad dissemination are eminent tasks of river basin management. To increase policy relevance, data should be aggregated into meaningful information, for example in the form of indicators and systems for benchmarking. Compliance monitoring (reporting, reviewing and evaluating) is very important for promoting the implementation of plans.

- Sustainable aquatic resources development and management depends mainly on proper planning, implementation, operation and maintenance, which is possible with Geographic Information System (GIS) and Remote Sensing techniques, complement and supplement ground data collection in various facets of different kinds of water resources projects. The synoptic large area repetitive coverage provided by satellite sensors provide appropriate database.
- To support aquatic ecosystem management, a new analytical model should be developed that can aggregate socio-economic, political, institutional and technological potentials and hydrological constraints. This model should furthermore be capable of evaluating the actual management capacity.
- To support strategic planning, methods for analytical support should be developed that:
  - ✓ cover the whole basin and all significant impacts;
  - ✓ specifically consider the socio-economic processes that affect the basin;
  - ✓ predict the socio-economic effects of alternative strategies; and
  - ✓ present the issues in such a way that people can understand them.
- Methods for analytical support should furthermore reflect the fact that policy analysis can never rely on quantitative information only. Moreover, these methods should be transparent and flexible, promote policy learning by all actors, and facilitate negotiation processes. Appropriate methods may include argumentative policy analysis and role-playing supported by a computer model of the natural system and the socio-economic effects.
- There is a large role for appropriate decentralised information systems and networks that can promote interaction among sectors, provide a basis for consistent technical studies, help communication with the public, and stimulate participation.
- To implement the general principles of the integrated aquatic ecosystem management requires a cyclic policy development approach. Such an approach would include the following steps — Assessment of institutions, needs and resources, planning, implementation, compliance monitoring and evaluation.

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ANNEXURE

Guiding Principles for Water Management

Issues that have come up as a result of global consultations include the promotion of a greater focus on water demand management, and conservation within the framework of integrated water resources management; encouraging a shift from the supply driven approach to meet demand on water to the demand management approach and greater efficiency to match available resources; promoting greater focus on pollution control policies within the framework of integrated water resources management to safeguard the quality of water and to maximize the safe reintegration of recycled wastewater into the water cycle as a non-conventional water source; reviewing water demand and pollution control experience across the region and identify and examine replicable strategies and models; and demonstrating the viability of water demand management and efficiency policies (*http://www.idrc.org/wem/water*).

Event	*Guiding Principles*
Global Consultation on Safe Water and Sanitation for the 1990s, New Delhi, 1990	The New Delhi Statement formalised the need to provide, on a sustainable basis, access to safe water in sufficient quantities and proper sanitation for all, emphasising the "some for all rather than more for some" approach. Four guiding principles were postulated: • Protection of the environment and safeguarding of health through the integrated management of water resources and liquid and solid wastes • Institutional reforms promoting an integrated approach • Community management of services • Sound financial practices.
International Conference on Water and the Environment, Dublin 1992	Four guiding principles were formulated: • Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment • Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels • Women play a central part in the provision, management and safeguarding of water • Water has an economic value in all its competing uses and should be recognised as an economic good.
United Nations Conference on Environment and Development, Rio de Janeiro, 1992	Agenda 21 emerged from this Conference, with Chapter 18 dealing with water issues. Chapter 18 was titled: "Protection of the quality and supply of freshwater resources: Application of integrated approaches to the development, management and use of water resources". Seven programme areas were proposed for the freshwater sector:

- Integrated water resources development and management
- Water resources assessment
- Protection of water resources, water quality and aquatic ecosystems
- Drinking-water supply and sanitation
- Water and sustainable urban development
- Water for sustainable food production and rural development
- Impacts of climate change on water resources.

Second World Water Forum and Ministerial Conference in The Hague, March 2000

The World Water Vision which was presented at the Forum, defined three primary objectives: (1) to empower people and communities to decide how to use water, (2) To get more crops and jobs per drop and (3) to manage use to conserve freshwater and terrestrial ecosystems. It deemed five actions critical to the achievement of the objectives:

- Involving all stakeholders in integrated management
- Moving to full-cost pricing
- Increasing public funding for research and innovation
- Cooperating to manage international basins
- Massively increasing investments in water

The World Water Council which organized the Second World Water Forum, formulated the following Messages for a water secure world:

- A holistic, systemic approach relying on integrated water resources management must replace the current fragmentation in managing water
- Participatory institutional mechanisms must be put in place to involve all sectors of society in decision-making
- Fresh water must be recognised as a scarce commodity and managed accordingly.
- Full cost pricing of water services with targeted subsidies for the poor
- Fresh water must be recognised as a basic need, with adequate access ensured for the poor
- Incentives for resource mobilisation and technology change are needed
- Institutional, technological and financial innovation is needed
- Private investment and community action
- Political will is needed to go beyond Dublin and Rio
- Governments are key actors — as enablers and regulators
- Behavioural change is needed by all — no more business as usual