

MEMO : EN/INPA/DH-10
SUBJECT: LONG TERM WATER QUALITY PREDICTIONS
FOR TUCURUI AND BALBINA
TO : PPA-ELETRONORTE
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1. INTRODUCTION

THE MODEL PACKAGE WQ-ARM/STRATIF/METEO HAS BEEN APPLIED TO THE TUCURUI AND BALBINA RESERVOIRS TO PREDICT THE LONG TERM BEHAVIOUR OF THE WATER QUALITY. THE LONG TERM HAS BEEN DEFINED AS A PERIOD OF TEN YEARS AFTER THE START OF THE FILLING OF THE RESERVOIR. ONLY ONE SCENARIO WAS CONSIDERED FOR TUCURUI RESERVOIR, SEVERAL FOR BALBINA RESERVOIR.

THIS MEMO OFFERS A SHORT OVERVIEW OF THE QUANTIFICATION OF THE INPUT PARAMETERS AND THE RESULTS OF THE SCENARIO CALCULATIONS FOR BOTH THE RESERVOIRS AND THE DOWN-STREAM RIVERS. FINALLY, THE RESULTS ARE DISCUSSED, CONSIDERING HORIZONTAL INHOMOGENEITY, MACROPHYTES AND DE STRATIFICATION.

THE RESULTS AND CONCLUSIONS COULD BE TAKEN INTO ACCOUNT IN THE FUTURE MANAGEMENT OF THE BALBINA AND TUCURUI RESERVOIRS. MOREOVER, THEY MAY CONTRIBUTE TO THE SELECTION AND DESIGN OF FUTURE RESERVOIRS.

2. TUCURUI

2.1 THE LONG TERM SCENARIO

FOR TUCURUI ONLY ONE CASE WAS CALCULATED, CONSIDERING THE FACT THAT THE PRESENT WATER QUALITY IN THE RESERVOIR VARIES FROM GOOD TO ACCEPTABLE. IT WILL PROBABLY SHOW IMPROVEMENT IN ANY FUTURE SCENARIO. THE 'STANDARD' SCENARIO IS BASED ON THE ASSUMPTION, THAT THE HYDROLOGIC CONDITIONS (INFLOW, OUTFLOW, AND WATER LEVEL) WILL REMAIN THOSE OF THE SECOND YEAR FOR THE REST OF THE TEN YEAR PERIOD. AFTER TWO YEARS THE OUTFLOW THROUGH THE TURBINES IS FIXED AT 2000 M³/S. AN ALTERNATIVE SCENARIO COULD CONSIDER A FURTHER INCREASE OF THE OUTFLOW THROUGH THE TURBINES, WHICH MAY CAUSE SOME DECREASE OF THE OXYGEN CONCENTRATION IN THE DOWN-STREAM RIVER DURING THE DRY SEASON.

2.2 QUANTIFICATION OF MODEL INPUT

THE DISCUSSION IS RESTRICTED TO THOSE COEFFICIENTS, PARAMETERS AND VARIABLES, WHICH NEED SOME COMMENTS. THE QUANTIFICATION OF THE REMAINING INPUT IS CONSIDERED NON-PROBLEMATIC BECAUSE IT IS BASED ON SIMPLE AND UNEQUIVOCAL DATA.

STRATIF/METEO

THE COEFFICIENTS FOR THE LEVEL-AREA AND LEVEL-VOLUME RELATIONS WERE DETERMINED ON THE BASIS OF REFERENCE POINTS, THE MAXIMAL INUNDATED AREA (2635 KM²) AT LEVEL 74 M AND THE MAXIMAL VOLUME. USING THESE AS FIXED POINTS THE COEFFICIENTS GAMMA AND EXPO WERE DETERMINED FOR MINIMAL DIFFERENCES BETWEEN CALCULATED AND 'MEASURED' AREAS AND VOLUMES.

STRATIF'S ONLY INPUT PARAMETER CVEG, WHICH IS THE CORRECTION FACTOR ON ENTRAINMENT FOR THE PRESENCE OF OBSTACLES TO FREE FLOW (DROWNED VEGETATION AND HILLS), HAS RECEIVED THE VALUE 2.5. THIS VALUE HAS BEEN DETERMINED BY CALIBRATION ON BROKOPONDO RESERVOIR AND COULD BE MAINTAINED FOR TUCURUI RESERVOIR, AS APPEARED FROM TENTATIVE MODEL RUNS WITH VARIOUS VALUES FOR CVEG.

THE EQUILIBRIUM TEMPERATURE (TEQ), THE ENERGY TRANSFER COEFFICIENT (ETC) AND THE WINDSPEED (W AT 10 M LEVEL) WERE DETERMINED ON THE BASIS OF INPA'S METEOROLOGICAL MEASUREMENTS AT TUCURUI FOR THE PERIOD 1984-1986. TEQ AND ETC WERE CALCULATED WITH METEO, USING METHOD NUMBER TWO. THE WINDSPEED, MEASURED AT A 2 M LEVEL, WAS TRANSFORMED INTO THE WINDSPEED AT 10 M LEVEL AND MULTIPLIED WITH A FACTOR 1.5. THE REASONS HAVE BEEN MENTIONED IN MEMO EN/INPA/DH-06.

THE INFLOW AND OUTFLOWS WERE QUANTIFIED USING THE REGISTRATIONS AT TUCURUI FOR THE PERIOD 1984-1986. THE INFLOWS WERE CORRECTED IN ORDER TO REPRODUCE THE MEASURED WATER LEVELS (SEE MEMO EN/INPA/DHL-02). EVAPORATION AND PRECIPITATION WERE IGNORED

SINCE THEY DELIVER A VERY SMALL CONTRIBUTION TO THE WATER BALANCE.

THE MONTHLY AVERAGE TEMPERATURE OF THE INFLOW (TOCANTINS) WAS DERIVED FROM A GRAPH, IN WHICH THE BIWEEKLY MEASUREMENTS AT M5 FOR THE PERIOD SEPT. 1985-1986 HAD BEEN INTERPOLATED LINEARLY. THE TEMPERATURE WAS ESTIMATED FOR THE REMAINING PERIOD SEPT. 1984-AUG. 1985 ON THE BASIS OF RESERVOIR TEMPERATURES.

WQ-ARM

THE INITIALLY PRESENT AMOUNT OF DEGRADABLE PHYTO MASS (TOD11), THE FRACTION OF LITTER (FOD1) AND THE PARAMETERS WITH RESPECT TO INCORPORATION OF PHYTO MASS (RVEG, TLAG, HVEG) WERE DERIVED FROM DATA PROVIDED BY INPA (SEE TABLE 1). THE VALUE FOR THE PHYTO MASS INCLUDES A CORRECTION FOR THE ABSENCE OF PHYTO MASS ON THE RIVER BED (400 KM² AT LEVEL 72 M).

THE DEGRADATION RATES (ROD1B, ROD2B, RSODB), SEDIMENTATION RATE (RS1) AND STOICHIOMETRIC CONSTANTS (SA1, SP1, SA2, SP2) OF PHYTO MASS (LITTER, FRESH, ORG. MATTER ON THE BOTTOM) WERE MAINLY DETERMINED BY MEANS OF CALIBRATION. HOWEVER, INFORMATION IS AVAILABLE TO JUSTIFY THE SELECTED VALUES (INPA, KLINGE ET AL. 1983).

THE ADSORPTION/SEDIMENTATION RATE OF PHOSPHATE (RSAD), THE NITRIFICATION AND DENITRIFICATION RATES (RNITB, RDEBB), THE PARAMETERS FOR REAERATION AT THE SPILLWAY (REAR, GASVP), THE DISPERSION PARAMETERS (DMAX, DMIN, FDISP, FRICH) AND THE NUTRIENT RELEASE FACTORS (FAMR, FOPR) WERE DETERMINED BY MEANS OF CALIBRATION ONLY.

TABLE 1: THE INPUT PARAMETERS FOR TUCURUI RESERVOIR.

TOD11/2/3, FOD1	2260 G O ₂ /M ² , 0.5
RVEG, TLAG, HVEG	0.0055 1/D, 30 D, 30 M
ROD1B, ROD2B, RSODB	0.004 1/D, 0.04 1/D, 0.00065 1/D
RS1	3 M/D
SA1, SP1	0.05 G N/G C, 0.0025 G P/G C
SA2, SP2	0.06 G N/G C, 0.003 G P/G C
RSAD, RNITB, RDEBB	0.5 M/D, 0.15 1/D, 1 M/D
REAR, GASVP	1, 2 %
DMAX, DMIN, FDISP, FRICH	25 M ² /D, 0.3 M ² /D, 20, 0.02
FAMR, FOPR	1.5, 2.5
RCO1, RCO2	0.0916 1/OC, 3.03-4.38
SVOL, SIOP	500-80000 U ₃ , 75-115 W/M ²
SEXT, FMOR	0.15-0.5 L/(MG C.M), 1
SA3, SP3	0.15 G N/G C, 0.0125 G P/G C
RDETb, RS2	0.08 1/D, 1 M/D
CKL, CKLMIN	0.04 S ₂ /(M ² .D), 0.4 1/D
SOC, SODI	2.88 G O ₂ /G C, 600 G O ₂ /M ²
FAN, FREF	0.33, 0.1
SN, SD	4.57 G O ₂ /G N, 0.35 G N/G O ₂

THE VALUES OF ALL REMAINING PARAMETERS WITH RESPECT TO PHYTOPLANKTON (RCO1, SA3, SP3, FMOR AND SPECIES SPECIFIC RCO2, SVOL, SIOP, SEXT), DETRITUS (RDET8, RS2), REAERATION (CKL, CKLMIN), DEGRADATION OF ORGANIC MATTER (SOC, SODI, FREF, FAN), NITRIFICATION AND DENITRIFICATION (SN, SD) HAVE BEEN DERIVED FROM LITERATURE DATA (LOS 1984; SMITS 1979). THE MONTHLY AVERAGE CONCENTRATIONS IN THE INFLOW (COXI, CDETI, CAMI, CNII, COPI IN TOCANTINS) WAS DERIVED FROM GRAPHS, IN WHICH THE BIWEEKLY MEASUREMENTS AT M5 FOR THE PERIOD SEPT. 1985-1986 HAD BEEN INTERPOLATED LINEARLY. THE CONCENTRATIONS WERE ESTIMATED FOR THE REMAINING PERIOD SEPT. 1984-AUG. 1985 ON THE BASIS OF THE DATA FOR THE SUCCEEDING YEAR.

THE MONTHLY AVERAGE PHOTOREACTIVE IRRADIATION INTENSITY JUST BELOW THE WATER SURFACE (TIS) WAS CALCULATED FROM THE MONTHLY AVERAGE GLOBAL IRRADIATION INTENSITY, MEASURED IN TUCURUI:

$$TIS = FD \cdot (1-FR) \cdot (1-FP) \cdot GI \quad (2.1)$$

IN WHICH,

GI = DAILY AVERAGE GLOBAL IRRADIATION (W/M2)
 FD = 24 DIVIDED WITH THE DAYLENGTH (2)
 FR = FRACTION REFLECTED IRRADIATION (0.05)
 FP = FRACTION PHOTOREACTIVE IRRADIATION (0.48)

THE BACKGROUND EXTINCTION (BEXT) HAS BEEN QUANTIFIED WITH THE WELL-KNOWN RELATION BETWEEN EXTINCTION COEFFICIENT AND SECCHI-DEPTH:

$$BEXT = 1.7/SDEP - SEXT \cdot CP \quad (2.2)$$

IN WHICH,

SDEP = SECCHI-DEPTH (M)
 SEXT = SPECIFIC EXTINCTION COEFF. PHYT. (L/(MG C.M))
 CP = PHYTOPLANKTON CONCENTRATICN (MG C/L)

USING THE MEASUREMENTS FOR SECCHI-DEPTH AND CHLOROPHYLL FOR THE TUCURUI RESERVOIR AND A CARBON/CHLOROPHYLL RATIO OF 30, VALUES OF 0.3-0.5 1/M HAVE BEEN FOUND FOR THE BACKGROUND EXTINCTION COEFFICIENT.

THE OUTPUT OF STRATIF (INFLOW, OUTFLOW, POSITION OF THERMOCLINE, TEMPERATURES AND WINDSPEED) WAS USED AS INPUT TO WQ-ARM. SOME CORRECTIONS WERE MADE ON THE POSITION OF THE THERMOCLINE (15-45 M) ACCORDING TO THE MEASURED TEMPERATURE PROFILES. THE INPUT FOR THE SECOND YEAR WAS USED FOR ALL SUCCEEDING YEARS TO COMPLETE THE INPUT FOR THE LONG TERM CALCULATION. HOWEVER, THE OUTFLOW WAS REDISTRIBUTED AMONG SPILLWAY AND TURBINES, ASSUMING A CONSTANT OUTFLOW THROUGH THE TURBINES OF 2000 M3/S. SOME MINOR ADJUSTMENTS IN THE INFLOW WERE NECESSARY TO MAINTAIN THE 72 M WATER LEVEL.

THE COEFFICIENTS FOR THE DISCHARGE-FLOW VELOCITY AND THE DISCHARGE-DEPTH RELATIONS (AV, BV, AH, BH) FOR THE DOWNSTREAM

RIVER WERE BASED ON LINEAR REGRESSION ON DATA AVAILABLE FOR A LOCATION 25 KM DOWNSTREAM OF THE DAM. THE DOWNSTREAM RIVER WAS DIVIDED IN FOUR REACHES, EACH HAVING A LENGTH OF 50 KM. THE VELOCITY AND DEPTH MULTIPLIERS (AV , AH) FOR THE SECOND AND FOURTH REACH WERE ADJUSTED ACCORDING TO THE WIDTH OF THE RIVER. INFLOW FROM TRIBUTARIES AND DIFFUSE SOURCES IS UNIMPORTANT.

2.3 THE RESULTS

STRATIFICATION

THE RESULTS SHOW THE OCCURRENCE OF STRATIFICATION FROM JULY TO DECEMBER, OR IN OTHER WORDS DURING THE DRY SEASON. THE POSITION OF THE THERMOCLINE VARIES FROM 5 TO 45 M BELOW THE WATER SURFACE. THE EPILIMNION TEMPERATURES ARE BETWEEN 29.0 AND 30.5 °C AND THE DIFFERENCE OF EPILIMNION AND HYPOLIMNION TEMPERATURE IS USUALLY 0.5-1.5 °C. THE OUTPUT OF STRATIF AS ADJUSTED FOR WQ-ARM IS GIVEN IN FIGURE 2.1

DURING THE STRATIFICATION THE RIVER USUALLY ENTERS THE EPILIMNION, WHICH AUGMENTS THE RESIDENCE TIME OF THE HYPOLIMNION. AT THE END OF THE STRATIFICATION PERIOD THE RIVER MAY ENTER THE HYPOLIMNION AS WELL, WHICH CONTRIBUTES TO THE REMOVAL OF STRATIFICATION. A STRONG DOWNWARD ADVECTIVE FLOW ARISES DURING STRATIFICATION AS A CONSEQUENCE OF INFLOW INTO THE EPILIMNION AND OUTFLOW FROM THE HYPOLIMNION.

WATER QUALITY IN THE RESERVOIR

AS CAN BE SEEN IN FIGURE 2.2, STRATIFIED AND DESTRATIFIED PERIODS SHOW LARGE DIFFERENCES WITH RESPECT TO THE OXYGEN CONCENTRATION. THE CONCENTRATION REACHES VERY LOW NEGATIVE VALUES IN THE HYPOLIMNION DURING THE FIRST TWO YEARS. BOTH IN EPILIMNION AND DESTRATIFIED RESERVOIR THE OXYGEN CONCENTRATIONS ARE POSITIVE (USUALLY 3-6 MG/L). THIS IS MAINLY DUE TO THE INFLOW OF LARGE QUANTITIES OF OXYGEN RICH WATER FROM THE TOCANTINS RIVER.

AFTER 10 YEARS THIS SITUATION HAS EVEN IMPROVED SUBSTANTIALLY, AS IS DEMONSTRATED BY FIGURE 2.3. HOWEVER, THE LOWER PART OF THE HYPOLIMNION STILL CONTAINS NEGATIVE OXYGEN CONCENTRATIONS. THE EPILIMNION AND DESTRATIFIED RESERVOIR SHOW CONCENTRATIONS BETWEEN 4 AND 7 MG O₂/L.

THE OXYGEN BUDGET HAS BECOME MORE OR LESS STABLE AFTER 10 YEARS. THE BUDGET OF THE HYPOLIMNION IS NOW DOMINATED BY THE DEGRADATION OF DETRITUS IN STEAD OF THE DEGRADATION OF PHYTO MASS. EVIDENCE OF THIS GIVEN BY THE QUANTITY OF ORGANIC MATTER AT THE BOTTOM. INITIALLY BEING 1000-3900 G O₂/M² THIS QUANTITY DECREASES TO 800-500 G O₂/M², HAVING THE HIGHER VALUES IN THE UPPER LAYERS.

THE AMMONIUM CONCENTRATION REACHES HIGH VALUES IN THE HYPOLIMNION DURING THE FIRST YEARS (100-2400 UG N/L, FIGURE 2.4) AS A CONSEQUENCE OF THE DEGRADATION OF PHYTO MASS. THE

CONCENTRATIONS IN THE EPILIMNION REMAIN SMALL, BECAUSE AMMONIUM IS INCORPORATED BY PHYTOPLANKTON RAPIDLY AND BECAUSE THERE IS A STEADY AND RELATIVELY STRONG DOWNWARD ADVECTIVE FLOW, COUNTERACTING THE UPWARD TRANSPORT OF AMMONIUM BY DISPERSION. THE AMMONIUM CONCENTRATION IN THE DESTRATIFIED RESERVOIR IS SMALL (1-40 UG N/L) DUE TO A STRONG DILUTION WITH WATER FROM THE TOCANTINS RIVER.

THE HYPOLIMNION AMMONIUM CONCENTRATION IS STILL DECREASING SLIGHTLY AFTER TEN YEARS (15-450 UG/L), WHILE THE CONCENTRATIONS IN EPILIMNION AND DESTRATIFIED RESERVOIR HAVE BECOME STABLE (1-30 UG/L) (FIGURE 2.5).

THE NITRATE CONCENTRATION HAS INTERMEDIATE VALUES IN EPILIMNION AND DESTRATIFIED RESERVOIR DURING THE FIRST TWO YEARS (2-50 UG N/L, FIGURE 2.6). IT IS MORE OR LESS COMPLETELY ABSENT IN THE HYPOLIMNION BECAUSE OF DENITRIFICATION. THIS SITUATION PERSISTS DURING THE FOLLOWING 8 YEARS, ALTHOUGH THE CONCENTRATIONS DECREASE 20 % (FIGURE 2.7). THE INTERFACE WHERE NITRATE BECOMES ZERO IN THE HYPOLIMNION HAS SHIFTED DOWNWARD OVER A DISTANCE OF 20 M, WHICH IS IN AGREEMENT WITH THE SHIFT IN OXYGEN CONCENTRATIONS.

THE INORGANIC PHOSPHATE CONCENTRATION SHOWN IN FIGURES 2.8 AND 2.9 DEVELOPES IN A DIFFERENT WAY. THE CONCENTRATIONS REMAIN PRACTICALLY AT THE SAME LEVEL: 0-25 UG P/L IN THE DESTRATIFIED RESERVOIR, 0-10 UG P/L IN THE EPILIMNION AND 10-240 UG P/L. THE HYPOLIMNION CONCENTRATIONS HAVE DECREASED ONLY 10 % AFTER TEN YEARS. THE EXPLANATION CAN BE FOUND IN THE ACCUMULATION OF IRON-ADSORBED PHOSPHATE IN THE BOTTOM. THIS ACCUMULATED PHOSPHATE IS GRADUALLY RELEASED INTO THE OVERLYING WATER. SUCH AN ACCUMULATION IS ONLY POSSIBLE WHEN THE RESERVOIR BECOMES COMPLETELY AEROBIC DURING SEVERAL MONTHS.

THE PHYTOPLANKTON BIOMASS REMAINS AT THE SAME LEVEL DURING THE WHOLE PERIOD OF TEN YEARS. THE PRIMARY PRODUCTION IS ALSO MAINTAINED AT THE INITIAL LEVEL, WHICH APPEARS FROM THE CONSTANCY OF THE DETRITUS CONCENTRATIONS. THE MAIN EXPLANATION FOR THIS CAN BE FOUND IN THE SUSTAINED AVAILABILITY OF NUTRIENTS, PARTICULARLY PHOSPHATE. NITROGEN MAY BE SLIGHTLY LIMITING TO THE PRIMARY PRODUCTION FROM APRIL TO AUGUST. PHOSPHATE IS LIMITING FROM MAY TO NOVEMBER. LIGHT WILL BE THE LIMITING FACTOR IN THE REST OF THE YEAR. FIGURE 2.9 SHOWS THE PHYTOPLANKTON CONCENTRATIONS IN THE NINTH AND TENTH YEAR.

WATER QUALITY IN THE DOWNSTREAM RIVER

THE OXYGEN CONCENTRATION IN THE RIVER IMMEDIATELY DOWNSTREAM OF THE DAM IS USUALLY RELATIVELY HIGH BECAUSE OF INTENSIVE REAERATION AT THE SPILLWAY. THE REAERATION AT THE SPILLWAY EVEN CAUSES SUPERSATURATION (> 7.5 MG/L) DURING THE WET SEASON.

DURING THE FIRST TWO YEARS THE OXYGEN CONCENTRATION IS LOW IN AUGUST AND SEPTEMBER (3 MG/L), WHEN THE DISCHARGE OF THE TURBINES BECOMES LARGER THAN THE DISCHARGE OF THE SPILLWAY.

AFTERWARDS, THIS SITUATION IS DETERIORATED BECAUSE OF THE INCREASED DISCHARGE OF THE TURBINES: MORE OR LESS 3 MG/L DURING AUGUST, OCTOBER AND NOVEMBER, 1 MG/L IN SEPTEMBER. SEPTEMBER REMAINS THE CRITICAL PERIOD FOR MANY YEARS. FIVE YEARS AFTER THE FILLING OF THE RESERVOIR THE CONCENTRATION STILL IS SMALLER THAN 2 MG/L IN SEPTEMBER, WHILE IT EXCEEDS 4 MG/L DURING THE REST OF THE DRY SEASON. THE CONCENTRATION INCREASES FURTHER UP TO 3 MG/L AFTER TEN YEARS. LOW OXYGEN CONCENTRATIONS DISAPPEAR USUALLY WITHIN A DISTANCE OF 50 KM DOWNSTREAM OF THE DAM.

2.4 DISCUSSION AND CONCLUSIONS

A REMARKABLE FEATURE OF THE TUCURUI RESERVOIR IS THE ABSENCE OF STRATIFICATION DURING THE WET SEASON, WHICH IS MAINLY CAUSED BY THE HIGH DISCHARGES OF THE TOCANTINS RIVER AND THE SMALL DIFFERENCE BETWEEN RIVER AND EQUILIBRIUM TEMPERATURE. CONSEQUENTLY, THE AVERAGE OXYGEN CONCENTRATION USUALLY EXCEEDS 3 MG/L DURING THE WET SEASON. SINCE ALSO THE EPILIMNION OXYGEN CONCENTRATIONS ARE HIGHER THAN 3 MG/L DOWN TO A DEPTH OF 15 M, THE CONCLUSION CAN BE DRAWN THAT THE OXYGEN CONDITIONS ARE FAVORABLE TO AQUATIC LIFE IN GENERAL. THIS MAY NOT ALWAYS BE THE CASE IN (SMALL) MARGINAL AREAS, WHERE TEMPORAL PRESENCE OF MACROPHYTES MAY OBSTRUCT REAERATION AND FLUSHING.

SINCE THE WATERS FROM THE SPILLWAY AND THE TURBINES DON'T MIX COMPLETELY WITHIN A DISTANCE OF MORE THEN 50 KILOMETERS, OXYGEN PROBLEMS MAY OCCUR IN THAT PART OF THE RIVER, WHICH CONTAINS THE WATER COMING FROM THE TURBINES. HOWEVER, WQ-ARM CONSIDERS THE RIVER TO BE A HOMOGENEOUS SYSTEM (IN A CROSS-SECTION) AND IS THEREFORE UNABLE TO REPRODUCE THE LOW OXYGEN CONCENTRATIONS, THAT OCCUR NEAR THE WEST BANK. EVEN SO, LOW CONCENTRATIONS ARE PREDICTED AS AN AVERAGE FOR THE CUTFLOWS FOR SEPTEMBER (1-3 MG/L). CONCENTRATIONS OF 0-3 MG/L WILL BE HARMFUL TO AQUATIC LIFE.

DOWN-WARD FLOW LIMITS PRIMARY PRODUCTION BY CAUSING A BARRIER AGAINST UPWARD DISPERSION OF NUTRIENTS. NEVERTHELESS, PRIMARY PRODUCTION OF PHYTOPLANKTON MAY BE SUSTAINED ON A RELATIVELY HIGH LEVEL OVER THE YEARS BECAUSE OF THE ACCUMULATION OF PHOSPHATE AT THE BOTTOM AND ITS GRADUAL RELEASE INTO THE OVERLYING WATER. THIS MAY DELIVER FAVORABLE CONDITIONS FOR THE SECONDARY PRODUCTION (ZOOPLANKTON AND FISH), THE MAGNITUDE OF WHICH HIGHLY DEPENDS ON THE AMOUNTS OF PHYTOPLANKTON DETRITUS PRODUCED IN THE RESERVOIR.

3. BALBINA

3.1 THE SCENARIOS

SEVERAL SCENARIOS WERE CALCULATED FOR BALBINA RESERVOIR, FOR WHICH SERIOUS WATER QUALITY PROBLEMS ARE EXPECTED. THE SCENARIOS INCLUDE:

- STANDARD SCENARIO FOR LEVEL 29 M (VARIATION 2 M)
- SCENARIO FOR LEVEL 25 M (FIXED)
- SCENARIO FOR REMOVAL OF 25 % OF VEGETATION (PHYTOMASS=0.0 BELOW LEVEL 18 M)
- SCENARIO FOR LOW ESTIMATE OF THE QUANTITY OF DROWNED VEGETATION (TODI=2710 G O₂/M²)
- SCENARIO FOR FASTER DEGRADATION OF ORGANIC MATTER AT THE BOTTOM (MAINLY PHYTOMASS, RSODB=0.001 1/D)
- SCENARIO FOR LOW ADSORPTION/SEDIMENTATION OF PHOSPHATE (RSAD=0.1 M/D)

THE LEVEL 29 M SCENARIO IS CONSIDERED THE STANDARD SCENARIO BECAUSE THIS SCENARIO REFLECTS THE MOST PROBABLE FINAL HYDROLOGICAL CONDITIONS FOR BALBINA RESERVOIR. THE LEVEL 25 M SCENARIO AIMS AT A SHORTER RESIDENCE TIME AND A FASTER RECUPERATION OF WATER QUALITY. THE SCENARIO FOR REMOVAL OF A PART OF THE PHYTOMASS HAS TO SHOW THE EXTENT OF SUCCESS OF SUCH A MEASURE. 25 % WAS CHOSEN AS AN UPPER LIMIT FOR THE REMOVABLE QUANTITY FROM AN ECONOMIC POINT OF VIEW.

THE REMAINING SCENARIOS FIND THEIR GROUNDS IN THE FACT THAT THE VALUES OF SOME PARAMETERS ARE SUBJECT TO SUBSTANTIAL UNCERTAINTY. FOR TODI A VALUE WAS CHOSEN EQUAL TO THE RELATIVELY LOW VALUE FOR TUCURUI. RSODB WAS QUANTIFIED AS A HIGH ESTIMATE ON THE BASIS OF EXPERIMENTAL DATA ON THE DEGRADATION OF PHYTOMASS PROVIDED BY INPA. RSAD MAY HAVE A SIGNIFICANTLY SMALLER VALUE THAN WAS CHOSEN FOR TUCURUI BECAUSE OF THE ISOLATION OF THE EPILIMNION AND THE PROBABLY LOWER IRON CONCENTRATIONS IN THE EPILIMNION. SINCE A LACK OF SEDIMENTATION OF PHOSPHATE MIGHT INCREASE THE PRIMARY PRODUCTION, IT WAS CONSIDERED SENSIBLE TO TRY A LOW VALUE FOR THIS PARAMETER.

3.2 QUANTIFICATION OF INPUT PARAMETERS

STRATIF/METEO

THE COEFFICIENTS FOR THE LEVEL-AREA AND LEVEL-VOLUME RELATIONS WERE DETERMINED IN THE SAME WAY AS FOR TUCURUI RESERVOIR. THE REFERENCE POINTS ARE THE MAXIMAL INUNDCATED AREA (2360 KM²) AT LEVEL 29 M AND THE MAXIMAL VOLUME.

STRATIF NEEDS THE EQUILIBRIUM TEMPERATURE AND THE ENERGY TRANSFER COEFFICIENT AS INPUTS. THESE VARIABLES ARE CALCULATED WITH METEO, USING DATA FOR A NUMBER OF METEOROLOGICAL PARAMETERS. IN CASE OF BALBINA DATA FOR ONLY A FEW PARAMETERS

ARE AVAILABLE: MONTHLY AVERAGES OF MAXIMUM AND MINIMUM TEMPERATURES, RELATIVE HUMIDITY AND WINDSPEED (AVERAGES FOR 1978-1984). THEREFORE, IT WAS INEVITABLE TO USE THE DATA FOR RESERVA DUCKE FOR THE REMAINING PARAMETERS. (IRRADIATION), PROVIDED BY INPA (1983-1985). THE BRIGHTNESS WAS QUANTIFIED FROM THE IRRADIATION BY MEANS OF A LINEAR REGRESSION EQUATION DEVELOPED FOR TUCURUI, TAKING INTO ACCOUNT AN UPPER LIMIT OF 0.75 AND A LOWER LIMIT OF 0.3. THE EQUATION IS:

$$P = 0.0183 I - 2.71 \quad (3.1)$$

THE AVERAGE TEMPERATURE WAS CALCULATED FROM THE MAXIMUM AND MINIMUM VALUES BY MEANS OF A RELATION FOUND FOR TEMPERATURE DATA FROM A STATION NEAR MANAUS:

$$T = T_{MIN} + 0.4(T_{MAX} - T_{MIN}) \quad (3.2)$$

BOTH RELATIVE HUMIDITY AND WINDSPEED DATA WERE NOT SUITABLE FOR OUR PURPOSE, BECAUSE:

- THE CALCULATED EQUILIBRIUM TEMPERATURES (TEQ) WERE UNREALISTIC (35 OC).
- CALCULATION OF THE EVAPORATION WITH THE PENNMAN EQUATION GAVE FAR TOO SMALL VALUES COMPARED TO THE MEASUREMENTS.
- THE WINDSPEED WAS 3 TIMES SMALLER THAN IN TUCURUI, THE RELATIVE HUMIDITY WAS MUCH HIGHER (> 0.95).

THERE ARE ARGUMENTS TO JUSTIFY OUR MISTRUST IN THE BALBINA DATA. THE POSITION OF THE METEOROLOGIC STATION IN BALBINA HAS BEEN CRITICIZED IN THE PAST BY INPA. MOREOVER, FROM INQUIRY APPEARED THAT THE RELATIVE HUMIDITY IS MEASURED ONLY ONCE A DAY (IN THE EARLY MORNING) AND THE WINDSPEED IS MEASURED 0.5 M ABOVE AN EVAPORATION TANK. THEREFORE, THE WINDSPEED (10 M LEVEL ASSUMED) AND RELATIVE HUMIDITY DATA FOR RESERVA DUCKE WERE USED IN STEAD OF THE DATA FOR BALBINA. THIS TIME METEC CALCULATED REALISTIC VALUES FOR TEQ AND ETC. IT BECAME ALSO POSSIBLE TO REPRODUCE THE MEASURED EVAPORATION WITH THE PENNMAN EQUATION.

THE INFLOW WAS QUANTIFIED USING THE LONG TERM MONTHLY AVERAGES OF THE DISCHARGE OF THE UATUMA RIVER, REGISTERED NEAR THE FUTURE DAM. THE INFLOW WAS DISTRIBUTED AMONG RIVER, SMALL CREEKS AND PRECIPITATION-SURPLUS. THE DISTRIBUTION WAS CARRIED OUT ACCORDING TO THE SURFACE AREAS OF RESERVOIR AND DRAINAGE AREA. THE PRECIPITATION-SURPLUS WAS CALCULATED FROM THE MONTHLY PRECIPITATION MEASURED IN BALBINA (AVERAGES FOR 1978/84) AND THE CALCULATED EVAPORATION.

THE OUTFLOWS FOR SPILLWAY AND TURBINES WERE PROVIDED BY ELETRONORTE FOR THE THE 29 AND 25 M LEVEL SCENARIOS. THE STRATIF CALCULATIONS WERE PROLONGUED TO A PERIOD OF FOUR YEARS, SINCE THE OUTFLOW SCENARIOS COMPRISED FOUR YEARS.

THE MONTHLY AVERAGE TEMPERATURE OF THE INFLOWS FROM THE RIVER (UATUMA/PITINGA) AND THE CREEKS WERE ESTIMATED ON THE BASIS OF

SCARCE DATA, PROVIDED BY INPA FOR 1985. THE TEMPERATURE OF THE CREEKS IS ASSUMED TO BE 2 OC LOWER THAN THE TEMPERATURE OF THE RIVER. THE TEMPERATURE OF THE PRECIPITATION WAS CHOSEN EQUAL TO THE EQUILIBRIUM TEMPERATURE.

WQ-ARM

THE INITIALLY PRESENT AMOUNT OF DEGRADABLE PHYTO MASS, THE FRACTION OF LITTER AND THE STOICHIOMETRIC CONSTANTS OF PHYTO MASS WERE DERIVED FROM DATA PROVIDED FOR BALBINA BY INPA: $TOD_{11}=0$ (BELOW A LEVEL OF 5 M), $TOD_{12/3}=3840$ G O₂/M², $FOD_1=0.26$, $SA_1=0.037$ G N/G C, $SPI=0.0019$ G P/G C, $SA_2=0.044$ G N/G C, $SP_2=0.0022$ G P/G C.

THE PARAMETERS FOR REAERATION AT THE SPILLWAY WERE ADJUSTED IN ORDER TO TAKE THE LACK OF A SKI-JUMP INTO ACCOUNT: $REAR=0$, $GA_{SVP}=0.5$.

THE DISPERSION PARAMETERS WERE ADJUSTED FOR THE MUCH MORE QUIESCENT CONDITIONS IN BALBINA: $DMAX=3$ M²/D, $DMIN=0.05$ M²/D, $FDISP=20$, $FRICH=0.001$.

ALL OTHER PARAMETERS HAVE THE SAME VALUES AS FOR TUCURUI (SEE TABLE 1).

THE MONTHLY AVERAGE CONCENTRATIONS IN THE INFLOW FROM RIVER AND CREEKS WERE ESTIMATED, USING THE SCARCE DATA PROVIDED BY INPA FOR 1985 AND BY LITERATURE ON THE COMPOSITION OF AMAZONIAN WATERS (FURCH ET AL. 1984).

EVAPORATION AND PRECIPITATION HAVE BEEN MENTIONED ABOVE. THE CONCENTRATIONS OF NUTRIENTS IN THE PRECIPITATION HAVE BEEN ESTIMATED ON THE BASIS OF ONE SINGLE OBSERVATION MADE BY INPA (DECEMBER 1986): $CAMP=0.05$ MG N/L, $CNIP=0.05$ MG N/L, $COPP=0.02$ MG P/L.

THE DAILY AVERAGE PHOTOREACTIVE IRRADIATION INTENSITY JUST BELOW THE WATER SURFACE (TIS) WAS CALCULATED WITH EQUATION (2.1) FROM THE DAILY AVERAGE GLOBAL IRRADIATION INTENSITY, MEASURED IN RESERVA DUCKE (INPA). THE BACKGROUND EXTINCTION HAS BEEN QUANTIFIED WITH EQUATION (2.2), USING THE SECCHI-DEPTH DATA FOR THE UATUMA RIVER: $BEXT=0.8$ 1/M. THIS HIGH VALUE REFLECTS THE PRESENCE OF HIGH HUMIC ACIDS CONCENTRATIONS IN THE WATER OF THE (BLACK) RIVER UATUMA.

THE OUTPUT OF STRATIF, DIFFERENT FOR THE 29 AND 25 M SCENARIOS AND EXTENDED TO 4 YEARS, WAS USED AS INPUT TO WQ-ARM. THE EPILIMNION INFLOW WAS DIMINISHED WITH THE PRECIPITATION-SURPLUS, SINCE PRECIPITATION AND EVAPORATION ARE TAKEN INTO ACCOUNT DIRECTLY IN WQ-ARM. MOREOVER, SOME MINOR ADJUSTMENTS OF THE OUTFLOWS WERE NECESSARY TO MAINTAIN THE REQUIRED WATER LEVELS. THE INPUT FOR THE THIRD AND FOURTH YEAR WAS COPIED THREE TIMES TO COMPLETE THE INPUT FOR A TEN YEARS PERIOD.

THE COEFFICIENTS FOR THE DISCHARGE-FLOW VELOCITY AND THE DISCHARGE-DEPTH RELATIONS (AV , BV , AH , BH FOR DOWNSTREAM RIVER)

WERE BASED ON LINEAR REGRESSION ON DATA AVAILABLE FOR A LOCATION 35 KM DOWNSTREAM OF THE DAM. THE DOWNSTREAM RIVER WAS DIVIDED IN FIVE REACHES, HAVING A LENGTH OF 25 OR 50 KM (THE FINAL REACH ONLY). THE VELOCITY MULTIPLIERS (AV) FOR THE FIFTH REACH WAS ADJUSTED ACCORDING TO THE WIDTH OF THE RIVER.

INFLOW FROM TRIBUTARIES IS CONSIDERED UNIMPORTANT. INFLOW FROM DIFFUSE SOURCES HAS BEEN QUANTIFIED ON THE BASIS OF THE SIZE OF THE DRAINAGE AREA. THE CONCENTRATIONS OF OXYGEN, DETRITUS AND AMMONIUM IN THIS DIFFUSE INFLOW ARE EQUAL TO THE YEARLY AVERAGES MEASURED IN THE CREEKS BY INPA.

3.3 THE RESULTS

IN THE DISCUSSION OF THE RESULTS ATTENTION WILL BE PAID MAINLY TO THE STANDARD SCENARIO. THE OTHER SCENARIOS ARE DISCUSSED FOR AS FAR AS THEY SHOW SIGNIFICANT DIFFERENCES.

3.3.1 THE STANDARD SCENARIO

STRATIFICATION

THE CALCULATIONS INDICATE PERSISTENCE OF STRATIFICATION THE WHOLE YEAR ROUND. THE THERMOCLINE IS USUALLY LOCATED AT A DEPTH OF 5 M, BUT SHIFTS TO GREATER DEPTH (6-9 M) DURING THE MONTHS JUNE, JULY AND AUGUST. THIS SHIFT CAN BE EXPLAINED FROM THE LOWER EQUILIBRIUM TEMPERATURE IN THIS PERIOD. THE EPILIMNION TEMPERATURES ARE BETWEEN 29.5 AND 31.2 OC AND THE DIFFERENCE OF EPILIMNION AND HYPOLIMNION TEMPERATURES VARIES BETWEEN 1.8 AND 3.5 OC. THE OUTPUT OF STRATIF IS GIVEN IN FIGURE 3.1

EXCEPT FOR THE PRECIPITATION-SURPLUS ALL INFLOW ENTERS THE HYPOLIMNION. SINCE MOST OF THE OUTFLOW IS WITHDRAWN FROM THE HYPOLIMNION, THROUGHFLOW OCCURS ALMOST COMPLETELY IN THE HYPOLIMNION, WHICH IMPLIES A RELATIVELY SMALL RESIDENCE TIME FOR THE HYPOLIMNION.

WATER QUALITY IN THE RESERVOIR

FIGURE 3.2 SHOWS THE EXTREME LOW CONCENTRATIONS OF OXYGEN, WHICH MAY OCCUR IN BALBINA RESERVOIR DURING THE FILLING PHASE. EVEN THE EPILIMNION CONCENTRATIONS REMAIN RELATIVELY LOW (1-5 MG O₂/L). THIS SITUATION IS MAINLY DUE TO THE LARGE QUANTITY OF DROWNED PHYTOMASS, THE PERSISTENCE OF STRATIFICATION AND THE LONG RESIDENCE TIME OF THE RESERVOIR DURING MOST PART OF THE YEAR. HOWEVER, THE CONDITIONS IMPROVE SUBSTANTIALLY DURING THE PERIOD JUNE THROUGH AUGUST, WHEN THE THERMOCLINE IS LOCATED AT GREATER DEPTH. THE DOWNWARD SHIFT OF THE THERMOCLINE CAUSES A DECREASE OF THE HYPOLIMNION VOLUME. CONSEQUENTLY, THE HYPOLIMNION BECOMES FLUSHED MUCH MORE STRONGLY WITH RIVER WATER, WHICH RESULTS IN IMPROVEMENT OF THE WATER QUALITY.

AFTER 5 YEARS THE EPILIMNION OXYGEN CONCENTRATIONS HAVE BEEN RESTORED TO AN ACCEPTABLE LEVEL: 5-6.5 MG/L (FIGURE 3.3). THE

HYPOLIMNION STILL CONTAINS NEGATIVE OXYGEN CONCENTRATIONS (-1/-70 MG/L).

THE OXYGEN BUDGET IS STILL UNSTABLE AT THE END OF THE TEN YEAR PERIOD, ALTHOUGH THE DEGRADATION OF DETRITUS HAS BECOME THE DOMINATING FACTOR (FIGURE 3.4). THE QUANTITY OF ORGANIC MATTER AT THE BOTTOM HAS DIMINISHED FROM 1300-6300 G O₂/M² IN THE INITIAL PERIOD TO 120-300 G O₂/M². THE HYPOLIMNION HAS BECOME AEROBIC PARTIALLY DURING THE WET SEASON AND ALMOST COMPLETELY DURING THE DRY SEASON.

THE AMMONIUM CONCENTRATION IS VERY HIGH IN THE HYPOLIMNION AND VERY LOW IN THE EPILIMNION DURING THE FIRST YEARS: 300-10000 UG N/L VERSUS 1-20 UG N/L (FIGURE 3.5). THE LOW CONCENTRATIONS IN THE EPILIMNION ARISE MAINLY FROM DOWNWARD ADVECTIVE FLOW AND EXTREMELY SLOW UPWARD DISPERSION. BESIDES THIS, INCORPORATION INTO PHYTOPLANKTON AND NITRIFICATION CONTRIBUTE SUBSTANTIALLY IN MAINTAINING LOW CONCENTRATIONS.

THE HYPOLIMNION AMMONIUM CONCENTRATIONS DECREASE RAPIDLY IN TIME, MAINLY BECAUSE OF THE FLUSHING EFFECT MENTIONED ABOVE. THEY HAVE BECOME 4 TIMES AS SMALL IN THE EPILIMNION AND 10 TIMES AS SMALL IN THE HYPOLIMNION AFTER 5 YEARS (FIGURE 3.6). THIS DEVELOPMENT CONTINUES EVEN AFTER 10 YEARS, WHEN THE CONCENTRATIONS HAVE BEEN REDUCED TO 0-5 UG/L IN THE EPILIMNION AND 5-250 UG/L IN THE HYPOLIMNION (FIGURE 3.7).

THE NITRATE CONCENTRATION HAS LOW VALUES FROM THE START AND IS ONLY PRESENT IN THE EPILIMNION (FIGURE 3.8). IT DOES NOT EXCEED 25 UG N/L. THE CONCENTRATIONS DECREASE DRASTICALLY DURING THE FOLLOWING YEARS TO 0-5 UG/L. AFTER TEN YEARS DENITRIFICATION IS STILL STRONG ENOUGH TO REMOVE NITRATE FROM A LARGE PART OF THE HYPOLIMNION. HOWEVER, THIS IS NOT THE CASE FROM MAY THROUGH AUGUST, WHEN FLUSHING RETURNS AEROBIC CONDITIONS TO THE HYPOLIMNION (FIGURE 3.9).

THE INORGANIC PHOSPHATE CONCENTRATION SHOWN IN FIGURES 3.10, 3.11 AND 3.12 DEMONSTRATE ESSENTIALLY THE SAME BEHAVIOR AS AMMONIUM. THE EPILIMNION PHOSPHATE CONCENTRATIONS REMAIN VERY LOW FROM THE START: 0-2 UG/L. A DRASTIC DECREASE OF THE CONCENTRATIONS IN THE HYPOLIMNION FROM 50-900 UG P/L TO 1-20 UG P/L IN TEN YEARS CAN OCCUR BECAUSE OF THE LACK OF ADSORPTION/SEDIMENTATION DURING THE FIRST 8 YEARS. IN THE MEAN TIME PHOSPHATE IS FLUSHED FROM THE RESERVOIR AND ACCUMULATION AT THE BOTTOM IS IMPOSSIBLE.

THE PHYTOPLANKTON BIOMASS AND PRIMARY PRODUCTION DECREASE DRASTICALLY AFTER THE INITIAL PERIOD THE BIOMASS GOES FROM 0.15-0.22 MG O₂/L TO 0.02-0.04 MG/L AFTER 10 YEARS (FIGURES 3.13 AND 3.14). THE PRIMARY PRODUCTION DECREASES A FACTOR 5, WHICH APPEARS FROM THE DECREASE IN DETRITUS CONCENTRATION. PHOSPHATE IS THE MAIN LIMITING FACTOR FROM THE START. THE LIMITATION GROWS STRONGER GRADUALLY, DUE TO THE DEPLETION OF PHOSPHATE. A

STABLE SITUATION SEEMS TO BE REACHED AFTER 8 YEARS. NITROGEN ACTS AS A SECOND LIMITING FACTOR IN THE FINAL TWO YEARS.

WATER QUALITY IN THE DOWNSTREAM RIVER

SINCE REAERATION AT THE SPILLWAY IS LARGELY ABSENT AND MOST PART OF THE WATER LEAVES THE RESERVOIR THROUGH THE TURBINES ANYWAY, LOW OXYGEN CONCENTRATIONS MAY BE EXPECTED TO OCCUR IN THE RIVER DOWNSTREAM OF THE DAM. DURING THE FIRST TWO YEARS THE CONCENTRATION IS NEGATIVE IN THE OUTFLOW, INDICATING THE PRESENCE OF REDUCED SUBSTANCES, SUCH AS Fe^{2+} AND S^{2-} . METHANE HAS BEEN REMOVED FROM THE NEGATIVE OXYGEN EQUIVALENT, SINCE IT IS ASSUMED THAT METHANE IS OXIDIZED RELATIVELY SLOWLY AND ESCAPES TO THE AIR. CONCENTRATIONS BETWEEN -1 AND 3 MG/L PREVAIL WITHIN A DISTANCE OF 100 KM. THE CONCENTRATIONS ARE KEPT LOW BY A STRONG NITRIFICATION, A CONSEQUENCE OF HIGH AMMONIUM CONCENTRATIONS (SEE FIGURE 3.23).

THE OXYGEN CONDITIONS IMMEDIATELY DOWNSTREAM OF THE DAM HAVE NOT IMPROVED AFTER FIVE YEARS. HOWEVER, A DRASTIC DECREASE OF THE AMMONIUM CONCENTRATION ALLOWS A SLIGHTLY FASTER RECUPERATION. THE OXYGEN CONCENTRATION EXCEEDS 3 MG/L BETWEEN 65 AND 90 KM DOWNSTREAM.

ANAEROBIC CONDITIONS PREVAIL IN THE OUTFLOW OF THE RESERVOIR EVEN AFTER 10 YEARS. POSITIVE OXYGEN CONCENTRATIONS OF 0.5-2 MG/L MAY OCCUR IN THE OUTFLOW FROM JUNE TO OCTOBER. THE LOW OXYGEN CONCENTRATIONS DISAPPEAR USUALLY WITHIN A DISTANCE OF 25 TO 70 KM DOWNSTREAM OF THE DAM.

3.3.2 THE 25 M SCENARIO

THE MAIN FEATURE OF THIS SCENARIO IS THAT THE WATER QUALITY OF THE RESERVOIR RECUPERATES FASTER, AS CAN BE OBSERVED IN FIGURES 3.15, 3.16 AND 3.17. THE ACCELERATED RECUPERATION IS THE CONSEQUENCE OF A SMALLER HYPOLIMNION VOLUME, LEADING TO STRONGER FLUSHING OF THE HYPOLIMNION. EVIDENCE IS GIVEN BY THE SUBSTANTIALLY HIGHER HYPOLIMNION OXYGEN CONCENTRATIONS IN THE PERIOD FROM MAY TO AUGUST, WHICH BEGIN TO GET POSITIVE AFTER FIVE YEARS. THE IMPORTANCE OF FLUSHING IS STIPULATED BY THE FACT THAT THE QUANTITIES OF ORGANIC MATTER AT THE BOTTOM ARE COMPARABLE TO THOSE IN THE STANDARD SCENARIO: 2100-5700 G O_2/M^2 INITIALLY, 120-300 G O_2/M^2 AFTER 10 YEARS.

WITH RESPECT TO THE NUTRIENTS INCREASED FLUSHING MAINLY AFFECTS THE PERIOD MAY-AUGUST, IN WHICH THE CONCENTRATIONS BECOME 2-3 TIMES AS SMALL AS IN THE CASE OF THE STANDARD SCENARIO. SMALL DIFFERENCES PREVAIL DURING THE REST OF THE YEAR.

AFTER 10 YEARS THE PHOSPHATE CONCENTRATION BECOMES EVEN HIGHER (1.5*) THAN IN THE STANDARD SCENARIO, WHICH IS THE RESULT OF THE INCREASED IMPORTANCE OF THE INFLOW. CONSEQUENTLY, THE PHYTOPLANKTON CONCENTRATION STABILIZES ON A SOMEWHAT HIGHER LEVEL (0.03-0.04 MG O_2/L).

DURING THE FIRST FIVE YEARS LITTLE DIFFERENCE EXISTS IN THE INITIAL OXYGEN CONCENTRATION OF THE DOWNSTREAM RIVER BETWEEN THE 29 M AND 25 M SCENARIOS. HOWEVER, A SLIGHTLY FASTER RECUPERATION OCCURS IN THE RIVER BECAUSE OF LOWER AMMONIUM CONCENTRATIONS DURING THE PERIODS APRIL-AUGUST. AFTER FIVE YEARS LOW OXYGEN CONCENTRATIONS (<3) DISAPPEAR BETWEEN 50 AND 90 KM DOWNSTREAM. FROM THEN ON IMPROVEMENT OF THE OUTFLOW OXYGEN CONCENTRATION STARTS TO DEVELOPE. THE CONCENTRATION REACHES VALUES OF 0-4 MG/L AFTER TEN YEARS IN THE PERIOD MARCH-OCTOBER. LOW OXYGEN CONCENTRATIONS ARE NOT ENCOUNTERED ANY LONGER AT DISTANCES OF MORE THAN 50 KM DOWNSTREAM.

3.3.3 THE SCENARIOS WITH REDUCED PHYTOMASS

REMOVAL OF 25 % OF THE VEGETATION PROVED MODERATELY EFFECTIVE WITH RESPECT TO IMPROVEMENT OF THE WATER QUALITY, BRINGING THE INITIAL QUANTITY OF ORGANIC MATTER DOWN TO 1300-3200 G O₂/M². THE OXYGEN CONCENTRATION IS LESS NEGATIVE (FIGURE 3.18) AND THE NUTRIENT CONCENTRATIONS ARE SMALLER IN THE HYPOLIMNION DURING THE FIRST FIVE YEARS (DIFFERENCES 40 %). AFTER 10 YEARS THE WATER QUALITY PICTURE RESEMBLES THAT OF THE STANDARD SCENARIO, ALTHOUGH THE OXYGEN CONCENTRATIONS ARE 0-1 MG/L HIGHER (FIGURE 3.19) AND THE AMMONIUM CONCENTRATIONS ARE ABOUT 25 % LOWER.

THE SCENARIO WITH THE LOW ESTIMATE FOR THE QUANTITY OF PHYTOMASS ESSENTIALLY OFFERS THE SAME RESULTS, ALTHOUGH THE VERTICAL DISTRIBUTION OF ORGANIC MATTER AT THE BOTTOM IS DIFFERENT: 1100-4600 G O₂/M², MORE ORGANIC MATTER IS PRESENT AT THE BOTTOM OF THE LOWER LAYERS COMPARED TO THE FORMER SCENARIO. THIS FACT RESULTS IN SOME CHANGES IN THE VERTICAL DIRECTION. THE NUTRIENT CONCENTRATIONS ARE LOWER IN THE UPPER LAYERS AND HIGHER IN THE LOWER LAYERS. THE CONSEQUENCE IS A 20 % SMALLER PHYTOPLANKTON CONCENTRATION. HOWEVER, THESE DIFFERENCES HAVE DISAPPEARED LARGELY AFTER 10 YEARS.

BOTH SCENARIOS HAVE THE SAME MINOR EFFECT ON THE OXYGEN CONCENTRATION IN THE DOWNSTREAM RIVER. THE CONCENTRATIONS IMMEDIATELY DOWNSTREAM OF THE DAM ARE MORE OR LESS THE SAME AS IN THE STANDARD SCENARIO. THE OXYGEN CONCENTRATION IN THE RIVER MAY BE 5-20 % HIGHER, BECAUSE OF REDUCED NITRIFICATION (LOWER AMMONIUM CONCENTRATION |). DURING THE FIRST FIVE YEARS. THE EFFECT OF A SMALLER QUANTITY OF DROWNED VEGETATION BECOMES GRADUALLY VISIBLE DURING THE SECOND PERIOD OF FIVE YEARS. THE OXYGEN CONCENTRATION IN THE OUTFLOW BECCMES POSITIVE (0-2.5 MG/L) FROM APRIL TO NOVEMBER AFTER 10 YEARS. LOW CONCENTRATIONS DISAPPEAR BETWEEN 20 AND 60 KM DOWNSTREAM.

3.3.4 THE SCENARIO WITH FASTER DEGRADATION OF PHYTOMASS

NOT SURPRISINGLY, THE INITIAL OXYGEN CONCENTRATION IS QUITE LOWER THAN IN THE STANDARD SCENARIO (FIGURE 3.20). THE DIFFERENCE IS SOME 30 % AND IN 60 % OF THE EPILIMNION THE CONCENTRATION DOES NOT EXCEED 3 MG/L. HOWEVER, RECUPERATION IS FASTER DUE TO A MORE RAPID DECREASE OF THE QUANTITY OF ORGANIC

MATTER AT THE BOTTOM (40-70 G O₂/M² AFTER 10 YEARS). THE OXYGEN CONCENTRATION IS 30 % HIGHER AFTER FIVE YEARS AND THE HYPOLIMNION HAS BECOME ALMOST COMPLETELY AEROBIC (FIGURE 3.21). ANOTHER FIVE YEARS LATER THE CALCULATIONS SHOW A COMPLETELY AEROBIC HYPOLIMNION WITH OXYGEN CONCENTRATIONS USUALLY HIGHER THAN 2 MG/L (FIGURE 3.22).

THE NUTRIENT CONCENTRATIONS ARE 30 % HIGHER IN THE BEGINNING AND 30 % LOWER AFTER FIVE YEARS. THE AMMONIUM CONCENTRATION IS 1-10 UG/L IN THE WHOLE HYPOLIMNION, WHEN TEN YEARS HAVE GONE BY, A LITTLE LOWER THAN IN THE STANDARD SCENARIO BECAUSE OF INCREASED NITRIFICATION. THE PHOSPHATE CONCENTRATION STABILIZES ON A HIGHER LEVEL: 1-40 UG/L IN THE HYPOLIMNION. CONSEQUENTLY, NITROGEN BECOMES MORE IMPORTANT AS A LIMITING FACTOR, ALTHOUGH THE PRIMARY PRODUCTION HAS MORE OR LESS THE SAME MAGNITUDE AS IN THE STANDARD SCENARIO.

THE OXYGEN CONCENTRATION IN THE DOWNSTREAM RIVER IS COMPARABLE TO THAT IN THE STANDARD SCENARIO DURING THE FIRST FIVE YEARS. LATER ON THE CONCENTRATION IN THE OUTFLOW INCREASES GRADUALLY AND REACHES PREDOMINANTLY POSITIVE VALUES IN THE EIGHTS YEAR. AFTER TEN YEARS THE SITUATION HAS IMPROVED SUCH THAT OXYGEN PROBLEMS WILL HAVE SEAZED TO EXIST IN THE RIVER. THE OXYGEN CONCENTRATION EXCEEDS 2.5 MG/L IN THE OUTFLOW THE WHOLE YEAR ROUND (FIGURE 3.24).

3.3.5 THE SCENARIO WITH REDUCED ADS./SED. OF PHOSPHATE

THE DIFFERENCES WITH THE STANDARD SCENARIO ARE VERY SMALL IN GENERAL. HOWEVER, THE PHOSPHATE CONCENTRATION INCREASES FROM A FEW PERCENTS IN THE BEGINNING TO 100 % (1-20 UG/L) AFTER TEN YEARS, WHICH IMPLIES THAT NITROGEN EVENTUALLY BECOMES THE MOST IMPORTANT LIMITING FACTOR. THE PHYTOPLANKTON BIOMASS AND PRIMARY PRODUCTION INCREASE 25 % AS A RESULT OF THE MORE AMPLE AVAILABILITY OF PHOSPHATE. IN OTHER WORDS, LITTLE IMPROVEMENT OCCURS WITH RESPECT TO THE AVAILABILITY OF FOOD FOR ZOOPLANKTON AND FISH.

3.4 DISCUSSION AND CONCLUSIONS

THE MODEL CALCULATIONS FOR BALBINA RESERVOIR INDICATE BAD WATER QUALITY DURING AT LEAST THE FIRST FIVE YEARS OF ITS EXISTENCE. A STRONGLY AND COMPLETELY ANAEROBIC HYPOLIMNION WILL DEVELOP, ONLY A SHALLOW EPILIMNION WILL BE AEROBIC. THERE IS A HIGH RISK OF KILLING MOST OF THE AQUATIC ORGANISMS DURING STORM EVENTS, SINCE A PARTIAL OR COMPLETE TURN-OVER (DESTRATIFICATION) MAY RESULT IN VERY LOW OXYGEN CONCENTRATIONS NEAR THE WATER SURFACE. INTOXICATION OF AQUATIC ORGANISMS WITH SULFIDE MAY OCCUR AS WELL. ANOTHER POTENTIAL RISK IS THE RELEASE OF LARGE QUANTITIES OF METHANE TO THE AIR AT THE DAM-SITE, SINCE METHANE ACCOUNTS FOR MOST OF THE NEGATIVE OXYGEN CONCENTRATIONS.

THE DOWNSTREAM RIVER WILL RECEIVE ANAEROBIC WATER DURING 90 % OF THE TIME IN A 10 YEARS PERIOD. LOW OXYGEN CONCENTRATIONS ($-1/3$ MG/L) WILL PREVAIL IN A REACH OF 50-100 KM DOWNSTREAM OF THE DAM.

FILLING OF THE RESERVOIR UPTO LEVEL 25 M IN STEAD OF LEVEL 29 M WILL ACCELERATE THE RECUPERATION OF THE WATER QUALITY SOMEWHAT, BUT ON THE WHOLE IT CAN BE CONCLUDED THAT SUCH AN APPROACH DOES NOT HAVE CLEAR BENEFICIAL EFFECTS. THE SAME GOES FOR REMOVING 25 % OF THE VEGETATION. A MUCH HIGHER PERCENTAGE WOULD BE NECESSARY TO PRODUCE AN ACCEPTABLE WATER QUALITY.

A MORE OPTIMISTIC PICTURE IS DERIVED FROM THE ASSUMPTION THAT THE DEGRADATION RATE OF ORGANIC MATTER HAS BEEN UNDERESTIMATED. A HIGHER RATE LEADS TO FASTER RECUPERATION OF WATER QUALITY. BUT EVEN SO, THE CONDITIONS DO NOT BECOME ACCEPTABLE BEFORE FIVE YEARS HAVE GONE.

THE PRIMARY PRODUCTION OF PHYTOPLANKTON IS EXPECTED TO BE SMALL (AND THEREFORE LITTLE DIURNAL VARIATION WILL OCCUR) IN THE RESERVOIR, ESPECIALLY AFTER THE FIRST TWO YEARS. THIS IS THE RESULT OF THE FOLLOWING CONDITIONS:

- ABSENCE OF PHOSPHATE ACCUMULATION AT THE BOTTOM,
- HIGH FLUSHING RATE FOR THE HYPCLIMNION DURING A PART OF THE YEAR,
- 'ISOLATION' OF THE EPI LIMNION BECAUSE OF A PREDOMINANT DOWNWARD ADVECTIVE FLOW AND SLOW VERTICAL DISPERSION,
- LOW NUTRIENT CONCENTRATIONS IN THE INFLOWS.

SMALL PRIMARY PRODUCTION WILL CREATE LESS FAVORABLE CONDITIONS FOR ZOOPLANKTON AND FISH.

WQ-ARM ASSUMES HOMOGENEOUS MIXING IN THE HORIZONTAL DIRECTIONS. IN REALITY THERE WILL BE SUBSTANTIAL INHOMOGENEITY, SINCE THE PRESENCE OF MANY ISLANDS WILL REDUCE FLUSHING OF THE MARGINAL AREAS. THE OVER-ALL RESULT IN COMPARISON WITH THE MODEL PREDICTIONS IS:

- LOWER OXYGEN CONCENTRATIONS AND HIGHER NUTRIENT CONCENTRATIONS NEAR THE MARGINS.
- HIGHER OXYGEN CONCENTRATIONS AND LOWER NUTRIENT CONCENTRATIONS IN THE CENTRAL BODY OF THE RESERVOIR AND THE DOWNSTREAM RIVER.

HOWEVER, THE WATER QUALITY CONDITIONS WILL PROBABLY BE NOT MUCH FAVORABLE TO AQUATIC LIFE THAN APPEARS FROM THE CALCULATIONS. LESS NEGATIVE OXYGEN CONCENTRATIONS DELIVER THE SAME HARMFUL ANAEROBIC CONDITIONS.

THE PRESENCE OF MACROPHYTES ON A LARGE SCALE COULD SIGNIFICANTLY ALTER THE PREDICTED WATER QUALITY PICTURE. THE AREAS COVERED WITH FLOATING WATER PLANTS ARE SUBJECT TO REDUCED REAERATION AND

FLUSHING. STRATIFICATION WILL BE PREVENTED IN THESE AREAS. THE EFFECTS WILL INCLUDE:

- OCCURRENCE OF ANAEROBIC AND TOXIC CONDITIONS IMMEDIATELY BELOW THE WATER SURFACE,
- STORAGE OF NUTRIENTS INTO THE ORGANIC MATTER OF THE MACROPHYTES,
- RETARDATION OF THE RECUPERATION PROCESS BECAUSE OF THE REDUCTION OF NUTRIENT REMOVAL AND REAERATION.

ON THE WHOLE IT MAY BE CONCLUDED THAT LARGE SCALE COVERAGE WITH MACROPHYTES WILL INDUCE A WATER QUALITY, WHICH IS EVEN WORSE THAN THE PREDICTED WATER QUALITY. HOWEVER, UP TO DATE UNCERTAINTY EXISTS WITH RESPECT TO THE POSSIBILITY OF EXCESSIVE GROWTH OF MACROPHYTES IN BALBINA RESERVOIR.