

Water for Food and Ecosystems

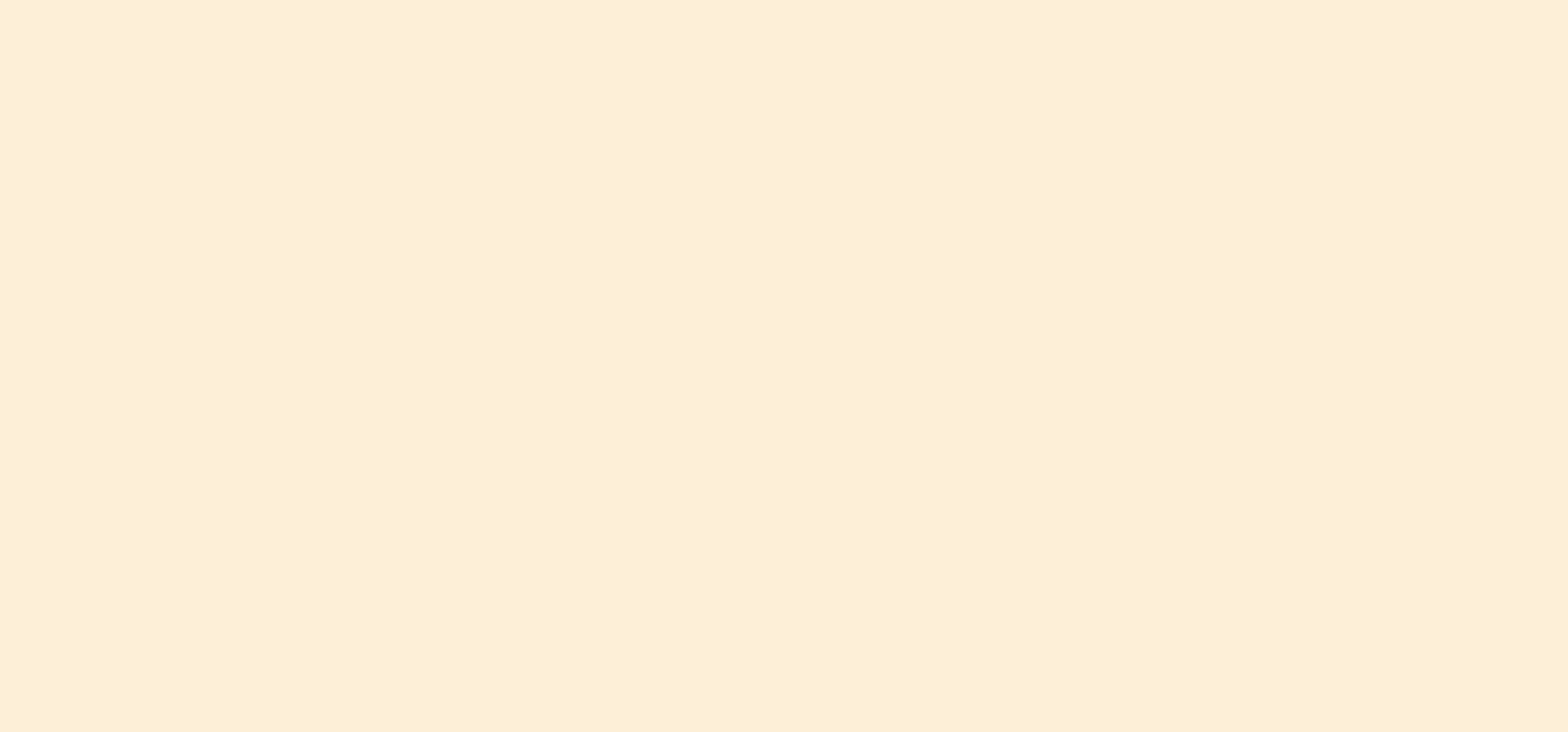
Pantanal-Taquari;

Tools for decision making in Integrated Water Management



PANTANAL TAQUARI





Water for Food and Ecosystems

Pantanal-Taquari; Tools for decision making in Integrated Water Management

Editor:

R.H.G. Jongman

PANTANAL TAQUARI



Partners for Water

This Project of the Water for Food and Ecosystems Programme has been made possible with financial support from the Partners for Water Programme, which combines the efforts of the Netherlands Government and private sector towards worldwide sustainable, integrated water resources management. Partners for Water had a □ 30 million budget for the 2000-2004 time frame

April 2005

Preface



This is the summary report of the Pantanal-Taquari project with all the documentation of importance on CD-ROM in the back of this booklet. The project has been carried out in the framework of Partners for Water under Project number 02.045. It has been a joint project of Dutch institutes and EMBRAPA Pantanal. It serves as one of the pilot projects of the Dutch involvement in the World Water Forum. The products and information of this report are also an extension of the following projects: "Avaliação das imagens da câmara MMRS no estudo da dinâmica da deposição de sedimentos e do regime de inundação do leque aluvial do rio Taquari no Pantanal: Monitoramento hidrossedimentológico", approved by CONAE da Argentina, which provided the images of the sensor MMRS, satélite SAC-C and the project "Avaliação da dinâmica de inundação para o gerenciamento dos recursos naturais do leque aluvial do rio Taquari através de geoprocessamento", supported by FUNDECT.

The authors of this report thank all those who contributed to this project especially Dr Mario Dantas, who draw the attention on the problem of the Taquari, Antonio R. Ioris and Jörgen Leeuwestein both working for the Programa Pantanal when the project was in preparation and in its first phase and who supported us strongly in the important contact with the authorities in Brasília, Campo Grande and Cuiabá. We also thank all those who helped us without being mentioned in the institute of EMBRAPA but especially all the people, farmers and local authorities and NGOs in the Pantanal who are strongly involved in the problems of the Taquari and are impacted by the present situation. This project has been made possible through funding of the Dutch Programme Partners for Water, Project Number 02.045.

We thank the Embrapa-Pantanal staff and the students for the collaboration. Important data were collected during a field survey on the Taquari in March-April 2004. We would like to thank our excellent 'boatsmen' Isaac and Valdomiro (EMBRAPA-Pantanal). Grain size analyses of sediment samples collected in the field were carried out at the soil laboratory of EMBRAPA-Pantanal (Corumbá). Radiocarbon age determinations were carried out at the Robert J. van de Graaff Laboratory (Utrecht, The Netherlands) under supervision of Dr. Klaas van der Borg, who also calibrated the 'modern' radiocarbon ages.

For the field survey use was made of sounding and DGPS equipment. The method for quick bathymetric surveys using portable sounder linked to GPS and integration with GIS was developed by Mr. Ing. Remco Dost from the Department of Water Resources, ITC. The dual frequency GPS used was provided by Drs. Klaas Verwer, Department of Sedimentology, Free University of Amsterdam, The Netherlands.

Furthermore we would like to express our thanks to Roberto de Ruyver MSc from Argentina who was instrumental in developing the appropriate correction procedures for hydro-DEM optimization. We are also grateful to the ILWIS development team at ITC for their effort in programming the necessary routines and algorithms needed for DEM hydro-processing.

This final report is available in both English and Portuguese.

On behalf of the Pantanal Taquari team.

Rob Jongman

Wageningen 14-4-2005

Summary



In the 1970s the Planalto, the highlands around the Pantanal - a savannah wetland of 250.000 km² - have been colonised. Until then the Planalto was covered by dry open bush (cerrado). The soil is highly erosive and the colonisation has taken place without consideration of the impact on the Pantanal, one of the world's most important biodiversity areas.

The Pantanal in Brazil consists of a number of large rivers in a joint wetland area. The economy is based on cattle breeding, fishing and ecotourism. Large areas are dominated by the river regime of the Paraguai and its tributaries. In the wet season large areas of the savannah are flooded. Now erosion and silting up make the Taquari into an unstable braiding system. This is at the moment a major problem causing permanent inundation in an area of around 11.000 km² in the subregion Paiaguas in stead of periodic inundation. The result is a decline of the fish populations and a decline of the area for cattle breeding.

The main conclusions of the project are:

- Putting science into context: The important added value of the project is that knowledge has been set into context of the river as an ecosystem and a socio-economic unit. Within that context the links between science fields (hydrology, ecology and economics) have been made.
- Biodiversity can be important for regional economy: Less aquatic biodiversity means less fish, less fishing tourism, less ecotourism, less income and more isolation. The relationship of the hydrological behaviour of a river system and its ecological functioning (the flood pulse) can also be an important lesson to be learned for river management in Europe.
- The role of stakeholders and capacity building: In a situation where politics is important, it is essential that all are involved and discuss matters using political and scientific arguments and the right economic and hydrological models to explain the situation. Proper knowledge appeared the only convincing argument for taking decisions.
- Organisation of water management: It is important that the results of the project will be accepted both in the region and by authorities that supervise the region.
- Technical solutions are not always the best solutions: Technical solutions such as building a dam have been proposed by different stakeholders and the project was capable of showing the consequences, both positive and negative.
- Research coordination and cooperation: An important aspect that has been learned is that the cooperation between and the coordination of policy and research can be improved considerably; both can benefit from this.

In general, understanding the hydrological dynamics and related ecology of rivers at the basin scale and communicating this with the organisations and people involved is the basis of economically and ecologically sustainable river management.

The problem of the Taquari and the challenge of the project



The landscape of the Pantanal is a paradise. It consists of vast rivers, marvellous wetlands, temporary waters, small lakes, forests and grasslands that are extensively used for cattle breeding, fishing and ecotourism. It has the largest population of alligators, there are giant otters and it is rich in birds such as Tuiuius, Herons, Emas and animals of prey such as the Jaguar and Puma. The Pantanal is the largest complex of wetlands in the world and it is part of the Upper Paraguai River Basin.

The Pantanal wetlands comprise nearly 250,000 km². The Taquari is one of its largest rivers; it has a length of about 800 km of which about 500 km in the wetlands of the Pantanal. The city of Coxim is the border between 'Bacia do médio e baixo Taquari' or Pantanal and 'Bacia do alto Taquari' or the highlands. The size of the high Taquari River basin is 29,000 km² and the area of the river basin in the Pantanal is about 50,000 km². The Taquari is unique in the world, because it has the largest alluvial fan in the world and it is a natural river showing all its characteristics. The largest part of the high Taquari is situated in the state of Mato Grosso do Sul, a smaller part in the state of Mato Grosso. The lower Taquari basin is situated in Mato Grosso do Sul. The location in two states makes the river formally a federal river (under responsibility of the federal government).

Managing water wisely is very important but difficult to put into practice especially in the vast areas of the Pantanal. Water is not only a local but also a regional factor. Water links everything in the Pantanal. If there are water problems, they do not only have local but also an important regional component. In the Pantanal, water is a treasure because it is the basis of life and existence of man and biodiversity. The wet tropical savannah is a system that is based on regular flooding of the land. The difference between land and river is temporarily. The flooding regime determines the fertility of the land and the rhythm of cattle breeding system: before the new flood the cattle is grown and for a large part is sold on the market. The flooding regime also determines the richness of the region in fish and natural aquatic communities. The aquatic food chain is built upon the detritus and plan eating fish populations. They are the food suppliers for the larger fish that in their turn are the prey of the top predators: fish, alligators, birds and giant otters. Both the larger fish and the top predators are the basis of important elements of the regional economy: professional fishing, sport fishing and ecotourism.

This paradise of the Pantanal seems under threat. The landscape of the highlands that surround the Pantanal, the Planalto is part of the biogeographic zone of the Cerrado. The Cerrado biome is situated south of the Amazon from the dry northeast to the Pantanal. It consists of poor soils, of fine sand and silt with a low organic content. It is highly erosive and its soil can easily be transported by rain or wind. In the upper Taquari the erosive area is about 13,380 km² (46 % of its area). A considerable change has taken place in land use. The loss of soil is high on an area of 12,603 km² (44 % of the high catchment). The yearly average potential loss here is at present is 556 tonnes/ha. This results in a sediment discharge at Coxim in 1995 of 2000 m³ per day.

The sanding up of the Rio Taquari is at the moment a major problem, because of the nearly permanent inundation of large area in a region of about 11,000 km² in the sub-region Paiaguás. Solving that problem is difficult as there is no coherent river management organisation and the behaviour of the river, especially in the lower reach is unknown. The knowledge to make decisions for tackling both problems is lacking. It is the challenge of this project to deliver that knowledge.

The main problem that has been indicated by the people living in the area of the Pantanal has been the national colonisation in the 1970s that completely changed the land cover and land use on the Planalto. There is where they search the main cause of their present problems.

If you indeed look at the enormous amount of erosion on the Planalto and sediment in the river, then there is no doubt that sedimentation is a serious problem. However, the river is also a natural system and in deciding if the problem is caused by man it is also needed to look at other possible causes. Natural processes might be ongoing; it is natural that a river moves out of its bed and forms a new one. It might also be that climate is changing and that this causes more precipitation. This again can have caused problems in discharge of water and sediment. This is even more important to consider as the Paraguay shows an increase in water levels. As a zone of 100 km wide on each side is under influence of the river Paraguay, the discharge of the Taquari is surely influenced in its lower course.

In the present stage of the study the causes of the changes in the river system can be considered both natural and man induced:

- Natural river processes
- Climate change, increased precipitation:
 - Increased erosion and sediment transport
 - Changes in vegetation: increase in superficial and subsurface flows
- Land use changes and related vegetation changes
 - Increased erosion and sediment transport
 - Changes in discharge patterns due to drainage
 - Changes in vegetation: increase in superficial and subsurface flows
- Incorrect river management

Of course, changes in river regime have an impact on society. The economic consequences of biodiversity decline can therefore mean less income through fisheries and hunting. This can mean for this part of the Pantanal:

- Less ecotourism and fishing tourism in the Pantanal
- Less air transport and more isolation due to decline in tourism
- Smallholders will increasingly become dependent on public support
- Capital leaving the region

Box 1 Inundated area in the Taquari Basin

Table 1. Flooded and non flooded areas in km² and percentages for the Taquari alluvial fan, extracted from the classification of the images MMRS, SAC-C satellite of September, 28, 2002, dry season and April, 24, 2003, flood season.

	Total fan area	Flooded in the dry season	Flooded the flood season	Not flooded in the dry season	Not flooded in the flood season	Flooded area difference
Value	52.156	6.002	19.534	46.154	32.622	13.532
Percentage	100,0	11,5	37,4	88,5	62,5	-

The flooded area in the dry season, represented 11,5% and in the flood season 37,4% of the Taquari alluvial fan. The 6.002 km² (11,5%) of flooded area in the dry season represented, to the studied date, the permanent flooded area of the Taquari alluvial fan. The permanent flood, defined as the area flooded in the flood season and that keeps flooded in the dry season, represents 31% of the flooded area in the flood season. The seasonal flood, defined as the difference of the area flooded in the flood season and dry season, represents 69,3% of the total area flooded in the flood season. Table 2 shows the quantification of the flooded and no flooded area for the Taquari alluvial cone.

Table 2. Flooded and non flooded area (km² and %) of the Taquari alluvial cone, extracted from the classification of images MMRS, SAC-C satellite of September, 28, 2002, dry season and April, 24, 2003, flood season.

	Total area of the cone	Flooded in the dry season	Flooded the flood season	Not flooded in the dry season	Not flooded in the flood season	Flooded area difference
Value	11.285	5.125	8.218	6.160	3.067	3.093
Percentage	100,0	45,4	72,8	54,6	27,2	-

The Project approach



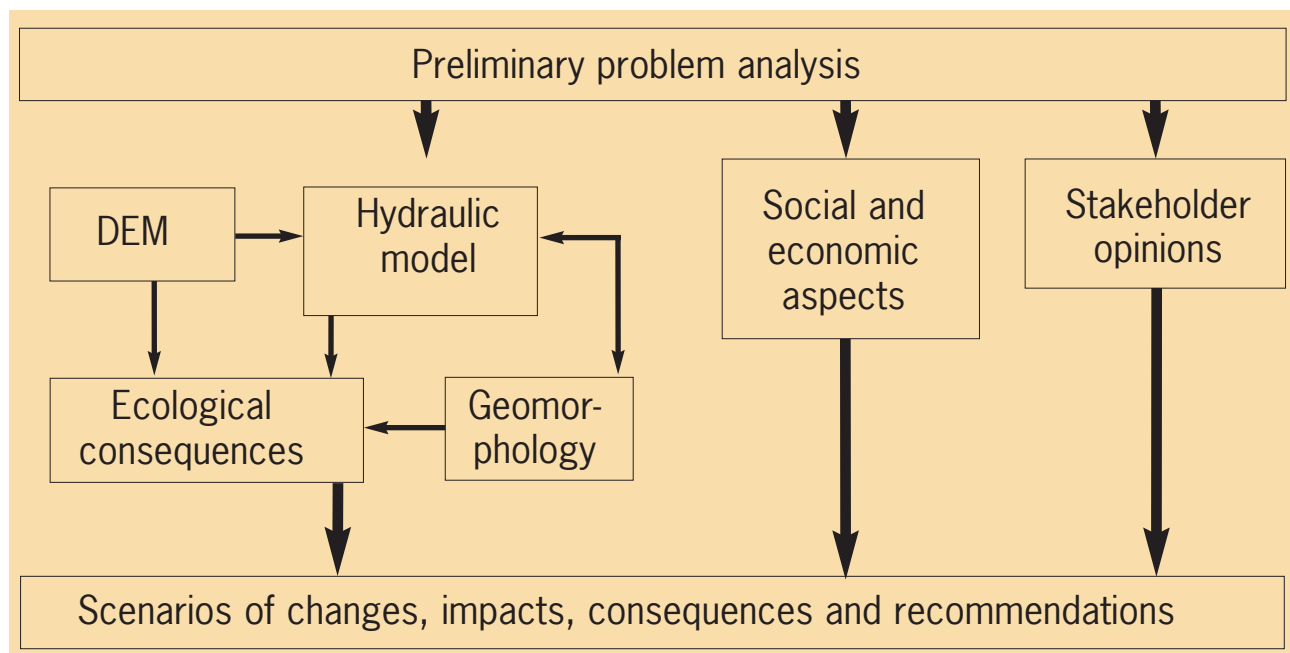
The project focuses on the acquisition of knowledge for the solution of problems in the Taquari. The first thing to be done is making clear to each other what the problems are and where we think to find causes and solutions. This is not done by researchers in the first place. The problem is a societal problem and the solution to it should also be based in society. Therefore the project has been split into several parts: the discussion with the problem owners, the farmers the fishing community and the people in the street. Others who have been approached and with whom the project has been communicated were the representatives of the city of Corumbá, the State representatives and the regional and national agencies. These all have been approached during the project. The project started and ended with a joint session to discuss problems, causes, results and possible solutions.

In the meantime the technical work had to be done. Insight had to be gained into the functioning of the system and in the potential solutions and their consequences. This has partly been tasks allocated at one or several partners in the project. Joint actions and joint data were needed as the Digital Elevation Model (DEM) was essential for the whole project. Understanding where the water comes from and where it goes is essential. It is as much important to understand the geomorphological history of the region, to understand what the natural processes are. If there is an impact of man it has to be superimposed on natural processes in historical times and in recent times. Therefore also the hydraulics of the river and the land use history has been included.

A special aspect of the project was the expedition on the river Taquari. The expedition was needed to collect data from the field to calibrate the DEM for height and location data, to sample cores for dating the sediment, to measure the profile of the river, to examine the geomorphology and to examine the groundwater. This was a joint effort done by members from all teams and it took six days on the river with two boats. This was coordinated work that had to be done to get the data needed.

Moreover, also the knowledge that is available in the region has been explored and exploited. The research done in the past and reported in the Plano de Conservação da Bacia do Alto Paraguai (PCBAP), done at universities and institutions and by individual researchers have been used as much as possible. That made it possible to get a comprehensive picture of the processes in the area.

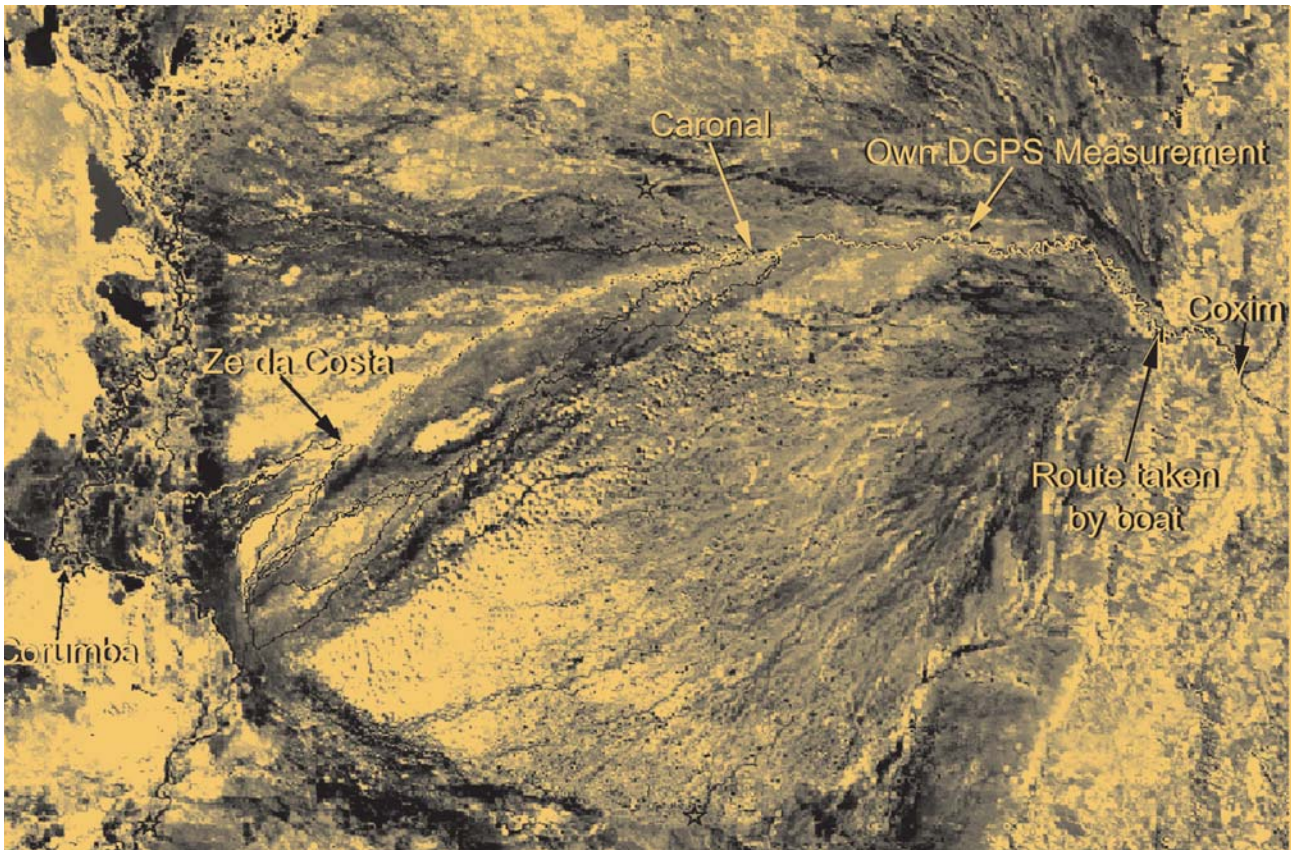
Very important steps in the process were the data mining sessions with the researchers from region in which standard ecological knowledge was translated into profiles of specific species and species groups. These profiles allowed translation of species information into spatial patterns and scenarios. As natural fauna and cattle were included it allowed also the analysis of both biodiversity and land use.



The expedition on the Taquari

For good insight in the processes and patterns in the Taquari it was needed to organise an expedition on the river. During this expedition (29 March till 9 April) measurements were done to determine location, exact height, river profiles, to take soil samples and measure vegetation height. During the boat trip the main river system differences observed are:

- The stretch along the road from Campo Grande to Coxim passed partly through the upper watershed of the Taquari river (the Planalto). At several places local erosion was observed. Most of the area is under soybean and during February soybean is at maturing stage, about 20 cm above surface. Locally, especially at steeper terrain sections degraded forest is found. The almost vertical sandstone escarpments near Coxim are hardly vegetated, other more gently sloping sandstone sections are covered with forest.
- From Coxim till approximately 30 km east of the Caronal avulsion the Taquari incises the fan surface and is confined to a narrow active floodplain. The difference between the fan surface and the river level is 5 to 6 m at the entrance of the Taquari into the Pantanal. This difference in elevation is decreasing towards the west. The average longitudinal slope is in the order of 30 cm/km and the river depth in general is over 2,5 m. The river width is over 300 m. The river has a strong meandering pattern and especially in the outer bends is showing frequent signs of active bank erosion. Many cut-off meanders exist in this river reach. The flood marks observed show that only the active floodplain is flood affected. Flood marks are observed at 1,2 to 1,5 m above the water level. Flow velocities generally exceed 4-5 km/hr and the river is carrying suspended sediments. The maximum water levels do not reach the fan surface.
- In the reach 30 km east of the Caronal avulsion till approximately the Ze da Costa avulsion the river is not incised any more. The levees are about 30 cm above the water level. There are hardly any signs of river bank erosion. The width of the Taquari decreased to less than 200 m. The river depth is in general less than 2m. The longitudinal slope in this reach is between 20 to 30 cm/km. The meandering pattern has disappeared and the river has become straighter and is showing a more braided appearance with many bars and shallows. In the upper part of this reach a number of avulsions exist, both on the left and right banks of the river, diverting a substantial amount of the river's discharge. Flow velocities are less, 2,5 to 4 km/hr but still suspended sediments are transported. In general flood marks are situated 10 to 20 cm above the levee surface adjacent the river indicating that large regions are flood affected during high river stage.
- Downstream the Ze da Costa avulsion the longitudinal gradient becomes very gentle, about 10 cm/km. Large lakes are present in this area and given the stage fluctuations of the Paraguay river combined with the small topographic differences the area will be affected by backwater effects from this river. The more anastomosing pattern of the fluvial system in this reach might be attributed to this. Flow velocities recorded during the survey are in the order of 1 to 2 km/hr. In general the surveyed reach is having river depths of over 3 m. The amount of suspended sediment has gradually disappeared. Further downstream fossil Paraguay levees are found as well as some low hills. Apart from these slightly higher elevated areas the region is prone to extensive flooding
- The vegetation is well adapted to slight changes in elevation along the river. Evergreen vegetation within the active floodplain along the river on the levees is more than 10 m high; locally trees are over 15 m. Natural deciduous vegetation on the fan surface is open and generally lower, about 5 to 10 m. A major portion of the fan surface is used for cattle ranging and is dominated by grasslands. Near the Caronal avulsion many lakes are found, on the shallow levees dead trees are present; in general the vegetation is 0,5 m above the (water) surface and composed of grass and reed species. Further downstream at the river banks the vegetation is dense and consists of water hyacinth and a type of reed/tall grasses making it difficult to determine the actual river bank. Especially further downstream lakes are covered by water hyacinth.



Avulsions, flooding and sedimentation



The Taquari is special because of its natural character and its size. With its radius of 250 km it is unbelievably large and its gradient of in average 24 cm/km is low. The climate is humid, with an average yearly precipitation ranging from 1100 to 1800 mm. December and January are the wettest months with a monthly precipitation well over 200 mm in most of the area, whereas July and August are dry with an average monthly precipitation mostly below 30 mm.

Three basic processes characterise alluvial fans in general and also are important here:

1. Rapid aggradation of sediment in the active lobes of the fan
2. Channel entrenchment in upper fan
3. Avulsions, this is the sudden tearing away of land by change in the course of the stream and switching from an existing river course to a completely new river course;

The Nhecolândia area south of the present river bed is where the oldest river channels of the Taquari can be found. As a response to changing climate during the Holocene (the last 10.000 years), new fan lobes developed on several places. Relatively rapid aggradation of the fan lobes in the north resulted in the development of an increasing gradient in a west-northwestern direction. This ultimately resulted in a major avulsion on the upper fan near the location where the Taquari River now turns west. An abandoned channel belt that runs parallel to the Taquari a few km's north of the Caronal area probably belongs to the oldest generation of channel belts. A few big abandoned channel belts with two associated sub-lobes can be observed south of the present Taquari. These channel belts resulted from southwestward avulsions near the fan-lobe apex.

At present avulsions are taking place in two areas. In the middle-fan area, near the apex of the present active fan lobe, the so-called 'Caronal avulsion' is ongoing. Satellite images and aerial photos show that the avulsion route is guided by an abandoned channel belt. Near the avulsion point the relief of the old levees forces the Caronal avulsion path westward. More downstream, the floodwater follows reaches of abandoned channels.

In the fan-toe area, the Zé da Costa avulsion has started around 1988. This avulsion is virtually completed now, in the sense that the old Taquari channel immediately downstream of the avulsion point is totally plugged by sand. The avulsion belt, however, is still rapidly evolving. There are no levees and channel is not confined. Therefore this new reach of the Taquari strongly forms a network of branches, it anastomoses in extensive wetlands. The development of a sub-lobe of the fan has just started and in the future it will fill up a gap between previous sub-lobes on the lower fan.

Farmers observe that the Río Taquarí in that area is now much shallower than before 1974 and, therefore, ascribe the flooding problems to sedimentation. Therefore an important aspect of discharge pattern is the actual river morphology. Longitudinal measurements of the water depth and at 26 locations in the Rio Taquari and in the Caronal avulsion area the water depth was measured perpendicular to the river axis in order to obtain representative cross-sections. The boat with the sonar was able to reach the river banks only within one or a few metres. Therefore, for each cross-section a rough sketch was made of the left and right banks above the present water level. The dimensions of the banks were estimated.

Most of the measured cross-sections in the lower region, of which an earlier cross-section reference was available, show an increase of the main channel width of approximately 20m within the last 10 years. This confirms that widening has occurred. The immediate effect is a decrease in water levels, but also localized sedimentation that gradually increases its extent over the river.

The recent avulsions have severe impact on the economic activities in the area. Previous major avulsions that affected large areas, like the Caronal avulsion does nowadays, maybe happened too long ago to be remembered by people in the region. Therefore, for local population the recent avulsions represent a sudden, unexpected and dramatic change of the river system. The reconstruction of Taquari avulsion history, however, demonstrates that the recent avulsions fit into the natural pattern of channel shifting on the Taquari alluvial fan that has been ruling the geomorphological evolution of this area for millennia.

The sediment transport in the river can be divided into bed-material load (= bedload + suspended load) and washload. The bed-material load consists of sands and contributes to sedimentation on the river bed as well as on terrains close to the river (natural levees). This sedimentation produces the lobes that are a central element in the evolution of alluvial fans. Accelerated sedimentation might lead to an increased probability of avulsion within the next decades. The washload consists of fine materials (silt, possibly clay) and contributes to sedimentation all over the area in zones where slowly flowing or stagnant water bodies occur during and after a flood.

The sedimentation related to bed-material load manifests itself in vertical and horizontal morphological changes of the river. Sedimentation related to washload manifests itself all over the Pantanal where it is flooded. The sedimentation has accelerated considerably after the 1970s. This may have had an important effect on the ecosystem.

If the water levels on the Rio Paraguai are becoming higher, they push up the water levels on the Rio Taquari and its surrounding terrains by causing a 'backwater effect'. The water levels in the Rio Paraguai at the confluence with the Rio Taquari have probably risen with 1m up to 6m compared to the hydrological situation of 1974.

The flooding and sedimentation problems can be explained from a combination of higher discharges of the Taquari, higher water levels on the Paraguai, river widening and a developing avulsion at Caronal. An important finding is that the sedimentation problems cannot simply be ascribed to changes in land use on the Planalto. As a consequence, a dam at Coxim would not be an effective solution.

Considering the possible causes of the flooding and sedimentation problems, only mitigating measures that affect the process of avulsions and associated channel evolution seem feasible. For this, it is recommended to study the processes at the bifurcations in more detail.

The major conclusions are:

1. There are indications of a recent increase in overbank sedimentation on the Taquari alluvial fan. Whether this increase in sedimentation is caused by human activities in the Taquari catchment is unclear. Increased floodplain sedimentation probably has not significantly contributed to the recent avulsions.
2. Because of the existence of alternative flow paths that are energetically more favourable than the present Taquari channel, the recent avulsions can hardly be redirected. Local measures such as closing the entrance of an avulsion channel are not sustainable, because critical conditions exist not only at the avulsion point but extend along the channel for considerable distance upstream and downstream of the avulsion point. Rapid lateral channel migration and a sandy subsurface (facilitating erosion and groundwater seepage) further complicate technical measures, especially in the Caronal area.
3. Measures in the upper catchment will most effectively prevent excessive flooding on the Taquari alluvial fan. It may be expected, however, that reservoirs for retention of floodwaters will rapidly fill up with sediments, given the high sediment production of the catchment. Seepage through the permeable sandstone underlying the reservoirs may be another problem.
4. Although sometimes seen as harmful for the Pantanal ecosystem, the long-term effects of avulsions for the area as a World Natural Heritage Site are probably favourable. Recurrent avulsions rejuvenate vegetation, create landscape diversity and thereby, contribute to biodiversity.

The locations, causes and timing of the recent avulsions

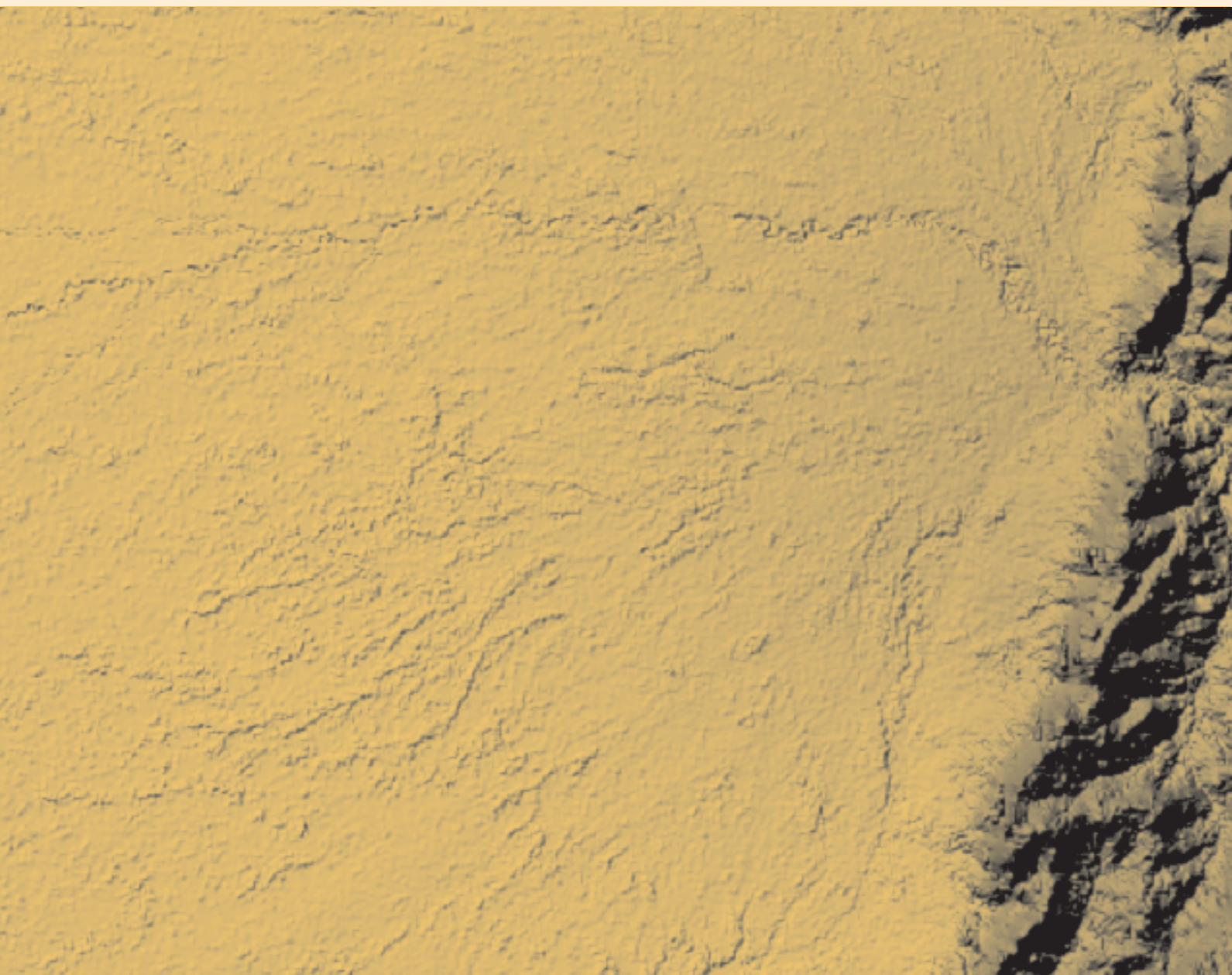
It seems that most of the flooding and sedimentation problems in the area are the result of the recent avulsions. In natural river systems, sedimentation on the bed and banks of a river is much more rapid than further away from the channel on the floodplain. As a result the channel belt is gradually lifted up on an alluvial ridge above the floodplain. After a long period of sedimentation the slope across the natural levee to the floodplain has become much steeper than the channel slope. At this stage the river becomes liable to avulsion: i.e. it is close to the avulsion threshold and the river is easily triggered to break through the levee. The preparation of the river and the floodplain for avulsion is a geological process that is slow in human perception. Although the river seems stable during this process, in fact it is gradually moving towards critical conditions. When critical conditions are reached, an extreme flood or a temporary obstruction can trigger the avulsion.

In the case of the Zé da Costa and Caronal avulsions, the development of critical conditions can be explained by natural alluvial fan processes. The Zé da Costa avulsion occurred at a logical spot: a sharp outer bend of the river where erosive power of the flow is highest. The Zé da Costa avulsion route crosses a number of abandoned channels and seems more or less unrelated to previous topography. High flood levels on the Paraguai River floodplain cause backing up of water in the lower course of the Taquari, especially when floods in both rivers coincide. This is usually not the case, but it may occur and then contribute to development of an avulsion. When backwater effects cause extensive flooding of the fan-toe area, local water gradients and consequently water flow become more or less detached from underlying local floodplain topography. Since the early 1970s, average annual Paraguai River flood levels have risen more than 3 m, with respect to average flood levels. Having been initiated in 1988, since then, backwater effects can have strongly contributed to the relatively rapid development of the Zé da Costa avulsion.

The trigger that caused the Caronal avulsion seems to have been different. It was most likely triggered by extreme floods from the upper Taquari catchment. The Caronal avulsion flow path is strongly influenced by existing topography; it parallels and reactivates abandoned channels. Higher flood levels of the Taquari since the early 1970s are likely to be due to climatic change and/or change in vegetation cover on the Planalto. Increased peak discharges could not be accommodated by the present Taquari bed. Avulsion took place at the first suitable location downstream of the point where the floodplain widens, in the apex area of the present active fan lobe.

Strong increase in floodplain sedimentation since the 1970s was reported. During the field survey up to 80 cm thick sand beds were observed on top of clayey levees on the Taquari upper fan and in the apex area of the present active lobe upstream of the Caronal avulsion. Increased sediment delivery from the catchment does not necessarily imply increased in-channel sedimentation, since the bulk of Taquari bedload consists of fine sand that can easily be transported in suspension with increased peak discharges, as long as the maximum sediment transporting capacity is not reached. An increase in sediment transport therefore does not automatically mean an increase in in-channel sedimentation that could invoke overbank flooding and avulsions. Cause-effect relationships between sediment production in the catchment, sediment transport under changing discharge regimes and sedimentation on the alluvial fan, are far too complex to assume a straightforward relationship between the recent avulsions and human activities causing erosion in the catchment. With respect to the Caronal avulsion, the timing (start around 1979) indicates that critical conditions already were reached prior to major developments in the Planalto in the 1970s, because it requires substantial sedimentation. Even with rapid sedimentation much more time would have been needed than the few years between the early 1970s and 1979. It rather seems that increased peak discharges since the early 1970s directly triggered the avulsion, with already existing favourable floodplain conditions that have evolved during the preceding centuries. The increased sediment load is an extra burden on the system.

The Digital Elevation Model



Major characteristic of the Pantanal is that it is an extensive area, it is flat and large parts are permanently or frequently inundated. Therefore, making a Digital Elevation Model (DEM) is a complex task. However, it is basis for the understanding of river flows and for the interpretation of the savannah processes and the consequences of flooding. To cover the whole area only a mosaic consisting of several individual images can be used. Given the revisit time of medium resolution satellites and occurrences of clouds, a mosaic can only be constructed from images acquired over a longer period of time. Therefore the flooding phenomena depicted on the individual images differ strongly.

The Digital Elevation Model has been developed in its first stage in the laboratory with help of Radar images, Landsat images topographic maps and GIS tools. However, as the altitude error in satellite images is larger than the terrain differences in the field, it was needed to improve the accuracy of the DEM by measurement in the field.

This has been combined with a number of other activities, such as soil sampling and river profile measuring.

In the Pantanal the Taquari river is traversing three distinct main landscape units and the avulsion areas are occurring in the gradual transition zones between these main landscape units: the Caronal avulsion is found in the stretch between the upper and the middle zone and the Ze da Costa marks the transition between the middle and lower zone.

The Digital elevation model and field survey

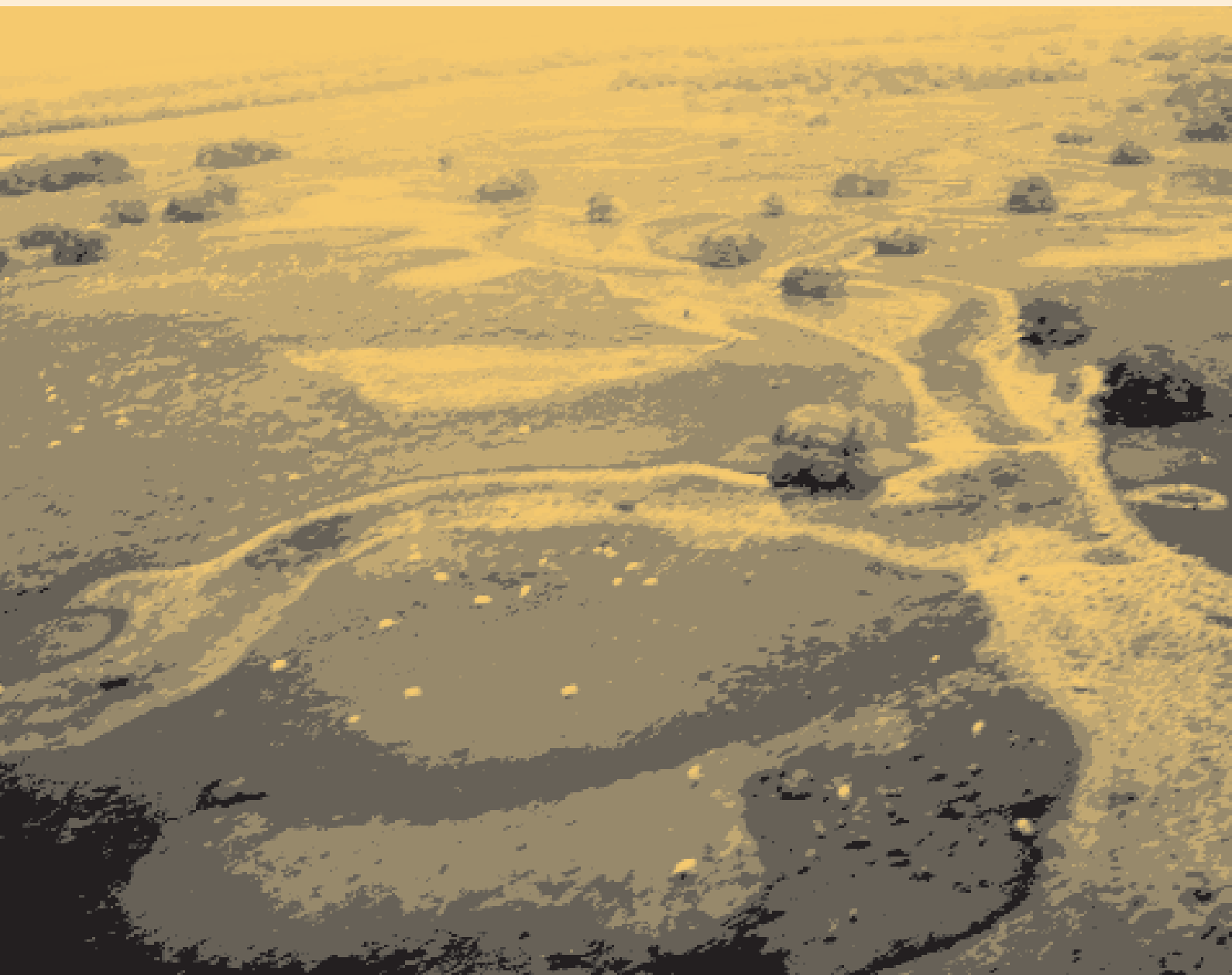
The major elevation data have been acquired from the GTOPO30 (30 arc-second DEM, roughly 1 km spatial resolution) and the Shuttle Radar Topographic Mission (SRTM) of February 2000. The spatial resolution available is 90 m (3-arc-seconds at equator is 90 m). Other data that were collected were SAC-C images from different dates with a spatial resolution is 180 m, a mosaic of Landsat TM, representing the dry season conditions in 30 m and 180 m resolutions and GIS data such as topographic maps, photographs and field observations.

From 28 March till 9 April 2004 a field campaign to collect additional information was conducted. The following data were collected:

1. Sounding and GPS information along the river, the whole section, from Coxim to Corumbá, water depth, height and location information, longitudinal profile, 1 point per 10 seconds (approximately 1 point per 80 metres), covering the main bed configuration changes within the river and cross-sections, 1 point per 2 seconds (approximately 1 point per 2,5 metres).
2. DGPS measurements, six points along the Taquari, two along the Paraguay Merin, a point at Corumbá harbour, 2 observations on geodetic points at University of Corumbá, one from the aviation authority and one from the Department of Geodesy, Brazil (IBGE). On every point between 1½ to 2 hours of continuous recording has been carried out. Data converted to RINEX format for later post processing at SOPAC-SCOUT. Also a geodetic point at ITC was measured for quality control.
3. Sediment samples taken from the river bed using sediment grabber along cross-sections and flow velocities and visual observations for the whole duration of the boat trip (7 days).

All data collected by sounder, (D)GPS were downloaded and pre-processed successfully and exported as Arcview Shape files. The measurements need to be corrected for sounder depth offset (+30 cm) and GPS height offset (-60 cm).

Groundwater



The underground of the Taquari consists of material that can contain and transport water. Therefore it is important to gain insight in the regional hydrology and the groundwater behaviour. Geohydrological knowledge such as hydraulic conductivity, presence of aquifers and aquitards, thicknesses of layers is very scarce. The PCBAP study contained some information about measurements of k-values.

A hydrological model has been built, comprising the High Taquari, the whole lower alluvial fan and the area in between. This is done by using SIMGRO (SIMulation of GROundwater flow and surface water levels) that simulates regional groundwater flow in relation to drainage, water supply, sprinkling, subsurface irrigation and water level control. The model simulates the flow of water in the saturated zone, the unsaturated zone and the surface water in an integrated way. The model area that has been chosen is larger than the catchment. The reason is that there is no hard definition of the Taquari River basin. In the lower Taquari (the fan region) there are many avulsions and old river channels. The river system is a maze of channels. Also the lack of knowledge about groundwater urged to expand the model area. Although the Taquari catchment is assumed to be very narrow at the intersection between the BAT and the Pantanal it is not for sure that groundwater is bounded to the borders of the surface water system.

By means of the model the effects of increase of rainfall and cultivation have been estimated. The conclusion is that increase of precipitation has large effects on the hydrology of the Pantanal. The maps of inundated area show that increased rainfall causes an increase in total inundated area. However, the increase is significantly bigger in area compared to the precipitation amount. In the dry scenarios the average inundated area is around the 7.000 km², while for the wet scenarios this value has increased to 26.000 km². Hence, an increase of precipitation from 1.131 mm to 1.545 mm (37%) has resulted in an increase of discharge in Coxim of 130% and an increase in inundated area of 270%.

A sensitivity analysis has been carried out for hydraulic conductivity of soil, stage-discharge relationships and drainage resistance. Comparisons were made for the discharges at Coxim that in the first place showed small differences for the changes made to the parameters. Estimates of the discharges at Coxim were satisfying; the average monthly discharge deviated 14% of the measurements on the average and the series had an overestimation of 11%. At Porto Rolon and São Francisco the resemblance between measured and calculated discharge is even smaller. The underestimations of the total discharge are 18% and 26% respectively and the seasonal variance shows some deviations as well.

Hydrological modelling with SIMGRO

In SIMGRO the unsaturated zone is modelled in 1-D models or 'columns'. Each type of land use, within any nodal subdomain, is modelled separately. The 1-D column model consists of two reservoirs, one for the root zone and one for the subsoil. If the equilibrium moisture storage for the root zone is exceeded, excess water will percolate to the saturated zone. If the moisture storage is less than the equilibrium moisture storage, upward flow from the saturated zone is simulated through capillary rise. The height of the phreatic surface is calculated from the water balance of the subsoil, using a storage coefficient which is dependent on the depth of the groundwater table. Special processes are included in the unsaturated zone model, such as surface runoff and hysteresis.

Evapotranspiration is determined by crop and the moisture content in the root zone. For these calculations, recorded values of precipitation and potential evapotranspiration of a reference crop must be available. The potential evapotranspiration for other crops or vegetation types are derived from the values for the reference crop, by means of a multiplication factor that is specified for each crop and day of the year.

Input data for calculation periods exists of meteorological data, land use and initial conditions. Simgro gives the possibility to work with different meteorological stations. By means of the Thiessen method the nearest station has been attributed to each node. This process is carried out automatically with the programme AlterraAqua that can work with stations situated up to 15 km out of the model area. In each period all stations with complete (2-year) measurement series have been used.

River flows



For developing insight in the river flows it is needed to know how river flows develop in space and time. Hydraulic and hydrological conditions are combined in a one-dimensional and two-dimensional model. The objective was to better understand the hydrodynamic process in the Lower Taquari basin and providing an answer to the questions:

- In what direction does the water flow?
- Which areas are flooded and for how long are they flooded?
- What are the water depths in the flooded areas?

Scenario time series are required as alternative input series for the SOBEK model. SOBEK is a hydraulic model developed by Delft Hydraulics. For the Taquari the model has been calibrated on the actual series of the hydrological year 1999 - 2000. For the alternative model runs, the following alternative series are required:

- 90% dry year
- average year
- 90% wet year

The 1999 - 2000 hydrological year clearly shows the influence of the relatively wet conditions in the Taquari basin in the latter half of the year. The water levels at Porto Esperança in the latter half of the year exceed the average conditions, whereas at Amolar the conditions remain under the average conditions.

The DEM from data from the SRTM 2000 mission was too detailed for the SOBEK model resulting in a very long simulation time. Accordingly, using the mean elevation from each hundred grid cells, a coarser grid with a resolution of 900*900 metres was created. This means that the detailed information that has been used in other parts of the analysis has not been used in SOBEK modelling.

For the calibration of the SOBEK model data, for the hydrological year 2000 (01-10-1999 to 30-09-2000) have been used. SOBEK can be calibrated using many different parameters. For the calibration of the model it is common to use the parameters, which are the most uncertain. In this case it is hard to say which parameters are the most uncertain. The parameters hydraulic roughness and the infiltration capacity have been chosen based on experience with previous models.

Three scenarios were created to make three alternative runs with the SOBEK-model. These alternative runs will give an idea about the observed extremes based on a historical dataset that the natural system has to deal with. The scenarios are (1) a 90% dry year, (2) average year and (3) a 90% wet year.

The results of the hydro-meteorological data processing suggest that recent years are substantially wetter than the 1970s. The present model does provide insight in the extreme variations that the natural system has to deal with. This insight has been obtained by making computations for wet-year, ordinary-year end dry-year scenarios that had been derived from a historical dataset.

Impact of different scenarios on vegetation and fauna



New developments may occur at the expense or in favour of nature and farming. Planners wonder what the consequences are of the possible scenarios for nature or what kind of system will develop. For decision making it is important to know which of the different scenarios is most favourable for nature or farming. A spatial analysis and evaluation is most preferably because it provides more information. Models that can be used are called Decision Support Systems (DSS). They help planners and policy makers to make choices in the spatial arrangement and related measures.

The use of a DSS facilitates the evaluation of measures and enables the analysis of different measures and planning targets. The purpose of the LEDESS-Pantanal model is to create dynamic spatial ecotope scenarios of the Pantanal-Taquari area. The model has been used to evaluate ecological effects of variations in the flooding regime within the Pantanal and land use changes in the alluvial fan of the Taquari. These spatial scenarios are based on changes in flooding regime, on economical driving factors and political arguments such as nature conservation considerations. The typology for the Pantanal-ecotopes is based on:

- The basic river processes that drive the Pantanal system;
- Land use and land management.

To perform calculations, a typology for the ecotopes and species involved has been defined and combined with data and calculation rules. These data and knowledge sources are related in schemes for scenario calculation. The ecotopes are based on morphodynamics, hydrodynamics and vegetation dynamics. The species have been selected among the natural and domesticated (cattle) species. This makes it possible to calculate different scenarios based on the ecotope maps of the Pantanal-Taquari area for natural and domesticated species or for nature conservation and farming.

From 1979 to 1983 the amount of fish caught in Taquari river basin ranged from 300 - 620 ton per year. Since 1994 fish catch was less than 100 ton per year and is about 5-6% of the catches in the whole Pantanal in Mato Grosso do Sul, although it is one of the largest river basins. This is an important indication that the stock size has declined and is below the average.

Due to sedimentation and permanent flooding there is a lack of flood pulse in the Taquari river basin. For the scenario development, a time horizon of more or less 50 years is used. In some decades, major changes in the study area can occur. The scenarios that are assessed with LEDESS and LARCH are taking into account the autonomous developments in the basin of the Taquari river, such as climate variability, the geological development of the fan, the sedimentation as well as proposed measures formulated in the first stakeholder workshop. In this first workshop at EMBRAPA in Corumbá all kind of solutions have been proposed, that all have potential in solving the flooding problems. These were:

- Dredging of the Taquari
- Closing of the Caronal Avulsion
- Prevent new avulsions
- Help the river to create a new river channel from the Caronal to the west
- Construction of dikes
- Construction of a dam
- Prevention of erosion by planting forest along rivers on the Planalto
- Prevention of erosion by capacity building on erosion and river management
- 'Doing nothing' but buy out the inundated land and make it a national Park.

These possible solutions to the problem have all been analysed taking the results of the study into account and using the scenarios as part of the tools to estimate and calculate the impacts or cost and benefits.

The basic scenarios that have been formulated are:

Present situation: The average situation of the Taquari floodplain area at present based on the DEM and the land cover in the Landsat 1998 interpretation of flooded areas. It is a picture of this moment that can change due to sedimentation, changes in discharge and impact of man.

- Wet scenario: This reflects the situation when more discharge (20%) is entering the area resulting in longer flooding periods. Also, this scenario can be used to interpret how for smaller areas the result of local measures in the river will work out causing more flooding. This scenario is based on the DEM and the land cover of the LANDSAT images of 1998 with maximum flooding. This also reflects the situation of further sedimentation in the cone of the Taquari fan causing more inundation.
- Dry scenario: This situation reflects the situation in which less water is entering the study area. Also, this scenario can be used to interpret how local measures in the river will work out reducing flooding. In the "dry scenario", the effect of less flooding can be assessed for the specific locations where these relatively dryer circumstances are expected. This scenario reflects the dry period of the early 1970s.
- Closing Caronal avulsion: This scenario is constructed especially for one of the measures that can be taken to influence the flooding pattern of the Taquari river and that has been proposed by the stakeholders. With LEDESS the effects on the distribution of ecotopes is assessed.

In the March 2004 workshop in Corumbá, species specialists of the Pantanal have elaborated the required spatial characteristics of these species and made expert based estimates of the carrying capacity of the ecotopes for both terrestrial and aquatic species. The results of these workshops have been elaborated in profiles for species groups (fish) and selected species (terrestrial). The terrestrial species have been further elaborated in scaling of the different habitats in their suitability for the species. Unfortunately this was not yet possible for the fish species as the habitat characteristics could not yet be made spatially explicit. Characteristics of fish habitat and of the spatial images do not yet match.

The data that have been produced are available at EMBRAPA-Pantanal and at Alterra. The results are summarised in ecotope suitability and dispersal capacity. A number of species are further used in modelling. A large range of ecotope groups are used by the species and the landscape is utilised at various scale levels (variation in dispersal capacity)

Ecotope Classification

26

The geographical confinement of the ecotope map is the alluvial fan of the Taquari River. Based on the following principles the ecotopes are classified on three general characteristics influencing physiologies, vegetation and fauna:

1. **Morphodynamics:** Mechanical forces exercised by water and sediment (erosion, transport and deposit of sediment, flow of water and surge); to model these morphodynamics for the Pantanal new geomorphology-data had to be developed.
2. **Hydrodynamics:** Physiological and chemical effects of water (duration, depth and time of flooding, as well as the type of the water); In the LEDESS-Pantanal model duration has been specified by the use of satellite data and the use of hydrological models. The type of water (rain, flooding or groundwater) has been modelled and combined from several models and data sources.
3. **Land use/vegetation dynamics:** Effects of mainly human intervention i.e. conscious landscaping and management from grazing or rough pasture management to intensive agricultural use. In addition, the development from pioneer vegetation to forest or savannah after natural set back of vegetation is part of this factor. For the Pantanal, satellite data has been combined with expert knowledge and existing vegetation maps to model current vegetation, as well as the change of vegetation type under scenario conditions.

The flood pulse concept

Running waters are far more than mere longitudinal river corridors and modern ecology recognises them as complex systems. The science of river ecology has reached a stage where explanations for patterns rely on links at a variety of spatial and temporal scales, both within the river and between the river and its landscape.

The links operate in three spatial dimensions:

1. Longitudinal links along the length of the river system, such as the river continuum downstream barriers to migration
2. Lateral links with the adjacent terrestrial system, such as the flood pulse concept.
3. Vertical links with and through the riverbed

The hypothesis, developed in the natural tropical and subtropical rivers of Brazil on fish populations in river is the flood pulse concept. The Flood Pulse Concept has been developed partly in the Pantanal (Cuiabá river) and it states that the pulsing of the river discharge that extends the river into the floodplain is the major force controlling biota in rivers with floodplains. The flood pulses control biota in three ways:

1. Directly by facilitating migration of animals,
2. Indirectly by enhancing primary production in the floodplain and by
3. Habitat structuring.

The floodplains provide important factors for driving ecological processes in the riverine ecosystem. During floods biota migrate both actively and passively between different habitats in the river floodplain system, where they feed and spawn. The lateral exchanges between main channel and floodplain, and nutrient recycling within the floodplain has more direct impact on biota than the processes described in the River Continuum Concept. Fish move along their corridor in different speed and with different steps and try to reach their optimum habitat as birds do by seasonal migration. The strong interaction between the river and the riparian ecosystems in its ecotone provide a huge exchange of energy, matter and nutrients. In this way networks of river corridors maintain the genetic exchange between populations in natural and impacted landscapes.

Distribution of the ecotopes and their abundance changes considerably between the different scenarios. In the wet scenario the permanent flooded area increases considerably as does the area of pioneer vegetation. In general forested areas decline and are replaced by flooded areas and pioneer situations. In the situation that the fan gets dryer, the cerrado related ecotope types such as cerrado forest and forested savannah will increase.

The cohesion of habitat of the species in the present situation is calculated with LARCH-SCAN. The resulting cohesion is calculated on the basis of the amount of suitable habitat on a site in combination with the surrounding area. The habitat that is within dispersal distance of the species assessed is taken into account. Also the degree isolation of populations can be derived from this analysis.

For species that are confined to the wetter habitats such as Marsh deer three main areas are identified where relatively strong populations occur. Habitat within these cores areas are far better connected for species such as the Jaguar than for species such as the Marsh deer, because of their larger dispersal capacity. Changes in the flooding regime can result in a better or worse cohesion of these core areas.

For the species that are more confined to the dryer and more open parts in the Taquari basin as Greater rhea and Pampas deer, the habitat is coherent. The part north of the Taquari River seems better suited than the part south of this river. The wet area along the Taquari River can act as a barrier between the northern and southern habitat areas. Furthermore, in the relatively dry area in between the lower Taquari branches, the populations of species as Greater rhea and Pampas deer are relatively isolated.

The centre of gravity of populations of species as Red brocket deer and White lipped peccary, with a habitat in more forested dry parts of the wetland is mainly situated south of the Taquari river. The habitat of White-lipped peccary is more coherent than of Red brocket deer due to the larger dispersal capacity of the White-lipped peccary (respectively 25 km and 10 km).

The methods that have been used combine the regional knowledge of field and species experts and methods of landscape ecological modelling. The results as the distribution and abundance of species presented on the ecotope maps are checked by several field experts and appear to provide a truthful image of the Taquari. This information of the area was not available in such detail until now. The results herewith provide a good basis for further exploration of the situation in the Taquari area and the landscape processes in this area as well as its potential expansion to the whole Pantanal.

The modelling of ecotopes and ecological coherence has been calibrated and validated for the Taquari area. A small number of scenarios has been assessed to analyse the effects of changes in land use on species. With this experience and model settings, it is possible to develop and assess future scenarios for this area. The model setting also can be used as a starting point for the assessment of other parts of or the entire Pantanal.

For aquatic species, a set of ecoprofiles have been constructed. However, for these species, less information is available on habitat characteristics, abundance and life history. To make a spatial analysis of the habitat suitability for aquatic species, more and different data are needed than available at present. That should make it possible to develop more detailed ecotope maps of the aquatic environment, tailored to the habitat requirements of aquatic species of interest. A pilot study on aquatic habitat, processes and species on a case study level, is therefore recommended.

Conclusions on the assessment of the viability of species:

- The effect of some extreme scenarios has been assessed. With the result of these assessments, the effect of all kind of measures on the presence and the cohesion of habitat and its effect on the viability of species have been estimated. Effect of measures for the mitigation of on undesirable flooding on the distribution of individual species has not been assessed.
- Based on the results of the scenario analysis the effects that can be expected of plausible measures are assessed further.
- The overall effect of the extreme wet and dry scenarios on the carrying capacity of the Taquari area is not very large for most species; some parts of the study area become not suitable, whereas other parts of the area become more suitable. Only for species linked explicitly with wet or dry habitats the effect is larger.

Fish typology

Longitudinal migratory piscivorous fish

Key species: Pintado

Group: Cachara, Dourado, Jau, Barbado, Jurupoca, Jurupesen.

They feed on fish and migrate between the Planalto and the floodplains. In the dry season the adult fishes migrate to the rivers in the planalto to reproduce. When the water rises the eggs, larvae and adults flow with the river to downstream areas. There they forage in every water body that is connected to the river. The water can be shallow. If the water level decreases after the wet season they go back to the river and swim upstream to the Planalto. From this we can conclude the need for connection between flooded habitats and the river channel.

Longitudinal migratory omnivorous fish

Key species: Pacu, *Piaractus mesopotamicus*

Group: Pitaputanga

This group also migrates upstream to the Planalto for reproduction and downstream to the floodplain for feeding. In the floodplain they feed on animals, (especially) fruit, seeds, flowers and insects from the riparian vegetation and flooded pioneer and cerrado vegetation. Because of permanent flooding, some of these forests died resulting in a loss of their feeding habitat.

Longitudinal migratory detritivorous fish

Key species: Curimbata, *Prochilodus lineatus*

Group: *Potamorhina squamoralevis*

This longitudinal migration group feeds on detritus (decomposed organic matter), periphyton and perizoon coming from the temporary flooded terrestrial vegetation. The optimal habitat is in slow flowing shallow flooded vegetation (water depth < 1 m). Due to their migrating characteristic their feeding habitat has to be connected to the river.

Floodplain spawners, piscivorous fish

Key species: Piranha, *Pygocentrus nattereri*

Group: Dourado cachorro, Traira, *Serrasalmus marginatus*, *Serrasalmus spilopleura*, *Pygocentrus natterei*, *Roeboides paranensis*, *Roeboides prognathus*, *Charax gibbosus*, *Acestrorhynchus pantaneiro*, *Hoplias malabaricus*

The floodplain spawners lay their eggs and larvae in the floodplain. In the dry season they stay in lakes and some of them go to the main river channel. They feed in slow streaming/standing water which is connected to the river.

Floodplain spawners, detritivorous fish

Key species: Sairu, family Curimatidae

Group: *Curimatopsis myersi*, *Curimatella dorsalis*, *Psectrogaster curviventris*, *Cyphocharox gillii*

The group of the Sairu feeds on detritus and has an optimal habitat in the connected lakes, oxbow lakes, corixos and flooded Savanna Gramineo lenhosa and pioneer vegetation.

Stakeholders and decision making



For decision making participation of stakeholders is important. They have been involved in the project in all phases. In the first meeting the problem of the Taquari has been discussed with all stakeholders, local and regional authorities, farmers, NGOs and researchers. This has led to the problem statement. In later phases discussion with stakeholders and authorities involved has been maintained through direct contact (Programa Pantanal, Agência Nacional de Águas, Secretaria de Recursos Hídricos) and stakeholder meetings. A workshop has been organized with individual knowledge bearers on species from the region for participation in the scenario building.

In the first workshop the existing knowledge from Brazil and the Netherlands has been compared and matched; the problems and the possible solutions discussed. Already in this workshop the disappearance of the flood pulse in the Taquari basin as important mechanism was one of the foci in the discussion. The decline of fish stock and data are compared for the periods 1979 until 1983 and 1994-1999 and the difference was obvious. In the first period fish was abundant, but this is now reduced especially in the river Taquari. The cause of this reduction can be found in the disruption of the flood pulse and the high content of suspended matter. The regular flooding of the Pantanal area provides the river water with an influx of organic material which is food for many fish species at the bottom of the food chain. Statistics show that especially the fish in the basis of the food chain have become greatly reduced in the river Taquari with enormous consequences for the whole ecosystem.

In this first stakeholder meeting the farmers as the other party that suffered from the flooding of the Taquari, were well represented. Some have reduced production capacity due to flooding and some have even lost all their land.

The outcome of the project has been discussed with the stakeholders. It has been concluded, that when evaluating plans and policies it must be considered that:

- Measures to protect the environment are not always non-economic. On the contrary, there are many examples where nature and economy have benefited both as it is the case in recycling and saving energy.
- It should be possible to value the importance of nature also in a non-economic sense. Up to now, there are different ways to assess the value, such as the objective for visiting and enjoying nature and the relation with the ecosystem involved. That gives a link with local or regional economy.
- It is important that people participate, because participation appears essential when dealing with public-private interactions.

How people can participate and what their influence is has been demonstrated by the example from Mato Grosso on the Upper Paraguai River. The perception of these stakeholders on the ecological, social and cultural aspects of the spatial changes in the area shows clearly the levels of influence, interaction, competition and collaboration among stakeholders. The stakeholders can be roughly divided into four groups:

1. Public representation, such as the Ministry of Environment, Agência de Águas, IBAMA, Programa Pantanal
2. Land owners, Enterprises, Fishermen
3. Local NGOs, local forum, community associations
4. Public policy, Transportation, Waterway (Hidrovia), Energy (dams), Fishery legislation, Tourism, Pantanal Program

Committees and councils can facilitate an integrated and participative management of the Pantanal as long as it includes all stakeholders and is based on local social organization and as long as it strives for consensus in a process of decision making that is equitable and transparent.

From the workshops the following conclusions have been drawn:

- The local fish population has been impoverished by the breaking of the food chain. According to the people involved the reaction of authorities to the problems has been late; care must now be taken that all stakeholders will be treated equally in the process. The law must be used to protect environment and people likewise. The project is designed to help stakeholders in making decisions on the solution of the problem. The Taquari area is complex and highly sensitive and therefore one should not rush conclusions.
- Within Brazil the hydro-electrical companies have established already 60 water committees which are

democratic and participative. The Taquari region urgently needs water boards like these. The government has started the process by establishing a technical committee that is developing an Action Plan and starting pilot projects with aspects in participation and monitoring.

- Attention should be given to the livestock sector as an important economic factor in the region.
- Scenarios developed with LEDESS are not used for simply assessing cause and effect but for structuring spatial knowledge and showing effects of measures taken.

The farmers' organization proposed a number of possible solutions, such as:

- Constructing a dam to keep the sediment from coming into the river
- Re-establish the flood pulse and therefore remove sand from the river bed.

The Pantanal-Taquari project assists the stakeholders in their search for a solution, but it must first create an understanding of this complex problem. Important is that all parties are involved and that solutions will benefit all and not reallocate problems.

During the project contact has been maintained with the stakeholders in several moments. Communication has taken place between the research groups and stakeholders at various levels (authorities (ANA, Ministry of Environment, FEMA, IMA-P), agricultural and environmental non-governmental organizations, researchers, individual farmers and fisherman and people in the street.

With people in the Corumbá interviews have been held to develop insight in their visions and ideas. The questions asked were:

- What do you see happening in the Pantanal?
- What does the Pantanal mean to you?
- What is your dream for the Pantanal of the future?
- What needs to be done to reach this dream?

This resulted in three different social scenarios:

- Using and developing the natural resources carefully: This future is based on cattle breeding and fishing, allowing for tourism, with sufficient social services for the local population. It is a continuation of the existing development path, but with more attention to nature conservation and to social services.
- Conservation scenario: Many people mentioned the beauty of the Pantanal that needs to be preserved. In this scenario the region is a nature sanctuary, to be visited and enjoyed by those who love it and for research purposes. It requires international and national funding. The example of the Mamirauá reserve in the Amazon has been mentioned showing that this is possible.
- Industrialisation to the region: Many people mentioned the gasoduct with Bolivia and the plans to make an electricity generating plant and new industries in Corumbá. This would provide jobs, reduce poverty and make the conservation of the Pantanal possible.

32

By differentiating between scenarios and alternatives it becomes clear that the list of alternative solutions was really a mix of scenarios and alternative solutions, each addressing different problems and therefore most not being alternative solutions to the same problem.

The absence of a decision system where stakeholders define common problems to which alternative solutions are sought at an appropriate scale of control, is an important reason for the confusion. Principles of decision making were discussed with the stakeholders in a special session as well as the principles of multicriteria evaluation.

On November 23 2004 the final results were presented at the building of the Sindicato Rural, the farmers' organisation in Corumbá MS. Causes, scenarios and technical solutions have been discussed. Present were about 70 persons, farmers, members of NGO's, EMBRAPA staff as well as policy officials.

After the presentations of the research results and the analysis of the potential solutions a lively discussion started. The conclusion was that there are several technical and economic options, but the financial situation

makes it best to look for the cheaper solutions. All agreed that solutions downstream have to be integrated with upstream solutions. The meeting decided at the end to set up a working group of all stakeholders to bring solutions into practice and be a partner for other groups in the river basin. This means the objective to support the region to take decisions on water management has been reached. The participants were satisfied with the results of the projects and many complemented the team with the results of only two years work. Now the real work in the region has to be started.

Solutions, benefits and costs



If you analyse the solutions for the problem off the Taquari, then you have to include all aspects. It has no sense to give short term solutions. Therefore all directions have to be explored seriously. The team and experts from Corumbá have analysed them in some working sessions to bring back the solutions to benefit and cost levels that reflect the situation in Brazil. The the results of the project have been used as a reference and a tool for analysis. The aspects that have been considered are

- Technical feasibility
- Ecological and land use consequences
- Costs

In the analysis and the valuation of the results the scope has been that the Pantanal should remain a world Natural Heritage Site and its functioning as a wetland should not be endangered. The regional and local economic situation should be improved in a sustainable way, developing long term solutions. The costs must be reasonable for the region and the people involved.

Dredging the River

This solution is mentioned as the most logical one. However, as the river is the largest alluvial fan, where sedimentation is unavoidable there will be some severe obstacles. The distance of the river stretch to be drained is about 350 km. If a depth of 3 metre is accepted making the river accessible for ships, the amount of material to be dredged has been calculated as 60.000.000 m³, not including the daily increment. This increment can be based on the 2000 m³ daily sediment discharge at Coxim in 1995. If that sediment is getting directly or step-wise towards the avulsion area is not taken into account. Part of the daily sediment discharge will be in-channel and part will be overbank sedimentation. How the division between the two categories is, is unknown. The ships that are available in Corumbá to do this job can dredge 300 m³ per hour. If three are available the time needed to do this is 10-30 years and the costs are estimated on R\$ 180.000.000 based on cost figures for dredging the Paraguay not including the daily increment.

Another aspect is that if dredging is started then it must be set up as a continuous activity; dredging cannot be stopped without losing its effect in a relatively short time. There is need for a supervising organisation, but finally the river pulse, biodiversity of terrestrial species and populations of fish will recover. Part of the land will get relatively dryer.

Closing the Caronal Avulsion

Closing the avulsion at Caronal can only be carried out after or in combination with the river dredging. If this is not done in combination then other areas around the existing Taquari will be flooded. For damming the avulsion hard material must be used, because the area involved is unstable. Based on the transport route, the distance and the costs elsewhere the estimated costs are R\$ 3.500.000

The closing of the Caronal will mean that there will be less water in Paiaguás, but there is no guarantee that the original situation will return, because as can be concluded from the geomorphological history and the DEM the situation is very sensitive. The logical direction for the Taquari to move its bed is the direction from Caronal to the west. There will always be a tendency that the river will form a new bed into this direction.

If the avulsion is closed without dredging the river, it will have no consequences for cattle breeding and biodiversity in general as the wet/dry area ratio will remain more or less the same. However, the closing will cause a reallocation of wet and dry areas. The farmers along the Taquari will have to meet more floods and in Paiaguas less. Species related to wet conditions will also swap position.

Prevent new avulsions

Downstream of Figueiral, east of Caronal, an area is situated that is very sensitive for avulsions. The length is about 300 km. Prevention of avulsions is a continuous activity and should be supervised by a management organization. New avulsions can be natural or illegal and man-made. It is not well possible to estimate costs for this activity. It might be expected that the situation can be kept stable in the first years, but the possibility of new avulsions will increase after a certain period, because sedimentation in the river bed continues. On the short term the impact on cattle breeding and biodiversity will be neutral as there is no change in wet and dry areas.

Create a new river bed westward from Caronal

It is also suggested by some stakeholders to develop a new channel starting in the avulsion of Caronal in western direction. It could be dredged out artificially to create a river bed. The distance to the Paraguay is about 230 km. If a depth of 3 m is taken then about 80.000.000 m³ should be excavated. The time needed for this is depending on the equipment available but can be estimated between 10-30 years and the costs can be estimated at about R\$ 240.000.000.

The consequences are that in the long term there will be less inundations in this part of Paiaguas but the old riverbed will dry out as all the water will go the new direction. This might cause transport problems for the farmers in that region. They might have to use the roads over Nhecolândia or keep some waterways open.

For cattle breeding and biodiversity this solution means that at least after the channel is created that there will be a period of better drainage and discharge. There will be more land available for cattle breeding and species using dry land will be favoured. If the flood pulse returns it also means that the fish population will recover.

However, although the solution seems promising, it is rather expensive and how the sedimentation process will continue and how stable the new channel will be also not yet included.

Construction of dikes

The subsoil of the downstream stretch of the river consists of erosive and instable material. The material needed for stable dikes is not available along the river and should be brought in from. Moreover dikes need permanent supervision. The costs are difficult to establish as these depend very much on the type of dike that is wanted, transport costs and the way they have to be built. These uncertainties the rapid sedimentation in the river and the expected high costs make that this solution is not considered to be realistic.

Construction of a dam in the Planalto

A dam for retention of sediment can be constructed at a single site or at several places in the Planalto. The more places are selected the lower the dam can be and the lower the costs for each dam. If the dam is used for other functions as well such as water storage or electricity production then the dam should be high and will be more expensive. The costs are estimated on the costs of a dam in a comparable river in Argentina that just has been realised (Rio Mendoza). This dam has been made for drainage and electricity production. Estimated costs are

- For a dam for water retention (40 m high) and sediment retention R\$ 1.400.000.000
- For a dam for sediment retention only (10 m high) R\$ 20.000.000
- For three smaller dams for sediment retention: R\$ 30.000.000

The consequences are that in all cases the sediment is retained, but it will stimulate downstream erosion as every river needs bedload. If there is only one dam, then the flood pulse and fish migration will disappear or be severely hampered. This means that the fish production might not return in the river and ecological and economic damage might happen. If only three smaller dams are placed for sediment retention, then the impact on the flood pulses and fish migration might be less. However as the Planalto has not been part of the spatial and ecological analysis the real affects cannot be confirmed without further research on the Planalto.

An important management consideration in building a dam for sediment retention is that the sediment will have to be removed regularly and not be passed on to the Pantanal to prevent further sedimentation.

Afforestation of river margins on the Planalto

The discharge of the Taquari from the Planalto has increased since the 1970s. There is more water and more sediment transported. A possibility to diminish the increase in water and sediment is replanting forest on the Planalto. By planting forest evapotranspiration is stimulated. The Brazilian Código Florestal obliges to keep 10% of the land forested. For the Planalto this would mean an area of 2.700km², but that is not the case at present. If this is done in a planned way along rivers and streams, in the most vulnerable areas for erosion, then it might be a tool in river basin management. However, this requires planning and supervision. It also requires that the farmers on the Planalto, if they are cattle farmers use pumps for their water needs preventing cattle to go down to the water.

The costs estimated for this solution are R\$ 8.000.000, but it also requires an organisation that is capable of planning and supervision on the actions in the field. Actually such plans should be part of a river basin management plan.

The consequence is decrease in erosion and water discharge due to increased evapotranspiration. The consequences for cattle breeding and biodiversity can only be estimated as a long term effect because it has no direct effect on the downstream river. The river has to stabilise its bed. How quickly that happens depends on natural processes and eventual measures taken downstream. If no measures are taken, then this might last several decades, depending on natural developments.

Capacity building and river management organisation

River management organization is a relatively long term solution. It will take at least ten years to develop the capacity for river management. Capacity building is therefore part of a long term solution. Training means that teachers will have to be trained to train the organizations and the farmers in sustainable water and land management. Estimated costs are between R\$100.000 for minimal programmes to R\$1.000.000 for the whole basin.

The consequences are that joint decisions will be taken, costs can be shared. It is only wise to do this in the context of a river management organisation with supervision and clear tasks in management. There are no direct consequences for biodiversity. It might be advantageous for farmers on the Planalto.

Develop a National Park

One of the solutions mentioned is to develop a National Park in the inundated area. What the costs of such a solution will be depends on the national strategy of developing National Parks. In some countries National Parks are State owned; in other countries they can also be private. In any case the inundated area of maximum of 5000 to 8.000 km² will have to be compensated when no cattle ranging is allowed. Eventually farmers should be reallocated elsewhere. It is a quick solution for the farmers and a long term solution for biodiversity.

Recommendations

From these solutions it can be concluded that the following actions have the best perspectives:

- Develop an organisation for river management at the basin level.
- Prevent erosion on the Planalto by application of the código florestal for the river edges.
- Compensate the farmers for the flooding by creating a National Park;
- Eventual construct some small dams for sediment trapping when needed.
- The technical solutions appear too expensive and without perspective when there is no coherent management in the river basin.

Lessons learned



Lesson 1: putting science into context

In countries as Brazil that have already a well developed scientific infrastructure, the knowledge in the field of water sciences, erosion, sedimentation and climate is substantial. The important added value of the project has been that this knowledge has been set in context of the river as an ecosystem and that the links between science fields (hydrology, ecology and economics) have been made. This can be the basis for sustainable river management.

Lesson 2: The role of stakeholders and capacity building

The project started with a stakeholder workshop and the role of the stakeholders has been stressed. However, stakeholders develop their own ideas and expect solutions that support their ideas. The knowledge in the project however comes from the interaction between stakeholders and science. Stakeholders do not always have the capacity to be flexible; neither do the researchers and the water managers. In a situation where politics is important, it is essential to be there and discuss matters with them using scientific arguments and the right economic and hydrological models that can explain the situation. That is the only convincing argument. It is also the tool to help the region to start thinking at the basin level.

Lesson 3: Organisation of water management

Alto Paraguai and the Pantanal are part of the Plata basin and the Plata river commission is the highest authority. The Project has been used to communicate with policy makers at the level of national and international water management. It is important that the results of the project will be accepted both in the region and with the authorities that supervise the region. Making water management work and sustainable is an important political issue. Water management at the basin level is not yet organised and within the large basins coordination is difficult. Roads are lacking, transport is expensive: internet is the best tool for fast regional communication.

Lesson 4: Research coordination and cooperation

An important aspect that has been learned is that the cooperation between and the coordination of policy and research is not as it should be. Policy makers within the countries involved and research groups are focussing on their own issues and priorities and exchange between them is not well organised especially between disciplines. Research is organised in traditional ways and the European expertise in the region does not cooperate in Europe. NGOs play an important role and also here cooperation is a difficult issue.

Lesson 5: Europe can learn from the Pantanal

The Pantanal has undisturbed rivers and wetlands as well as river basins in change such as the Taquari. This has important ecological consequences and through these ecological consequences also economic and social implications. The relationship of hydrological behaviour of a river system and its ecological functioning (the flood pulse) can be an important lesson to be learned for river management in Europe. The question how to apply the flood pulse in river management is an essential question for further ecological and river management research and river restoration in Europe.

Colophon

Pantanal, Tools for decision making in Integrated Water Management

Editor: R.H.G. Jongman

Partners for Water project 02.045

Water for Food and Ecosystems

© Alterra, Wageningen UR, © Basic reports: see report cover.

Photographs: Rob Jongman, Ben Maathuis, Bart Makaske

Design: Team Graphic Design and Desktop Publishing, Alterra

Print: van Eck & Oosterink

ALTERRA Special Publication 2005/02

ISSN 1574-8227

This report is printed in English and Portuguese and free available in pdf-format through the website www.alterra.nl or www.pantanal-taquari.alterra.nl. The reports can be used freely with source reference.

Participating institutes and staff members in the project:

Alterra:

Rob Jongman,
Michiel van Eupen,
Bart Makaske,
Sabine van Rooij,
Gerard Groenveld,
Erik Querner,
Remco Jonker

Embrapa-Pantanal:

Carlos Padovani,
Walfrido Tomás,
Emiko Kawakami de Resende,
Agostinho Capella,
Balbina Soriano,
Sergio Galdino,
Suzana Salis

WL|Delft Hydraulics:

Erik Mosselman,
Bob van Kappel,
Marcel Ververs,
Chris Stolker,
Marjolijn Haasnoot

ITC:

Ben Maathuis,
Luc Boerboom

Arcadis:

Sjors Hein

Regenboog Advies:

Helena Berends

Please visit our website at www.waterfoodecosystems.nl

For further information about the project, its results and its follow-up, please contact:

Dr R.H.G. Jongman
Alterra, Wageningen UR
PO box 47 6700 AA Wageningen, The Netherlands
Email: rob.jongman@wur.nl
Website: www.alterra.nl; www.pantanal-taquari.terra.nl

or:

Carlos Padovani
EMBRAPA-Pantanal
Rua 21 de setembro 1880
Caixa Postal 109
79320-900 Corumbá, Mato Grosso do Sul, Brazil
Email: guara@cpap.embrapa.br
Website : <http://www.cpap.embrapa.br/>

This book and the CD Rom with the final report and additional information has been made by the institutes depicted here:

