CNET.WK1 - Reservoir Eutrophication Modeling Worksheet

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CNET.WK1 is a Lotus-123 worksheet which implements empirical models for predicting eutrophication and related water quality conditions in reservoirs and lakes. The worksheet is a condensed and simplified version of BATHTUB, a program developed for the U.S. Army Corps of Engineers (Walker, 1987). The models estimate reservoir eutrophication responses, as measured by phosphorus, chlorophyll-a, transparency, organic nitrogen, and hypolimnetic oxygen depletion, as a function of watershed runoff, inflow phosphorus concentrations, and reservoir morphometry. The formulation, calibration, and testing of the models based upon various reservoir and lake data sets are described in reports prepared for the Corps of Engineers (Walker, 1981,1982,1985,1987). BATHTUB documentation (Walker, 1987) summarizes the relevant equations and provides general guidance for using the model and interpreting the output. As distinct from BATHTUB, CNET.WK1 applications are restricted to single-segment reservoirs in which nitrogen limitation of algal growth is not important (nitrogen balances are not formulated). Optional models for phosphorus sedimentation and chlorophyll-a are identical to those described in the BATHTUB documentation (Walker,1987, pp. IV-7 to IV-10).

The worksheet is organized in columns; each column (C-G in the following example) is a separate case. Additional columns may be added using the Lotus Copy command. Input cells (shown in green, Lotus unprotected cells) are located at the top of each column. Input, output, and calculation sections of the worksheet are shown in Tables 1, 2, and 3, respectively. In this example, each column contains data from a different year. Several named graphs are included to facilitate case comparisons.

REFERENCES

Walker, W.W., Jr., "Empirical Methods for Predicting Eutrophication in Impoundments - Report 1 Phase I: Data Base Development", prepared for Department of the Army, US Army Corps of Engineers, Washington DC, Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi, May 1981.

Walker, W.W., Jr., "Empirical Methods for Predicting Eutrophication in Impoundments - Report 2 Phase II: Model Testing", prepared for Department of the Army, US Army Corps of Engineers, Washington DC, Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi, September 1982.

Walker, W.W., "Statistical Bases for Mean Chlorophyll-a Criteria" in "Lake and Reservoir Management: Practical Applications", Proceeding of Fourth Annual Conference, North American Lake Management Society, pp. 57-62, 1984.

Walker, W.W., Jr., "Empirical Methods for Predicting Eutrophication in Impoundments - Report 3 Phase II: Model Refinements", prepared for Department of the Army, US Army Corps of Engineers, Washington DC, Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi, March 1985.

Walker, W.W., Jr., "Empirical Methods for Predicting Eutrophication in Impoundments -Report 4 Phase III: Applications Manual", prepared for Department of the Army, US Army Corps of Engineers, Washington DC, Technical Report E-81-9, Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi, July 1987.

TABLE 1 - CNET.WK1 INPUT SECTION

Corps of Engineer Reservoir Model Network - P Limited Systems W. Walker

CNET.WK1 VERSION 1.0 LOCH RAVEN RESERVOIR ‑ APRIL‑SEPTEMBER

VARIABLE UNITS 1983 1984 1985 1986 1987

PROBLEM TITLE ‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑> LOCH RAVEN RESERVOIR ‑ APRIL‑SEPTEMBER

CASE LABELS ‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑‑> 1983 1984 1985 1986 1987

WATERSHED CHARACTERISTICS...

Drainage Area km2 770.9 770.9 770.9 770.9 770.9

Precipitation m/yr 0 0 0 0 0

Evaporation m/yr 0 0 0 0 0

Unit Runoff m/yr 0.466 0.572 0.253 0.294 0.311

Stream Total P Conc. ppb 228.4 212.4 95.2 77.8 157.5

Stream Ortho P Conc. ppb 43.8 40.5 26.8 19.3 34.5

Atmospheric P Load kg/km2‑yr 30 30 30 30 30

Atmospheric Ortho P Load kg/km2‑yr 15 15 15 15 15

POINT SOURCE CHARACTERISTICS...

Flow hm3/yr 0 0 0 0 0

Total P Conc ppb 0 0 0 0 0

Ortho P Conc ppb 0 0 0 0 0

RESERVOIR CHARACTERISTICS...

Surface Area km2 9.1 9.1 9.1 9.1 9.1

Mean Depth m 8.46 8.46 8.46 8.46 8.46

Non‑Algal Turbidity 1/m 0.08 0.08 0.08 0.08 0.08

Mean Depth of Mixed Layer m 5 5 5 5 5

Mean Depth of Hypolimnion m

Observed Phosphorus ppb 36.6 21.7 25.1 51.8

Observed Chl‑a ppb 6 7.7 9.5

Observed Secchi meters 2.99 3.59 3.8 3.3

MODEL PARAMETERS...

BATHTUB Total P Model Number (1‑8) 1 1 1 1 1

BATHTUB Total P Model Name AVAIL P AVAIL P AVAIL P AVAIL P AVAIL P (output)

BATHTUB Chl‑a Model Number (2,4,5) 4 4 4 4 4

BATHTUB Chl‑a Model Name P‑LIN P‑LIN P‑LIN P‑LIN P‑LIN (output)

Beta = 1/S vs. C Slope m2/mg 0.025 0.025 0.025 0.025 0.025

P Decay Calibration 1.95 1.95 1.95 1.95 1.95

Chlorophyll‑a Calibration 0.97 0.97 0.97 0.97 0.97

Chla Temporal Coef. of Var. 0.57 0.57 0.57 0.57 0.57

Chla Nuisance Criterion ppb 20 20 20 20 20

Notes:

Drainage Area is exclusive of reservoir surface area.

Refer to BATHTUB documentation for definition of phosphorus and chlorophyll-a model numbers

Additional P Model 8 = Model 1 with availability factors set to 1.0 for total P and 0.0 for ortho P (use if ortho phosphorus loading data are not available).

Calibration factors for phosphorus decay and chlorophyll-a are analogous to those used in BATHTUB.

Variables used in calculating algal nuisance frequencies (Walker, 1984):

Chla Temporal Coef. of Var. = within-year standard deviation of loge(chl-a)

Chla Nuisance Criterion = instantaneous chlorophyll-a associated with nuisance conditions ("bloom")

TABLE 2 - CNET.WK1 OUTPUT SECTION

CNET.WK1 VERSION 1.0 LOCH RAVEN RESERVOIR ‑ APRIL‑SEPTEMBER

VARIABLE UNITS 1983 1984 1985 1986 1987

WATER BALANCE...

Precipitation Flow hm3/yr 0.00 0.00 0.00 0.00 0.00

NonPoint Flow hm3/yr 359.24 440.95 195.04 226.64 239.75

Point Flow hm3/yr 0.00 0.00 0.00 0.00 0.00

Total Inflow hm3/yr 359.24 440.95 195.04 226.64 239.75

Evaporation hm3/yr 0.00 0.00 0.00 0.00 0.00

Outflow hm3/yr 359.24 440.95 195.04 226.64 239.75

AVAILABLE P BALANCE...

Precipitation Load kg/yr 354 354 354 354 354

NonPoint Load kg/yr 57445 65375 16215 14261 28425

Point Load kg/yr 0 0 0 0 0

Total Load kg/yr 57798 65728 16569 14615 28778

Sedimentation kg/yr 41124 44858 11336 9266 20452

Outflow kg/yr 16674 20870 5233 5349 8326

PREDICTION SUMMARY...

P Retention Coefficient ‑ 0.712 0.682 0.684 0.634 0.711

Mean Phosphorus ppb 46.4 47.3 26.8 23.6 34.7

Mean Chlorophyll‑a ppb 12.6 12.9 7.3 6.4 9.4

Algal Nuisance Frequency % 13.7 14.4 2.0 1.1 5.4

Mean Secchi Depth meters 2.53 2.49 3.81 4.16 3.17

Hypol. Oxygen Depletion A mg/m2‑d 852.1 860.5 647.9 607.6 737.1

Hypol. Oxygen Depletion V mg/m3‑d ERR ERR ERR ERR ERR

Organic Nitrogen ppb 450.4 456.1 329.2 309.2 378.1

Particulate Phosphorus ppb 20.2 20.7 10.8 9.2 14.6

Chl‑a x Secchi mg/m2 31.9 32.0 27.8 26.7 29.9

Carlson TSI P 59.5 59.8 51.6 49.8 55.4

Carlson TSI Chl‑a 55.5 55.7 50.1 48.8 52.6

Carlson TSI Secchi 46.6 46.8 40.7 39.4 43.4

OBSERVED / PREDICTED RATIOS...

Phosphorus 0.00 0.77 0.81 1.06 1.49

Chlorophyll‑a 0.00 0.00 0.82 1.20 1.01

Secchi 0.00 1.20 0.94 0.91 1.04

OBSERVED / PREDICTED T‑STATISTICS...

Phosphorus ERR ‑0.95 ‑0.78 0.23 1.47

Chlorophyll‑a ERR ERR ‑0.56 0.52 0.02

Secchi ERR 0.65 ‑0.22 ‑0.32 0.15

Notes:

OBSERVED / PREDICTED T-STATISTIC = [ log10(Observed Value) - log10(Predicted Value)] / SE

SE = residual standard error derived from model development data set.

A |T| value greater than 2.0 suggests that the deviation between observed and predicted value is unusually large.

Algal Nuisance Frequency = % of time chlorophyll-a exceeds nuisance criterion specified in input section.

TABLE 3 - CNET.WK1 CALCULATION SECTION

CNET.WK1 VERSION 1.0 LOCH RAVEN RESERVOIR ‑ APRIL‑SEPTEMBER

VARIABLE UNITS 1983 1984 1985 1986 1987

RESPONSE CALCULATIONS...

Reservoir Volume hm3 76.986 76.986 76.986 76.986 76.986

Residence Time yrs 0.2143 0.1746 0.3947 0.3397 0.3211

Overflow Rate m/yr 39.5 48.5 21.4 24.9 26.3

Total P Availability Factor 0.33 0.33 0.33 0.33 0.33

Ortho P Availability Factor 1.93 1.93 1.93 1.93 1.93

Inflow Ortho P/Total P 0.193 0.192 0.285 0.252 0.221

Inflow P Conc ppb 160.9 149.1 85.0 64.5 120.0

P Reaction Rate ‑ Mods 1 & 8 8.5 6.8 6.9 4.7 8.5

P Reaction Rate ‑ Model 2 14.6 11.6 7.9 6.2 12.7

P Reaction Rate ‑ Model 3 6.7 5.1 6.5 4.3 7.5

1‑Rp Model 1 ‑ Avail P 0.288 0.318 0.316 0.366 0.289

1‑Rp Model 2 ‑ Decay Rate 0.230 0.253 0.297 0.329 0.244

1‑Rp Model 3 ‑ 2nd Order Fixed 0.318 0.356 0.322 0.381 0.304

1‑Rp Model 4 ‑ Canfield & Bachman 0.304 0.332 0.332 0.383 0.306

1‑Rp Model 5 ‑ Vollenweider 1976 0.526 0.551 0.449 0.468 0.475

1‑Rp Model 6 ‑ First Order Decay 0.705 0.746 0.565 0.602 0.615

1‑Rp Model 7 ‑ First Order Setting 0.953 0.961 0.917 0.927 0.931

1‑Rp Model 8 ‑ 2nd Order Tp Only 0.288 0.318 0.316 0.366 0.289

1‑Rp ‑ Used 0.288 0.318 0.316 0.366 0.289

Reservoir P Conc ppb 46.4 47.3 26.8 23.6 34.7

Gp 1.048 1.070 1.003 1.012 1.015

Bp ppb 39.3 40.4 18.6 15.6 26.4

Chla vs. P, Turb, Flushing 2 17.3 17.3 11.4 10.0 14.2

Chla vs. P Linear 4 12.6 12.9 7.3 6.4 9.4

Chla vs. P 1.46 5 21.3 21.9 9.6 7.9 14.0

Chla Used ppb 12.6 12.9 7.3 6.4 9.4

ml ‑ Nuisance Freq Calc. 2.4 2.4 1.8 1.7 2.1

z 1.095 1.060 2.056 2.281 1.604

v 0.219 0.227 0.048 0.030 0.110

w 0.733 0.739 0.594 0.569 0.652

x 0.137 0.144 0.020 0.011 0.054

ORTHO P LOADS...

Precipitation kg/yr 137 137 137 137 137

NonPoint kg/yr 15735 17859 5227 4374 8271

Point kg/yr 0 0 0 0 0

Total kg/yr 15871 17995 5364 4511 8408

TOTAL P LOADS...

Precipitation kg/yr 273 273 273 273 273

NonPoint kg/yr 82050 93659 18568 17633 37761

Point kg/yr 0 0 0 0 0

Total kg/yr 82323 93932 18841 17906 38034

Note:

Above portion of worksheet contains intermediate calculations.