Key Issue:
5-Water Quality
3 -Fish Migration

Climate Zone:
Tropical Humid

Subjects:
- Various measures to maintain fish habitat and migration as a consequence of a fish mortality incident

Effects:
- Restoration of original fish habitat and migration by special operations and structural measures

Project Name: Yacyretá Hydroelectric Project
Country: Argentina and Paraguay

Implementing Party & Period
- Project: Entidad Binacional de Yacyretá (EBY)
1994 (Completion of Construction) -
- Good Practice: EBY (Departamento de Obras Complementarias, Sector Medio Ambiente, Departamento Técnico), Universidad Nacional del Nordeste, Corrientes and with assistance of the Consulting Engineer CIDY (Harzay Consorciados)
1994 -

Key Words:
Total Dissolved Gases, Supersaturation, Spillway, Fish Mortality

Abstract:
In August 1994, massive fish mortality was observed downstream of the project's main spillway. EBY (Entidad Binacional de Yacyreta) immediately changed the spillway operation in order to alleviate supersaturation of total dissolved gases (TDG), the cause of the mortality. The long-term solution was a change in the geometry of the spillway. No fish have died since these measures were implemented.

1. Outline of the Project

The Yacyretá scheme is some 1000 km north of Buenos Aires on the Paraná River. Energy production is the main purpose. 20 Kaplan turbines with a discharge of 800 m^3/s each, are installed during the first stage. With a head of 22m and an installed capacity of 3'100 MW the project will generate some 20,000 GWh/year. The head will be obtained through an earth dam, max. 43 m high. To avoid the flooding of large areas on the right Paraguayan side, a 62 km long lateral dam is required, Fig. 1 (project layout).

At the site, the Paraná River is divided into two branches forming the Yacyretá island. This also lead to divide the spillway into two structures. One spillway is on the main branch with a capacity of 55'000

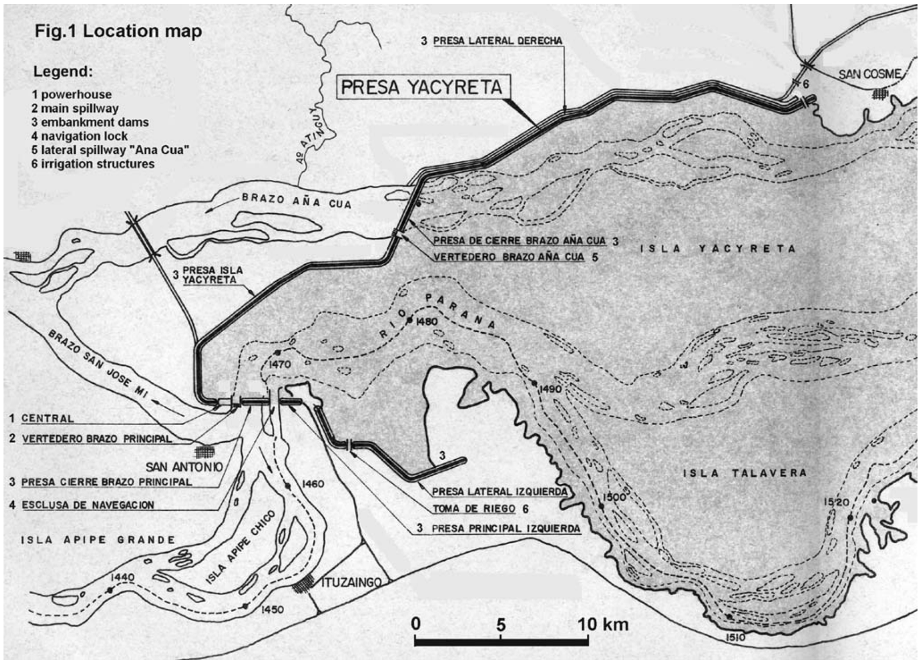

Fig. 1: Dam location map

m^3/s through 18 bays controlled by tainter gates, the other spillway is on the Aña Cua branch, with a capacity of 40,000 m^3/s controlled by 16 tainter gates. River flow which exceeds the generation capacity is discharged first though the Aña Cua spillway to provide ecological water flow in the Aña Cua branch and to minimize tailwater fluctuations for the powerhouse. Major floods are then discharged through the main spillway too.

The project includes a navigation lock, migratory fish transfer structures and irrigation intakes.

Momentarily, the project operates under a reduced head (present full supply level 76 m as compared to 83 m a.s.l.) because of outstanding expropriation settlements.

2. Features of the Project Area

The Paraná River drains a 10^6 km^2 catchment area of tropical to subtropical climate with a mean annual precipitation of 1'500mm. The flow regime is governed by two rivers, the Alto Paraná and the Iguazú, with different flow characteristics. The following river flow values were obtained from hydrological studies and from statistics of 101 years of daily stage readings at Posadas:

Recurrence	Peak flow in m^3/s
PMF	95,000
Historic flood	53,000
Mean annual flood	23,000
Mean discharge	12,600
Historic low discharge	4,300

The reservoir capacity varies between 21.10^9 and 26.10^9 m^3 for normal and maximal reservoir levels with negligible retention effects since the mean annual discharge volume of the river is 380.10^9 m^3.
The dam site is characterized by a flat pampas-type riparian river plain surrounded by so-called "esteros" (marsh). The presence of the reservoir does not markedly change the original environment because the meandering slow flowing river with an average width of 2 to 5 km and wide flood plains is now replaced by a shallow lake of similar dimensions, Fig. 2.
A special feature of first impounding was floating islands which were dragged slowly towards the spillway and the powerhouse intake. These islands, between 100 and 6'500 m^2 large and 0.8 to 2m thick, were detached from the pasture land, very likely due to uplift created by gas emissions. The gases are formed by anaerobic decomposition of root systems and organic soil. The phenomenon was short lived. Larger islands were sawed in order to allow their discharge over the spillway without causing damages.

Fig.2: Dam under construction with main spillway (in front) and the excavation for the powerhouse

3. Major Impacts

3.1 Event of Fish Mortality

During August 1994 a massive fish mortality was observed downstream of the main spillway. This phenomenon coincided with a change in spillway operation from unsymmetrical discharge through totally opened gates to symmetric flow through equally partially opened gates. Immediate studies indicated that the cause was gas bubble disease associated to supersaturation. The majority of the affected fish were mainly "nodorados de fondo" (catfish, scates) but also salmons, "doradores and bogas". 10 days thereafter the gates operation was changed to avoid the most critical supersaturation, Fig.3. Similarly, in October of the same year, dead fish were also observed, however in much less quantity, at

the Aña Cua spillway, Fig.4. There, the spillway operation was changed immediately.
It should however be mentioned that critical spillway operation was restricted to the time when the power unit were still under construction and not yet ready for operation. This condition increased the spillway discharges and thus the levels of supersaturation.

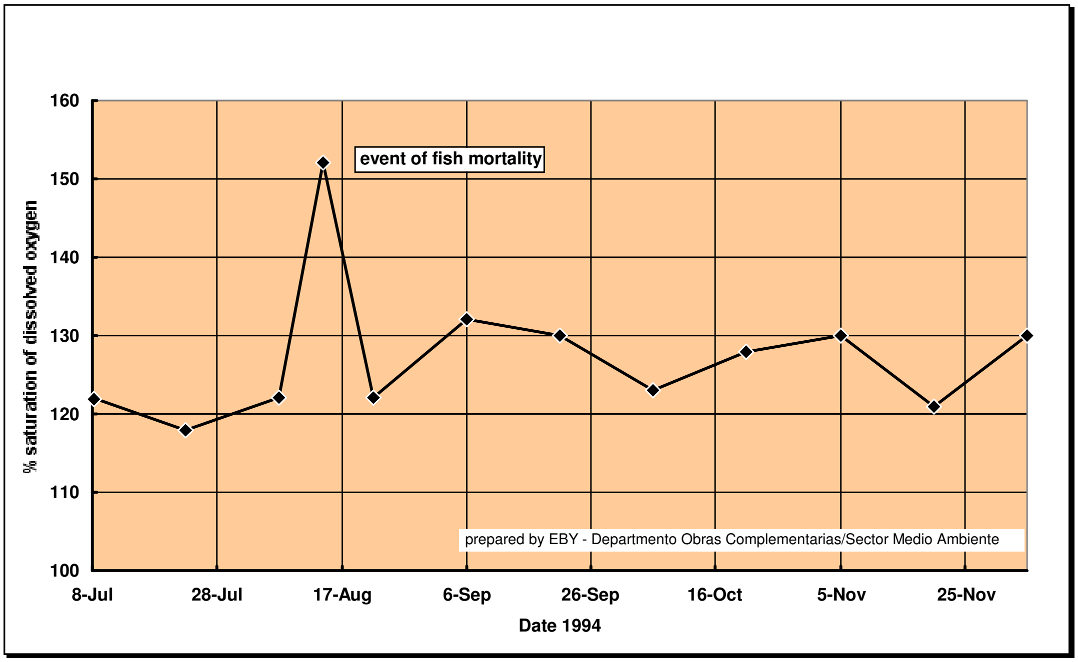

Fig.3: Evolution of dissolved oxygen in the stilling basin of the main spillway

Fig.4: Aña Cua spillway operation at the time when fish mortality occurred

3.2Experimental Actions to Investigate the Cause

To investigate the incident in all details, a scientific experimental program was put together by a team of EBY's Environmental Department with assistance of foreign experts, Dr. James Thrall, Dr. Weslay Ebel.

Dr. John Cassidy and several representatives of the US Army Corps of Engineers. Both, field and laboratory studies were implemented. The first program comprised the following investigations:

- Measurement of total dissolved gas (TDG) levels as related to different spillway operation (partial/full gate opening and number of gates open), discharge and tailwater depth.
- Field studies with fishes of known age and degree of damage, captured in cages and exposed to a known level of supersaturation.

The objective of these investigations was:

- to find the best operation scheme for the spillway gates in order to obtain lower supersaturation values,
- to study the distribution of the saturated flow downstream of the spillway,
- to assess an "acceptable" level on supersaturation for the local types of migrating fish,
- to get information about the exposure time to assess the development of symptoms and death rate for different levels of supersaturation,
- to estimate the approximate capacity of recuperation for typical fish species,
- to get indications for improving further studies.

The applied method was to selectively capture fish of known species in the fish transfer structure, such as fish of high vitality and without injury from supersaturation (no bubbles in the fins). The fish were then transported in 100 l containers without aeration into the test area where they were kept in 1mx0.5mx0.5m cages. The cages were exposed to three conditions:

1) close to the surface, hardly covered by water, at locations with different supersaturation.
2) at the same location but in different depth above and below the depth of compensation
3) fish affected form exposure 1 and 2 were placed below the calculated depth of compensation in order to observe their capacity to recuperate.

The cages were then observed daily to register symptoms of gas bubble decrease individually, and to asses their vitality and death rate. The saturation was measured such that the percentage of saturation with respect to depth of the cage was recorded.

Correspondingly, mortality rates are related to the degree of supersaturation, the depth available for the fish and the duration of exposure time. The following threshold values were evaluated:

Exposure Time [hours]	**Depth**		
	Near surface	**1 to 2m**	**3m**
24	115	117	124
48	110	117	123
72	106	116	-
96	105	116	-

Tests demonstrate that no symptoms of embolism are detected up to 104% of absolute supersaturation and up to 120 hours of exposure.

The measurements were made at more than 36 different locations in the reservoir and downstream of the spillway at a max. distance of 100 km. The results can be summarized as follows:

- The reservoir showed 100% saturation whereby immediately downstream of the main spillway 140 to 150% of saturation of total gases was measured.
- During floods 120% saturation was measured in the reservoir immediately upstream of the spillway with no significant increase from previously values downstream of it.

- The spillway has an air vent system installed in the ogee crest. Opening or closing this system showed insignificant difference in total saturation levels
- The dissipation of the gases is very slow: 90 km downstream of the spillway 125% saturation was measured.
- The turbine discharge water with similar saturation levels as those measured in the reservoir.
- The supersaturated discharge flows without mixing with the turbine discharge.

Other actions implemented were in-situ monitoring of river flow and water quality conditions and checking the effectiveness of fish transfer structures.

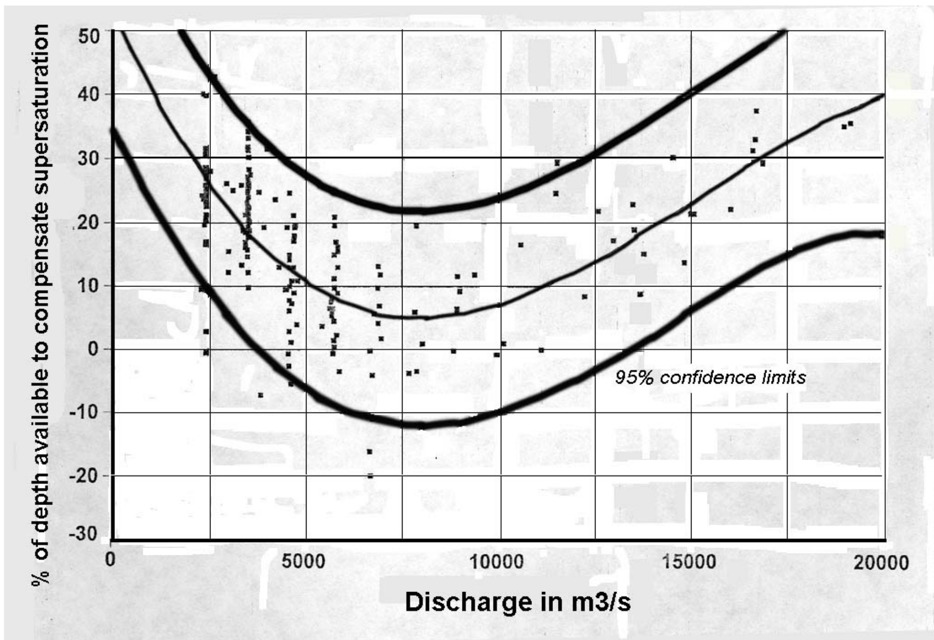

Fig.5: Depth available for fish in order to escape into regions with lower supersaturation

4. Mitigation Measures

As a consequence of these investigations it was decided to

- continue measurement of TDG at different flow conditions
- continue systematic study of stocks of fish in the area
- change the spillway operation rules
- perform hydraulic model studies to investigate hydraulic jump characteristics, influence of aeration, and the effect of spillway deflectors
- investigate the reasons for the relatively high natural saturation level of the Paraná River.

These investigations lead to two major mitigating measures:

1. A structural modification of the spillway ogee crest by adding deflectors.
2. Modifying the gate opening rules.

To 1: 2D and 3D hydraulic model studies conducted by AMNP, Asunción and INCYTH, Buenos Aires, investigated several deflector design options at the downstream slope of the spillway, finding that a 4m long deflector at els. 57 and 62 respectively (Main and Aña Cua spillways) appeared to provide the most

efficient reduction of air entrainment in the flow entering the stilling basin, Figs. 6.
The deflectors turned out to be a very efficient solution. Due to the particularities of the site (wide river bed and very low tailwater fluctuations), high supersaturation rates are avoided for a large range of flows.

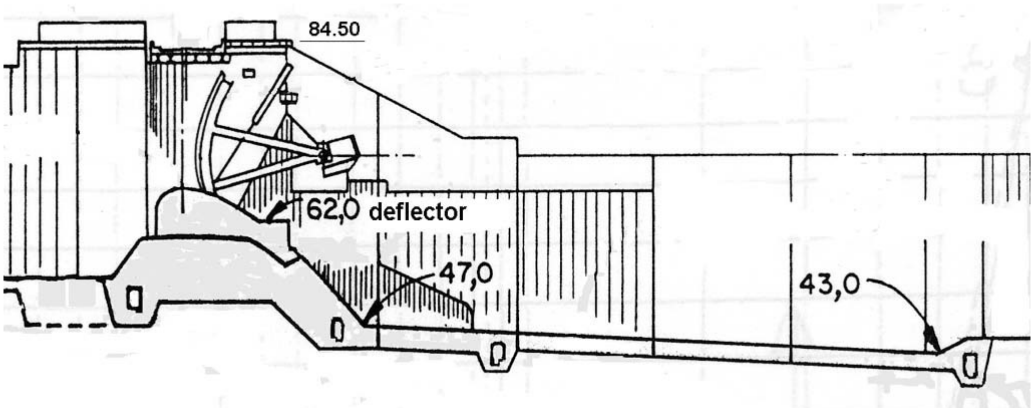

Fig.6a: Spillway section (Aña Cua spillway) with deflector for mitigating flow regime with too high saturation.

Fig 6b: Aña Cua Spillway: flow over deflector at partially opened gate

To 2: Observations of model test results and supersaturation measurements in the prototype, lead to a spillway operation without partly opened gates as long as the deflectors were not yet installed. With installed deflectors, more flexibility in gate opening rules can be achieved in that also partly gate opening are allowed as long as they are uniform, i.e. as long as all gates are opened similarly.
It should also be mentioned that during regular operation of the completed project size, the main spillway will discharge only 4 to 5% of time in an average year. This means that the fish mortality problem was an isolated one during the time when not all power units were installed and therefore high and enduring

discharges passed the spillway.

5. Results of the Mitigation Measures

A considerable reduction in the saturation values and no more fish mortality observed since installation of the spillway deflectors.

6. Reasons for Success

1) Immediate and full fledged start of investigations and a consequent change in the spillway operation rules stopped a continuation of fish mortality during the phase of frequent and high discharges (partial operation of generating units).
2) The application of spillway deflectors provided the final remedy to avoid fish mortality during the lifetime of the hydropower plant.
3) Unbureaucratic and efficient cooperation of the parties involved, no putting blames of guilt, expedient financing of expenditures for remedial works and investigations.