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LIMNO/2: A BASIC program for calculation of whole lake stability, heat content and volume-weighted averages of oxygen concentration and salinity

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LIMNO/2: A 'BASIC' PROGRAM FOR CALCULATION OF WHOLE LAKE STABILITY, HEAT CONTENT AND VOLUME-WEIGHTED AVERAGES OF OXYGEN CONCENTRATION AND SALINITY

by

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ABSTRACT

LIMNO/2 calculates heat content, mechanical stability and Birgean wind work for freshwater dimictic and warm monomictic lakes. The Walker modification of Schmidt stability is calculated for meromictic lakes. For saline and hypersaline lakes the program accepts directly measured density profiles as input data.

Detailed notes about implementation of the program, its assumptions and restrictions are provided. A tape copy of the program is available upon request.

1. INTRODUCTION

LIMNO/2 is a modified version of LIMNO, an interactive program written in BASIC by D.H. Merritt in 1975. The original program is referred to in Johnson et al. (1978) and a listing or punched tape copy may be obtained by writing to Dr N.M. Johnson, Earth Sciences Department, Dartmouth College, Hanover, NH 03755, USA.

In its original form LIMNO calculates, for the whole lake:

1. heat content (cal cm^{-2}), also for the whole lake volume (calories) and ice sheet (calories)
2. volume-weighted average temperature (°C)
3. volume-weighted average salinity (ppm)
4. volume-weighted average oxygen concentration (ppm)
5. depth of the centre of density (m) Idso (1973)
6. Idso-modified Schmidt stability (gm-cm cm^{-2})
7. Birgean wind work (gm-cm cm^{-2})

The program gives the same physico-chemical averages for a 1 cm^2 water column in the lake.

The program also prints out depth profiles (at 1 m intervals) of the following parameters:

1. temperature (°C)
2. salinity (ppm) or conductivity (µmhos)
3. density (gm cm^{-3})
4. oxygen concentration (ppm) and % saturation
5. Idso-modified Schmidt stability (gm-cm cm^{-2})
6. Birgean wind work (gm-cm cm^{-2})

LIMNO/2 has extended capabilities:

1. The Walker-modified Schmidt stability (Walker 1974), for both 'open' and 'closed' meromictic lakes (Hutchinson 1957) is calculated in profile and as a whole lake total.
2. LIMNO/2 will accept directly measured densities from which to calculate the lake stability. This facilitates its use with data from saline lakes.
3. The initial condition for the calculation of Birgean wind work can be specified in the data set, which generalises the calculation to include lakes outside the cool temperate zone (i.e. warm monomictic lakes).
4. Two external data files are used instead of data statements within the program. This streamlines data handling.

2. SETTING UP LIMNO/2

2.1 PROGRAM TRANSFER TO NON-BURROUGHS COMPUTERS

Burroughs BASIC should transfer readily to other installations. There are, however, certain language elements that may need to be changed. The following changes to the original program had to be made before it ran successfully on the B6800.

1. REM, is used here to denote a remark; an apostrophe may be required at other installations.
2. Relational expressions, (<=, <>) may be different (i.e. LE, NE).
3. Burroughs BASIC uses the ampersand '@' to represent 'times 10 to the power' (i.e. 1@4 = 1×10^4) whereas LIMNO had 'E'.
4. Burroughs BASIC denotes exponentiation by '**' as opposed to '^' in the original program.
5. The various characters appearing in Burroughs BASIC 'PRINT USING' commands may differ at other installation.

The following is a list of BASIC line numbers where the program elements, listed above, occur in LIMNO/2, outside of comments or strings.

REM Lines 10-570, 630, 850, 870, 940, 990, 1010, 1030, 1070, 1130, 1170, 1440, 1580, 1630, 1770, 1830, 2150, 2390, 2550, 2570, 2590, 2610, 2660, 2670, 2680, 2710, 2780, 2820, 3050, 3070, 3090, 3150, 3170, 3200, 3240, 3250, 3270, 3290, 3310, 3400, 3440, 3460, 3490, 3750, 3770, 3820, 3900, 3960, 3990, 4090, 4120-4160, 4180, 4190, 4310, 4450, 4790, 5620

<= 700, 3720, 3790, 3980, 5280, 5340

>= 890

<> 1060, 1610, 1650, 2170, 2700, 3360, 3380, 3540, 3570, 3600, 3630, 3680, 4020, 5040

@ 1290, 1410, 1560, 1960, 2100, 2380, 2510, 3160, 3260, 4360, 4370, 4390, 4410, 5130, 5170, 5580, 5600

** 2620, 3180, 3410, 3470, 3580, 3760, 3970, 4100, 4260, 4290, 4460, 4470, 4480, 5130, 5170, 5220

PRINT USING images i.e. # and 'E occur only at lines 4690-4740

2.2 MAGNETIC TAPE LIBRARY

Three 1200 foot magnetic tapes have been recorded with triplicate copies of:

1. LIMNO/2: the most recent modification of the original LIMNO
2. LIMNO/ANS: A version of LIMNO/2 which reads answers to the interactive questions from a third external data file 'LIMNIN' (a data file of strings). This makes the process faster, and duplicate copies of,

(a) LIMNO: the original program as implemented on the B6800 (contains data for Mirror Lake).
(b) Test files from Mirror Lake (USA), Deep Lake (Antarctica), and Lake Burragorang (NSW). These files are for LIMNO/2 and LIMNO/ANS. Copies of the expected output appear in this Research Note.
(c) LIMNIN: A file containing text strings answering the interactive questions that are asked by LIMNO/ANS. This file is appropriate for the Mirror Lake and Lake Burragorang test data files only and not in the case of the Deep Lake file which uses directly determined density data.

Tapes have been written using TAS/TAPE/EXPORTER, a utility program which uses a generalised format for transfer of files to non-Burroughs computers. Tapes are unlabelled, multi-file reels, with fixed length records, arranged in blocks of ten records, and using the ASCII character set (see Appendix I).

Tapes are available from Mr H.R. Burton, Australian Antarctic Division, Channel Highway, Kingston 7050, Australia. If your computing installation uses a large (B5900/6700/7700 series) Burroughs computer then an alternate tape format is preferable and a fourth tape, with the Burroughs format, should be specifically requested.

3. USING LIMNO/2

3.1 DATA FILES

Two data files, external to the program, are used. HYPSOG contains lake hypsography. Without it, LIMNO/2 will print a limited amount of data pertaining to a 1 cm^2 column of water. DYDATA is mandatory and contains physico-chemical profiles for a single sampling. Examples of data files for Mirror Lake, Deep Lake and Lake Burragorang are given in Figures 1 and 2. These files illustrate the two modes of density input and the specification of a Birgean initial condition, other than isothermy at 4°C.

The following output is printed by LIMNO/2 if you answer 'YES' to the question 'Do you need help?' The instructions include the original data set for Mirror Lake (from LIMNO).

In the following examples lines beginning with 'C' are comments and should not appear in an actual data file. Data files should not have BASIC line numbers as these may be regarded as data.

```
     DATA FILE 'HYPSOG'
C LAKE IDENTIFICATION STRING, FOR OUTPUT
 '*** HYPSOGRAPHY FOR MIRROR LAKE ***'
C MAX. LAKE DEPTH (>= ANY INDIVIDUAL DAILY DEPTH), AND
C ELEVATION OF THE LAKE BOTTOM ABOVE M.S.L. (metres)
11.1,200
C LIST OF AREAS WITHIN CONTOURS AT 1 METRE INTERVALS FROM
C TOP TO BOTTOM (GIVE EXACT BOTTOM AREA). (metres 2)
C NB: @ DENOTING '10 TO THE POWER OF' MAY BE DIFFERENT AT
C YOUR FACILITY.
15@4,13.6@4,12.4@4,11.5@4,10.5@4,9.86@4,8.96@4,6.79@4
3.21@4,1.61@4,0.609@4,0.1@4,0

     DATA FILE 'DYDATA'
C SAMPLE DAY I.D. STRING (FOR OUTPUT)
 'MIRROR LAKE 19 AUGUST 1969'
C LAKE DEPTH ON THE DAY (<= MAX. LAKE DEPTH IN HYPSOG),
C AND THE DESIRED PRINTOUT INTERVAL (METRES, >= 0.1)
C DEFAULT IS A PROFILE AT 1 METRE INTERVALS
11.0,0.5
C THICKNESS OF ICE (0.0 IF NO ICE : ACCURACY TO 0.01 M)
0
C  TEMP., CHEMICAL, D.O., AND DENSITY FOLLOW THE SAME
C  THREE-PART INPUT STRUCTURE.
C NUMBER OF DEPTHS SAMPLED FOR TEMPERATURE
11
C LIST OF SAMPLE DEPTHS (MAY OCCUPY > 1 LINE)
0,1,2,3,4,5,6,7,8,9,10
C LIST OF TEMPS. AT SPECIFIED DEPTHS
25,25,25,24.13,21.9,17.72,13.74,10.52,9.34,8.75,8.06
C NUMBER OF CHEMICAL SAMPLE DEPTHS (COND. OR SALINITY)
```

```
6
C TWO STRINGS, 'COND' OR 'SALINITY' AND 'UMHOS' or 'PPM'
'COND','UMHOS'
C LIST OF SAMPLE DEPTHS
0,2,4,6,8,10
C LIST OF CHEMICAL MEASUREMENTS
20.5,21.9,22.5,25.3,26
C DATA FOR OXYGEN PROFILE (PPM), as for TEMP.
11
0,1,2,3,4,5,6,7,8,9,10
7.35,7.44,7.46,7.54,8.3,7.62,6.61,1.52,0.18,0.1,0
C NB: IF A PARAMETER WAS NOT MEASURED (IE. OXYGEN)
C THEN THE NO. OF SAMPLE DEPTHS = 0, AND MOVE ON TO THE
C NEXT PROFILE.
C A PROFILE OF DIRECTLY MEASURED DENSITIES MAY BE PUT
C IN HERE, USING THE SAME THREE-PART STRUCTURE. IF THIS
C DATA DOES NOT EXIST THEN PUT NOTHING AT ALL; ONLY
C ANSWER THE APPROPRIATE INTERACTIVE QUESTION 'NO'.
C SECTION FOR SPECIFYING BIRGEAN INITIAL DENSITY VALUE.
C STRING(S), EITHER 'DENS' OR 'TEMP' FOLLOWED BY 'COND'
C OR 'SALINITY': (NB: IF 'TEMP' IS USED THEN A SECOND
C STRING MUST FOLLOW, ''(null string) WILL DO IF NEITHER OF THE OTHER
C OPTIONS IS TO BE USED.)
'TEMP','COND'
C ONE OR TWO NUMBERS CORRESPONDING TO THE STRING(S)
4.0,26
```

3.2 OUTPUT

Figures 3, 4 and 5 show the LIMNO/2 output from the three chosen examples.

3.2.1 *Mirror Lake, 19 August 1969*

Density is calculated from the temperature and conductivity profiles. The initial density for Birgean wind work is assumed to be 1 gm cm^{-3} (density of fresh water at approximately 4°C).

3.2.2 *Deep Lake, 26 January 1977*

The lake is hypersaline (concentrated c. ten times from seawater) and sub-zero water temperatures are common so that the density/temperature relationship employed by LIMNO/2 is inappropriate. Density is input directly and the initial density for Birgean wind work is specified as 1.1921 gm cm^{-3}. A slight density anomaly is also found in this data set and LIMNO/2 asks whether it is to be be left in, or removed. In this instance removal involves declaring the water column below 33 m to have a density of 1.1918 gm cm^{-3} rather than 1.1917 gm cm^{-3}. Density anomalies are relatively common near the lake surface during the cooling phase.

3.2.3 *Lake Burragorang, 18 August 1980*

A winter profile is given for this warm monomictic lake, in which temperature and conductivity are used to calculate the density profile and the initial density for Birgean wind work. Unless density is corrected for volumetric contraction due to depth, the lake is declared non-stratified. In

LIMNO/2 this declaration is printed when the density at the lake bottom (equivalent to density at deepest sampled depth) is less than, or equal to the volume weighted mean density of the lake.

Figure 6 shows the output from the original LIMNO, as implemented on the University of Tasmania Burroughs B6800 mainframe computer. The data are for Mirror Lake. LIMNO/2 gives slightly different results for the stability measures. The differences result mainly from a change in the value of the lake surface area. Due to a peculiarity in incrementation of the counter in BASIC for/next loops, LIMNO uses a surface area 0.1 m above the actual lake surface (at least as implemented on our system). This led to the situation where LIMNO was unable to accept a daily depth (in DYDATA) equal to the maximum lake depth (in HYPSOG).

Figure 1. HYPSOG files for Mirror Lake, Deep Lake, and Lake Burragorang. Elevation and maximum depth (m), area data (m²).

```
100   "*** HYPSOGRAPHY FOR MIRROR LAKE ***"
200 11.1,200
300 15@4,13.6@4,12.4@4,11.5@4,10.5@4,9.86@4,8.96@4,6.79@4
400 3.21@4,1.61@4,.609@4,.1@4,0
#
```

```
100  *** HYPSOGRAPHY FOR DEEP LAKE (ANTARCTICA) ***
200 36.0,-86.0
300 635.227@3,613.382@3,591.537@3,569.693@3,547.848@3,526.003@3
400 515.990@3,505.977@3,495.963@3,485.950@3,475.937@3,466.538@3
500 457.139@3,447.741@3,438.342@3,428.943@3,415.640@3,402.337@3
600 389.034@3,375.731@3,362.428@3,344.314@3,326.200@3,308.086@3
700 289.972@3,271.858@3,252.946@3,234.035@3,215.123@3,196.212@3
800 177.300@3,149.188@3,121.075@3,92.963@3,64.850@3,36.738@3
900 0.446@3
#
```

```
100  *** HYPSOGRAPHY FOR LAKE BURRAGORANG ***
200 105.0,11.7
300 7500@4,7338@4,7172@4,7009@4,6847@4,6682@4,6518@4,6356@4
400 6197@4,6041@4,5889@4,5739@4,5591@4,5442@4,5291@4,5137@4
500 4987@4,4842@4,4702@4,4562@4,4421@4,4279@4,4141@4,4007@4
600 3878@4,3754@4,3634@4,3520@4,3404@4,3285@4,3159@4,3038@4
700 2924@4,2821@4,2717@4,2609@4,2496@4,2382@4,2270@4,2157@4
800 2048@4,1948@4,1856@4,1768@4,1749@4,1665@4,1583@4,1503@4
900 1426@4,1350@4,1277@4,1205@4,1136@4,1069@4,1004@4,942@4
1000 881@4,822@4,766@4,712@4,660@4,610@4,562@4,516@4,473@4
1100 431@4,392@4,355@4,320@4,287@4,256@4,227@4,201@4,176@4
1200 154@4,134@4,116@4,100@4,86@4,74@4,65@4,58@4,52@4,49@4
1300 48@4,46@4,44@4,41@4,39@4,37@4,34@4,32@4,30@4,27@4,25@4
1400 23@4,21@4,18@4,16@4,14@4,11@4,9@4,7@4,5@4,2@4,0
#
```

Figure 2. DYDATA files for Mirror Lake, Deep Lake and Lake Burragorang. Temperature (°C), Density (gm cm^{-3}).

```
100  "MIRROR LAKE 19 AUGUST 1969"
200 11.0,1.0
300 0
400 11
500 0,1,2,3,4,5,6,7,8,9,10
600 25,25,25,24.13,21.9,17.72,13.74,10.52,9.34,8.75,8.06
700 6
800 "COND","UMHOS"
900 0,2,4,6,8,10
1000 20.5,21,21.9,22.5,25.3,26
1100 11
1200 0,1,2,3,4,5,6,7,8,9,10
1300 7.35,7.44,7.46,7.54,8.3,7.62,6.61,1.52,.18,.1,0

100  "DEEP LAKE  26 JAN 1977"
200 35.8,2
300 0
400 21
500 0,4,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,25
600 30,33,34
700 7.5,7.5,7.4,7.3,5.2,-0.9,-3.7,-5.5,-6.5,-7.9,-8.8
800 -10.4,-11.9,-13.4,-14.3,-14.6,-15.0,-15.5,-15.7
900 -15.7,-15.6
1000 5
1100 "SALINITY","PPM"
1200 0,9,16,20,34
1300 224120,224120,223920,224900,224900
1400 0
1500 21
1600 0,4,5,8,9,10,11,12,13,14,15,16,17,18,19,20
1700 21,25,30,33,34
1800 1.1807,1.1807,1.1808,1.1808,1.1817,1.1844,1.1856,1.1864
1900 1.1868,1.1874,1.1877,1.1884,1.1894,1.1903,1.1910,1.1913
2000 1.1915,1.1917,1.1918,1.1918,1.1917
2100 "DENS"
2200 1.1921

100  "L. BURRAGORANG 3D 18 AUG 1980"
200 96.7,6
300 0
400 10
500 0,6,12,18,24,30,36,48,60,72
600 12.8,12.8,12.8,12.8,12.8,12.8,12.8,12.8,12.8,12.8
700 1
800 "COND","UMHOS"
900 0
1000 190
1100 10
1200 0,6,12,18,24,30,36,48,60,72
1300 8.7,8.7,8.4,8.5,8.6,8.4,8.5,8.4,8.4,8.0
1400 "TEMP","COND"
1500 12.8,190
#
```

Figure 3. LIMNO/2 output for Mirror Lake (19 August 1969).

```
DO YOU NEED HELP ??
NO
IS YOUR LAKE'S AREA DATA IN FILE HYPSOG ?
YES
DO YOU WANT A PROFILE PRINTED ?
YES
DO YOU WANT DATA PRINTED AS DEPTH OR ELEV ?
DEPTH
ARE YOU USING PRE-CALCULATED DENSITIES ?
NO
CORRECT DENSITY FOR VOLUMETRIC CONTRACTION DUE TO DEPTH ?
NO
DO YOU WANT DENSITY CORRECTED FOR SALINITY ?
YES
DO YOU WANT O2 % SATURATION DEPTH CORRECTED ?
NO
IS THE LAKE *OPEN* OR *CLOSED* (WALKER-SCHMIDT CALC) ?
CLOSED


*** HYPSOGRAPHY FOR MIRROR LAKE ***

DATA FOR MIRROR LAKE 19 AUGUST 1969

DEPTH   TEMP    COND  DENSITY     OYGEN        SCHMIDT       BIRGEAN
METRES  DEG(C) UMHOS   GM/CM**3   PPM  %SAT   IDSO : WALKER (GM-CM/CM**2)

   .0   25.00    20.5  .997093   7.35  90.17   3.68    .00         .00
  1.0   25.00    20.8  .997093   7.44  91.28   2.53    .00        2.62
  2.0   25.00    21.0  .997094   7.46  91.52   1.58    .00        4.80
  3.0   24.13    21.5  .997313   7.54  91.09    .59    .22       6.16
  4.0   21.90    21.9  .997840   8.30  96.30    .02    .91        6.05
  5.0   17.72    22.2  .998692   7.62  81.58    .39   2.25        4.28
  6.0   13.74    22.5  .999323   6.61  65.12   1.44   3.22        2.36
  7.0   10.52    23.9  .999695   1.52  13.92   2.05   3.10         .90
  8.0    9.34    25.3  .999798    .18   1.60   1.39   1.76         .32
  9.0    8.75    25.7  .999842    .10    .88    .88   1.03         .14
 10.0    8.06    26.0  .999887    .00    .00    .40    .44         .04
 11.0    8.06    26.0  .999887    .00    .00    .00    .00         .00

DATA FOR THE TOTAL LAKE
THE TOTAL HEAT CONTENT OF THE LAKE IS  1.7446283+13 CALORIES
HEAT CONTENT OF THE LAKE IS  11740.43 CAL/CM**2
AVERAGE TEMPERATURE IS  20.501
AVERAGE SALT CONC IS  14.954  PPM
TOTAL AMOUNT OF SALT IS  12725896.433  GRAMS
AVERAGE O2 CONTENT IS  6.605  PPM
TOTAL MOLES O2 IS  175654.87192
THE CENTRE OF DENSITY IS  4.154  METRES BELOW THE SURFACE
MEAN DENSITY OF THE LAKE IS 0.9979831  GM/CM**3
THE IDSO - SCHMIDT STABILITY IS   131.73  GM-CM/CM**2
EPILIMNION IS ** CLOSED **
THE WALKER - SCHMIDT STABILITY IS  130.36  GM-CM/CM**2

          THE BIRGEAN WIND WORK IS  278.16  GM-CM/CM*2
INITIAL DENSITY FOR BIRGEAN WORK =  1  GM/CM**3

LAKE SURFACE AREA =  148600  SQ. METRES
TOTAL LAKE VOLUME =  851010  M.**3

DATA FOR A CM X CM COLUMN
HEAT CONTENT OF WATER COLUMN IS  18234.3  CALORIES
AVERAGE SALT CONC IS 15.932536365  PPM
AVERAGE O2 CONTENT IS  4.6193181818  PPM
TOTAL MOLES O2 IN CM**2 COLUMN IS  1.58789063-4  MOLES
```

Figure 4. LIMNO/2 output for Deep Lake (26 January 1977).

```
DO YOU WANT A PROFILE PRINTED ?
?YES
DO YOU WANT DATA PRINTED AS DEPTH OR ELEV ?
?DEPTH
ARE YOU USING PRE-CALCULATED DENSITIES ?
?YES
CORRECT DENSITY FOR VOLUMETRIC CONTRACTION DUE TO DEPTH ?
?NO
DO YOU WANT O2 % SATURATION DEPTH CORRECTED ?
?NO
IS THE LAKE *OPEN* OR *CLOSED* (WALKER-SCHMIDT CALC) ?
?CLOSED

ANOMALOUS DENSITY FOUND AT  33.1  METRES
DO YOU WANT TO REMOVE THE ANOMALY ?
?NO

*** HYPSOGRAPHY FOR DEEP LAKE (ANTARCTICA) ***

DATA FOR DEEP LAKE  26 JAN 1977
```

DEPTH	TEMP	CHEM	DENSITY	OXYGEN		SCHMIDT		BIRGEAN
METRES	DEG(C)	PPM	GM/CM**3	PPM	%SAT	IDSO :	WALKER	(GM-CM/CM**2)
.0	7.50	224120.0	1.180700	.00	.00	59.48	.00	.00
2.0	7.50	224120.0	1.180700	.00	.00	45.65	.00	21.18
4.0	7.50	224120.0	1.180700	.00	.00	33.26	.00	39.21
6.0	7.43	224120.0	1.180800	.00	.00	22.54	.19	55.19
8.0	7.30	224120.0	1.180800	.00	.00	13.65	.19	70.71
10.0	00-.0	224091.4	1.184400	.00	.00	1.61	13.37	57.80
12.0	-5.50	224034.3	1.186400	.00	.00	.20	21.58	49.31
14.0	-7.90	223977.1	1.187400	.00	.00	2.65	26.12	45.48
16.0	-10.40	223920.0	1.188400	.00	.00	7.43	30.75	38.69
18.0	-13.40	224410.0	1.190300	.00	.00	17.64	40.40	19.81
20.0	-14.60	224900.0	1.191300	.00	.00	26.21	44.64	9.08
22.0	-15.13	224900.0	1.191550	.00	.00	30.39	43.17	6.17
24.0	-15.38	224900.0	1.191650	.00	.00	32.63	40.59	4.89
26.0	-15.54	224900.0	1.191720	.00	.00	33.28	37.41	3.89
28.0	-15.62	224900.0	1.191760	.00	.00	32.30	33.60	3.17
30.0	-15.70	224900.0	1.191800	.00	.00	29.49	28.95	2.43
32.0	-15.70	224900.0	1.191800	.00	.00	21.88	20.67	1.74
34.0	-15.60	224900.0	1.191700	.00	.00	11.96	11.09	1.25
35.8	-15.60	224900.0	1.191700	.00	.00	.00	.00	.00

```
DATA FOR THE TOTAL LAKE
THE TOTAL HEAT CONTENT OF THE LAKE IS -4.8314599+13 CALORIES
HEAT CONTENT OF THE LAKE IS -7658.55 CAL/CM**2
AVERAGE TEMPERATURE IS -3.779
AVERAGE SALINITY CONC IS  224323.177  PPM
TOTAL AMOUNT OF SALINITY IS  2.8678016+12  GRAMS
THE CENTRE OF DENSITY IS  11.405  METRES BELOW THE SURFACE
MEAN DENSITY OF THE LAKE IS  1.1859243000  G/CM**3
*** A MAXIMUM DENSITY GREATER THAN 1 HAS BEEN USED ***

THE IDSO - SCHMIDT STABILITY IS     7865.76  GM-CM/CM**2
EPILIMNION IS ** CLOSED **
THE WALKER - SCHMIDT STABILITY IS  7838.12  GM-CM/CM**2

         THE BIRGEAN WIND WORK IS  8687.65  GM-CM/CM**2
INITIAL DENSITY FOR BIRGEAN WORK =  1.1921  GM/CM**3

LAKE SURFACE AREA =  630858  SQ. METRES
TOTAL LAKE VOLUME =  12784241.000  M.**3

DATA FOR A CM X CM COLUMN
HEAT CONTENT OF WATER COLUMN IS -26708.5  CALORIES
AVERAGE SALINITY CONC IS 225104.21780  PPM
```

Figure 5. LIMNO/2 output for Lake Burragorang (18 August 1980).

```
DO YOU NEED HELP ??
NO
IS YOUR LAKE'S AREA DATA IN FILE HYPSOG ?
YES
DO YOU WANT A PROFILE PRINTED ?
YES
DO YOU WANT DATA PRINTED AS DEPTH OR ELEV ?
DEPTH
ARE YOU USING PRE-CALCULATED DENSITIES ?
NO
CORRECT DENSITY FOR VOLUMETRIC CONTRACTION DUE TO DEPTH ?
NO
DO YOU WANT DENSITY CORRECTED FOR SALINITY ?
YES
DO YOU WANT O2 % SATURATION DEPTH CORRECTED ?
NO
IS THE LAKE *OPEN* OR *CLOSED* (WALKER-SCHMIDT CALC) ?
CLOSED

*** HYPSOGRAPHY FOR LAKE BURRAGORANG ***

DATA FOR L. BURRAGORANG 3D 18 AUG 1980
```

DEPTH METRES	TEMP DEG(C)	COND UMHOS	DENSITY GM/CM**3	OXYGEN PPM	%SAT	SCHMIDT IDSO	: WALKER	BIRGEAN (GM-CM/CM**2)
.0	12.80	190.0	.999536	8.70	82.94	.00	.00	.00
6.0	12.80	190.0	.999536	8.70	82.94	.00	.00	.00
12.0	12.80	190.0	.999536	8.40	80.08	.00	.00	.00
18.0	12.80	190.0	.999536	8.50	81.03	.00	.00	.00
24.0	12.80	190.0	.999536	8.60	81.99	.00	.00	.00
30.0	12.80	190.0	.999536	8.40	80.08	.00	.00	.00
36.0	12.80	190.0	.999536	8.50	81.03	.00	.00	.00
42.0	12.80	190.0	.999536	8.45	80.56	.00	.00	.00
48.0	12.80	190.0	.999536	8.40	80.08	.00	.00	.00
54.0	12.80	190.0	.999536	8.40	80.08	.00	.00	.00
60.0	12.80	190.0	.999536	8.40	80.05	.00	.00	.00
66.0	12.80	190.0	.999536	8.20	78.14	.00	.00	.00
72.0	12.80	190.0	.999536	8.00	76.27	.00	.00	.00
78.0	12.80	190.0	.999536	8.00	76.27	.00	.00	.00
84.0	12.80	190.0	.999536	8.00	76.27	.00	.00	.00
90.0	12.80	190.0	.999536	8.00	76.27	.00	.00	.00
96.0	12.80	190.0	.999536	8.00	76.27	.00	.00	.00
96.7	12.80	190.0	.999536	8.00	76.27	.00	.00	.00

```
DATA FOR THE TOTAL LAKE
THE TOTAL HEAT CONTENT OF THE LAKE IS  2.0218678+16 CALORIES
HEAT CONTENT OF THE LAKE IS  32874.83 CAL/CM**2
AVERAGE TEMPERATURE IS  12.8
AVERAGE SALT CONC IS  129.96  PPM
TOTAL AMOUNT OF SALT IS  205282762632  GRAMS
AVERAGE O2 CONTENT IS  8.534  PPM
TOTAL MOLES O2 IS  421278996.51

** THE LAKE IS NOT DENSITY STRATIFIED **

DATA FOR A CM X CM COLUMN
HEAT CONTENT OF WATER COLUMN IS  123904  CALORIES
AVERAGE SALT CONC IS 130.09439508  PPM
AVERAGE O2 CONTENT IS  8.337072562  PPM
TOTAL MOLES O2 IN CM**2 COLUMN IS  .00251935911  MOLES
```

Figure 6. Output from the original LIMNO for Mirror Lake (19 August 1969).

```
LIST THIS PROGRAM FOR INSTRUCTIONS

IS YOUR RESERVOIRS DATA IN THIS PROGRAM ?
#?
?YES
DO YOU WANT A PROFILE PRINTED ?
?YES
DO YOU WANT DATA PRINTED AS DEPTH OR ELEV ?
?DEPTH
DO YOU WANT DENSITY CORRECTED FOR VOLUMETRIC CONTRACTION ?
DUE TO DEPTH
?NO
DO YOU WANT DENSITY CORRECTED FOR SALINITY ?
?YES
DO YOU WANT O2 SATURATION DEPTH CORRECTED
?NO
*** HYPSOGRAPHY IS FOR MIRROR LAKE ***

DATA FOR MIRROR LAKE FOR19 AUGUST 1969


DEPTH    TEMP  COND   DENSITY      OXYGEN     SCHMIDT  BIRGEAN
METRES   DEG(C) UMHOS GM/CM**3    PPM   %SAT       GM-CM/CM**2

-    .0 -25.0 -20.5 - .997093 - 7.35 -90.17   - 3.64   -   .00
-   1.0 -25.0 -20.8 - .997093 - 7.44 -91.28   - 2.51   - 2.60
-   2.0 -25.0 -21.0 - .997094 - 7.46 -91.52   - 1.57   - 4.75
-   3.0 -24.1 -21.5 - .997313 - 7.54 -91.09   -  .59   - 6.10
-   4.0 -21.9 -21.9 - .997840 - 8.30 -96.30   -  .02   - 5.99
-   5.0 -17.7 -22.2 - .998692 - 7.62 -81.58   -  .39   - 4.24
-   6.0 -13.7 -22.5 - .999323 - 6.61 -65.12   - 1.42   - 2.34
-   7.0 -10.5 -23.9 - .999694 - 1.52 -13.92   - 2.03   -   .89
-   8.0 - 9.3 -25.3 - .999798 -  .18 - 1.60   - 1.38   -   .32
-   9.0 - 8.8 -25.7 - .999842 -  .10 -   .88  -  .88   -   .14
- 10.0 - 8.1 -26.0 - .999887 -  .00 -   .00  -  .40   -   .04
- 11.0 - 8.1 -26.0 - .999887 -  .00 -   .00  -  .00   -   .00
- 11.0 - 8.1 -26.0 - .999887 -  .00 -   .00  -  .00   -   .00

DATA FOR THE TOTAL LAKE
THE HEAT CONTENT OF THE TOTAL LAKE IS 1.7446283+13 CALORIES
HEAT BUDGET OF THE LAKE IS 11630.855384 CAL/CM**2
AVERAGE TEMPERATURE IS 20.500679282
AVERAGE SALT CONC IS  14.953874142  PPM
TOTAL AMOUNT OF SALT IS 12725896.433  GRAMS
AVERAGE O2 CONTENT IS  6.6050409531  PPM
TOTAL MOLES O2 IS  175654.87192
THE CENTRE OF DENSITY IS  4.1541913066  METRES BELOW THE SURFACE
THE SCHMIDT STABILITY IS  130.48689826  GM-CM/CM**2
THE BIRGEAN STABILITY IS  275.59336654  GM-CM/CM**2

DATA FOR A CM X CM COUMN
HEAT CONTENT OF WATER COLUMN IS  18234.3  CALORIES
AVERAGE SALT CONC IS 15.932536365  PPM
AVERAGE O2 CONTENT IS  4.6193181818  PPM
TOTAL MOLES O2 IN CM**2 COLUMN IS  1.58789063-4  MOLES
```

4. DISCUSSION

4.1 ASSUMPTIONS

LIMNO/2 assumes:

1. That a single temperature profile represents the whole lake. If this is unacceptable, a single profile averaged over several sample sites may be used.
2. That the temperature, or concentration for the deepest sampled depth can be extrapolated to the lake bottom.
3. That the centre of density (Idso 1973) is unique in the water column. This is not always true, especially during the late cooling phase of a warm monomictic lake. If LIMNO/2 is told not to correct such a density anomaly then the centre of density is taken as the deepest point at which the volume-weighted mean density occurs in the density profile.

4.2 RESTRICTIONS

LIMNO/2 has the following restrictions:

1. Data are linearly interpolated to provide an integration interval of 0.1 m. Several large data storage arrays are used (more than in LIMNO), and consequently running the program requires considerable memory space, and is presumably more expensive than if these arrays could be used more efficiently. The size of these arrays (declared at lines 300-320) is currently sufficient to handle a lake up to 120 m deep. If much shallower lakes are under study, the arrays dimensioned to (1200) may be reduced to ten times the maximum lake depth, and those dimensioned to (120) may be reduced to the maximum anticipated number of sample depths.
2. For each parameter (except density, which is the subject of one of the interactive questions), at least a surface value must be given. All depths should be specified to the nearest 0.1 m, except ice thickness which may be given to the nearest 0.01 m.

4.3 UNITS

The use of older units such as calories and gram-centimetres has faded in recent times to be replaced by the single unit for energy, the Joule.

Heat content (cal cm^{-2}) is most conveniently converted to mega-Joules per square metre (MJ m^{-2}): cal $cm^{-2} \times 4.19\ 10^{-2}$ = MJ m^{-2}

Schmidt stability and Birgean wind work (gm-cm cm^{-2}) may be reported as Joules per square metre (J m^{-2}): gm-cm $cm^{-2} \times 0.9807$ = J m^{-2}

Units of concentration and conductivity have equivalents as follows: ppm ≈ mg dm^{-3}, µmhos = µS cm^{-1}

4.4 GENERAL

The implementation of the Walker-modified Schmidt stability is specifically suited to meromictic lakes, or lakes in which mechanical stability is primarily due to factors other than temperature. If the epilimnion (mixolimnion) is declared 'CLOSED' then the calculation yields a total lake stability very similar to the Idso-modified Schmidt stability. If the epilimnion is considered

'OPEN' then the Walker-Schmidt stability is increased. It should be noted that it is valid to assume an 'OPEN' epilimnion only when the contribution of temperature to the overall stability is minimal. It would be an unusual lake where the conceptual mixing event led to holomixis at the temperature of the surface water, rather than at the volume-weighted mean temperature of the lake. This would clearly violate Schmidt's definition of stability as 'The amount of work needed to mix the entire body of water to uniform temperature without addition or subtraction of heat' (Hutchinson 1957). The difference between the Idso-Schmidt stability and the Walker-Schmidt stability for an 'OPEN' system should give a stability range corresponding to that between complete closure and a totally open system.

A more powerful version of LIMNO, by the original author, is discussed in Johnson and Merritt (1979). The newer version is apparently capable of accepting input from more than one site in the lake, and allows a Birgean initial profile, as opposed to a single value, to be specified for a monomictic lake. Recently, a modified (MSDOS) version of LIMNO/2 has been written for IBM personal computers. Copies of this program, called LIMNOX, are available from R.J. Banens, Department of Resource Engineering, University of New England, Armidale 2351, Australia.

ACKNOWLEDGMENTS

My association with this program and its possibilities would not have begun without the active, involvement and encouragement of Harry Burton, who deserves my sincerest thanks. I also thank Bob Banesn for permission to mention LIMNOX.

APPENDIX I. EXTRACT FROM TAS/TAPE/EXPORTER

The following extract is from the University of Tasmania Information Bulletin (TAS/TAPE/EXPORTER: R.K. Allen 1982). Points of greatest relevance are marked * or **.

1. The files to be copied to the tape are either explicitly named or implied by naming a directory.

However, no codefiles and other Burroughs specific files are copied, in fact the only files that will be copied are symbolic files (which CANDE knows as SEQ, COBOL, FORTRAN, PASCAL, JOB, etc.) and DATA files (DATA and CDATA). Unfortunately the program cannot distinguish between data files containing only character data and those containing machine-specific binary data. Files in the second category are meaningless when listed by CANDE; this includes saved SPSS system files. They will be copied by the program but will be useless at a 'foreign' installation (SPSS users see note 11).

2. Normal character files (including all symbolic files) will be written using the ASCII character set with the eighth bit zero.

3.* All symbolic files will be written as eighty character records, and so will fourteen-word DATA files (the program assumes these are created by the CANDE command MAKE filename DATA).

4.* The record length for all other files (i.e. CDATA and DATA files that are not fourteen-word) will be the same as that on the Burroughs disk. Hence printfiles, that is, program output directed to disk, may have record lengths of 120, 132, 133 or 138 characters depending on the program that created them. (The latter two lengths allow space for 132 columns plus FORTRAN carriage control.)

5.* Records are grouped into blocks. There are ten records per block unless this would give more than 2048 characters in a block, in which case a smaller blocking factor is used.

6.* Files on the tape are unlabelled and separated by single tapemarks; a double tapemark follows the last.

7. The program produces a printer listing of the first file.

8.** The first file on the tape consists of eighty character records in eight hundred character blocks and contains a list of files written. For each file the following information is given: number along the tape, length in records, iecord length (in characters), blocksize (in characters), type (as known to CANDE, e.g. SEQ, DATA), Burroughs title (up to a maximum of forty characters). The first file itself is shown with the title A/DIRECTORY.

9.* By default the tape is written *phase-encoded (PE) at a density of 1600 BPI*. For NRZI encoding with 800 BPI give the following file equation immediately after the RUN command: FILE OUTPUT(TAPE9);

APPENDIX II. EQUATIONS AND MAJOR CALCULATION STEPS IN LIMNO/2 (IN ORDER OF APPEARANCE)

The integration interval (dz) is a constant equal to 0.1 m.

1. Volume, calculated from interpolated area data.
   $V_z = (A_z + A_{z+0.1}/2)\ dz$ (V_z is equivalent to $A_z dz$)

$$V_{tot} = \int_{z_0}^{z_m} V_z \qquad \text{(units: m}^3\text{)}$$

2. Totals of heat content, O_2 concentration, salinity and density are calculated (after interpolation to 0.1 m intervals) according to the following general formula.

$$\text{Total} = \int_{z_0}^{z_m} \text{parameter x } V_z \text{ x constant}$$

   where the 'constant' is to arrive at the desired units.
   These totals may subsequently be expressed per unit surface area (i.e. heat content) or per unit volume (i.e. average O_2 and salinity).

3. Heat content of ice sheet.
   $H_i = V_{tot,i}$ x 0.917 (density) x 79.6 (latent heat of fusion) x constant (to give correct units) (units: calories)

4. Conversion of conductivity to salinity (conductivity assumed to be measured at 18°C).
   Salinity (ppm) = conductivity (µmhos) x 0.684

5. Conversion of depth to pressure.
   $P_z = z/10.17$ (units: atmospheres)

6. Conversion of altitude (of lake surface) to pressure.
   P_o = (758.39 - (0.08758 x surface elevation AMSL))/760 (units: atms)

7. Density due to temperature (distilled water, Tilton and Taylor 1937).
   $p_{t,z} = 1 - (((t_z-3.9863)^2/508929.2) \times ((t_z+288.19414)/(t_z+68.12963)))$ (units: gm cm^{-3})

8. Multiplier to correct for density increase with depth
   $M_{D,z} = 1/(1 - (P_z\ 0.00005))$ (0.00005 = coefficient of volumetric contraction)

9. Additive contribution, to density, due to salinity
   $p_{s,z}$ = salinity x ($8\ 10^{-7}$) (units gm cm^{-3})

10. Final density term, at depth z, including contributions from temperature, salinity and depth.
    $p_z = (p_{t,z}\ M_{D,z}) + p_{s,z}$

11. % saturation of oxygen at depth z.
    Saturation (O_{sat}) at a given temperature and pressure (P), where P may include contributions from both depth and altitude, or just the latter.
    $O_{sat,z} = P_z/(0.06719 + (0.00209\ t_z))$ (units: ppm)
    $O\%_{sat,z} = (O_z/O_{sat,z}) \times 100$

12. Corrections of density anomalies (if requested).
A loop compares adjacent density values (p_z) from the surface downwards.
if $p_z > p_{z+0.1}$ then replace $p_{z+0.1}$ with p_z
LIMNO/2 re-calculates the volume weighted mean density of the lake if such a correction is performed.

13. Centre of density (z_p) (Idso-modification of Schmidt stability).
The position (z_p) of the volume weighted mean density in the stratified water column is found by a loop which searches from the lake bottom upwards. (units: m)

14. Walker-Schmidt stability: Calculation of mean density and centre of density of the downward mixing layer.
Depth of the volumetric centre of gravity ($z_{g,z}$) of water above depth z.

$$z_{g,z} = 1/V_{tot,z} \int_0^z z\, V_z \qquad \text{(where } V_z \text{ is equivalent to } A_z dz\text{)}$$

Mixed density of water above z (m)

$$p_{m,z} = 1/V_{tot,z} \int_0^z p_z\, V_z \qquad \text{(where } V_z \text{ is equivalent to } A_z dz\text{)}$$

15. Stability calculations are made for each 0.1 m layer and representative values are printed in the output table (see Figures 3, 4, 5 and 6)

$$S_{I,z} = A_0^{-1} (z_p - z)(p - p_z) V_z \times \text{constant}$$

$$B_z = A_0^{-1} z (p_i - p_z) V_z \times \text{constant}$$

Walker-Schmidt stability for a 'Closed' lake

$$S_{W,z}^{\text{closed}} = A_0^{-1} (z - z_{g,z})(p_z - p_{m,z}) V_z \times \text{constant}$$

Walker-Schmidt stability for an 'Open' lake

$$S_{W,z}^{\text{open}} = A_0^{-1} (z - z_{g,z})(p_z - p_0) Vz \times \text{constant}$$

Totals of the above stability measures are accumulated and printed beneath the output table (see Figures 3, 4, 5 and 6)

$$\text{Stability total} = \int_{z_0}^{z_m} \text{Stability}_z \quad \text{(i.e. } S_I = \int_{z_0}^{z_m} S_{I,z}\text{)}$$

Symbols

1. Area : A : m^2
   - A_0 = surface area of the lake
   - A_z = area at depth z
   - $A_{z+0.1}$ = area at 0.1m below z

2. Density : p : gm cm^{-3}
   - p = volume weighted mean density of the lake
   - p_i = initial density for Birgean wind work
   - $p_{m,z}$ = mixture density of water above z. (Walker stability)
   - p_0 = density of surface water
   - $p_{s,z}$ = density, at depth z (m), due to salinity (additive)
   - $p_{t,z}$ = density, at z, due to temperature (for distilled water)
   - p_z = total density term for water at depth z
   - $p_{z+0.1}$ = total density term for water at z + 0.1 m

   Density correction for depth : M : none
   - $M_{D,z}$ = multiplier to correct for density increase due to overlying z m water column

3. Depth : z : m
   - d_z = integration interval, 0.1 m in LIMNO/2
   - z = depth (unspecified)
   - z+0.1 = z + d_z, 0.1m deeper than z
   - $z_{g,z}$ = depth of volumetric centre of gravity above z (Walker stability)
   - z_0 = lake surface
   - z_m = maximum daily depth
   - z_p = depth of p in stratified profile (Idso stability)

4. Heat content : H : calories
   - H_i = heat content of the ice sheet

5. Oxygen : O : ppm
   - $O_{sat,z}$ = concentration equivalent to saturation of oxygen at z
   - $O_{\%sat,z}$ = O_z as percentage of $O_{sat,z}$ (no units)
   - O_z = oxygen concentration at depth z

6. Pressure : P : atmospheres
   - P_0 = pressure, due to altitude, at lake surface
   - P_z = pressure due to weight of z m water column

7. Stability : S ; B : gm-cm cm^{-2}
   - $S_{I,z}$ = Idso-Schmidt stability at z
   - $S^{closed}_{W,z}$ = Walker-Schmidt stability at z, for an ideal 'closed' lake
   - $S^{open}_{W,z}$ = as above, for an ideal 'open' lake
   - B_z = Birgean wind work at depth z
   - $S_I : S^{closed}_W : S^{open}_W : B$ = whole lake totals

8. Temperature: t : °C

t_z	=	temperature at z m

9. Volume : V : m^3

V_{tot}	=	total lake volume
$V_{tot,i}$	=	total volume of i m thick ice sheet
$V_{tot,z}$	=	total volume above z
V_z	=	volume vector at depth z

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