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Ecohydrology towards the sustainable development: An approach based on South American case studies

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Abstract
On the race for sustainable development, the lack of methods for achieving it is remarkable. In this paper, we discuss how eco-hydrology may guide watersheds management towards sustainability based on the evaluation of three different realities: dam cascades and conservation areas in macro basins and urban rivers exploration in a densely occupied micro-basin. A framework for managing water is proposed, followed by the presentation of prospects and challenges on its application.
Key words: Water management framework; environmental sustainability; developed and protected areas

1. Unsustainable Development

WCED (1987) stated that *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. Although it may seem a consensus goal, there still remain two challenging questions over this very topic:
- Is it possible to achieve sustainable development in any project/watershed?
- How to design or retrofit projects to achieve sustainability?

Aiming to address these focusing on water sustainable management, this paper was drawn in three sections to discuss it:
- a preliminary assessment of actual developments and their distance from sustainability, specifically (a) dam cascades; (b) urban rivers exploration and (c) conservation areas threats.
- a discussion over how ecohydrology may guide projects towards sustainable development through the analysis of (i) a macro-basin and; (ii) an urban sub-catchment.
- an evaluation on prospects and challenges to implement eco-hydrology.

2. Actual developments and their lack of environmental concern

Aiming to enlighten some of actual developments problems, we review three cases, specifically the exploration of great river basins through the assessment of dam cascade developments, the exploration of urban rivers/catchments and the threats to conservation of ecologically important areas.

Dam cascades

Hydropower generation has played a strategic role on the provision of electrical energy in South America, especifically in Brazil. However, environmental effects have damaged some anthropic activities, mainly for riverine communities. In this very topic, we present some of the history of two dam cascades: one in the São Francisco River and the other in the Upper Paraná River.

São Francisco River dam cascade

The São Francisco River runs (Rebouças *et al*. 2002) c. 2700 km, draining a c. 640 000 km^2 basin, which presents high physiographical heterogeneity including humid mountains (c. 1600 m a.s.l.) in central Brazil, semi-arid and arid Cerrado and Caatinga in the waterway northward, reaching deep canyons of coastal mountains and floodplains eastward into the Atlantic Ocean. At least 6 tribes of indigenous people (Pankuaru, Pancararé, Atikum, Kimbiwa, Trukas and Kiriri; Gutberlet *et al.* 2007) lived in this watershed until the arrival of the Portuguese settlement in the early sixteenth century. The valley now contains urban centers, mining, farming, hydropower generation and both rich and very poor communities. The São Francisco river presents five falls (Callisto *et al.* 2005) which were attractive for hydroelectrical construction resulting in Sobradinho, Itaparica, Apolônio Sales (former Moxotó), the Paulo Afonso (PA I, II, III, IV) complex, and Xingó hydroelectrical plants, thus forming a reservoir "cascade". Some environmental[1] and societal losses resulted from these constructions, including:

- Reduction on fish abundance due to blocking migrations and to changing the river into reservoirs, eliminating riverine spawning and non-spawning habitats, and possibly, causing extirpation of populations, as Godinho *et al*. (2007a) assessed for surubim (a migratory species) in the mainstream and Pompeu, Godinho (2006) for fish assemblages (48 species) richness and abundance in three marginal lagoons;
- Decline of fish populations, in the lower reaches, affects most of the fishing communities that are now poor, socially excluded, and with few alternative livelihood options (Gutberlet *et al*. 2007);
- Severe erosional process in the river mouth that has caused the destruction of a village and the partial immersion of a lighthouse constructed in 1856. Bittencourt *et al*. (2007) suggest that the permanent reduction in streamflow and solid river discharge, in response to construction of large dams, probably will have two direct consequences: (i) a chronic shoreline erosion downdrift of the mouth and (ii) a progressive deflection of the mouth in the downdrift direction.

Upper Paraná river dam cascade

The upper Paraná River drains an area of 880 000 km^2, and it represents 10.3% of the Brazilian territory. The most important feature of this basin is the presence of the highest human occupation in the country (54 640 000 inhabitants; 32% of the population), and several industrialized centers. In addition, agriculture, ranching and construction of dams are historical widespread activities. Consequently, few areas are still found in pristine conditions.

Compared to other large Brazilian basins, the upper Paraná River is considered one of the most intensively studied. Surveys started during the first half of the 20th century as observation of fish migrations (for spawning) in some tributaries (Godoy 1957). Other studies have shown that a major part of the biological diversity found in the Atlantic Forest biome is found in the upper Paraná River basin, although the overall number of species is certainly underestimated (Agostinho *et al.* 2005).

Since the second half of the 19th century, the Paraná River and its main tributaries have been increasingly used for hydropower generation, through the construction of dams. Impoundments affected mainly migratory species due to habitat fragmentation and regulation of floods. The closure of Itaipu Dam (October 1982), for example, modified a narrow stretch of the Paraná River (170 km long), forming a lake of 1350 km^2. As a consequence, riverine and highly valuable commercial species, like *Salminus brasiliensis*, *Pseudoplatystoma corruscans* and *Piaractus mesopotamicus* virtually disappeared in the new semi-lentic environment. This impoundment drowned Sete Quedas Falls, which constituted a natural barrier for fish movement, allowing upward dispersions of at least 17 species. Some of these (*Serrasalmus marginatus*, *Lorycariichthys platymetopon* and *Parauchenipterus galeatus*) are now widespread in the floodplain located above Itaipu (Agostinho *et al.* 2007).

Porto Primavera Dam, completed in 1998, formed the Porto Primavera Reservoir (area of 2200 km^2). This dam, subtracted half of the former Paraná River floodplain area, interrupted fish migration routes and altered hydrological dynamics, interrupting floods in some periods or leading to severe decreases in flood intensity, duration and amplitude. Impacts related to its operation have affected floodplain assemblages and have been documented in some recent studies (Agostinho *et al.* 2004a). The lack of flooding during the spawning period of most fish species is a great concern,

[1] Once it has been the usual approach in literature, we preferred to assess man and environment as dissociated domains (although they are not in reality).

since recruitment may not occur due to inaccessibility to marginal lagoons. Fish abundance and species richness in experimental fisheries decreased in years marked by low water levels, especially for migratory species (Agostinho *et al.* 2004b). After the closure of Porto Primavera Dam, water transparency increased, submerged macrophytes proliferated and the introduced peacock bass (*Cichla* spp.), a visual predator, became abundant downstream of the dam (Agostinho *et al.* 2007). The increased sedimentation rates and retention of matter and energy upstream, prompted by cascade of dams, lead to a pattern of decreasing primary productivity toward lower stretches (Barbosa *et al.* 1999). Based on recent evidence, the impoverished waters that reach the upper Paraná River floodplain are removing nutrients (phosphorus and nitrogen) and organic matter from its habitats. Therefore, the upper Paraná River no longer acts as a source of nutrients for floodplains (Agostinho *et al.* 2007), differing from the dynamics observed in other large rivers (Junk *et al.* 1989).

Among all perturbations, the effect of the operation of the upstream dams seems to cause the most severe impacts observed in the river-floodplain system. Such perturbations can be included in the category of "downstream impacts of reservoirs chains" and they affect the physical and biological environment, interfering direct or indirectly upon the habitat structure, communities composition and functional aspects of the system. In addition to the impacts upon nutrient cycling and solid concentrations, considered previously, other impacts associated with the alterations of the water level were identified:

- Changes of the natural hydrological regime, with direct impacts upon species whose life cycles depend on such fluctuations and upon the connectivity among habitats;
- Presence of barriers to migratory fishes, which spawn upstream the floodplain but use its habitats as nursery and feeding sites.

These impacts has potential do lead to biodiversity losses because several species that live in the region use the floodplain during a certain stage of the life cycle (Agostinho *et al.* 2007).

Urban rivers exploration

Human communities have settled mainly in water-rich areas, where streams used to provide water and convey wastes. Herein, we present the Tietê River exploration and its natural resources changes, which are seriously related to catchment management.

Tietê River

The Tietê river crosses the Brazilian state of São Paulo, running c. 1100 km, from east to west until it joins the Paraná river. Its upstream reach goes through the São Paulo Metropolitan Region, the most urbanized area in Brazil, with a total population of 19.8 million inhabitants (Brazil 2007). Although Tietê river presents relevant economic importance, it became internationally known due to its environmental problems:

- The environmental degradation began with the industrialization process from the beginning of the 1940's followed by its demographical boom. Great development was observed in the following decades, where vegetated areas gave place to a chaotic urbanization, which also occupied floodplains and valleys. The imperviousness increased runoff volume, peak flow and flood frequency, damaging the population (DAEE/SP 2008; SABESP 2007; Barros *et al.* 2005).
- Under a hygienist concept, where the idea is rapid evacuation of "undesirable" water, several drainage networks system were constructed and Tietê river's meanders were cut and channelized (DAEE/SP 2008; SABESP 2007). These procedures resulted in water quality losses, mainly caused by scarce control of stormwater's first flush, inexistence of sewerage systems, illegal piping connections and garbage production (Anton 1993), besides water quantity problems which demand new solutions.
- Such permanent land movements also generate problems related with erosion and sedimentation, demanding constant river bank dredging to avoid floodings and to keep navigability conditions.
- To address electrical energy, water supply, industrial and agricultural uses, recreation and navigation demands from its increasing population, a total of six dams (Barra Bonita, Álvaro de Souza Lima, Ibitinga, Mário Lopes Leão, Nova Avanhandava and Três Irmãos) were built between the 1960's and 90's (Rodgher *et al.* 2005). These regulations changed the natural hydrological regime, including changes in water quality (Abe *et al.* 2003; Rodgher *et al.* 2005) and trophic structure due to lake storage. For instance, Matsumura-Tundisi, Tundisi (2005) found greater plankton richness in the eutrophic reservoir of Barra Bonita then in natural lakes in the same region, highlighting the environmental disturbance caused by the dam.

Actually, large amount of money is annually spent (*c.* US$ 350 million per year) within the Projeto Tietê (Tietê Project) in an attempt to reduce water pollution (DAEE/SP 2008; SABESP 2007) towards the conservation of the remaining fauna and flora. Moreover, small actions have been conducted in the same way to define water management rules (CETESB 2001). Besides these aspects, the development of partnerships in the Tietê river basin management, through research system, public and private sectors, and community participation, as advocated by Tundisi, Straškraba (1995), is still incipient.

Threatened conservation areas

Anthropic demands for economical development has put in jeopardy even conservation areas, well-known by their great biodiversity. We present some human interventions effects on Ramsar areas, especifically the Pantanal wetland complex, which depends greatly on Cerrado upstream reaches, and the Taim wetland, a wetland-lake system.

The Pantanal wetland complex

The Brazilian Pantanal, one of the largest and still rather pristine wetlands on the planet (Da Silva 2000; Junk, Cunha 2005), comprises 160 000 km^2 of lowland floodplain of the upper Paraguay River basin which drains the Cerrado biome. Climatological conditions induce a monomodal flood pulse (Junk, Cunha 2005) which is the Pantanal landscape driving force (Junk, Da Silva 1999; Junk 2000), creating a great habitat diversity and, consequently, a huge biodiversity, including the existence of some threatened species (Da Silva 2000). Besides the ecological value, as highlighted by Junk, Cunha (2005), a diversity of landscape units gives the Pantanal a high aesthetic value, i.e., as parkland landscape, and still the provision of water, flood risk regulation (Swarts 2000) and waterway for its inhabitants transportation (Harris *et al.* 2005).

Intergovernmental plans to develop the region intensified the natural resources exploitation, accelerated by the construction of roads and lines for electrical energy transmission toward integrating the region with the national development scheme (Junk, Cunha 2005). Indeed, these changes stimulated the region's agricultural development (Swarts 2000), mainly in the highlands (Cerrado reaches), where large soybean farm exist. Alongside, gold mining began to be explored in the lowlands near the city of Poconé in the 80's (Junk, Cunha 2005). In the last decade, a large hydroelectric power plant was constructed on the Manso River, which is a large Cuiabá River tributary (Girard 2002), being the first dam built also to control the flood pulse in the Pantanal. There is still the plan to build the Paraná-Paraguay Waterway, through the connection of this interior zone reaches with the Atlantic Ocean, which would facilitate crop's commercial navigation.

Although the Pantanal wetland is a National Heritage (Brasil 1988), proclaimed in 1993 by UNESCO as a Ramsar site and in 2000 as a World Biosphere Reserve (Junk *et al.* 2006), only 2.5% of the Upper Paraguay River basin is formally protected (Harris *et al.* 2005), and multiple natural resource uses as presented are planned for the remaining watershed area. These conditions threathen ecosystems and society as noticed in:

- Water quality degradation by mining activities, due to mercury contamination (Junk, Cunha 2005; Swarts 2000) - high levels of mercury have been found in fish and in fish-eating birds (Swarts 2000). These species are also affected by fertilizers, herbicides and pesticides used in agriculture activities (Alho, Vieira 1997), besides domestic sewage and garbage (Swarts 2000) coming from the Cerrado reaches.
- Erosion and sedimentation increases due to changes in land use and dredging for waterways (Junk, Cunha 2005), which in turn increases flood risk, lowers biodiversity and disrupts the overall basin's sediment budgets (Swarts 2000). For instance, the Taquari River, one of the major Paraguay River tributaries has received an exponential increase in sedimentation (Swarts 2000; Junk, Cunha 2005); resulting in substantial alteration of the channel, besides significant commercial and sports fishing industries yield losses (Swarts 2000).
- Local dam constructions which change the Pantanal's natural hydrologic regime (Swarts 2000; Girard *et al.* 2003; Junk, Cunha 2005). The damming of streams alters water-flow patterns, affects sediment budgets changing the channel morphology, disrupts the natural balance between wet and dry seasons altering the normal flood pulses regime into the floodplain, which impacts diversity and productivity of species dependent on specific aquatic environments (Swarts 2000).

All these anthropic activities lead to large-scale, irreversible wetland degradation, increasing loss of biodiversity (Swarts 2000) and seriously affecting the indigenous communities living conditions (Ponce 1995; Hamilton 1999).

The Taim Wetland

Taim Wetland (Banhado do Taim) is a subtropical coastal freshwater wetland-lake system, c. 315 km^2 of great biodiversity, including macrophytes, mammals, reptiles and migratory birds (Tassi, 2008). Although the wetland was declared a federal environmental conservation unit in 1978, there still exists rice crop irrigation on its watershed (Tassi *et al.* 2007). Over the summer, large amounts of water (c. 100 m^3s^{-1}) are diverted to agriculture, potentially changing Taim's natural hydrological regime (Tassi *et al.* 2007; Tassi, 2008). Furthermore, fertilizers are widely applied in rice monocultures, contaminating soil and water bodies that flows to the Mangueira Lake, the major tributary of the Taim Wetland.

Even with the recoinassance of Taim Wetland's conservation requirement by many species that depend on specific habitat conditions to thrive and survive (Tassi *et al.* 2007), the rice monoculture is still seen as the only source of income for a great number of indigenous people (Villanueva 1997;

IPH 1996). While adequate water management rules are not established in the sense of balancing regional economy development while maintaining ecosystem's production of goods and services, water abstraction will threaten the ecosystem in the following ways:

- Patterns of water circulation and water quality are deeply altered due to changes in the vegetation structure, specially the dominant giant grass *Zizaniopsis bonariensis* (Guasselli 2005), an emergent macrophyte that plays a key role in the Taim Wetland hydrodynamics and in the carbon metabolism (Motta-Marques *et al.* 1997; Giovannini, Motta-Marques 1999). In the Taim Wetland-Mangueira Lake interface, stands of *Z. bonariensis* increase the hydraulic roughness, reducing water velocity, and consequently water and material exchanges in the wetland-lake system (Paz *et al.* 2005).
- Suitable habitat for migratory birds are eliminated when the pattern and characteristics of flood pulses required by some bird species are altered (Tassi, 2008);
- Areas originally wet become dry due to water lowering, reducing aquatic corridors. The displacement of species is inhibited by isolation, leading to a shortage of resources, reducing the specimen abundance and biodiversity or even eliminating some of them (Tassi *et al.* 2007; Tassi, 2008).

3. Common ground (or how far we are from sustainability)

These three cases exemplify the different type of problems faced by many other watersheds, with diverse sizes and physiographies, but with a similar exploratory approach, which relies on the development focused on short-term and single goal results. There are at least two potential reasons for such failures. Firstly, as testified by Capra (1982) and Zalewski (2002), the mechanistic approach (*i.e.*, reductionism or cartesianism) applied in projects' design and institutional arrangements, where it is emphasized the urge for a systematic multi-purpose planning and for anticipation and mitigation of project's externalities. Solutions should, therefore, consider financial and energy constraints noticed in usual engineering solutions. Secondly, the lack of environmental goods and services consideration, *e.g.*, through market incorporation, which would help on mitigating the mechanistic approach flaws. Reinforcing this viewpoint, Diamond (2005) advocates that lack of consideration of natural processes may result in society's failure, once its social, cultural and economic processes depend on them. From this, we would like to turn the sustainable development concept into development that maximizes human goods and services production without harming environmental production of goods and services that sustain society's demands.

Based on worldwide experiences, recent approaches try to encompass the knowledge that outcomes from such developments, considering hence natural ecosystems as infrastructure (Zalewski *et al.* 1997; Zalewski 2002; Zalewski *et al.* 2003) and natural ecological and hydrological processes (Poff *et al.* 1997; Falkenmark, Folke 2002) as guides to resource management towards the sustainable development.

4. Eco-Hydrology

Naiman *et al*. (2007), in an effort to unify worldwide concepts, presents eco-hydrology as the use of ecosystem processes as a tool to meet resource management goals, grounded on the dual regulation (Zalewski *et al.* 1997) performed by ecology and hydrology and its effects on the production of natural goods and services which sustains the society. Some basic ecohydrology principles include (Falkenmark, Folke 2002; Zalewski 2002; Zalewski *et al.* 2003; Zalewski, Krause 2007):

- Local critical ecological and hydrological processes demands shall prevail over single species or human production demands;
- Natural systems and phytotechnologies address multi-purpose goals in a cost-effective manner, if compared with artificial human constructed structures;
- The nature of hydrological and ecological processes is dynamic, which demands conservation of biodiversity for coping with changes (resilience), *i.e.*, assuming stability in resource management shall be replaced by adaptive management, and the absorbing capacity of basin ecosystems against human impacts shall be enhanced;
- Strategies must be site specific, *i.e.*, there is no single rule or methodology applicable to every development/basin, as regional ecological and hydrological processes and human demands vary in space and time.

We suggest including two additional considerations on the ecohydrology implementation, which will be explained next: the hydrosolidarity approach and the establishment of pristine conditions as a goal for natural resource management.

The term hydrosolidarity, depicted by Falkenmark and Folke (2002), highlights the necessity of conciliating interest conflicts through solidarity towards the minimization of ecological consequences, *i.e.*, the necessity of legitimizing ecosystems as water users of high priority (Naiman *et al.* 2002). Perhaps, this approach may lay ground for the desired inter-generational equity, stated in the sustainable development concept, through the prioritization of long-term ecosystem processes over human production short-term benefits.

Pristine resource conditions may be a particular interesting management goal, due to the lack of knowledge on anthropo-eco-hydrological relations and its non-linear nature, which inhibits our prediction capacity, guiding us to manage towards the predictable. Moreover, man and the whole biota are adapted to abiotic pristine conditions, which made possible the evolution of societies.

Under this set of principles, an adaptation of the Ecologically Sustainable Water Management framework (Richter *et al*. 2003) seems to be useful in any application. This adaptation would consist of 7 steps:
- Estimate ecosystem requirements, based on pristine hydrological, geomorphological, ecological baseline conditions, which will help on elucidating hydrological and ecological processes potentialities and vulnerabilities, as well as, on defining a benchmark management goal;
- Human water requirements inventory, considering actual and potential (time domain), as well as, local and regional (space domain) demands;
- Identification of potential incompatibilities, for the most conservative up to the most exploratory scenario;
- Propose a set of operating rules, which should be designed from the benchmark management goal defined in step 1 down to an affordable exploratory goal, along with the presentation of potential effects of each choice on the environment and on human activities;
- Foster collaborative dialogue to define the operating rules to be implemented, considering that err against ecosystems demands may result in irreversible damages;
- Conduct water management experiments to resolve uncertainties;
- Design an adaptive management plan, including research and monitoring, funding, governance and adaptability.

5. Eco-hydrology and spatial scales

Aiming to clarify how the eco-hydrology concept may be applied on water resource management or on a development design, we will recommend some activities that might be accomplished in general applications over two different spatial scales, which are clearly related to the examples presented in the former article section ('UNsustainable development'): (a) Macro-basin; (b) Urban sub-catchment.

Macro-basin

Step 1 - Estimate ecosystem requirements
- Research actual and pristine soil, vegetation, topography, hydrology, climate, and biota characteristics;
- Identify sites to be preserved in order to maintain hydrological (springs, floodplains, steep slopes, permeable soils, seepage areas, harmful composition soils) and ecological processes (spawning sites, ecotones, single interest habitats);
- Identify hydrological (flow regime) and ecological (species composition, ecological corridors) patterns to be conserved.

Step 2 - Human water requirements inventory
- Actual human activities inventory;
- Identify optimum sites for human activities;
- Identify optimum periods for human activities.

Step 3 - Identification of potential incompatibilities
- Information overlay;
- Identify restrictions to pristine conditions (processes) re-establishment.

Step 4 - Propose a set of operating rules
- Evaluation of an environmental flows set, with varying degrees of processes conservation/ exploration;
- Evaluation of a zoning set, in accordance with the proposed environmental flows set.

Step 5 - Definition of operating rules to be implemented
- Economic valuation of (ecosystems and men) goods and services produced in each scenario;
- Presentation to society of pros and cons (production yield) from each scenario;
- Social definition of operating rules.

Step 6 – Conduct water management experiments
- Control natural resources exploitation (including water right granting system, dam releases, fisheries management, river sand abstraction, soil use);
- Control development's installation.

Step 7 – Design an adaptive management plan
- Identify research areas and monitoring characteristics (including spots and species);
- Identify fund raising and governance.

Urban sub-catchment

Step 1 - Estimate ecosystem requirements
- Research actual and pristine soil, vegetation, topography, hydrology, climate, and biota characteristics;
- Identify sites to be preserved in order to maintain hydrological (springs, floodplains, steep slopes, permeable soils, seepage areas, harmful composition soils) and ecological processes (spawning sites, ecotones, single interest habitats);
- Identify hydrological (flow regime) and ecological (species composition, ecological corridors) patterns to be conserved.

Step 2 - Human water requirements inventory
- Actual human activities inventory;
- Identify optimum sites for human activities (*e.g.*, proximity to public utilities);
- Identify optimum periods for human activities (*e.g.*, construction during dry season).

Step 3 - Identification of potential incompatibilities
- Information overlay;
- Identify restrictions to the re-establishment of pristine conditions (processes).

Step 4 - Propose a set of operating rules
- Evaluation of a local set of water management goals, which will guide towards the maintenance of hydrological and ecological processes, with varying degrees of processes conservation/ exploration;
- Evaluation of a zoning set, in accordance with the proposed set of water management goals (including restrictions to construction activities and maintenance of open areas).

Step 5 - Definition of operating rules to be implemented
- Economic valuation of (ecosystems and men) goods and services produced in each scenario, including technical, social and environmental viability analysis;
- Presentation to society of pros and cons (production yield) from each scenario;
- Social definition of operating rules.

Step 6 – Conduct water management experiments
- Control natural resources exploitation (particularly through technologies that integrates the diverse human interests with natural ecosystem processes as suggests the low impact development technology, which provides opportunities for stormwater management, wastewater management, water supply, soil use, sediment control and solid wastes management);
- Control development's installation, clearly limiting sediment production.

Step 7 – Design an adaptive management plan
- Identify research areas and monitoring characteristics (including spots and species);
- Identify fund raising and governance.

Macro-basin and Urban sub-catchment interfaces

In both spatial scales, one may notice that similar activities are recommended, but the urban sub-catchment application shall be better detailed in space and time. For this reason, efforts applied in one scale shall address demands from the other one, saving efforts, time and money. For instance, the monitoring of umbrella species (*e.g.*, certain migratory fishes as suggested by Agostinho *et al.* 2005) would be beneficial for the protection of aquatic biodiversity and habitats, which should be applied in both scales. However, species decline in abundance or richness in the smaller scale may not represent the same magnitude loss in a greater scale. In the same way, the lack of management efficiency in one scale may harm the other one, or, on the other hand, an efficient management may help on the broader scale. For instance, the application of integrated resource management through planning, conservation of natural processes and application of phytotechnologies to mitigate human disturb on natural cycles may address demands for macro-basin recovery (Walsh 2000; Holman-Dodds *et al.* 2003; Walsh *et al*. 2005).

Case Studies Observations

The maintenance of eco-hydrological processes and of eco-hydrologically interesting areas could help some environmental damages for the case studies cited.

In the São Francisco River dam cascade, Godinho *et al.* (2007b) forecast that supplemental water releases, resembling natural floods, can bring fisheries benefits that surpass the lost hydropower generation revenue. The minimization of sediment budget changes would also help on reducing the erosional process in the river mouth. This kind of consideration could, although, avoid unpredicted positive effects (Callisto *et al*. 2005) as the increase in benthic macroinvertebrate diversity, due to water-quality improvement along the system. However, the habitat suitability enhancement for benthic macroinvertebrates may favour exotic species, possibly affecting endemic aquatic communities (Agostinho *et al*. 2005).

The maintenance of ecosystem's goods and services in the last dam-free segment of the Paraná River in Brazil, especially with regard to the populations of large migratory species, depends on the integrity of the land - inland water ecotone represented by the floodplain. The maintenance of this integrity should necessarily be linked to the disruption of the current process of human occupation in the region and especially to a greater rationalization of dam operation upstream. The artificial control of the floods by the dams upstream (controlling discharge) has a great potential to improve recruitment performance, particularly of large migratory fishes. Dam operation has some flexibility, but there are some pitfalls (e.g. the scarce information about fish biology and specific responses to the floods). More detailed studies are necessary in order to assess the biological requirements of the threatened species and to identify the minimum water level, duration and timing of the floods that trigger spawning and assure the viability of the eggs and larvae (Agostinho *et al.* 2007).

Regarding the myriad of Tietê river problems, an eco-hydrological approach on drainage systems design through planning and small-scale phytotechnology controls in its basin could reduce the need for river channeling and dredging, including the provision of opportunity for water supply by rooftop facilities, as presented in (Kloss, Calarusse 2006).

In the Pantanal, cattle losses due to unexpected flood releases by the Manso Dam in 2002 (Germano 2003), awkwardly built for flood control besides hydropower generation, would be avoided if natural flood timing was respected.

6. Prospects

Recent scientific and technological advances, specifically through the application of a systematic approach, have presented opportunity to enhance the human-nature relationship. Among those, the management of resources towards the conservation of natural processes and the use of phytotechnologies have been identified as the best ways to prevent great loss of natural goods and services production and to deal with financial and energy restrictions found in usual developments. However, this great step forward demands a greater effort towards its application in broad scale, which may be eased through the development of proper economic incentives as green stamps or certificates.

The most prominent challenge relies on the adaptation of institutional arrangements towards an adaptive management of resources, which demands political and managerial flexibility. This difficult task shall be even greater in developing countries, once they present a greater lack on education of their professionals and on information over actual and pristine ecosystems processes (baseline conditions).

Possibly, advances on ecological economics to incorporate ecosystem goods and services on project's feasibility assessments may be the best way to conserve desirable eco-hydrological processes. Nowadays, economic feasibility assessments are biased once usually only human produced (market) goods and services are considered.

Hopefully, advances over eco-hydrological modeling will continue, allowing to manage natural resources towards increasing ecosystems capacity on absorbing human impacts, including the possibility of predicting environmental responses.

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