

***Optimizing the ecosystem services
of the
Kolleru Ecosystem, India***

**A GAWI case study for the enhancement of sustainable
agriculture-wetland interactions.**

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of the
Kolleru Ecosystem, India***

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Foreword

The Kolleru Lake is the largest fresh water lake in southeast India. It has been a lake for centuries and pressures by people on the lake as an ecosystem were marginally; they probably never seriously jeopardized any of the lake's natural broad range of ecosystem services. This started to change in the 1940s and since then the lake has been the scene of a series of developments that each time dramatically changed the state of the ecosystem. Some of these changes actually increased pressures on the lake as an ecosystem, whereas other developments undid these pressures and ultimately resulted in the restoration of the ecosystem services.

This report is an analysis of the Kolleru ecosystem system using the DPSIR analytical framework. The elements of the DPSIR framework are Drivers, Pressures, State, Impact, and Responses. The framework allows us to look at any ecosystem from the perspective of its potential to deliver ecosystem services, and to understand how changes in the state of an ecosystem, and therefore of the services it is capable of delivering, has an impact on the people and communities that depend on these services for their incomes and wellbeing. It further allows us to formulate responses, meaning possible actions to address the drivers of change, the pressures on an ecosystem, the state of an ecosystem, or socio-economic conditions directly. The responses that are formulated follow from the analysis of the D, P, S, and I elements. They are therefore not motivated by some development ideology, but are more neutral. Important to remark also is that the responses are offered for discussion. They are not prescriptions of what should be next. Ultimately the responses result in the state of an ecosystem and the range of ecosystem services that are desired by those who agreed on the responses.

The factual information in this report is derived from mainly one document and from field visits and discussions with resource persons. The document is the Integrated Management Plan of the Kolleru Wildlife Sanctuary, written by Wetlands International South Asia, on request of the Forestry Department of Andhra Pradesh, that acted upon an order from the Supreme Court of India (2008). Field visits took place during the first half of November 2010. In the field meetings took place with farmers and fishermen. Discussions took place with notably two resource persons, Dr. Pranay Waghray, director Nallamalai Foundation and Dr. Ritesh Kumar, head Wetlands International South Asia. I'm grateful to the support received from each of them. Finally, the report befits greatly from section 4. of which the main author is my colleague Dr. Gerardo van Halsema.

1. **Introduction**

The Kolleru Lake is a typical example of the furthestmost inland part of an ancient lagoon which silted up except for a narrow canal connecting the sea with a now inland lake. That canal still exists today and is called the Upputeru canal. It is the only downstream outlet of the lake. The lake is now a fresh water lake, as the inland basins drain on the lake. The lake still experiences the influence of the sea. Every high tide, the flow of fresh water towards the sea in the Upputeru canal is temporarily blocked. At the height of the dry season, when the lake does not receive (enough) water from the catchments upstream, salt water flows into the lake. This explains why the downstream part of the lake is brackish during the summer. The larger part of the lake is then dry. The total area of the lake ranges from 135 km² in the summer season to 900 km² in the monsoon season.

The lake is capable of providing a range of ecosystem services. Of these regulating water flows in the downstream part of the basins that drain on the lake is particularly important in the sense that this has a direct impact on a large number of people both inside and outside the lake. The Kolleru Lake serves an important function in the drainage of the floodplains of the Krishna and Godavari rivers. It serves as a buffer when supplies of water are big and as a reservoir when supplies are limited. Another important regulating service of the lake is purifying water. The upland areas that drain on the lake are the scene of productive agricultural lands and of a range of rural industries. The waters that come from these lands are contaminated with both organic and chemical substances, which to the extent possible, are broken down by the lake. Also important are the provisioning services. The lake provides all kinds of products, ranging from drinking and irrigation water, different kind of fishes, to materials to make artifacts like mats, baskets, etc. Another service is provided, not directly to humans but to wildlife. The lake is an important stepping stone for migratory birds and the permanent home to many kinds of stationary birds, as well as to all kinds of amphibians, mammals, insects and, mostly aquatic, plants. Literally thousands of birds of many different kinds stay in the lake when it is winter in the northern hemisphere. It is also the largest pelicanry of Asia.

In the last 50-60 years, people have interfered in an unprecedented way with the natural state of the lake. Typically the interventions focused on the exploitation and expansion of one or two of the services that the lake could provide. Typically also this was only possible at the expense of other ecosystem services. All interventions concerned developing agriculture or aquaculture in the lake itself and in its immediate surroundings. Traditionally the lake was used extensively by the inhabitants of villages inside the lake and at its fringes (fishing, collecting of other productive service goods). People interfered little with the state of the Kolleru Lake (they also did not have the technical means to do so).

This started to change in the 40's of last century, when the government, in an effort to increase living standards in the area, started to parcel out the lake for crop cultivation. The agricultural production fields that were created were protected by dikes. Gradually the entire lake area was converted into agricultural production land – some 850 km² were licensed for crop cultivation. Initially extensive crop cultivation methods were practices, but gradually crop cultivation became more intensive (high yielding varieties replaced traditional varieties, usage of chemicals, and development of more and higher bunds to keep water out). Parallel to these developments, the state of the Kolleru Lake changed dramatically and the ecosystem will have been capable of providing some of its original services. Moreover, in order to make high agricultural yields possible inputs were brought in that could not be delivered by the Kolleru Lake ecosystem itself, like high yielding rice varieties, chemicals, labour and expertise, etc. Then a cyclone hid the area and wiped out agriculture completely. This happened in 1969. Many people were killed, people lost their livelihoods, and many people did not see an alternative but to migrate out of the area. The cyclone reestablished the lake in its former state, at least to some degree. The lake was a lake again; it contained water and that water could flow largely uninterrupted once again. Its ecosystem services will have become more diverse again.

A comparable process unfolded in the following decades (seventies till first decade of the 21st century). This time not agriculture, but aquaculture was introduced, and allowed to boom at the expense of the lake itself. Fish tanks were established almost over the entire lake. The fish was exported to markets that had become accessible by the expansion of the rural network of all weather roads and by improved railroad connections. Certain provisioning services of the lake, like making available fresh water and allowing waste water to be absorbed, were being exploited to the full. This means that other services, like regulating floods, providing fish captured the wild, providing all kind of other products, providing a living environment for wild life, were marginalized or not available any more.

Concern about the degradation of the Kolleru Lake as a unique ecosystem, and the associated loss of ecosystem services, especially its function as a foraging and shelter area for migratory birds, started in the sixties of last century. It culminated in the declaration of the Kolleru Lake as a bird sanctuary in 1995; an official notification to this effect was issued in 1999. The sanctuary concerns the area demarked by the 5 feet contour line; in the monsoon season the lake itself will fill up at times to the 8 feet contour line. Although declared a wildlife sanctuary, this did not immediately lead to a change in the state of the ecosystem. The fish tanks remained where they were and were operated as before. Even more fish tanks were established. Restoration of the ecosystem's functions happened in 1998, in which year all illegal fish tanks inside the sanctuary were demolished. It took a decision of the Supreme Court of India, acting upon a formal petition by a concerned NGO after lower level authorities had failed to take necessary actions, to make this happen. Once again the lake was an open water. Once again its original (natural) ecosystem functions were – at least partly – restored.

Of further importance to understand the state of the Kolleru Lake ecosystem at present are the many interventions that took place in the basins that drain on the lake. Over the last five to six decades, numerous structures have been built, drainage and irrigation canals have been dug, and reservoirs been constructed to improve water supply conditions to agriculture and fight floods. Today, most of the water flowing into the lake comes from irrigation and drainage canals, not from the rivers that used to drain into the lake. The overall effect with regard to the Kolleru Lake is that water levels are generally lower, and the water retention periods shorter.

2. DPSIR analyses of the Kolleru ecosystem

2.1. Introduction

The DPSIR tool is applied to analyze the wetland-agriculture relations in the Kolleru ecosystem. The focus is not exclusively on the Kolleru sanctuary, which is the lake area defined by the +5 feet contour line, but also on its immediate surroundings. Geo-physically the wetland area is larger than the sanctuary. Kolleru Sanctuary forms a part of the wetland system. Current definition is based on hydrological regimes, and 900 sq km is the peak inundation. That land outside the sanctuary is all being used for fish cultivation in tanks and for the production of agricultural crops; it naturally existed as agricultural land.

The DPSIR framework is a dynamic analytical tool that makes it possible to describe a certain area and how it has evolved to the situation as it exists today. The tool describes the drivers (D) of change; how the drivers lead to pressures (P) on the ecosystem and its resources; how this results in state (S) changes, meaning how different elements of the ecosystem undergo changes; how this leads to changes in the ecosystem services that the ecosystem generates and the impact (I) it has on socioeconomic parameters; and finally what the responses (R) are to achieve optimal conditions.

Two remarks need to be made before we continue to describe the different elements of the Kolleru ecosystem. Firstly, the optimal conditions that are to be achieved must be a balanced situation between ecosystem services and socioeconomic development. What exactly this

balance is does not follow from the DPSIR analyses itself, but is to be determined in some sort of decision making process. Ideally this is a controlled process in which all stakeholders directly concerned with Kolleru wetland system are involved. The information that came available through the DPSIR analysis is expected to be helpful in that process.

Secondly, even before the Responses are formulated, different stakeholders will have found answers to challenges that they faced. These are also responses. In as far as these are known – there will have been made many ‘responses’ by stakeholders that, although important to the stakeholders that formulated them, are not known - we will describe these responses with a small ‘r’. The responses that actually follow from the DPSIR analysis are written with a capital R.

2.2. Drivers

Drivers are any natural (biophysical) or human-induced (socio-economic) factors that lead directly or indirectly to a change in the wetland ecosystem, or in socio-economic processes that influence wetlands and agriculture-wetland systems. Simply put, drivers are the underlying causes that lead to pressures on wetlands or agriculture-wetland-related processes. Examples are: population dynamics, market development, natural environmental processes, government policies, and community behaviour. Some drivers operate by influencing ecosystem processes

For example, market opportunities may lead to the establishing of a sugar-cane estate and so changing land use in a wetland, while population growth may cause agricultural expansion into a wetland. Some drivers operate more diffusely, by altering other drivers. They may be seen as “deeper causes”, such as broad policies or their failings, international economic circumstances, and the cultural value systems in a society, which create other specific influences on people’s behaviour and situations¹.

Population growth

Population growth is an important driving force behind the state changes in the Kolleru wetlands system. Population growth has forced people to open new land in the wetlands, and the respective governments (British, followed by Indian) to stimulate this. Information about conditions before the British government is lacking.

Poverty and profit seeking

Directly related to population growth is poverty. Attempts to reduce poverty are an important driver. Such attempts include actions by private persons and communities, as well as governments. Examples are bunding parts of the Kolleru Lake to develop agricultural fields (before 1969) and later fish tanks (until 2008). Fish tank development has evolved into a profit seeking action.

Improved transport facilities, access to new markets

In the sixties and later the government has invested in the expansion of the network of rural roads. These new roads were metalled and therefore all-weather roads. They connected the Kolleru Lake with new markets at further distances for fish.

Increases in general welfare

More recently, increases in the welfare of the urban populations in particular has led to an increase in demand of products that the Kolleru wetlands can deliver. Cultivated fish is the outstanding example. Fish are cultivated in fish tanks since the late eighties or early nineties of last century and are sold at markets in India and even overseas.

Migration into the Kolleru Lake area

¹ The definition of the Drivers and the examples are copied from Wood and Halsema (2007). Also the definitions and examples of the other elements of the DPSIR framework as given in the section below are derived from this source.

People from outside the Kolleru wetland system have migrated into the area and have gained access to the area's resources. People have migrated into the area in order to offer their labour to those exploiting the ecosystem's provisioning services (e.g. fish tank operators and labourers, and possibly also rice farm labourers). Aquaculture was introduced as a poverty alleviation scheme, which was latter transformed to industrial levels.

Resource exploitation by absentee resource managers

Entrepreneurs from elsewhere have invested in, and have organised the construction and operation of fish tanks. Since the nineties of last century, this category of fish tank owners has increasingly dominated the industry, at the expense of local fish tank owners who has started their activities in the seventies and eighties.

Demand for road connections in the area

During the monsoon season, when water levels were high, inhabitants of the villages and hamlets inside the lake used boats to communicate with other population centres. More recently they demand roads to be constructed. Today not all population centres are connected to the road system by all-weather roads with concrete bridges, a situation that the populations concerned regret. Many roads also exist that were built to connect fish tanks with the main road.

Government policies and government empathy

Rural development in general and alleviating poverty in particular are the corner stones of rural policy of the Government of India. These policies have contributed to agricultural innovation (introduction of high yielding rice varieties, more intensive and also more water demanding cropping patterns, investments in irrigation and drainage infrastructure, the construction of roads, etc.) Not long after Independence the government has also carried out a land reform that lead to a more even distribution of land ownership.

At the other end of the extreme is the empathy of the government to take action when needed. A good example is the history of fish tanks and the events that eventually lead to the demolishing of tanks inside the sanctuary. The Kolleru Lake was declared a sanctuary in 1995, but the actual formal establishment of the sanctuary took place 4 years later, in 1999. From that moment onwards it was illegal to operate or develop fish tanks in the sanctuary. However, new tanks were still developed. This came to end when in 2008 all tanks were destroyed following an order to that effect by the Supreme Court of India.

Bio-physical processes

Drivers of change are not necessarily only actions by people. Among the most outstanding drivers of change are the irregularities of the climate, and in the case of the Kolleru ecosystem, the occurrence of cyclones. Andhra Pradesh has a long history of cyclones and many of these have caused tremendous pressure on the Kolleru ecosystem as well as on the population. The cyclone of 1969 is a good example of the impact a cyclone can have.

2.3. Pressures

Pressures are the consequent results of the drivers on the wetland environment or wetland-related agriculture and any associated socio-economic developments. Pressures are how the drivers manifest themselves on the wetlands and wetland related societies/activities through processes related to the transformation of wetlands or the disturbances of their ecological state. In other words, they represent strategies to satisfy the drivers. They are seen here as processes, or activities, that are operating on a generalized scale.

Examples are: agricultural colonization in wetlands, vegetation clearance, agricultural intensification, nature conservation, and water resources management and use.

Different pressures occurred at different time periods during the last 60 years of the existence of the Kolleru Lake.

Irrigation and drainage development, and flood control measures

Interfering with ad-hoc and structural measures with the hydrological systems of the basins of which the Kolleru Lake is a part has been a continuing activity since the late seventies. It is still ongoing today.

Agricultural intensification also meant the construction of many irrigation canals, drainage canals, reservoirs, dams, water distribution structures, etc. These are all constructed in an effort to improve water supply to agriculture or for another use, to drain excessive water out of an area, or to transport drinking water. Such decisions were often taken in response to a locally felt need and did not take, or did not take fully, into account the implications for the hydrology of the basin. The result is changes in the hydrological system, and increased pressure on the water resources in the Kolleru ecosystem.

The Krishna and Godavari rivers, the two main rivers that used to discharge in the Kolleru Lake, are now bunded and do not flow in the lake anymore. Today the lake is fed by 15 irrigation and 15 drainage canals and a few smaller rivers. The waters of the two rivers do not flow directly in the lake, but through regulated channels. The lake is still the flood balancing reservoir, meaning it is used to divert excess waters in the two rivers to prevent floods.

In an effort to effectively fight flooding of the lands outside the Kolleru wetland system, the Upputeru outlet, which is the only outlet of the lake, has been deepened and widened. Upstream of the lake, thus in the river basins proper, several reservoirs and water flow diversion structures have been constructed, also in order to fight flooding.

Agricultural development

In the period from 1940-1969 the lake area itself was converted into an agricultural production area. This process came to an end when a cyclone destroyed all agricultural production infrastructure that had been built in the previous years, and people's livelihoods in the process. From an ecosystem perspective one could say that the cyclone undid the pressure imposed on the ecosystem by the agricultural development activities.

The increase in demand for cultivated fish has led to the construction of fish tanks. Fish tanks were constructed both inside and outside the lake. Fish production per unit of land was pushed to high levels, using all kind of inputs (fertilizers, pesticides, other chemicals), at great costs to the environment. The environmental costs are not included in the balance sheet of the operations, meaning that part of the costs are paid for by the ecosystem, thus society². After the lake became a sanctuary, the fish tanks were destroyed (2008). Although this was done and thus pressure on the wetlands system was reduced, it was not done thoroughly enough, as much of the material of which the bunds surrounding the tanks were constructed, was left in the lake. This has led to a partitioning of the waters in the sanctuary (more apparent when water levels are low). Tanks outside the sanctuary continue to exist.

The agricultural innovation policies and drives have led to the introduction of high yielding rice varieties, double cropping, larger areas under sugar cane, etc. in the areas upstream of the Kolleru Lake.

Industrial development

In the water catchments upstream of the Kolleru sanctuary, different factories, production plants and mills have been established in the past decades. These include sugar cane processing mills, tanneries, and paper mills. The industries that are of relevance within the framework of the present analyse are those that stimulate the production of a certain agricultural or aquaculture product, use water as an input, and more importantly, that release water or waste products onto the environment, and ultimately into the water bodies in the catchments.

Road development

² The Integrated Management Plan for the Kolleru Wildlife Sanctuary (2008) provides details of the costs involved (p.).

In response to the demand for roads between the population centres of the Kolleru wetland system roads have been constructed. Generally these roads are built on dikes and include – too – few bridges or culverts. This leads to the obstruction of water flows and further fragmentation of the lake. The demand for roads inside the sanctuary has not been exempted; this pressure continues to exist.

The operation centres of the fish tanks, usually a simple concrete building next to a tank, are also often connected to the existing road system by a road. These roads are often simply dikes and impede the free flow of water. In addition to connection the operation centre to the main road, they also serve to make it possible that the fish ready for consumption is transported to the markets.

2.4. State

State changes in the (wetland) ecosystem can be described in terms of biophysical processes that determine the ecological character of the ecosystem and/or the natural resources base. They include changes in the quantity and quality of the various environment elements in the wetland (soil, water, plants, animals, etc.) and their consequent ability to support the demands placed on them (for example, biodiversity, environmental functioning and their ability to support human and non-human life, and supply resources) – in other words, the state of the ecosystem and especially its regulating and support services. Examples are: water resources, water quality and pollution, soil characteristics (chemical and biological), and biodiversity.

The services that an ecosystem is capable of providing in one way or another are of the following types:

- Provisioning – crop production, fish, grazing, domestic water, reeds etc.
- Regulating – flood control, water infiltration, groundwater recharge, etc
- Cultural –religious, recreational, tourism, etc
- Support – soil formation, cycling of nutrients, carbon storage, etc.
- Sustaining biodiversity – natural habitats for plants, animals and insects.

Below only the changes with regard to the provisioning and regulating services delivered by the Kolleru wetland system are discussed, and to some extent the changes with regard to biodiversity^{3,4}.

Water holding capacity of the lake

Water levels in the sanctuary are lower than they would have been if there would not have been interferences in the upstream parts of the hydrological systems of which the Kolleru Lake is a part. Water levels are generally lower, and the period during which water is in the lake is shorter. This results in a lower-than-optimal water holding capacity of the lake. For example, in some parts there is only water during 5 months of the year, whereas this could have been 8 months or more (exact details not available).

Free flowing water in the lake

Lower water levels, debris not being removed after demolition of the fish tanks in the sanctuary, and the construction of roads on dikes without sufficient opening has let to partitioning and fragmentation of the lake into three distinct compartments.

Flooding and water logging

³ Further work needs to be done to also understand the changes in the cultural and support services. These two aspects were also not discussed in the Integrated Management Plan for Kolleru Wildlife Sanctuary (Wetlands International South Asia, 2008).

⁴ It is noted that the exclusive emphasize on these 5 services does not do justice to the fact that ecosystems also have an implicit value: even an ecosystem that does not deliver any of these services, or that delivers negative services, has a right to exist.

Flooding probably always has been natural condition of the area. The area is very flat, the gradient very low, and the monsoon rains can be heavy. Flooding today is also a consequence of interferences with the natural flows of water. An outstanding example is the construction of fish ponds without regarding the impact this may have on the hydrology of the area. This has caused water logging immediately upstream of the tanks.

Water quality

The quality of surface waters is compromised by both point-source and dispersed pollution. Point source pollution is generally caused by the tanneries, sugar mills, paper factories, etc.; dispersed pollution by the rice growing and sugar cane sectors, which use chemicals to achieve high output levels.

Biodiversity

The conditions that less water is available in the lake throughout the year and that the lake is dry for longer periods during the year has affected the biodiversity in the wetland system. Although data to substantiate it are lacking, it is probably true to say that the number of water birds visiting the area during the winter has been relatively low at the times that the lake was turned into agricultural productions fields (before 1969) and in fish tanks (before 2008), and was high when the lake was an open water (as it is today).

2.5. Impacts

These are the socio-economic results that come from changes in the state of the wetland environment. In other words, they are the way in which the socio-economic characteristics and condition of a wetland society are affected, especially the provisioning services. Examples are: livelihood gains from market-oriented production, food and nutritional changes in subsistence situations, socio-economic differentiation and conflicts, and recreational development.

In describing the socio-economic impact of the state changes it is important to differentiate between categories of ecosystem service (resource) users. Key analytical questions to be answered are i) how have changes in the state of the ecosystem affected and changed the livelihoods of the various categories of resource users?; ii) how have the driver-processes created benefits and to what extent have different categories enjoyed benefits – or suffered losses?; iii) how have these processes affected changes in access (and titles) to resources for the various resource users; and finally, (iv) how does this all relate to absolute poverty levels? Resources include, but are not necessarily limited to, land, water, fishing grounds, hatching grounds, products harvested from the ecosystem.

The data available allow for general answers to the above questions only, and for questions i) and ii) to be answered to some extent, whereas information that sheds light on the issues of rights to resources (iv) and changes in poverty levels (v) is not available at all⁵.

farmers upstream at irrigation canals⁶

⁵ The Integrated Management Plan for Kolleru Wildlife Sanctuary (2008) collected data at village level only and mentions the number of households per villages. It further distinguishes between main workers and marginal workers (without defining these categories; these are probably categories used in formal descriptions of villages).

⁶ Stakeholders within the wetland/agricultural system

- Intensive users of the agriculture/wetland system who have property and water rights, with access to technology and resources for increasing agricultural production;
- Extensive users of the agriculture/wetland system with limited property and water rights and limited access to resources and technology for increasing agricultural production;

This category of farmers has generally benefited from the investments in irrigation infrastructure, which resulted in more water available throughout the year and in improved predictability of water availability. They have responded to this and to other innovations available to agriculture by adopting more intensive and more water-consuming cropping patterns.

The Integrated Management Plan for the Kolleru Wildlife Sanctuary states that rich farmers changed their cropping patterns (p. 48). It is likely that other categories of farmers with land in the upstream sections of irrigation canals did the same. Cropping patterns in these parts, as well as elsewhere in the basin, seem to fairly homogeneous.

farmers downstream of irrigation canals and upstream of the ring of fish tanks surrounding the sanctuary

Fish tanks are found surrounding the sanctuary. Agricultural (rice) fields upstream of these tanks are at the downstream end of irrigation canals. They seem to suffer from water logging caused by the existence of the fish tanks. Observations in the field and discussions with informants revealed that this year's harvest is lost, as has been regularly the case in previous years.

fish tank owners, operators, and labourers

In 2008 fish tanks inside the sanctuary were demolished. Many of these were illegal (built after the establishment of the sanctuary in 1999; their owners were not compensated, their operators and labourers lost this source of income, which affected their livelihoods. Other fish tanks were legal. Their owners claimed and were formally granted compensation for the loss of their property from the state⁷. Labourers were partly recruited from the village inside and outside the sanctuary. Many of them had been traditional fishermen; they returned to this income earning activity.

Fish tank owners outside the sanctuary continue to benefit from the state changes, as do their operators and labourers.

In contrast to more traditional systems of land use, the larger share of the income produced in fish tanks goes to the owner, who is often an absentee resource user, and in second place, to the operator, who in many cases also comes from elsewhere. It is estimated that up to 90% of the benefits generated in fish ponds goes to people outside of Kolleru; only 10% goes to Kolleru communities (IWM, p.50).

fishermen active in the lake using traditional methods to catch fish

The inhabitants of the villages in the lake are again predominantly engaged in catching fish using traditional methods. They saw their livelihoods changing dramatically over the last half century. They have been agriculturalists – land owners, tenants, share croppers, or labourers – at the time that the entire lake was turned into agricultural fields. This lasted up to 1969, when a cyclone destroyed what had been built up during previous years. Subsequently they

-
- Occupants of settlements close to wetlands who have selected the site in order to benefit from its valuable attributes, or due to lack of alternative
- Users located upstream of the wetland/agriculture system
- Farmers withdrawing water for irrigation purposes and discharging waste into the stream
 - Industry withdrawing water and discharging waste
 - Urban centers withdrawing water and discharging waste
- River basin users located downstream of the wetland/agriculture system
- Farmers depending on irrigation water (quantity and quality) flowing from the wetland/agricultural system
 - Industry (including tourism and recreation) depending on water
 - Urban centers depending on water
- Other stakeholders
- Nature conservation and amenity groups
 - Non-users who attribute value to wetlands

⁷ In November 2011 it was officially stated that the government would indeed pay out the compensation.

become involved in the business of cultivating fish in tanks. And now they are traditional fishers, supplementing their income with earnings from elsewhere in the state.

To further illustrate this, in 1976 every village inside the lake bed was transformed into a fishermen cooperative society under the Kolleru Lake Management Scheme (a World Bank assisted project). 70 New tanks were developed under the scheme, paid for by the project. The new livelihood systems that were made available to the villagers had the potential to generate an output per ha that was three times higher than the required inputs (IMP, p. 54). However, the villagers appeared not to be able to take advantage of the scheme and soon people from outside took over their fish tanks and developed new ones.

2.6. Drivers, Pressures, State Changes, and Impacts in time (summary)

As is clear from what was said above, conditions in the Kolleru system have been subject to important changes during the last couple of decades. The table below summarizes these changes in terms of the drivers, pressures, state changes, and socio-economic impacts of the DPSIR framework.

Period	driver	Pressure/ de-pressure	State changes	Socio-economic impact
Pre-1940	Bio-physical events, processes (e.g. cyclones)	unknown	unknown	unknown
1940-1969	Government policies to alleviate poverty	Lake turned into agricultural production fields	Water holding capacity greatly reduced, free flow of water hampered, area of open water reduced. Certain providing services (fertile land and sufficient water) exploited to the full, at the expense of other services (e.g. flood absorption capacity, foraging area for migratory birds)	Increases in income of local inhabitants. Immigration of labourers
1969	Bio-physical event: cyclone	De-pressure Lake restored to conditions prevailing before agricultural boom	Re-establishment of lake as open water. Restoration of broader range of original ecosystem services	Destruction of livelihoods. Different set of income earning opportunities.
Eighties, nineties and years until 2008	Population growth, new roads, increases in overall welfare, poverty alleviation policies New markets for fish.	Development of tanks inside and outside the lake. Later: illegal development of tanks inside the sanctuary	Area of open water greatly reduced Drainage of upland areas hampered Less water flowing into the lake	First phase: incomes for local inhabitants Subsequent phase: incomes for absentee ecosystem exploiters

	Profit seeking by absentee ecosystem service users Government policies (notably declaration of sanctuary, and also rural development policies) Government empathy (e.g. late in enforcing decision to establish sanctuary)	Road construction inside the lake	Free flow of water in the lake hampered Certain providing services (sufficient quantities of water, absorption of waste water) exploited to the full, at the expense of other services (e.g. flood absorption capacity, foraging area for migratory birds)	
2008	Demolition of fish tanks inside the sanctuary	De-pressure Lake restored to conditions comparable to original conditions	Re-establishment of lake as open water. Restoration of broader range of original ecosystem services	Absentee ecosystem service exploiters see their source of income evaporating Local labourers see source of income evaporating
2008 - date	<i>Actions to fully restore ecosystem functions</i> <i>Actions to upgrade income earning capacities</i>	<i>No pressures or de-pressures as yet</i>	<i>Lake functioning sub-optimal</i> <i>Reduced water holding capacity, fragmented lake, relatively short periods with water in the lake</i> <i>Sub-optimal biodiversity</i>	As yet no actions at local level to increase incomes from ecosystem services (e.g. optimized production of wild fish, ecotourism)

The last row explains about conditions in the past and anticipates certain Responses. It is to the Responses that we turn now.

2.7. Responses

These are actions in response to drivers, pressures, state changes and impacts. These may be technical and institutional or involve policies and planning. They can be implemented by a range of actors. Some examples of responses are:

- technical or socio-economic actions that try to address specific impacts;
- institutional development by communities that respond to state changes by improving wetland site management coordination;
- planning by basin-level organizations that respond to pressures within a river basin with initiatives for water and land-use management;
- national-level policies and economic development measures that try to address the needs in the society and especially achieve sustainable and ecologically sound economic development;

- international-level responses, including government-to-government types of cooperation, actions of international NGOs (NGOs), and international agreements to which national governments adhere.

The Integrated Management Plan for Kolleru Wildlife Sanctuary (2008) presents a set of Responses that, if implemented, would achieve two objectives: 'conserve the wildlife sanctuary with its rich biodiversity', and provide 'sustained benefits to the communities that depend on the wetland for their sustenance' (IMP, p.6).⁸ The Responses suggested in the plan are presented as projects and the costs associated with each project are also given, as well as annual budgets (the project is planned to be completed in 5 years time. Costs of all projects combined are estimated at lakh Rs.95,000 (appr. \$210 million). The projects are grouped in five fields: land and water resources management, biodiversity conservation, ecotourism development, livelihood improvement, and institutional development. For the purpose of management planning, the lake area itself is divided into a core area, which is the sanctuary (area within the 3 feet contour line), and a buffer zone.

The projects proposed in the IMP are listed below. A short description explains the kind of activities that are planned. For each project it is indicated whether it is a technical, economical, institutional or political activity (DPSIR categories for different kind of responses), and whether local or higher level stakeholders are involved.

Project ¹⁾	Activity/targets ¹⁾	Type	Non-government parties involved
<i>1. Ecosystem improvement</i>			
Delineation of management zone	Demarcation of Kolleru wetland and sanctuary area based on hydrological regimes using Integrated Wetland Inventory and Assessment approach	Technical	Communities in core zone (sanctuary) and buffer zone
Enhancing vegetative cover in degraded watersheds through biological and small scale engineering measures	Enhancing dense forest cover to 30% of direct catchment area	Technical	
Reducing pressure on forests through promoting alternate sources of energy and sustainable agro practices	- Reducing current fuel wood dependence on forests by 50% - Improved land use management practices in 60% of area presently under agriculture and horticulture	Technical	Households in local communities
<i>2. Improve water regimes of Kolleru Lake to restore ecological services and economic benefits</i>			
Enhancing water holding capacity	Enhance present water holding capacity by 23% providing opportunity to accommodate high flows, which in absence of adequate storage creates severe inundation within the upstream areas of Kolleru Basin	Technical	
Enhancing lake circulation and flushing	Ensuring effective water circulation and flushing in the entire lake system	Technical	
Water quality improvement	- Provision of access to safe sanitation in 64 settlements in and around Kolleru - Control of pollution from 7 major settlements contributing major	Technical Institutional	

⁸ Note that the commissioning of the management plan is itself also a Response. In this case a rather mechanical Response by the Department of Forestry of the State Government of Andhra Pradesh, which by law has to produce integrated plans for all the wildlife sanctuaries for which it is responsible. The integrated management plan for Kolleru Lake was submitted in 2008, accepted by all government departments in Andhra Pradesh, but has not been implemented as yet.

	proportion of pollution within Kolleru Lake		
Allocation of water for human and ecological purposes	Ensuring a rational water allocation system at basin level integrating ecological demands with human demands	Technical Institutional	Upstream and downstream farmers, fish tank owners and operators, fishing communities
<i>3. Biodiversity conservation</i>			
Enhancement of wetland bird population	- Improved knowledge of year-round habitat requirements of birds, especially migratory and breeding water birds in the Kolleru Lake and surrounding wetlands and conservation priorities - Increased carrying capacity of the Kolleru Lake and surrounding wetlands for birds, especially migratory and breeding water birds - Improved knowledge of migration strategies, precise international and national migration routes (including breeding, staging and non-breeding sites) and linkages of water birds using the Kolleru Lake and surrounding wetlands - Control of poaching through strengthening existing network of protected areas - Establishment of a bird sanctuary/conservation area in unprotected areas of the Lake - Involvement of local communities through formation of bird protection committees - Improved understanding of the health of birds (particularly of zoonotic diseases, which have the potential for transmission to people)	Technical	Fishing communities
Habitat improvements of water birds	- Enhancement of native food and cover plants as a resource base for water birds - Maintenance of open water areas and proportionate emergent vegetation belts to respond to the wide diversity of feeding and nesting habitats required by different water bird species	Technical	
Enhancement of capture fisheries	- Achieving self-sustaining native and endemic fish populations through targeted restocking - Enhancement of diversity and abundance of air breathing catfishes and freshwater prawns - Improving knowledge of diversity of native and endemic non-commercial species	Technical	Fishing communities
Control of invasive species	- Reduce the prolific growth of exotic (non-native) aquatic plant species - Mitigate proliferation of introduced invasive fish species e.g. Tilapia sp.	Technical	
<i>4. Sustainable resource development and Livelihood Improvement</i>			
Sustainable fisheries development	Increase in annual capture fish yield from Kolleru Sanctuary area from present level of 767 t to 5,000 t within a period of five years	Technical	Fishing communities

Sustainable agriculture development	Enhance efficiency of water use in agriculture sector	Technical	Farmers in core area (sanctuary) and buffer zone
Sustainable aquaculture development in wetland area outside Kolleru Sanctuary	Regulate aquaculture development within + 5 feet amsl to + 10 feet amsl area (286.4 sq km) to sustainable levels	Technical	Fish tank owners in buffer zone
Improvement of harvesting, post harvesting and value addition infrastructure for enhanced economic returns to the fishers	- Revival of 6 fish landing centers within Kolleru Sanctuary 70% of fish landing from Kolleru to have access to hygienic icing preservation facility - Value addition to 24% of annual fish landing through fish drying and pickling - Provision of improvised crafts and gears to 60% of the fisher population	Technical	Fishermen villages
Strengthening of fisheries cooperatives for collective ownership and management of Kolleru fisheries through a community driven process	Management of capture fisheries resources through community institutions	Institutional	Fishermen villages
Livelihood Improvement	- Reduce poverty within communities by 50% within 2010 (Millennium Development Goal) - Improve quality of life through enhanced access to safe drinking water, sanitation and access to markets	Technical Institutional Economic	(unspecified)
<i>5. Communication Education and Public Awareness</i>			
Ecotourism Development	Development of ecotourism in and around Kolleru Lake for awareness generation and providing economic benefits to the local communities	Economic	Fishermen villagers, upstream and downstream farmers
Awareness Generation	Generate awareness about values, functions and attributes of Kolleru Lake wetlands system and approaches for the management	Technical	Fishermen villagers, upstream and downstream farmers, fish tank owners and operators
<i>6. Institutional development</i>			
<i>Institutional Development for effective management of Kolleru Lake</i>	<i>Establishment of Kolleru Management Authority with the mandate of coordination, regulation and financial management for conservation and wise use of wetland ecosystem</i> <i>Capacity building of KDA, government agencies and community organizations for sustainable management</i> <i>Monitoring and evaluation of management action plan implementation</i>	<i>Institutional</i>	Fishermen villagers, upstream and downstream farmers, fish tank owners and operators

¹⁾ source: Integrated Management Plan for Kolleru Wildlife Sanctuary (2008), p. 68-83

In particular the activities under headings 1-3, and also the activities under headings 4 and 6, will result in the restoration of the Kolleru ecosystem capable of delivering an optimal set of ecosystem services. The activities under headings 4 and 5 serve to boost people's incomes, in

particular that of the fishermen in the sanctuary, but also that of the other local communities. Activities under heading 6 serve to set up a full-fledged organisational structure (parallel to and linked to the existing government structure).

The plan also provides an evaluation of the potential outcomes of the proposed activities:

Wetland Survey and Demarcation

- Consolidation of the Kolleru sanctuary boundary and development of management zones for regulating developmental activities for maintenance of ecological character of the wetland ecosystem

Catchment Conservation

- Reduction in overall soil loss from degraded watersheds through enhancement of dense forest cover to 30% of direct catchment area, reduction in area under erosion enhancing agro practices to less than 15% of the catchment area and reducing harvest of fuel wood by 50%

Water Management

- Rejuvenation of hydrological functions of Kolleru lake through 23% enhancement to present water holding capacity and circulation and mixing patterns within the lake
- Reduce water logging by 60% in areas around Kolleru sanctuary by enhancing water holding capacity and reducing impediments to water flows
- Water quality of Kolleru improved to B category as per CPCB designated best use criteria through management of sewage and sewerage from adjoining settlements and water quality regulations
- Allocation of water for human and ecological purposes through formulation and operationalization of stakeholder endorsed water management plan

Biodiversity Conservation

- Enhancement of diversity of native endemic fish species
- Enhancement of water bird population through control of poaching, strengthening existing protected area network and habitat improvement
- Control of invasive species through effective flushing of lake

Ecotourism Development

- Development of ecotourism in and around Kolleru Lake for awareness generation and diversification of livelihoods of wetland dependant communities

Sustainable Resource Development and livelihoods Improvement

- Poverty within communities living in and around sanctuary reduced by 50% through regeneration of resources and additional livelihood options
- Enhanced quality of life of communities through access to safe drinking water, sanitation and rural markets

Institutional Development

- Establishment of an integrated policy framework for conservation and development of Kolleru and associated wetland
- Establishment of separate and accountable funding mechanism for conservation and management of Kolleru
- Enhanced awareness of decision makers and stakeholders on values, functions and attributes of Kolleru
- Enhanced technical and managerial capacity of KDA, government agencies and communities to implement wetland conservation and management initiatives
- Establishment of monitoring mechanisms for implementation of Action Plan
- Establishment of Hydro biological and GIS laboratory (IMP, 2008, p. 84-85)

The proposed activities are comprehensive in the sense that they address the required Responses that would allow the Kolleru ecosystem to deliver a more optimal set of ecosystem

services. These services would indeed address multiple interests across all sectors involved that presently are active in the ecosystem. Indeed the 'required Responses', as the plan has been well received by the responsible authorities and has not led to modifications at the time it was discussed.

However, given the fact that there is an urgent need to optimize the ecosystem services of the Kolleru ecosystem, and the projects proposed in the integrated management plan have not been implemented yet, appropriate Responses at this moment in time would be to prioritize certain actions, and to further explain the necessity for them. Three priority Responses are offered here for immediate approval.

Integrated water management as Kolleru basin level

Improving water management in the Kolleru basin level (sanctuary, buffer zone, and catchments) would be a priority Response, for several reasons.

The provisional and regulating ecosystem services of the sanctuary can only be optimal if the water holding capacity in the Kolleru Lake is higher, and water circulation and flushing are optimized. This requires among others removal of remains of bunds and dikes after the demolishing of fish tanks in the sanctuary, dredging, opening of vents in roads in the sanctuary, and reorganizing drainage systems were presently fish tanks block the free flow of water.

In particular the provisioning services of the Kolleru ecosystem would improve, which would boost the incomes of notably the fishing communities. There would be more fish in the Kolleru Lake and more varieties of fish. Other economic activities further down the chain of economic activities that link producers and consumers would also benefit from higher production levels by fishermen in the lake. Note: complementary activities along the lines presented in the IMP include suggest activities include protection of breeding and spawning grounds, construction of hatcheries, and annual restocking with fry.

Also the flood regulating service of the Kolleru Lake would be more optimal is water holding capacity, water circulation and flushing are improved. This is of great importance to farmers cultivating land in the buffer zone and further upstream, who frequently suffer from flooding and water logging. It was observed in the field that famers upstream of fish tanks suffered from serious water logging because the fish tanks effectively blocked the free flow of water. It was also observed in the field that water logging also occurs in and around villages in the sanctuary, for such long periods that it effectively frustrated communications over road between villages and their surroundings and markets. Essentially restoring the flood regulating service implies restoring the natural water buffering function of the Kolleru Lake in the hydrological system of the Kolleru Basin⁹.

Optimized water holding capacity and water circulation and flushing would also allow opportunities for numbers of wildlife to increase and would stimulate greater biodiversity. Numbers of birds of many kinds would increase (not necessarily also the variety of birds, as these seem to have been remarkably stable over the past century (IMP p. 34-36). Other forms of wildlife, including fishes and amphibians, would benefit also, as would probably different kinds of aquatic plants.

More water and more flushing would generally improve the quality of water in the Kolleru Lake (regulating service of water bodies). This would make it easier to use the water of the lake for sanitation and drinking water purposes.

Optimized water distribution between upstream sections and downstream sections of irrigation canals would result in more water flowing into the lake and thus in increasing water levels in the lake and extending the period during which there is water in it. Interviews in the field revealed that the lake is dry for up to five months in the year (February till July), and that this

⁹ The Kolleru Lake also has an important water quality regulating service. This is not presented as a first priority at the moment.

is preferably restricted to three. Fishermen in the sanctuary would benefit from this. It would effectively help reducing their dependence on subsistence support by the state. Households living in villages in the lake are up to 100% dependent on fishing. As there is no fish in the lake up to 7 months per year, they rely on the state-financed Minimal Employment Program, which provides a minimum income for 100 days per year. They further substitute their income with selling their labour to fish tanks owners and by doing odd jobs elsewhere.

Upstream farmers are known to exploit water-intensive cropping patterns. Regulating (optimizing) water distribution between upstream and downstream sections of irrigation supply canals, and between upstream and downstream sections of water distribution canals within Chaks, would result in more water becoming available downstream and flowing into the lake. There could be a conflict of interest between the required optimal flow of water into the lake and the quantities of water required to maintain the water intensive cropping patterns upstream. During the Rabi season, this is almost certainly the case. A balancing of interests is required.

At the time of writing this report, the Irrigation and Flood Control Department finished the integrated water management plan for Andhra Pradesh. This plan will contain details that are of direct concern for the larger Kolleru system in general and the sanctuary in particular. Unfortunately the plan could not be made available in time to learn about such details and process them in the present report.

Awareness creation and establishing communication links between resource users and managers

The IMP contains an activity to increase the general level of awareness among stakeholders. Stakeholders include all resource users in the Kolleru ecosystem; they will be instructed about the values, functions, and attributes of the ecosystem from which they benefit, as well as state government agencies, who should adopt sustainable development activities. This would indeed be a priority Response.

To be added to this is the need to establish functional communication links between resource users and resource managers. Resource managers is defined here as all persons or institutions taking decisions which have an impact on the quality of a resource in the Kolleru ecosystem. and the upstream catchments. Resources are notably land, water, and fishing grounds. Observations in the field and in-depth interviews lead to the conclusion that such links often do not exist, or are sub-optimal. This could explain for the fact that tensions exist between different resource users, as well as a tendency to resort to the juridical system to fight one's cause. Functional communication links between the following categories of resource users and managers would be promoted under this Response: upstream and downstream farmers along an irrigation supply canal; downstream farmers and fish tank owners and operators further downstream; fishermen and fish tank owners and operators (to discuss the issue of waste water from the tanks; not mentioned previously); fishermen and polluting industries (also to discuss maintenance of water quality; also not previously discussed); and finally to extend that this can be optimised, resource users and the different line agencies (Environment, Forestry, Agriculture, Fisheries).

Management authority for the Kolleru ecosystem

A third priority Response would be to establish a Kolleru management authority for the Kolleru ecosystem (sanctuary, including buffer zone, to accommodate negative and positive spill over effects from the buffer zone). The IMP suggests a full-fledged management structure, consisting of governing bodies, advisors, development teams for specific tasks, etc. Such a management structure would have been needed when all project activities would have been implemented and the project would have to be completed within the five years set for it. The reality today is that this is not happening. A Response strategy that focuses on priority Responses is more feasible.

The most appropriate institutional Response under the present conditions would be to set up one small unit and give this unit the mandate to advise stakeholders and government agencies on the most appropriate actions to be taken for the Kolleru agriculture and wetland

ecosystem. Minimal conditions for such a Kolleru management unit to be effective include, professional excellence and dedication of its manager and staff, formal letters from line agencies that stipulate role and function of the unit, formal agreements by relevant line agencies to seek advice from the Kolleru management unit for all their plans and policies that have a bearing on the Kolleru agriculture and wetland ecosystem, and the obligation for line agencies to either accept the advice rendered or to deviate from it with motivation.

The three priority Responses will have a bearing on either a Driver, a Pressure, the State of the Kolleru agricultural-wetland ecosystem and the services it provides, and/or on the socio-economic conditions and livelihoods of the users of these ecosystem services. They are presented here for consideration and decision taking.

3. Response effects

If executed, the Responses formulated above will affect the state of the Kolleru ecosystem, but also in different degrees the drivers, pressures, and impacts. The effects can be direct or indirect in nature. In this section a general overview of the effects of the Responses on the state of the ecosystem and on socio-economic conditions will be outlined. The following effects are likely:

Integrated water management at Kolleru basin level – state of the Kolleru ecosystem

The objectives of the integrated water management policy at Kolleru basin level include supplying sufficient quantities of water to the sanctuary throughout the year to increase the volume of water in the lake at any point in time. Water levels in the lake should generally be higher and water should remain in the lake longer (reduction of the period during which there is no water at all in the lake). Also the through flow of the water in the lake should be increased. Other objectives of the integrated water management policy will be to balance water supplies at the head ends and tail ends of the irrigation canals and to prevent flooding and water logging. To secure enough water for the lake requires a special effort. The demands for water from the agricultural sector and other uses that directly benefit humans are better articulated than that of the lake, and unless provisioning the lake is given some kind of a priority status, it is likely to suffer from sub-optimal water supplies.

Integrated water management should also have a focus on water quality improvement.

More optimal water supplies to the lake will affect the state of the Kolleru ecosystem in the following ways:

- Longer periods during which there is water in the lake will allow longer periods during which fishes are in the lake and longer periods during which all kind of water-dependent organisms will survive. This in turn will result in longer periods during which birds can forage and live in the lake. Although it cannot be said with certainty, it will also imply that biodiversity will increase.
- Higher water levels in the lake implies a larger surface of the water body. This will result in more fish and other organisms and increased potential to attract migratory birds, and improved conditions for survival of birds and other organisms. Higher water levels also make it possible that water flows more freely through the lake, perhaps even overcoming the present conditions of compartmentation.

Improving the quality of water flowing into the lake, regardless whether it comes from fish tanks, rural industries, or upstream agricultural fields, will expectedly result in healthier conditions for fishes and other forms of wild life. This too will stimulate the provisioning services of the ecosystem.

Integrated water management at Kolleru basin level – impact on socio-economic conditions

More water in the lake and longer periods during which there is water in the lake will both result in stimulating the provisioning services. Local people in general will have increased possibilities to harvest reeds and plants for other uses, as well as collect other materials and food for their home consumption, and fishermen catching fishes to earn an income can do so longer and in larger areas.

Households depending on the lake for drinking water and sanitation will experience easier access to these basic needs if there is more water in the lake and for longer periods.

More water will result in more through flow and this can be expected to stimulate the regulating service of the lake ecosystem to clean water flowing into the lake.

Awareness creation and establishing communication links between resource users and managers – state of the Kolleru lake ecosystem

There are people who directly intervene in the Kolleru lake ecosystem and there are people who indirectly affect its state. Examples of the former are the fishermen, the tank owners and operators, the people who build roads and dikes, etc. Examples of the latter are policy makers, absentee resource users, NGOs, researchers recommending actions to policy makers, etc.

Improved understanding among all these 'resource managers' of the Kolleru Lake ecosystem, its services, its relations with its environment, and the 'do's' and 'don'ts' when it comes to preserving its qualities, will have a direct effect on the state of the ecosystem. Informed people have a better understanding of the context in which they take their decisions, as well as of the impacts of their decisions.

There are resource managers with different and supposedly opposed interests active in the Kolleru Lake and its surroundings. Examples are upstream and downstream water users, agriculturalists and fish cultivators, fish tank owners and fishermen, local resource users and NGOs, etc. The condition today seems to be that communication between the different interest groups is not always optimal and sometimes lacking. It can be expected however, that improved communication will result in more balanced interests. This may result in more efficiency in using the lake resources, notably water, which will have a positive effect on the state of the lake.

Awareness creation and establishing communication links between resource users and managers – impact on socio-economic conditions

There is considerable potential in improving socio-economic conditions by improving awareness and stimulating communication. Improved communication will result in more efficient resource use, which will stimulate incomes (see above). Increased awareness of the how the ecosystem functions will improve understanding how to benefit from its provisioning capacities. The Integrated Management Plan for the Kolleru Wildlife Sanctuary gives examples of how fish catching can be improved. The insight is based on a more thorough understanding of fish life in the lake.

Management authority for the Kolleru Lake ecosystem – state of the Kolleru Lake/impact on socio-economic conditions

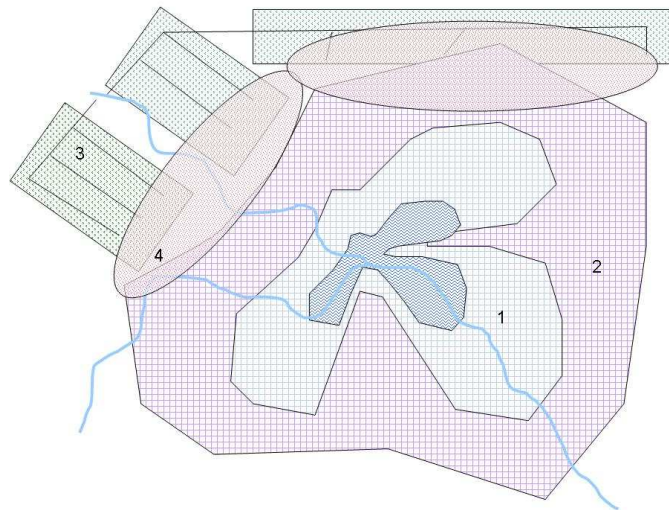
It would be a principal task of the management authority of the Kolleru Lake to be established to advise the line agencies on the effect of their policies on the state of the Kolleru ecosystem and on the most appropriate actions to realize previously agreed state conditions. Also it would be a task to assess the effect of policies on livelihoods and socio-economic conditions in general, and on the conditions of different categories of people in particular (rural poor, lower casts, women, youngsters, etc.). The actions of the Kolleru

Lake Management Authority would have a positive effect on both the state of the ecosystem and on socio-economic conditions; its actions would make a difference between the situation today, which is characterised by less focus on these issues.

4. Interventions in the hydrology of the Kolleru lake and associated catchments

Key to the optimization of ecosystem services of the Kolleru ecosystem is the revitalization of the hydrological state of the lake itself and its surrounding catchment. In order to achieve optimisation of ecosystem services the aquaculture sector needs to be better integrated in its environment; meaning that available provisioning and regulating services are used more optimal, and actions that compromise ecosystem services are discontinued.

Figure 1. Schematic presentation of the present state of the Kolleru lake and its surroundings



Hydrological perspective

Kolleru lake forms a natural depression in the landscape that acts as a (drainage) water collection and stagnation point. During periods of high water discharge (e.g. Monsoon) fresh water stagnates in Kolleru forming a seasonal lake, that swells during the wet season and shrinks during the dry season, when drainage inflow into the lake depression area is minimal.

These natural conditions have first been altered by construction of the large scale irrigation system and agricultural command area [3] that surrounds the Kolleru depression [1]. Surface water from the Krishna and Godavari rivers have been diverted through surface canals, that discharge/end into the Kolleru depression, a development that started at the time of British rule and that was continued by the Indian Government, and provide irrigation water to the agricultural command area surrounding it. Monsoon excess water, as well as irrigation intrinsic drainage flows (sub-surface and surface) would have kept supplying Kolleru depression water inflow during the monsoon and throughout the year, causing the seasonal swelling and shrinking of the lake.

The widespread boom in aquaculture in Kolleru through the building of large fish tanks (ponds) [2] has drastically changed the hydrological regime around Kolleru depression, resulting in significant hydrological state changes both up- and downstream of the aquaculture zone:

- the widespread and long term ponding (18 months for a typical aquaculture cycle) of surface water in the tanks significantly reduced the surface water inflow into Kolleru depression, with as immediate effect a reduction of the Kolleru lake;
- the artificial ponding of water in the aquaculture zone [2] leads to a stagnation of sub-surface and surface inflow into Kolleru depression, with the immediate effect of reducing drainage outflow of the agricultural zone [3] into Kolleru depression and water logging [4] (high water tables) at the periphery of the aquaculture and agriculture zones – this reduces agricultural production in the affected waterlogged zones through the dual menace of suffocation (oxygen deprivation in the rootzone) and salinization.

The core area of the Kolleru depression and lake [1] (together constituting the Kolleru wetland), though restored through the abandoning of aquaculture tanks, is still in a stressed state, as (i) the hydrological inflow of water is still hampered by water logging [4] and widespread surface water ponding in the aquaculture zone [2] that diminish the seasonal swelling of Kolleru lake; and (ii) the dykes of the old aquaculture tanks in the core zone still form a physical barrier that hampers the flow and water circulation in the core area and the lake – this significantly reduces the aquatic ecology of the core area and hampers the development of the fish stock in the lake.

In addition to the water quantity issues above, Kolleru depression and lake [1] is greatly affected by poor *water quality*. The poor water quality stems, for a major part, from the discharge of waste water from the intensive (high input based) aquaculture [2], that discharge its ponded water after intensive feeding and use into the core area, and from another part from various rural industries in the immediate vicinity of the lake that discharge untreated waste water onto the surface water. The water quality is further depressed by a lack of water circulation and flow in the core area, that diminishes the Kolleru wetland (depression and lake) capacity to purify the water.

Desired future state of Kolleru wetland

The desired future state of Kolleru wetland is informed by the objective of improving and sustaining the wildlife ecology of the wetland in the core zone in general, and the aquatic ecology in particular [1], whilst maintaining and sustaining the productive use of land and water uses in the agricultural [3] and aquaculture [2] zones in a sustainable manner. To this end, it is critical that the hydrological interrelations and interdependencies between the three zones and water uses is improved – both in terms of water quantity and water quality. Or, in other words, to restore the Regulating services of water retention, water regulation and water purification of Kolleru wetland. This can be achieved on three fronts:

Restoration of hydrologic connectivity – enhanced surface channeling

Through dredging and canalization of existing old irrigation canals (in particular the ends that stream into Kolleru) and streams, the hydrological connectivity between the agricultural zone [3] and the core Kolleru wetland [1] can be restored. Supplementary to this, clear passage ways through the aquaculture zone [2] are created and maintained. This will enhance the Monsoon discharge, and irrigation drainage outflow of the agricultural zone [3] into Kolleru wetland – thus enhancing the inflow of water and seasonal swelling of Kolleru lake. This may be supplemented with additional (surface) drainage channels in the agricultural zone [3] to optimize the drainage of the waterlogged area. This latter measure will have the immediate effect of raising the productivity of the waterlogged tail-end areas of the irrigation agricultural area adjacent to Kolleru. The current tail ends of the irrigation channels (nowadays ending before they reach Kolleru core zone) can be operated during Monsoon for active drainage into Kolleru core zone, using the old (unused) irrigation channel beds in the core zone. The interventions in the physical irrigation and drainage assets in the agricultural zone should be supplemented by the creation of adequate irrigation and drainage management institutions. These institutions should include the provision of adequate supplies of water into the Kolleru lake in their operational plans. This enhancement of surface channeling and connectivity may thus lead to three positive state changes and effects:

- increased surface water inflow into Kolleru wetland (increased seasonal lake swelling)
- reduction of water logging and flooding
- improved agricultural productivity

Polyculture and helophyte based aquaculture. Through innovation of the aquaculture sector a transformation of the single pond aquaculture into a poly-culture based aquaculture systems (either vertical within one pond, or horizontal through sequential ponds) that end into a helophyte waste water basin two hydrological state improvements can be realized:

- improved water flow from aquaculture zone [2] to core Kolleru area [1]
- improved water quality into core Kolleru area [1]
- enhanced wetland vegetation along the outer edge of Kolleru core (helophyte waste water basins)

Restoration of water circulation capacity in Kolleru core area: The Kolleru depression (as clearly decipherable from Google Earth) is still strewn with old (presently unused) irrigation canal sections, stream beds, demolished fish tank embankments and present day road and channel embankments. These obstruct the water circulation through Kolleru lake, which adversely affects the water quality and fish stock population and migration in the lake. This situation can be easily turned around through active leveling and cutting of the obstructions so as to enhance the water circulation of Kolleru lake, and its three compartments. The associated state changes will be:

- enhanced water circulation
- enhanced water purification capacity

All these measures combined will drastically enhance the (hydrological) state of Kolleru wetland ecosystem, by enhancing its surface (and sub-surface) water inflow – amplifying its seasonal swelling – and water circulation and purification capacity. This will greatly enhance the aquatic ecological state of the lake, and thereby the biodiversity services of the wetland (enhancement of bird life). In addition, the provisioning services for fisheries (fish catch in the core lake) will be enhanced by (i) enlarged seasonal swelling of the lake, and (ii) improved water circulation and quality. This can be further actively improved/optimized by active and purposeful seasonal stocking of the fish population with cultivated fingerlings (preferably multiple species). An enhanced helophyte (wetland cultivation) zone around the outer edge of Kolleru core zone, may be favorable for this in providing good fish stocking grounds.

Of all the measures proposed above, the innovation of the aquaculture sector may be the most difficult to achieve. Where the hydrologic connectivity and enhanced water circulation can be realized through a comprehensive management plan and action, the transformation of the aquaculture sector depends largely on the adoption by the sector of innovative cultivation techniques. This cannot be achieved through the imposition of new regulations and rules alone that favor poly-culture and helophyte based techniques. The critical element here is that the adoption of innovative cultivation techniques in aquaculture should also provide tangible benefits to the aquaculture sector itself, as well as the surrounding state of the ecosystem and adjacent sectors. Typically this means that its adoption should be economically attractive and beneficial for the fish farmers. This can depend on multiple factors:

- the innovative techniques of poly-culture and helophyte need to be actively researched and developed in the Kolleru context to optimize their productivity in the hydrological and ecological setting of Kolleru (e.g. species choice and density, feed choice and density, helophyte choice and size, water flow management etc.);
- prolonged intensified mono-culture and high feed and pest management inputs may lead to declines in economic return of traditional practices, that may favor transition to poly-culture based techniques -- which can be established through economic studies;

- WTO rules and international fish certification standards may favor innovative practices and enable higher economic returns on international certified trade markets – facilitating the access of Kolleru aquaculture sector to these markets and its compliance with strict certification rules and regulations is then, however, a prerequisite.

Given the critical impact the aquaculture sector in Kolleru has on both the hydrology and water quality of Kolleru lake, as well as the economic importance of the sector in the region, it is warranted to include a comprehensive strategy for innovation and increased sustainability of this sector in the Kolleru management plan and strategy. Such an aquaculture strategy needs to be comprehensive in stimulating the technical Research & Development of innovative practices in Kolleru, the facilitation of access to international certified fish markets (for instance by setting up a purposely build processing industry) and appropriate policy and economic support measures that may further stimulate the development and uptake of innovative aquaculture practices. The aim hereby should not be to target and force a mass transformation of the sector as a whole in the immediate future, but to stimulate and facilitate the innovation in the region thereby proving its economic feasibility and improved sustainability credentials. The success of well established pilots may be taken up by the wider sector, in a similar way as the initial boom in aquaculture has led to its widespread application in the region.

Figure 2. Schematic presentation of the desirable state of the Kolleru lake and its surroundings

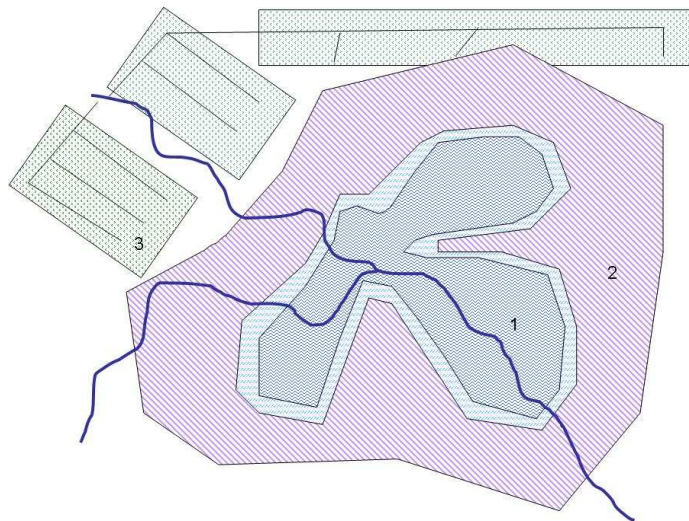


Figure 2 presents the desired state of the Kolleru lake and its surroundings. In this desirable state, the Kolleru lake would provide the following multifunctional ecosystem services:

Core lake area:

- I. Biodiversity
- II. Regulating services – water retention and water purification
- III. Provisioning services – stock managed fisheries and gathering of reeds/plants/fowls

Aquaculture periphery zone:

- I. Provisioning services – poly-culture and helophyte based aquaculture
- II. Regulating services – water regulation and water purification

Irrigated agricultural area:

- I. Provisioning services – irrigated agriculture
- II. Regulating services – water drainage

5. Closure

The Kolleru ecosystem is a unique natural phenomenon. Its wildlife, especially birdlife, is unsurpassed. Moreover, the ecosystem offers a range of ecosystems services from which also people benefit. The challenge for the future is to manage the Kolleru ecosystem in such a way that its ecosystems manifest themselves to their full potential, to the benefit of the many different categories of people living in the area, as well as to benefit of all forms of wildlife, in a balanced way. This report has meant to make a contribution to that challenge. Not by prescribing actions to be taken, but by offering a perspective – that of optimizing ecosystem services.

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