ECOLOGICAL BASIS FOR THE APPLICATION OF ECOTECHNOLOGIES TO WATERSHED/RESERVOIR AND MANAGEMENT

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ABSTRACT

Reservoirs play an important ecological, economic, and social role, interfering qualitatively and quantitatively with the hydrographical network and with several mechanisms in the major river basins of the world and in all continents. In Brazil, as in many other countries, reservoir construction has been used as a basis for regional development, being a catalytic agent for several multipurpose actions in the watershed. The protection, recovery and optimization of multiple uses of these artificial ecosystems, can only be achieved if a sound ecological basis is constructed, with long term observations, experimental studies, and theoretical approaches, in which seasonal changes, the ageing process of the reservoir under anthropogenic actions, and the interactions of the reservoirs with the watershed, are followed up. The application of principles of theoretical ecology will be extremely useful in the implementation of ecotechnological methods for reservoir recovery and management. This approach has been extensively developed at the Lobo-Broa reservoir watershed, as well as other reservoirs of the Tietê River Basin in the State of São Paulo. In this paper, the authors discuss the need for a theoretical basis for the application of ecotechnologies on reservoirs. An overview of the reservoir problem in Brazil is given as an introduction to a discussion on conservation and management of these artificial ecosystems.

INTRODUCTION

Monitoring of the ecological changes resulting from reservoir construction, and the ageing of these artificial ecosystems after filling-up, is a theroretical and practical study of general significance. Reservoirs are a qualitative and quantitative reference in the hydrographical network, and their interactions on the watersheds reflect the anthropogenic influences and human uses of the terrestrial and aquatic ecosystems. Reservoirs can, therefore, be used as an information system concerning the various uses of the watershed (MARGALEF et al, 1976) and as such an important tool for regional planning, acting as a catalytic agent for alternative strategies.

Reservoirs are constructed for a number of reasons, including hydroelectricity production, irrigation, stream and river regulation, biomass production, water storage for industrial or domestic use, navigation and recreation. Even when constructed for just one reason, such as hydroelectricity, multiple uses prevail for some time following the regional insertion of the reservoir. They are complex systems to manage. Being intermediate between rivers and lakes, several characteristic features should be taken into account, which relate to the functioning of the reservoir (or reservoirs in a cascade) to water use (single or multi-purpose), to the regional climate and hydrological cycle, and to human impacts.

In this paper, besides giving an overview of the general features of reservoirs and problems relating specifically to reservoirs in Brazil, we discuss some principles of theoretical ecology applied to these artificial ecosystems, to the watershed, and the uses of ecotechnologies for reservoir/watershed recovery and management. We also to summarize the application of ecotechnologies to watershed/reservoir/lake ecosystems, using the current research, recovery and management of the Lobo-Broa watershed and reservoir as an example.

THE RESERVOIR PROBLEM IN BRAZIL

RESERVOIRS IN BRAZIL

In Brazil, reservoirs play an important ecological, economic and social role, being key ecosystems for regional planning in many of the states. The tradition of constructing small reservoirs for water supply, and later for biomass production (fish stocks), in the northeast of Brazil is more than 100 years old. In the southeastern and southern regions, several small reservoirs (5 to 30 x $10^7 m^3$) were also constructed approximately 50–60 years ago with the purpose of hydroelectricity production (TUNDISI, 1986a, 1989).

The extensive reservoir system in the southeastern, southern and northeastern regions was built up successively in the last 30 years as a consequence of the need for energy supplies. Most of the large reservoirs were planned only for hydroelectric power, although multiple uses were developed later. In the last 20 years a large number of reservoirs for the storage of drinking water have also been constructed in many urban centres. For example, the town of São Paulo (12 million inhabitants), now has 13 large reservoirs for water supply, mainly for domestic use.

Figure 1 shows the largest reservoirs in Brazil. Besides producing several changes in the natural regions, with direct and indirect impacts, all these artificial ecosystems, have to be managed for multiple uses in order to avoid the impairment of water quality, as well as for economic reasons such as a better water use, while considering the increasing costs of treatment. Food supply and recreation are other important activities.

Four main problems affect these artificial ecosystems:

a) spread of water borne diseases;

b) increasing contamination with high levels of toxicity;

c) rapid eutrophication and

d) silting.

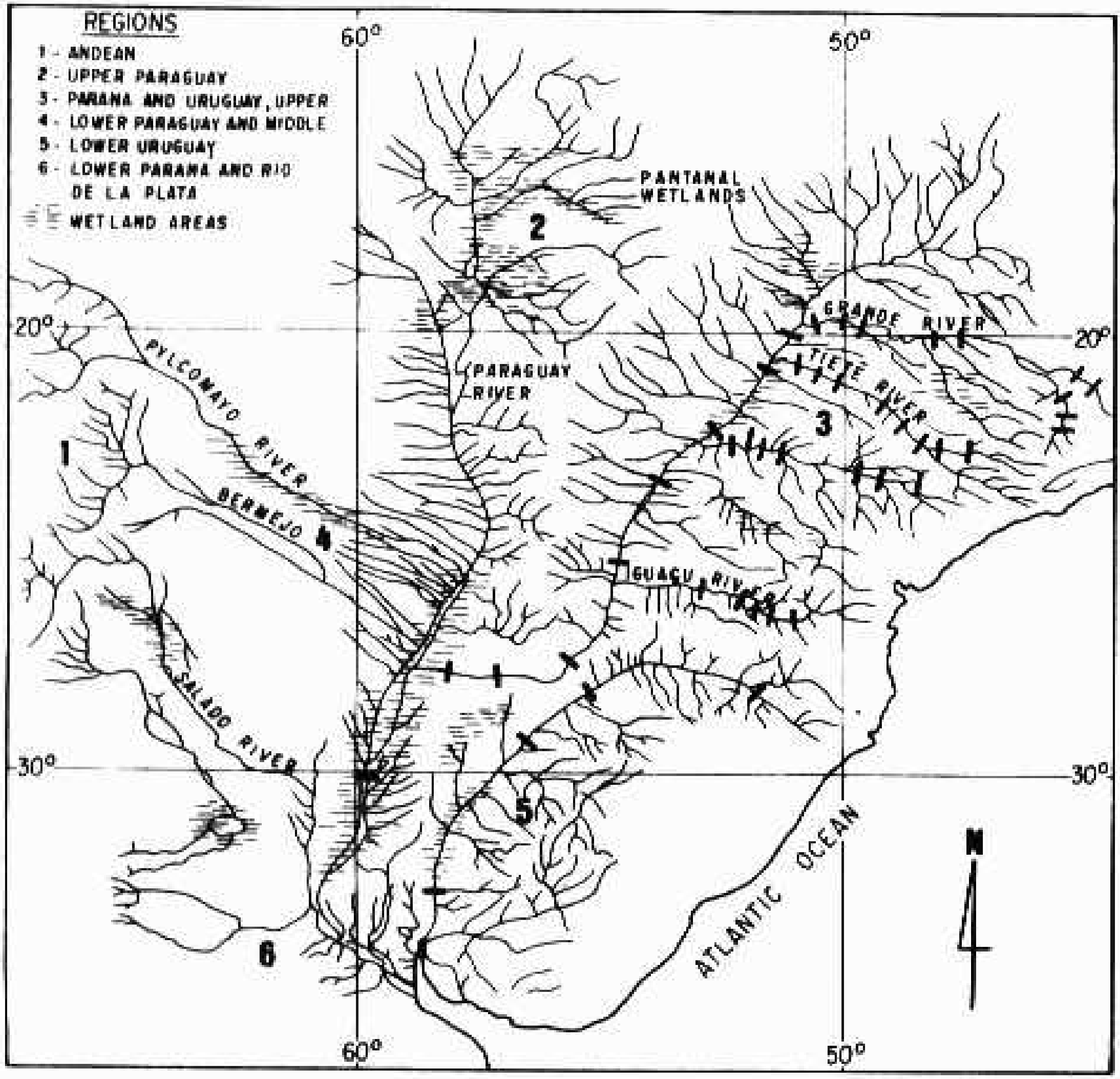

Fig. 1. Reservoirs of the Paraná/La Plata Basin. (Modified from BONETTO et al., 1987).

RESERVOIRS IN THE STATE OF SÃO PAULO

The construction of reservoirs in São Paulo was the most recent stage of land occupation in the state. This case illustrates very well the overall problems introduced by reservoir construction, and the conflicts generated by multiple uses. Today, all the major rivers have large reservoirs in cascades. Considering this reservoir system in relation to economic development, population growth, and widespread agroindustry, it becomes evident why these artificial ecosystems are key indicators in watershed uses, and as a result basic instruments for regional planning. The main uses of reservoirs in São Paulo include: hydroelectricity, transportation, recreation, irrigation, sport-fishing, commercial fisheries, and water supply. The conservation and/or recovery of these ecosystems poses a number of problems related to their multiple use, and the conflicting interests of industrial and social activities not least involving their location in basin (upstream/ downstream).

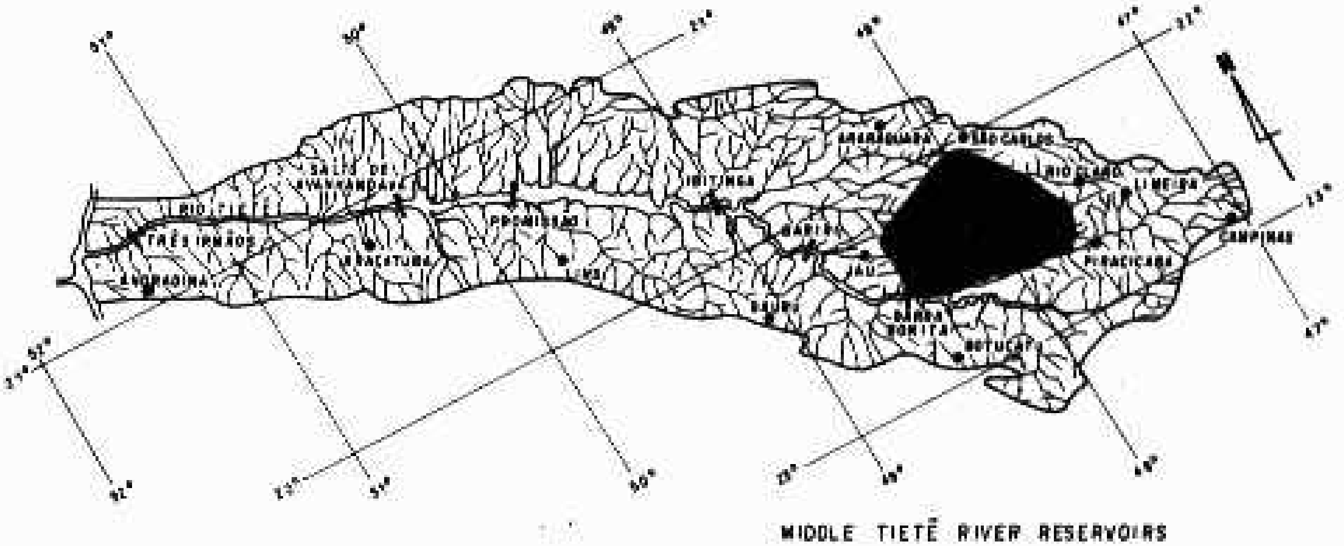

Fig. 2. A series of reservoirs in the middle Tietê River Upper La Plata basin. An example of integrated use for hydropower, generating several impacts and providing opportunity for regional planning and integrated management for multiple uses. In the shaded area the APA (Environmental Protection Area) of Corumbatai.

RESERVOIRS IN THE SEMI–ARID REGION

Small impoundments in the semi-arid region of northeast of Brazil were constructed with the aim of regulating rivers, irrigation, fish farming and water storage (size—one million up to 10 million m^3). These small systems present the following problems: salinization, spreading of water-borne diseases (schistosomiasis), growth of aquatic weeds, and loss of water quality. Large reservoirs in the São Francisco region were constructed mainly for hydroelectric power, but also for irrigation and fish production. These reservoirs in cascade, present several ecological problems, including: increasing eutrophication and toxicity; silting; widespread changes in the fish fauna; the need for relocation of human populations and compensation for loss of agricultural land and crops, a central problem in the social conflicts in this area.

LAKE PARANOÁ IN BRASILIA

Created during the construction of Brasília in the 1960s, Lake Paranoá (surface area 38km^2) provides an extreme example of eutrophication. This hypereutrophic reservoir is today the subject of a comprehensive research and monitoring programme. A recovery project was initiated in 1987, supported by the United Nations Development Programme (UNDP) (SOMLYODY et al, 1989).

LARGE RESERVOIRS IN AMAZONIAN TRIBUTARIES

Management of these large ecosystems is complex due to their large area, dendritic pattern, and the drowned tropical rainforest. Downstream effects are severe, along with serious conflicts involving amerindians and other local inhabitants (TUNDISI, 1989). The large dams in operation in the tropical forests of the Amazon also present a series of problems of an entirely different nature. Besides the waste of valuable timber, and the loss of a diversified and rich fauna and flora (the loss of genetic variations, including probably species of medical interest), the decay of the drowned vegetation produces eutrophic and contaminated water, with high concentrations of hydrogen sulphide.

The general effects on the reservoirs in the Amazon region may be listed as follows:

Chemical effects

Aerobic decomposition
Anaerobic decomposition
Oxygen reduction
Production of methane
Production of hydrogen sulphide
Chemical precipitation
Eutrophication
Increased acidity
Increased corrosion
Production of hydrogen

Biological and human effects

Loss of environmental "services"
Loss of timber
Loss of wildlife habitat
Proliferation of waterweeds
Curtailed multiple use
Increased disease vectors
Impaired water quality
Impediment to access

Physical effects

Reduction of reservoir volume
Reduction of vertical circulation
Mechanical interference with multiple uses
Mechanical interference with the dam
Biological and human effects

An attempt to compare Amazonian reservoirs with African ones is not feasible: the African reservoirs have been built mostly in savanna regions; the hydrogeo-chemistry and ionic composition of the water of the Amazon tributaries is different from the African rivers; and the pH of the Amazon waters is low and acidic (JUNK & MELLO, 1987).

This brief synthesis of the reservoir problem in Brazil demonstrates the need for sound management and recovery programmes based on an ecotechnology with a sound ecological basis (TABLE 1).

TABLE 1

MAIN RESERVOIR USES IN BRAZIL
Hydroelectricity
Water storage for irrigation
Storage for drinking water Biomass production (fish cultivation)
Extensive fisheries
Transportation
Recreation
Tourism
Water storage for cooling purposes
MAIN PROBLEMS OF RESERVOIRS IN BRAZIL
Eutrophication
Increased toxicity and general contamination
Silting and a rapid filling-up with sediment
Spread of water-borne diseases
Salinization (northeast)
Anoxic hypolimnion and severe downstream impacts (mainly in Amazonian reservoirs)
Low diversity of fish fauna, compared to rivers
High internal load (in eutrophic reservoirs) and toxic sediment
Extensive macrophyte growth (*Eichornia crasssipes, Pistia stratioides)* associated with eutrophication
Loss of arable land
Relocation of human populations, including amerindians

GENERAL FEATURES OF RESERVOIR ECOSYSTEMS

The interactions of a reservoir, or reservoirs, with the watershed is a dynamic process, given the watershed's uses, and its geographic location (geomorphological and climatic characteristics), which determine the basic features of the reservoir system, namely morphometry, seasonal cycles, and, to a limited extent, the chemical composition of the water. Temporal and spatial scales must be considered in relation to seasonal cycles, size, water storage and water uses. In many cases, reservoir drainage basins are elongated, with spatial gradients in suspended sediments, water quality and productivity. Gradients in reservoirs can be more pronounced than in lakes due to the withdrawal of water from various depths (RYDING & RAST, 1989). Reservoirs are much younger than lakes, and most of them develop a compartmentalized dendritic pattern.

Retention time varies widely depending on reservoir uses, hydrological cycles, and water availability. Retention time is a key factor in reservoir hydrology and ecology. Various patterns of flow occur in reservoirs, depending on the watershed's characteristics, such as the river network, declivity and the level (or levels) and quantities of water withdrawal. These patterns may have a strong influence on biomass loss to the downstream ecosystem, and on water level fluctuations, as well as the physical, chemical and biological conditions upstream and downstream. A number of vertical and horizontal circulation patterns occur in reservoirs, depending again on climate, and also on level of outlets, wind action, and degree of compartmentalization (TUNDISI, 1990a, 1990b). Flushing rates and retention times are regulated by the operation of the reservoir according to with the hydrological cycle and to the multiple uses of the reservoir water. Reservoirs in a cascade are, in many instances, controlled with a single operational procedure (TUNDISI, in press, 1991). Water level fluctuation, a consequence of uses and the hydrological cycle, is another strong factor in the ecological functioning of the system.

PRINCIPLES OF THEORETICAL ECOLOGY APPLIED TO WATERSHEDS AND RESERVOIRS

Certain principles of theoretical ecology can be applied to the river/reservoir system and the watershed in order to understand mechanisms, interactions and key processes. These are:

a) *The seccession of terrestrial and aquatic ecosystems.* Filling-up a reservoir abruptly ceases succession in the terrestrial ecosystem and creates a new pattern. Under the influence of anthropogenic activities, succession may take one of a number of directions in any specific reservoir. The filling phase has a distinct successional pattern (MATSUMURA-TUNDISI et al, 1991).

b) *The pulse concept.* Pulses in the watershed may be related to a number of factors, including those related to climate and hydrology. Human activities, including agriculture, discharge of pollutants and water withdrawal, produce pulses of varied magnitudes and frequencies (STRASKRABA et al, 1992, in press).

c) *The ecotone concept and the mosaic.* Spatial variations in the system and spatial heterogeneity are important characteristic features. Ecotones, such as wetlands, the reservoir shore, and the riparian forest, are key sub-systems in the mechanisms involved in the functioning of the reservoir system. Sustainable productivity, high degrees of denitrification, and high biological diversity are some functional properties of ecotones which maintain heterogeneity and mosaic patterns. Spatial heteregeneity enhances biological diversity (JØRGENSEN & LÖFLER, 1990).

d) *Connectivity.* Connectivity between subsystems and compartments is another concept that must be taken into account when considering watershed/reservoir interactions. Transportation of elements, substances, and organisms between subsystems is qualitatively and quantitatively important. Climatological functions, such as precipitation and wind, are transport factors. Upstream/downstream processes and their connections with the reservoir have also to be understood. The measurement of fluxes is essential to quantify connectivity (PIECZYNSKA, 1990; WETZEL, 1990).

e) *Spatial heterogeneity and biological diversity.* Maintenance of spatial heterogeneity is of prime importance for biological diversity. A balance between preserved areas and areas for agricultural/industrial/ recreational use is essential for conservation/restoration programmes. Preserved areas maintain "seed species" of plants and animals, that can be used for repopulation and recovery of biological diversity (KIRA, 1988).

f) *Theoretical approaches to the relationships between terrestrial and aquatic ecosystems.* It is of prime importante to consider organic and inorganic matter transfer from terrestrial to aquatic ecosystems, the role of ecotones as "filters" of contaminantes and pollutants, the role of large vertebrates in the transference of organic matter from one system to another, and the characteristics of biological diversity of both terrestrial and aquatic systems and the mutual influence each have on the other. Quantification of these interactions is most helpful in understanding the relationships.

The principles of theroretical ecology applied to the river/reservoir systems are very helpful in understanding how these ecosystems respond to disturbance, their possible recovery, and the dynamic changes which occur.

ECOTECHNOLOGY, RESERVOIR MANAGEMENT AND RECOVERY

Ecotechnology must provide alternative options for management, with approaches based on supporting ecosystem recovery, the adaptation of ecosystems to anthropogenic stress, and the use of natural ecosystems for recycling waste material, and as a source of key species for reintroduction. Another important basic principle is a knowledge of the feedback mechanisms, and regulation of ecosystem processes, which in reservoirs is enabled through the regulation of flow rates. A practical problem for the application of these technologies is the recognition of the compartmental structure (vertical and horizontal), which can be extensively used most especially in the larger systems.

TABLE 1 gives a synthesis of principles and ecotechnological methods that can be applied to watershed/reservoirs. TABLE 2 provides a summary of ecotechnological methods and the problems to solve, and TABLE 3 summarizes ecotechnological methods.

TABLE 2 – THEORETICAL PRINCIPLES AND THEIR USE IN WATERSHED RESERVOIR RECOVERY (modified from Straskraba et al. 1992)

PRINCIPLE	USE
Bottom up effects	Chemical factors determining biological production
Top down effects	Biomanipulation
Limiting factors concept	Eutrophication on reduction, upper limits
Sub-system interactions	Watershed/reservoir interactions
Negative feedback	Phyto-nutrient relationships
Connectivity	Upstream/Downstream
Ecological succession	Reservoir ageing
Ecosystem adaptability and Ecosystem self-organization	Ecosystem response to Anthropogenic influences
Ecosystem spatial heterogeneity	Protection of headwaters and shoreline
Biological diversity	Reforestation, wetlands, ecotone's protection
Competition	Introduction of exotic species
Pulse effect theory	Regulation of water withdrawal Maintenance of riparian forest
Colonization	Exploitation of pelagic environment

TABLE 3 – A SUMMARY OF ECOTECHNOLOGICAL METHODS APPLIED TO WATERSHED/RESERVOIR CONSERVATION, RECOVERY AND MANAGEMENT

PROBLEM TO SOLVE	METHOD
Reduce silting	Erosion control *(By several methods, including agricultural practices). Revegetation.*
Reduce sediment transport. Decrease of N, P load to reservoir. Improve ground water recharge. Increase spatial heterogeneity.	Reforestation with native species *(Succession of riparian vegetation)* *(Revegetation of slopes with native species)*
Reduce river eutrophication. Reduce oxygen depletion in rivers. Increase diversity of substrate. Reduce, N, P load to reservoir	River restoration *River bank rehabilitation.* *River reoxygenation.* *(Artificial substrate for river recovery).*
Decrease eutrophication and contamination. Increase species diversity. Maintenance of "seed" species.	Wetland recovery and conservation *(Maintenance and recovery of wetlands).* *(Construction of artificial wetlands).*
Reduce suspended material input. Reduce eutrophication and contamination. Improve water quality. Reduce load from point sources.	Preimpoundment of tributaries *Sequence of small reservoirs with controlled throughflow (with retention optimized).*
Increase of biomass production and diversity of native species. Increase and diversify niche exploitation.	Reintroduction of native fish species *(Riverine species). (Development of technologies for reservoir adaptation for riverine species).*

TABLE 3 – cont.

PROBLEM TO SOLVE	METHOD
Reduce eutrophication and silting. Increase spatial heterogeneity, and sites of key species for repopulation. Reintroduction of key native species.	Maintenance of preserved areas as buffer systems
Reduce sediment input and bank erosion. Reduce load of contaminants. Provide substrate for invertebrates and food for fishes.	Lake shore management *(Preserving natural shoreline. Constructing artificial shoreline and revegetation with native species). (Use of artificial substrate).*
Control of eutrophication providing fishes with supply of organic food as detritus and/or periphyton/macrophyte biomass. Decrease sediment load and improve water quality. Provide nursery grounds for fishes. Provide aquatic birds with feeding niches.	Management of littoral zone *(Maintenance of macrophyte stands). Control of macrophyte stands and reintroduction of native species). (Coupling of emersed/ submersed macrophytes to avoid excessive water loss). Control of insect growth.*
Control of eutrophication and undesirable algal blooms. Control of detritus and suspended matter. Improvement of water quality. Control of downstream ecological processes.	Control of retention time *(Throughflow regulation and selective withdrawal of water).*

TABLE 3 – cont.

PROBLEM TO SOLVE	METHOD
Reduce internal loading. Decrease eutrophication.	Removal and chemical isolation of sediment. *(Several chemical techniques & aeration to force phosphate to bottom).* *Use of bottom outlet for sediment discharge.*
Reduce internal loading and eutrophication. Reduce algal growth. Change of vertical structure of the reservoir.	Reservoir mixing *(Destratification, aeration, Zmix optimum several recirculation techniques).*
Increase fish biomass. Increase exploitation of pelagic zone. Increase species'diversity and exploitation of feeding niches of reservoir.	Reintroduction of native species in the reservoir. *Several technologies. Fish culture in cages. Exploitation of pelagic zone of reservoir.*
Reduce algal growth. Reduce internal loading capacity. Reduce eutrophication.	Biomanipulation *(Increasing grazing of herbivores)*
Depression of phytoplankton growth. Change in limiting factor.	Reduction of light penetration *(By vertical mixing and other techniques)*

Table adapted from several sources: RIDLEY et al, 1966; ULHMANN & BENDORF, 1976; 1980; JØRGENSEN, 1980; MITSCH & GROSSELINK, 1986; STRASKRABA, 1985, 1986; KIRA, 1988; JØRGENSEN & VOLLENWEIDER, 1989; JØRGENSEN & LÖFLER, 1990; TUNDISI, 1991.

THE LOBO-BROA WATERSHED AND RESERVOIR CASE STUDY

This small watershed (280 km^2) was chosen for the development of an intensive ecological project in 1970, mainly due to its proximity to a series of reservoir systems which could provide comparative studies, for its convenient location, and its properties for physical modelling and experimental research.

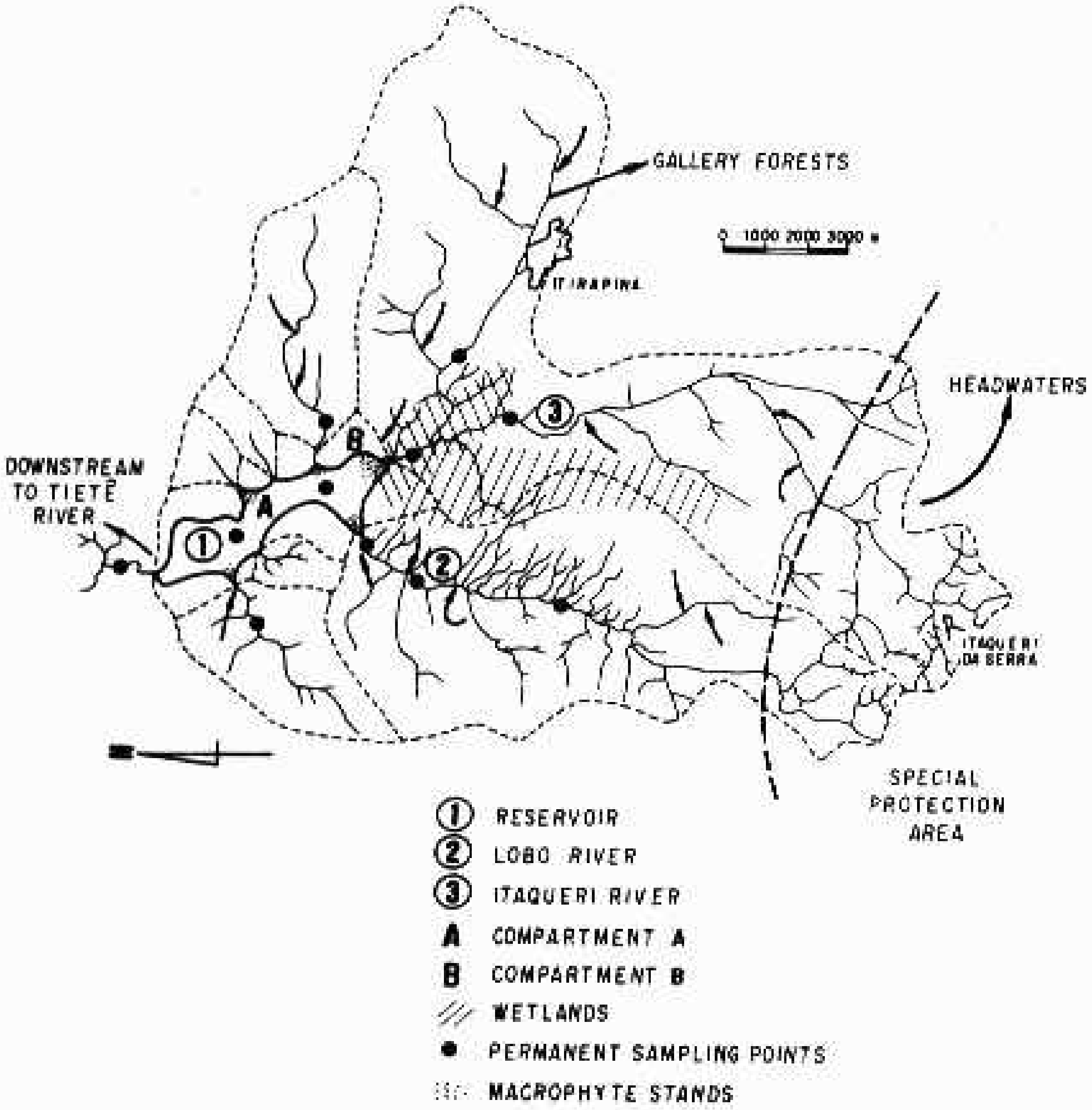

Fig. 3. The Lobo watershed its main characteristics, and basic structures.

The description of the principle functions involved in this ecosystem, such as wind and precipitation, and their interactions with the watershed and the reservoir, the coupling of primary productivity with biogeoghemical cycles, the diversity of the biological community, and seasonal patterns, was summarized by TUNDISI (1986a,b). Besides providing first hand information on the environmental processes, the objectives of the basic research were designed to produce a basis for management, conservation and the recovery of the system. The implementation of several methods and techniques in the last five years have helped in the establishment of the current framework for action. The first step was the creation of an Environmental Protection Area of 1.000 km^2, including the entire Lobo/Broa watershed, and several slopes where primary forest is still present. The second step was the recognition of several important (qualitatively and quantitatively) sub-systems that required protection. The third step was to define a recovery programme, with the problems identified by the research activities. Table 4 shows the ecotechnological methods currently in use, and the ecological principles supporting them. Table 5 gives the basic characteristics of the Lobo-Broa watershed wich were used for management and regional planning. Currently underway is the evaluation of each sub-system and the numerous processes involved (including biogeophysical, social and economic aspects) (GOLDESTEIN et al., 1991).

TABLE 4 – PRINCIPLES OF THEORETICAL ECOLOGY APPLIED TO THE MANAGEMENT AND RESTORATION OF THE LOBO-BROA WATERSHED ECOSYSTEM

SPATIAL HETEROGENEITY	– Conservation and management of riparian forest – Maintenance of wetlands as areas of higher diversity and denitrification sites – Protection of headwaters
ECOTONES	– Protection of shoreline – Maintenance of wetlands – Conservation and recovery of gallery forest
SUCCESSION OF TERRESTRIAL AND AQUATIC VEGETATION AND SELF ORGANIZATION OF ECOSYSTEM	– Recovery of riparian forest and protection of "cerrado" – Maintenance of "natural vegetation islands" in the agricultural areas – Protection and maintenance of natural vegetation in the slopes
CONNECTIVITY	– Management of upstream and downstream systems. Maintenance of riparian forests and wetland areas
BIOLOGICAL DIVERSITY: MAINTENANCE AND RECOVERY	– Protection of natural forests in the slopes – Protection of terrestrial and aquatic fauna – Preventing introduction of exotic species – Recovery of natural vegetation by special reforestation techniques – Maintenance of ecotones in the reservoir-river connection
DEPRESSING PULSE EFFECTS	– Pulse effects produced by precipitation may affect sedimentation rates. The maintenance of wetland areas around the reservoir and in the river/reservoir connection is fundamental to depress the pulse.
INTERACTIONS TERRESTRIAL/AQUATIC SYSTEMS	

TABLE 5 – BASIC CHARACTERISTICS OF THE LOBO-BROA ECOSYSTEM AND THE CORUMBATAÍ ENVIRONMENTAL PROTECTION AREA (APA), USED FOR MANAGEMENT AND REGIONAL PLANNING

- Biology of the terrestrial and aquatic systems: description of fauna and flora.
- Ecology of terrestrial and aquatic systems: driving functions, succession, interactions, main mechanisms.
- Climatology and water balance, hydrology.
- Water quality of rivers, reservoirs, wetlands.
- Geology and soils.
- Socioeconomic basis of the watershed: land use, agricultural development (large scale /small scale), industrial systems (including agroindustry). Regional water uses (domestic, irrigation, hydropower, industrial uses).
- Recreational and touristic value of the region.
- Preserved areas and rare species.
- Human health and aquatic systems.
- Magnitude of impacts: agroindustry, mining operations, recreation, water uses, deforestation, wildlife exploitation.

The activities also include a strong emphasis on environmental education throughout the region, and the continuous decodification of the research findings to the general public.

THE ROLE OF LONG TERM STUDIES IN CONSERVATION AND MANAGEMENT

The transfer of the results of basic research to management and regional planning is not easy. Translating ecological principles to technological solutions implies a highly coordinated interdisciplinary approach, complicated by the dynamic nature of the ecosystems and the impacts produced by man. Long term ecological research can provide the necessary basis for understanding dynamic processes and events, and produce significant inputs to management. A minimum of prediction for ecosystem responses is essential for management. This implies the need for long series of cumulative information, including simultaneous observation at several organizational levels such as populations, communities, ecosystems and landscapes (LIKENS, 1989; FRANKLIN, 1989).

Long term studies also provide a basis for the development of a continuous monitoring procedure. Monitoring in the aquatic system, for example, functions as a sensor of changes in the terrestrial system. This monitoring is a key tool for management. Preimpoundment monitoring and evaluation is also fundamental in the preparation of Environmental Impact Assessment for reservoir construction. Frequently EIAS in reservoirs, especially those in Brazil, emphasize structures rather than processes. A change towards a more dynamic approach, with a better evaluation of impacts, is necessary, and can be produced only with long term monitoring and research before impoundment (TUNDISI, 1991). Long term ecological research can also contribute to our understanding ecosystems subjected to disturbance, their responses, environmental variables involved, and changes in populations and communities. According to TILMAN (1989), three levels of long term ecological research are important: observational and comparative, experimental, and the development of theory. VOLLENWEIDER (1990) suggests that long term research with two approaches, in depth single-case and comparative cross-sectional, is extremely useful for providing a basis for the management of the problem of eutrophication.

CONCLUSIONS

The transfer of basic ecological principles to ecotechnology applied to watershed/reservoir systems is fundamental for their management and conservation. Although reservoirs cause considerable impacts and numerous changes in watersheds and rivers, it is important to consider the qualitative gain produced by reservoir construction in most cases, and their role in enhancing regional development in many countries. Reservoir construction also provides an important opportunity for the development of basic, integrated, ecological research, essential for management and planning activities.

It is fundamental to stimulate the use of ecotechnology, in water resource management and the improvement of watershed protection and multiple associated activities. Monitoring the permanent biogeophysical changes in the watershed and river/reservoir systems as a consequence of economic alterations over time provides the key for the management actions and planning activities. Equally important from a qualitative and quantitative point of view is the preparation of human resources with a strong theoretical basis and practical experience in the field.

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