

MEMO : EN/INPA /DH-06
SUBJECT: CALIBRATION OF OXY AND STRATIF
TO : PPA-ELETRONORTE
FROM : JOHANNES SMITS
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1. INTRODUCTION

THE CALIBRATION OF OXY AND STRATIF WAS PREPARED BY MEANS OF COLLECTING, AVERAGING AND TABELIZING ALL THE RELEVANT DATA WITH RESPECT TO TUCURUI RESERVOIR. (THIS WAS DONE BY HAND SINCE ONLY ONE THIRD OF THE AVAILABLE DATA HAVE BEEN STORED IN THE DATA-BASE.) THESE ACTIVITIES PROVIDED DATA FOR BOTH THE QUANTIFICATION OF THE INPUT PARAMETERS AND COMPARISON OF THE OUTPUT WITH THE OBSERVATIONS.

AN ANALYSIS OF THE DATA SHOWED A SUBSTANTIAL SPACIAL VARIATION OF WATER QUALITY, BOTH IN VERTICAL AND HORIZONTAL DIRECTIONS. THE MARGINAL AREAS OF TUCURUI COMPRISE ABOUT HALF OF THE TOTAL AREA AND ONE THIRD OF THE TOTAL VOLUME. THESE RELATIVELY SHALLOW PARTS SHOW A MUCH MORE DISTINCT STRATIFICATION THAN THE CENTRAL RELATIVELY DEEP PARTS. THE THERMOCLINE IS LOCATED AT A 10 M HIGHER LEVEL. THE TEMPERATURE DIFFERENCES BETWEEN EPI LIMNION AND HYPOLIMNION ARE TWICE AS BIG, WHICH MAY BE DUE TO A LARGE EXTENT TO LATERAL INFLOW OF RELATIVELY COLD WATER. AS A CONSEQUENCE THE AEROBIC-ANAEROBIC INTERFACE OCCURS AT A HIGHER POSITION TOO. THE NUTRIENT CONCENTRATIONS IN THE HYPOLIMNION ARE ABOUT ONE AND A HALF TIMES AS HIGH.

THE DIFFERENCES IN A LONGITUDINAL DIRECTION MAY BE SUBSTANTIAL. THE UPSTREAM HALF OF THE RESERVOIR IS STRONGLY AFFECTED BY THE INFLOW OF THE RIVER. THE THERMOCLINE IS LOCATED AT A LEVEL 10 TO 20 M LOWER THAN IN THE DOWNSTREAM HALF OF THE RESERVOIR. THE CONSEQUENCES FOR THE VERTICAL GRADIENTS IN WATER QUALITY PARAMETERS WILL BE OBVIOUS.

THE HORIZONTAL INHOMOGENEITY DOES NOT FACILITATE THE CALIBRATION OF OXY AND STRATIF, WHICH BOTH ARE ONE-DIMENSIONAL MODELS. THE INHOMOGENEITY WAS TAKEN INTO ACCOUNT IN THE CALIBRATIONS BY CONSIDERING UPPER AND LOWER LIMITS FOR THE WATER QUALITY PARAMETERS. THE CALIBRATION OF STRATIF TOOK ONLY LITTLE TIME, SINCE THE MODEL HAD ALREADY BEEN CALIBRATED DURING THE FIRST PHASE OF THIS PROJECT. THE CALIBRATION OF OXY APPEARED TO BE QUITE TROUBLE SOME. NOTWITHSTANDING, THE FINAL RESULT MAY BE CALLED SATISFACTORY.

DURING A FIRST ROUND OXY WAS CALIBRATED ON THE DATA OF TUCURUI IN A ROUGH WAY. THE MAIN PURPOSE OF THIS FIRST CALIBRATION ATTEMPT WAS TO TEST AND ASSESS THE PERFORMANCE OF THE MODEL AND TO IMPLEMENT SOME ADDITIONAL MODIFICATIONS, IF NECESSARY. IT PROVED NECESSARY TO MODIFY OXY IN SOME RESPECTS.

DURING A SECOND ROUND OF CALIBRATION FINE-TUNING OF THE INPUT PARAMETERS TOOK PLACE. THE CALIBRATIONS AS WELL AS THE ADDITIONAL MODIFICATIONS ARE DESCRIBED IN THIS MEMO.

2. CALIBRATION OF STRATIF

THE CALIBRATION WAS CARRIED OUT FOR THE PERIOD OF SEPTEMBER 1984 THROUGH AUGUST 1986. HYDROLOGICAL AND METEOROLOGICAL INPUT DATA ARE AVAILABLE FOR THE WHOLE PERIOD. TEMPERATURE INPUT DATA (M5) ARE AVAILABLE FROM OCTOBER 1985, WHICH IMPLIES THAT INPUT DATA HAD TO BE ESTIMATED FOR THE PRECEDING PERIOD. DATA FOR THE COMPARISON OF OBSERVATIONS WITH CALCULATION RESULTS ARE AVAILABLE FROM FEBRUARY 1985 (M1), SEPTEMBER 1985 (M3) AND JULY 1986 (MR).

AS HAS BEEN DESCRIBED IN MEMO 2 (APRIL 1986), IT WAS NECESSARY TO MULTIPLY THE MEASURED WINDSPEED WITH A FACTOR 1.5 TO PREVENT OVERPREDICTION OF THE TEMPERATURE. IT HAS BEEN IMPOSSIBLE TO CHECK THE VALIDITY OF THE ASSUMPTION, THAT THE WINDSPEED ABOVE THE RESERVOIR IS HIGHER THAN THE WINDSPEED OBSERVED AT THE WEATHER STATION IN TUCURUI. MEASUREMENTS OF THE WINDSPEED ABOVE THE RESERVOIR ARE LACKING.

AS A RESULT OF ADJUSTMENT OF THE WINDSPEED, THE CALCULATED TEMPERATURES AND POSITION OF THE THERMOCLINE MATCHED THE OBSERVATIONS SUFFICIENTLY. REPRODUCTION OF THE OBSERVED DURATION OF THE STRATIFICATION APPEARS TO BE THE MAIN PROBLEM. THE STRATIFICATION STARTS ABOUT ONE MONTH TOO LATE, PARTICULARLY IN 1985.

DECREASE OR INCREASE OF CVEG, (COEFFICIENT FOR THE CORRECTION OF ENTRAINMENT) WITH A FACTOR 2 HARDLY AFFECTED THE TEMPERATURES OR THE DURATION OF THE STRATIFICATION. INCREASE WITH A FACTOR 2 REDUCES THE MIXING DEPTH WITH 15-20 %, DECREASE WITH A FACTOR 2 ENLARGES THE MIXING DEPTH WITH 50 %. SINCE THIS ONLY DETERIORATED THE RESULTS, CVEG WAS GIVEN ITS ORIGINAL VALUE OF 2.5.

REDUCTION OF THE KINETIC ENERGY PRODUCTION (WIND AND RIVER INFLOW) WITH A FACTOR 2 UNDER THE ASSUMPTION THAT A PART OF THE ENERGY IS LOST TO FRICTION DID NOT DELIVER IMPROVEMENT. THE MIXING DEPTH APPEARED TO BE VERY SENSITIVE TO REDUCTION OF THE KINETIC ENERGY OF THE INFLOW. REDUCTIONS UP TO 90 % WERE OBSERVED. THIS ADJUSTMENT APPEARED UNSUCCESSFUL WITH RESPECT TO PROLONGATION OF THE STRATIFICATION.

USE OF THE OTHER OPTION FOR THE DISTRIBUTION OF OUTFLOW OVER EPI LIMNION AND HYPOLIMNION ACCORDING TO THEIR VOLUMES AFFECTED THE DURATION OF THE STRATIFICATION IN AN INCONSISTENT WAY AND WAS THEREFORE ABANDONED.

THE ONLY REAL IMPROVEMENT (FOR 1985) COULD BE FOUND IN AN INCREASE OF BOTH THE EQUILIBRIUM TEMPERATURE AND THE ENERGY TRANSFER COEFFICIENT FOR JULY 1985. SUCH AN ADJUSTMENT OF THE INPUT PARAMETERS CAN BE JUSTIFIED BY THE FOLLOWING: THE INPUT TEMPERATURES (ESTIMATED FOR THIS PERIOD) AND THE METEOROLOGIC DATA MAY NOT BE FULLY REPRESENTATIVE. IT CAUSED A SHIFT OF THE START OF STRATIFICATION FROM AUGUST TO JULY. THE CALCULATED TEMPERATURES AND MIXING DEPTHS CHANGED ONLY SLIGHTLY. HOWEVER, THE MIXING DEPTH FOR JULY 1985 IS TOO SMALL (5 M).

THE FINAL CONCLUSION MAY BE DRAWN, THAT ON THE WHOLE THE CALCULATIONS REPRODUCE THE OBSERVATIONS SUFFICIENTLY. HOWEVER, A PRECISE CALIBRATION OF STRATIF ON THE DATA OF TUCURUI RESERVOIR IS NOT POSSIBLE SINCE:

- THE TEMPERATURE INPUT DATA ARE PARTIALLY LACKING
- THE METEOROLOGIC INPUT DATA MAY BE UNREPRESENTATIVE
- THE VERTICAL DIFFERENCES IN THE OBSERVED TEMPERATURES ARE SMALL

3. FIRST CALIBRATION ROUND OXY

THE CALIBRATION WAS CARRIED OUT FOR THE SAME PERIOD AS STRATIF, THE OUTPUT OF WHICH WAS USED AS INPUT FOR OXY. INITIALLY THE RESULTS OF THE UNCORRECTED RUN (STRATIF) WERE USED. HOWEVER, IT APPEARED TO BE IMPORTANT FOR THE WATER QUALITY PREDICTION TO ADVANCE THE START OF STRATIFICATION. THE RESULTS OF THE CORRECTED RUN WERE USED LATER ON FOR THIS REASON. FURTHERMORE, THE POSITION OF THE THERMOCLINE WAS ADJUSTED FOR THE FIRST TWO MONTHS OF THE STRATIFICATION PERIODS ACCORDING TO THE OXYGEN CONCENTRATION PROFILES.

WATER QUALITY INPUT DATA ARE AVAILABLE FROM OCTOBER 1985, WHICH IMPLIES THAT INPUT DATA HAD TO BE ESTIMATED FOR THE PRECEDING PERIOD. DATA FOR THE COMPARISON OF OBSERVATIONS WITH CALCULATION RESULTS ARE AVAILABLE FROM MAY 1985 (M1), SEPTEMBER 1985 (M3) AND JULY 1986 (MR). SOME ADDITIONAL DATA HAVE BEEN PROVIDED BY INPA; MAINLY OXYGEN (M1) FROM NOVEMBER 1984 THROUGH APRIL 1985. NO DATA ARE AVAILABLE FOR TOTAL-NITROGEN.

THE CALIBRATION OF OXY WAS CHARACTERIZED BY PROBLEMS CONCERNING THE OXYGEN BUDGET AT THE ONE HAND AND THE NUTRIENT BUDGETS AT THE OTHER. THE PHYTOPLANKTON SUBMODEL APPEARED TO FUNCTION SATISFACTORY. THE PROBLEMS IN THE OXYGEN BUDGET COULD BE SOLVED RAPIDLY BY ADJUSTMENT OF SEVERAL PARAMETERS (DEGRADATION CONSTANTS AND SEDIMENTATION RATE). THIS PREVENTED

UNDERPREDICTION OF THE OXYGEN CONCENTRATION AND OVERPREDICTION OF THE NUTRIENT CONCENTRATIONS DURING THE FIRST SIX MONTHS AFTER THE START OF THE FILLING OF THE RESERVOIR.

THE STRONG UNDERPREDICTION OF THE NUTRIENT CONCENTRATIONS DURING STRATIFICATION WAS MUCH MORE DIFFICULT TO SOLVE. ADJUSTMENT OF THE STOICHIOMETRIC CONSTANTS CONTRIBUTED SUBSTANTIALLY TO IMPROVEMENT. SO DID INCREASE OF THE SEDIMENTATION RATE FOR PHYTO MASS (ORIGIN DROWNED VEGETATION), BECAUSE IT PREVENTED THE REMOVAL OF LARGE AMOUNTS OF PHYTO MASS FROM THE RESERVOIR BY MEANS OF OUTFLOW. SUBSTANTIAL INCREASE OF THE DEGRADATION RATE OF ORGANIC MATTER AT THE BOTTOM GAVE LESS REALISTIC RESULTS. THE QUANTITY OF ORGANIC MATTER AT THE BOTTOM DECREASED TOO RAPIDLY.

A VERY IMPORTANT IMPROVEMENT CAME FROM CORRECTION OF THE LEVEL OF THE OUTLET TO THE TURBINES. THE LEVEL WAS ELEVATED FROM 27 TO 39 M. THIS IMPLIES THE REDUCTION OF DOWNWARD VERTICAL FLOW AND DILUTION OF HYPOLIMNIC WATER WITH EPILIMNIC WATER.

YET, THE TOTAL RESULT OF ALL THESE MANIPULATIONS WAS NOT SUFFICIENT TO PREVENT UNDERPREDICTION, PARTICULARLY WITH RESPECT TO PHOSPHATE, THE CONCENTRATION OF WHICH WAS STILL A FACTOR 2 TOO SMALL. THE ONLY REMAINING OPTIONS CONCERNED MODIFICATIONS OF OXY. THE MODIFICATIONS INVOLVED THE INCORPORATION OF:

- A METALIMNION WITH SMALL DISPERSION COEFFICIENTS
- ADSORPTION/SEDIMENTATION OF PHOSPHATE
- ACCELERATED RELEASE OF NUTRIENTS ASSOCIATED WITH THE DEGRADATION OF ORGANIC MATTER AT THE BOTTOM
- DENITRIFICATION AT THE BOTTOM

ADSORPTION/SEDIMENTATION OF PHOSPHATE LEADS TO ACCUMULATION IN THE ANOXIC PART OF THE HYPOLIMNION AND TO DECREASE OF THE CONCENTRATIONS DURING THE PERIODS OF DESTRATIFICATION. THE LATTER BECAME NECESSARY WHEN THE ATTEMPTS TO COUNTERACT UNDERPREDICTION OF THE PHOSPHATE CONCENTRATIONS IN THE HYPOLIMNION HAD LED TO OVERPREDICTION DURING THE WET SEASON. THE INTRODUCTION OF DENITRIFICATION AT THE BOTTOM (IN COMBINATION WITH INCREASED NITRIFICATION) HAS THE SAME OBJECTIVE. THIS PROCESS AFFECTS THE NITROGEN BUDGET BY A NET REMOVAL OF NUTRIENT-NITROGEN FROM THE AQUATIC SYSTEM.

WITH EXCEPTION OF INTRODUCTION OF AN ADDITIONAL SOURCE OF NUTRIENTS (THICK BRANCHES, STEMS AND ROOTS OF THE DROWNED VEGETATION), ALL POSSIBILITIES FOR IMPROVEMENT WERE USED. THE FINAL RESULT WAS SATISFACTORY. THE UNDERPREDICTION HAD DISAPPEARED.

4. SECOND CALIBRATION ROUND OXY

THE SECOND ROUND STARTED FROM THE SAME POINT AS THE FIRST. IN THE FIRST RUN OF THE SECOND ROUND ONLY THOSE PARAMETERS WERE

ADJUSTED, THE CHANGING OF WHICH HAD PROVED TO GIVE LARGE IMPROVEMENTS IN THE FIRST ROUND. THESE PARAMETERS WERE THE DEGRADATION RATES, THE SEDIMENTATION RATES, THE LEVEL OF THE OUTLET TO THE TURBINES, THE NITRIFICATION RATE AND THE DENITRIFICATION RATE. THE INPUT CONCERNING STRATIFICATION, THE STOICHIOMETRIC CONSTANTS AND THE NUTRIENT RELEASE ACCELERATION FACTORS WERE SUBSEQUENTLY ADJUSTED IN THE REMAINING RUNS. FINALLY, THE NITRIFICATION AND DENITRIFICATION RATES WERE INCREASED TO PREVENT OVERPREDICTION OF AMMONIUM.

IT TURNED OUT NOT TO BE NECESSARY TO CHANGE ANY COEFFICIENT OF THE PHYTOPLANKTON SUBMODEL. THE SUCCESSION ASSUMED FOR THE QUANTIFICATION OF THE (INPUT) COEFFICIENTS SEEMS TO BE ACCEPTABLE: DIATOMS AND GREEN ALGAE DURING THE WET SEASON AND BLUEGREEN ALGAE DURING THE DRY SEASON. (SMALL FLAGELLATES MAY BE PRESENT TOO DURING THE DRY SEASON). THE PREDICTED BIOMASS CONCENTRATIONS MATCH THE OBSERVED ONES (ON BASIS OF CHLOROPHYLL). THE PREDICTED RATIO OF PHYTOPLANKTON BIOMASS AND DETRITUS EQUALS THE RATIO DEDUCED FROM THE CHLOROPHYLL AND BOD MEASUREMENTS. UNFORTUNATELY, IT IS IMPOSSIBLE TO CHECK THE PREDICTED PRIMARY PRODUCTION SINCE DATA ARE NOT YET AVAILABLE FOR THIS PARAMETER.

THE RESULTS OF THE CALIBRATION MAY BE CONSIDERED SATISFACTORY. BOTH AVERAGE VALUES AND SEASONAL AND VERTICAL VARIATIONS OF THE SIMULATED WATER QUALITY PARAMETERS MATCH THE OBSERVATIONS TO A LARGE EXTENT. IN ADDITION TO THIS GENERAL CONCLUSION THE FOLLOWING REMARKS CAN BE ADDED:

- THE NUTRIENTS ARE UNDERPREDICTED IN THE UPPER HALF OF THE HYPOLIMNION. THIS IS RELATED TO VERTICAL FLOW AND DILUTION WITH EPI-LIMNIC WATER. REDUCTION OF THE VERTICAL FLOW COULD BE ESTABLISHED BY REPLACEMENT OF THE NORMAL OUTFLOW DISTRIBUTION BY A SKEW (DENSITY GRADIENT CORRECTED) DISTRIBUTION.
- THE VERTICAL GRADIENTS ARE SOMEWHAT TOO STEEP. HOWEVER, INCREASE OF THE VERTICAL DISPERSION COEFFICIENT WOULD NECESSITATE A FURTHER REDUCTION OF THE TIMESTEP, WHICH IMPLIES AN UNWANTED INCREASE OF COMPUTERTIME.
- THE DIFFERENCES BETWEEN CALCULATED AND OBSERVED CONCENTRATIONS CAN BE EXPLAINED IN TERMS OF MODEL FEATURES AND MEASUREMENT ERRORS.
- ALL PARAMETERS VALUES, RESULTING FROM THE CALIBRATION, ARE CONSISTENT WITH DATA FROM LITERATURE OR EXPERIMENTS. THIS WILL BE SHOWN IN THE FINAL REPORT.

THE DOWNSTREAM PART OF OXY HAS NOT BEEN CALIBRATED YET, BECAUSE HYDRODYNAMICAL DATA (DISCHARGE, AVERAGE RIVER-DEPTH AND RIVER-WIDTH) ARE STILL LACKING.

5. ADDITIONAL MODIFICATIONS

ADJUSTMENT OF THE VERTICAL DISPERSION ACCORDING TO THE CONCEPT OF A METALIMNION WITH MINIMAL DISPERSION, COULD BE ESTABLISHED IN A SIMPLE WAY. THE METALIMNIC DISPERSION COEFFICIENT WAS ALREADY PROVIDED BY THE MODEL (SEE MEMO 4, DECEMBER 1986). IT WAS ONLY NECESSARY TO ASSIGN THIS VALUE TO THE UPPER AND LOWER BOUNDARIES OF THE LAYER CONTAINING THE THERMOCLINE.

ADSORPTION/SEDIMENTATION OF PHOSPHATE APPEARED TO BE MORE IMPORTANT THAN WAS ESTIMATED IN MEMO 4. THIS IS PROBABLY DUE TO THE FACT THAT THE IRON CONCENTRATION IS HIGHER THAN WAS ASSUMED ORIGINALLY AND TO CONTRIBUTIONS OF OTHER ADSORBENTS (AL ?). THE COMBINED EFFECTS OF ADSORPTION AND SEDIMENTATION HAVE BEEN INCORPORATED IN OXY BY MEANS OF A SIMPLE SEDIMENTATION RATE ACTING ON DISSOLVED PHOSPHATE:

$$R = -(RSAD/H) \cdot P \quad (4.1)$$

IN WHICH,

- R = SEDIMENTATION OF ADSORBED P (G P/(M³.D))
- RSAD = SEDIMENTATION RATE FOR ADSORBED P (M/D)
- H = AVERAGE HEIGHT OF THE WATER COLUMN (M)
- P = DISSOLVED PHOSPHATE CONCENTRATION (G P/M³)

THE SEDIMENTATION RATE RECEIVES A VALUE THROUGH THE INPUT. IN REALITY THIS PARAMETER IS A FUNCTION OF THE PH AND THE 'REACTIVE' IRON CONCENTRATION. RSAD GETS THE VALUE ZERO IN ANAEROBIC LAYERS. RESTRICTING THE ADSORPTION/SEDIMENTATION TO THE AEROBIC LAYERS RESULTS IN ACCUMULATION OF DISSOLVED PHOSPHATE IN THE ANAEROBIC LAYERS. THIS RESPONDS TO THE REDUCTION AND DISSOLUTION OF SEDIMENTING IRON, WHEN IT ENTERS THE ANAEROBIC LAYERS.

THE SEDIMENTED PHOSPHATE IS STORED IN THE ORGANIC MATTER AT THE BOTTOM, BY TAKING IT INTO ACCOUNT IN ITS STOICHIOMETRY. THIS MEANS, THAT IT CAN BE RELEASED AGAIN IN THE DEGRADATION OF THE ORGANIC MATTER. IN REALITY THE SEDIMENTED PHOSPHATE IS STORED IN AN OXIDIZED IRON-COMPOUND.

THIS SIMPLE APPROACH LACKS AN EXPLICIT ROLE OF IRON. THEREFORE, IT HAS THE ADVANTAGE THAT THE COMPLICATED IRON BUDGET CAN BE IGNORED. IT HAS THE DISADVANTAGE, THAT THE IRON-BOUND PHOSPHATE AT THE BOTTOM WILL BE LIBERATED TOO SLOWLY DURING STRATIFICATION, WHEN ANAEROBY OCCURS AND IRON IS REDUCED RAPIDLY. IT IS RELEASED TOO RAPIDLY DURING THE PERIOD OF HOMOGENEOUS MIXING, WHEN THE PHOSPHATE WILL REMAIN ADSORBED TO IRON FOR A LARGE PART.

ACCELERATED RELEASE OF NUTRIENTS FROM THE ORGANIC MATTER AT THE BOTTOM WAS ESTABLISHED BY MEANS OF MULTIPLYING THE DEGRADATION RATE WITH A CONSTANT (IN THE NUTRIENT EQUATIONS ONLY). THERE ARE DIFFERENT FACTORS FOR NITROGEN AND PHOSPHORUS, WHICH RECEIVE VALUES THROUGH THE INPUT.

THE DENITRIFICATION AT THE BOTTOM HAS BEEN FORMULATED AS A SIMPLE FIRST ORDER DECAY RATE WITH RESPECT TO THE NITRATE CONCENTRATION. THIS CAN BE JUSTIFIED BY THE FACT THAT THE DIFFUSION OF NITRATE INTO THE BOTTOM IS PROPORTIONAL TO THE NITRATE CONCENTRATION. THE FORMULA IS:

$$R = -(RDEB \cdot AB / V) \cdot N \quad (4.2)$$

IN WHICH,

- R = DENITRIFICATION (G N / (M³.D))
- RDEB = DENITRIFICATION RATE CONSTANT (M/D)
- AB = BOTTOM SURFACE AREA (M²)
- V = VOLUME (M³)
- N = NITRATE CONCENTRATION (G N / M³)

THE RATE CONSTANT IS DEPENDENT ON THE TEMPERATURE. IT RECEIVES A VALUE FOR 20 DC THROUGH THE INPUT.