Environmental Impact of an Amazon Reservoir, Curuá-Una /Pará: Limnological Aspects.

Gunkel, G.[1], Lange, U.[2], Walde, D.[3] and Rosa, J. W. C.[3]
[1]Technical University of Berlin, Dept. Water Quality Control, Germany
[2]Technical College of Berlin, Civil Engineering, Germany
[3] Universidade de Brasilia, Instituto de Geociências, Brazil

Abstract

The build up of a dam and the use of running water for water supply or energy production can lead to a severe impact of the environment, especially of the aquatic ecosystem, and little is known about the development of the reservoir as a new aquatic ecosystem. Environmental effects of a 23 years old tropical reservoir, the Curuá-Una Reservoir in Amazon, are studied. The river Curuá-Una was dammed up and the water level was raised up about 20 m, leading to a reservoir with a length of in total 140 km and a width of up to 3 km.

After closing the dam an eutrophication period occurred within the reservoir, the so called 'trophic upsurge'. But today, the reservoir is still at a high trophic level with an intensive production of floating vegetation (a Polygonum species), and a oxygen deficiency occurs in the hypolimnion of the reservoir. The abundance of phytoplankton is small to moderate (up to 3,000 cells per mililiter), but the diversity is high (nearly 30 species).

The inflow water of Rio Mojui dos Campos, Rio Mujú and Curuá-Una differ significantly in the water quality: Rio Mojui dos Campos and Rio Mujú have a very small ionic content (conductivity of 12 µS/cm) and contain only traces of calcium (0.2 mg/l); consequently the water is acid (respectively, pH = 4.7 and pH = 5.1). Curuá-Una has a higher ionic content with about 3 mg/l Ca (conductivity = 40 µS/cm) and the water has a higher buffer capacity (pH = 6.0).

Phosphorous is the limiting factor of the primary production, reaching concentrations of up to 10 µg/l SRP and 55 µg/l P-total. The source of the phosphorous is the Curuá-Una, which one has a significant higher concentration than the Mojui dos Campos and Mujú rivers. Only few settlements occur in the catchment of Curuá-Una, but they are located in a nutrient rich soil area. Besides, the catchment areas of the Rio Mujui dos Campos and the Rio Mujú had been settled intensively, and the nutrient poor soils lead only to a small phosphorus output.

No degradation of the inundated vegetation in the reservoir occurred , and the dead trees are still standing in the water, leading to an impact of boating and fishing. The degradation of the wood could be done by Asthenopus curtus, a mayfly larva, being present in the reservoir, but the development of a significant population seems to be prevented by the operation of the hydroelectric power station, that leads to the frequent water level changes in the reservoir.

The iron concentration in the water of the reservoir is very high, leading to a iron corrosion in the hydroelectric power station. This is a consequence of the high iron concentration in the sediments of the reservoir, being mobilized by redox chemical processes (reduction of the ferric ion to the soluble ferrous ions). This one is transported by the water currents in the anoxic hypolimnion to the electrical power station.

Keywords:

Curuá-Una Reservoir, Amazon, Limnology, Water chemistry, Eutrophication, Wood decay, Iron

Reservoir surface			102 km^2
Length	Curuá-Una		78 km
	Rio Mojui :		~ 15 km
	Rio Mujú		~ 45 km
Maximum width			3 km
Depth:	maximum		19.5 m
	mean		5.9 m
Reservoir volume		(level 68,00 m)	530 o 106 m^3
		(level 61,00 m)	130 o 106 m^3
Outflow	minimum		40 m^3/sec
	mean		180 m^3/sec
	maximum		640 m^3/sec
Water residence time			20 – 75 d
Watershed area			13,600 km^2
Catchment area			15,300 km^2
Factor watershed/lake surface			133
Dam height			35 m
Installed power			31 MW
Damming up			1977
Water level		normal	68.00 m
		maximum	68.50 m
		minimum	61.00 m

Tab. 1. Morphometric and technical data of the Curuá-Una-Reservoir

1 Introduction

The Curuá-Una Reservoir, located near Santarem/Pará, is now 23 years, one of the oldest reservoirs in the Amazon region, being used for electrical power production. The old stream valley with two inflows, Rio Mojuí dos Campos and Rio Mujú, was flooded, building up a long reservoir of about 140 km total length and up to 3 km width. The reservoir is dominated by shallow areas, mean water depth is nearly 6 m, maximum water depth is 19.5 m. Water residence time varies from 20 days (rainy season) to 75 days (dry season; Tab. 1).

The construction of a reservoir leads to many ecological problems (BAXTER, 1977; PETR, 1978; BAUMANN, 1984). Some of these effects can be quantified easily, e. g. the loss of forest, cultural areas and terrestrial species, but the impact of the water system is a very complex process. After damming up, a new aquatic ecosystem will be established with new species, with unknown biological processes, and a new state of water chemical processes. Up to now little is known about the ecological impact of a reservoir in the Amazon, and the knowledge gathered from reservoirs located in other climate zones and ecological areas cannot be applied to the Amazon (JUNK, 1987; KOHLHEPP, 1998).

Investigations were carried out in the Curuá-Una Reservoir in 1998 and 1999 to determine water chemical parameters, as well as to evaluate the biological processes within the reservoir. Aim of this study is an ecological evaluation of the Curuá-Una Reservoir under consideration of the environmental impact, and the development of a management plan of reservoirs.

First investigations were carried out in Curuá-Una by JUNK et al. (1981) and by JUNK (1982) to study the effects of the damming up, and pointed out the severe eutrophication process. In the past decades no monitoring was carried out to register further development of the trophic state. Today, 23 years after damming up, the ecological impact of the Curuá-Una Reservoir is determined by three main processes:

1) Inundated vegetation is still standing in the reservoir, and up to now no significant decay of trees within the reservoir can be observed.
2) Eutrophication process, which started immediately after filling - the so called 'trophic upsurge' - is still going on, and a mass development of floating vegetation occurs.
3) The water outflow of the Curuá-Una Reservoir has a very high iron content, and iron corrosion to the electro-mechanical equipment occurs, besides a damage of the drainage system of the dam is possible.

2 Material and Methods

A limnological investigation was carried out in the Curuá-Una Reservoir, Pará/Amazon in 1998 and 1999 to quantify the eutrophication process, to evaluate the decay of inundated trees, and to determine the source of iron in the water outlet. These investigations are part of the evaluation of the environmental impact of the Curuá-Una Reservoir (LANGE et al., 2000).

Water samples were taken in the inflows Rio Mojui dos Campos, Rio Mujú and Curuá-Una, as well as in the main reservoir under consideration of thermal stratification of the water body (Tab. 1). The following parameters were determined in a vertical profile in water: temperature, pH, conductivity and oxygen using electrodes as well as nitrogen total, nitrogen total soluble, phosphorus total, soluble reactive phosphorus, iron total, iron soluble and calcium, by using standard water chemical analyses (German standard methods).

Besides water transparency (secchi depth), phytoplankton abundance, diversity, as well as floating vegetation, were determined. Samples of inundated wood (died trees, as well as floating trunks) were studied for occurrence of the wood fragmenter Asthenopus curtus. Sediment samples were analyzed for iron content.

3 Results

3.1 Water chemical and physical parameters

Curuá-Una is more or less a black water river with a transparency of 2 – 3 m, and a relative high conductivity of 40 µS/cm, caused by the calcium content of 2.8 mg/l. Consequently, the water is well buffered with a pH of about 6.0. This high ionic content is caused by a natural and/or anthropogenic erosion in the upper water course, located in a carbonate stony area with a significant erosion by human settlements.

Rio Mujui dos Campos and Rio Mujú are typical Amazon rivers with an extreme low ionic content (12 µS/cm) and acid water (pH = 5.1, and 4.7, respectively). Both rivers flow in a tertiary sediment area, and in the catchment area of both, an intensive settling of humans occurred during the last 20 years, and pasture as well as agriculture were started.

In the main reservoir (after the inflows of the tributaries), a mixed water quality can be observed with a conductivity of 17 µS/cm, a pH of 5.6, and a calcium content of 1.2 mg/l. A significant temperature stratification occur with about 31 °C at the surface, a metalimnion at about 5 – 10 m

(29.4 - 30.5 °C), and a hypolimnion with about 29.2 °C. A corresponding stratification of the oxygen concentration can be registered: a high oxygen content in the epilimnion (0 – 3 m: ~ 5.5 mg/l, this corresponds to a saturation ≤ 80%), as well as a lack of oxygen in the hypolimnion > 8 m depth (anoxic conditions).

3.2 Decay of inundated vegetation

The decomposition of wood in tropical areas is quite different in the Várzeas as periodically flooded areas with a aquatic and terrestrial phase, and in reservoirs with a permanent water body. In the Várzeas, the decay is rapidly done by mechanical fragmentation (wind, waves), wood decomposer (bacteria and fungi), as well as wood consumer (termites and some larvae of Cerambycidae). The kinetic of the decay last from a few months (during the terrestrial phase) to a few years (during the aquatic phase; FURCH & JUNK, 1997; 1997a; MARTIUS, 1997).
The decay of inundated vegetation in the reservoir can only be done during the aquatic phase by mechanical fragmentation (by wind, waves and a fly larva, *Asthenopus curtus*), and by some wood decomposer (bacteria and fungi, but not by termites). *Asthenopus curtus*, an Ephemeroptera larva with a length of up to 17 mm, is constructing U-sharped tunnels in the wood. *A. curtus* is a wood fragmenter, not a wood consumer. The larva consumes phytoplankton, small floating algae in the water, as a filter feeder (SATTLER, 1967). Asthenopus is a very effective wood fragmenter, and secondary, a decomposition of the wood can occur in the tunnels by bacteria and fungi.
In the Curuá-Una Reservoir the wood decomposition is inhibited, and 23 years after inundation the trees are still standing in the water (Tab. 2). This inhibition of wood decay is not caused by the acidity of the water, being moderate in the main reservoir.

The development of *Asthenopus curtus* could too be demonstrated within the reservoir. The food supply of the larvae seem to be sufficient: A species rich phytoplankton community with 27 species (dominant species: the blue-green algae *Merisoipedium tenuissima*, the *Chlorococcale Chlamydomonas spp.*, *Cryptomonas spp.*, and *Trachelomonas volvocina*) with up to 3,000 cells/ml was registered. The occurrence of Asthenopus curtus was restricted to free floating trunks in a horizontal position at the water surface.
The inhibition of the wood decay seems to be a consequence of the water level changes, which happens frequently by the reservoir operation: a constant water level was only held for a few months in the year. *Asthenopus curtus* larvae live only near the water surface because of the high oxygen demand, and with raising water level they will be damaged by insufficient oxygen supply (the oxygen concentration is quite low due to the high temperature and to the intensive use of oxygen by mineralization processes).
A decreasing water level directly leads to a lethal damage of the larvae, because they have to leave their tunnels, and predation by fishes, as well as an impact by light input, may occur. Asthenopus curtus is reproducing during the whole year, but with a life spawn of 4 – 6 months, population development will be damaged by just a few water level changes during the year.

3.3 Eutrophication process

After damming up, a severe eutrophication of the reservoir occurred with a nearly complete (~ 90%) covering with floating vegetation, the so called 'trophic upsurge' (Fig. 3). This eutrophication process is caused by decomposition of leaves and by release of nutrients from the inundated soils. Beside the damming effect with a storage of the water (water residence time in the Curuá-Una Reservoir ranges

		Rio Muju	Rio Mojui dos Campos	Rio Curuá-Una	Curuá-Una Reservoir
Pteridophytas	*Salvinia auriculata*			+	+
Polygonaceae	*Polygonum portoriense*				+++
Onagraceae	*Ludwigia sedioides*			+	+
Pontederiaceae	*Eichhornia azurea*			+	+
	E. crassipes				+
Covering		0 %	0 %	< 5 %	~ 20 %

Tab. 2: Floating vegetation in the Curuá-Una Reservoir and its tributaries (sampling: 11/1999)

between 20 and 75 days), enables the development of algae and macrophytes.

Today, the development of the floating vegetation is more restricted (~ 20% covering), dominate species is *Polygonum portoriense*, but there are still high trophic conditions. This is too confirmed by the lack of oxygen in the deep water body: A deficit of oxygen occurs in a depth of 4 m, and below 8 m the water is free of oxygen.

After the trophic upsurge of a reservoir, a so-called cultural eutrophication can be registered, due to the increasing population density in the catchment area. An intensive settling took place in the catchment areas of Rio Mojui dos Campos and Rio Mujú, but the highest phosphorus concentrations were found in the Curuá-Una inflow (> 50 µg/l Ptotal). The N/P-relationship indicates that phosphorus is the limiting factor of primary production (N:P = 100 – 150 : 1). The source of the phosphorus seems to be a carbonate rocky area in the upper course of the river near the Transamazonica road, being settled, and where a natural erosion by the river, as well as an anthropogene erosion by deforestation occurs.

The nutrient input leads to a mass development of floating macrophytes (Tab. 2), as well as to the already mentioned lack of oxygen in the deep water body.

3.4 Iron content of the water

The iron concentration in the water is of high interest, because iron corrosion of the electro-mechanical equipment of the power station has been registered. The source of iron in running water may be

- leaching of soils and of the river bed sediments by acid water,
- redox chemical reduction of ferric ion (Fe^{3+}) to the soluble ferrous ion (Fe^{2+}) in groundwater or running water,
- mechanical erosion of soils in the catchment area, or erosion of the river bed by water currents.

Under oxic condition, the ferrous ions will precipitate as ferrous hydroxy complexes, and will be deposited in the sediments, consequently the iron concentration in lakes or reservoirs of water is moderate (< 0.5 mg/l). A high iron concentration in the outlet of a lake or reservoir is not common. But there are some mechanisms which lead to transportation of iron in running water, and to an increase of dissolved iron in a lake or reservoir:

- transportation of particulate material by load of the river,
- transportation of suspended material (iron-hydroxo flakes, iron oxidizing bacteria),
- adsorption of Fe^{3+} by humic substances, and transportation of the colloidal substances by water flow,
- redox chemical release of soluble iron under anoxic conditions by Eh < 200 mV (Fe^{3+} -> soluble Fe^{3+}), and transportation of Fe^{2+} by the water flow,
- photochemical reduction of Fe^{3+} in presence of humic acids, and transportation of Fe^{2+} by the water flow.

Presently, the deposited sediments in the Curuá-Una Reservoir contain a very high iron concentration (10 g/kg), being a consequence of one of the mentioned processes. Due to the deficit of oxygen in the reservoir, iron is transferred in the soluble ferrous ions form, leading to a concentration of total iron in water of < 2 mg/l, up to 90% is in the soluble ferrous ion state. Consequently the eutrophic state of the reservoir leads to the iron problem: Due to the lack of oxygen, the iron is reduced to the soluble ferrous ion and is moved by the water current to the reservoir outlet, leading to the iron corrosion of the electro-mechanical equipment, and a damage of dam drainage must also be assumed.

The iron concentration of the inflow of Curuá-Una in the reservoir must be evaluated as a high level, but within the range of observed iron concentrations in Amazon running water (FURCH, 1985, Fig. 4).

4 Impact of Curuá-Una Reservoir

The damming up of the Curuá-Una led to some well known effects to nature, as well as to some problems being not sufficiently known. The negative effect of dams to nature has been published by some authors (e. g. BAXTER, 1977; Petr, 1978; JUNK, 1987), who also studied tropical areas. 23 years after damming up the Curuá-Una, we can verify and evaluate the effects to develop a better planing for further reservoirs. First, we have to point out a lack of investigations and a missing monitoring of the Curuá-Una reservoir. Consequently many data are not available, and the knowledge of the environmental impact of this reservoir is limited.

Concerning the long-range effects of the dam, we have to distinguish:

- Microclimate: no significant effect, due to the small size of the river valley,
- Water balance: no data available,
- Groundwater hydraulics: no data available,
- Land use in the watershed: increasing population density beside the roads, and along the shore line, deforestation, unknown effect of nutrient input,
- Creation of land born diseases: occurrence of

Leishmaniasis, being promoted by deforestation,

- Creation of water born diseases: occurrence of Malaria.

The damming up of the river has significant effects on the water ecosystem:

- Loss of land: ~ 102 km^2,
- Loss of wood: ~ 50 • 10^6 m^3,
- Loss of species (fauna, flora): not registered,
- Loss of anthropogen/geological monuments: no monuments in this area,
- Translocation of the population: no settlements in this area,
- Shore erosion by water level fluctuation: water level changes of about 6 m, severe shore erosion and missing shore vegetation,
- Increased sedimentation with a reduced life span of the reservoir: no significant effect,
- Eutrophication process as a trophic upsurge of the reservoir: development of a long-term eutrophic state with an anoxic hypolimnion, and a mass development of floating vegetation (covering rate of 20 – 90 %),
- Water quality: high iron concentration, leading to iron corrosion to the electromechanical equipment,
- Resting vegetation: CO_2 emission of about 800 mg/m^2 d (DUCHEMIN et al., 1999) and CH_4 emission of about 100 mg/m^2 d (ALMEIDA et al., 1999), that are in total 4 • 10^5 t/a greenhouse gases,
- Decomposition of inundated organic matter: decrease of oxygen (~ 30 g/m^2 O_2) and an acidification of the water,
- Decay of inundated trunks: no significant decay within 23 years
- Migration of new species into the reservoir: no data available.

The damming up also leads to some effects downstream:

- Regulated flow of the river respective artificial flooding cycle by the reservoir management: no data available,
- Missing suspended load in the river, and river bed erosion: no data available,
- Loss of nutrients in inundation areas downstream: no data available,
- Barrier to fish migration, and reduced fish production downstream: no data available.

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6 Acknowledgement

The research project was carried out under the auspices of the Agreement on scientific-technological co-operation signed by the governments of Germany and Brazil. It was sponsored by the Federal Ministry of Education and Research (BMBF), and by the Brazilian Council for Scientific and Technological Development (CNPq), as a part of the SHIFT program - Studies on Human Impact on Forests and Floodplains in the Tropics (project BRA ENV 53).

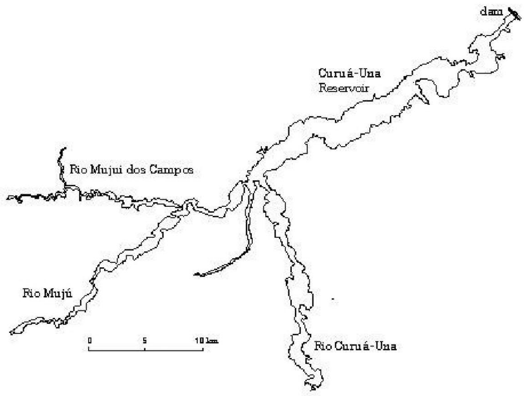

Fig. 1: The Curuá-Una Reservoir in the Amazon/Pará, near Santarem.

Fig. 2: Typical view on the Curuá-Una Reservoir: The inundated forest is still standing in the water, and no decay of the trunks can be registered.

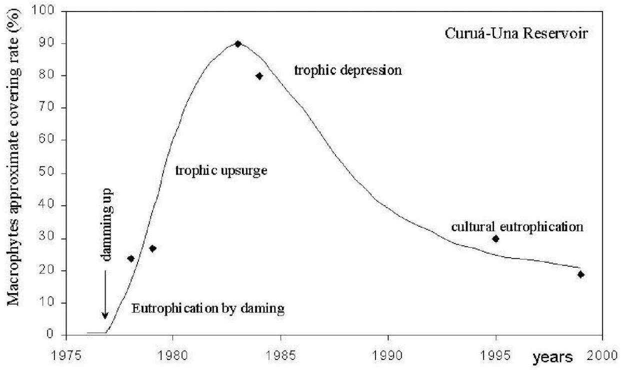

Fig. 3: Schematic eutrophication process of the Curuá-Una Reservoir: Three phases can be distinguished, the trophic upsurge, the trophic depression, and the cultural eutrophication

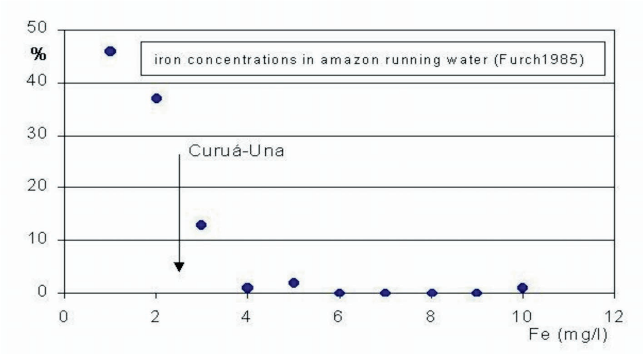

Fig. 4: Iron concentrations of running water in the Amazon, in total 80 creeks, rivers and streams were investigated (according to FURCH, 1985).

Editors Reinhard Lieberei [1], Helmut K. Bianchi [2], Vera Boehm [1], Christoph Reisdorff [1]
[1] Universität Hamburg, Institut für Angewandte Botanik, Ohnhorststr. 18, 22609 Hamburg, Germany
[2] GKSS-Forschungszentrum Geesthacht GmbH, Max-Planck-Straße 1, 21502 Geesthacht Germany

Layout Helmut K. Bianchi, GKSS, Karsten Bittner, Documedia, Geesthacht, Germany

Printing GKSS-Forschungszentrum Geesthacht GmbH, Geesthacht, Germany

ISBN 3-00-010691-X

Lieberei, R., Bianchi, H-K., Boehm, V., Reisdorff, C., (eds.) 2002:
Neotropical Ecosystems, Proceedings of the German-Brazilian Workshop,
Hamburg 2000. GKSS-Geesthacht .

The research cooperation has been carried out under the auspices of the German - Brazilian Govemmental Agreement on the Cooperation in Scientific Research and Technological Development.

The issuance of the Proceedings and the production of the CD-ROM was sponsored (Code 0339991) by the

bmb+f
Bundesministerium für
Bildung, Wissenschaft,
Forschung und Technologie

**Federal Ministry of
Education and Research**