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A COMPUTER PROGRAM USED TO ESTIMATE
PRIMARY PRODUCTIVITY
FROM pH AND CARBON DIOXIDE DATA
EMPLOYING THE UPSTREAM-DOWNSTREAM
METHOD

E. G. Wolf and R. J. Olson

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A Computer Program Used to Estimate Primary Productivity
From pH and Carbon Dioxide Data Employing the Upstream-Downstream Method

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Primary productivity of aquatic systems has been estimated by light-dark bottles (Gaarder and Gran 1927), ^{14}C (Steemann Nielsen 1952), diurnal pH (Moore 1924 in Johnstone et al. 1924), diurnal dissolved oxygen (Odum 1956) and the more recent upstream-downstream method (Odum 1956). Each of these methods is adaptable to in situ analysis but the diurnal curve and the upstream-downstream methods can be used in situ without altering the natural system. The other methods either introduce some component to the system ($\text{NaH}^{14}\text{CO}_3$, enclosing bottles) or remove essential environmental factors (flow, nutrient replenishment). These elements become significant when studying lotic systems (Odum 1957). Any method which will delete these variables provides a closer estimate of the true productivity of the system.

The use of the upstream-downstream method and the conversion of pH to carbon dioxide in freshwater systems has been thoroughly documented by R. J. Beyers et al. (1963) and H. T. Odum (1957). Their studies also included the adaptation of the method to computer analysis.

In the following sections is a description of the program as adapted from the original program of Beyers et al. (1963). The program was modified to include multiple station sampling and to interpolate readings that do not occur at hourly intervals. The program also utilizes mathematical equations fitted to the carbon dioxide-pH conversion data (Wolf et al. 1971).

Method of Computation

The basic equation for the upstream-downstream method for estimating productivity can be illustrated as follows (After, Odum 1956)

$$Q = P - R - D_{\text{out}} + A$$

Q = rate of change of carbon dioxide per area

P = rate of gross primary production per area

R = rate of respiration per area

D_{out} = rate of carbon dioxide diffusion out of the system per area

A = rate of accrual

The application of this formula to computer analysis is outlined in proceeding steps:

1. The pH values from the sampling stations are read in and converted to millimoles CO₂. This conversion is accomplished with data obtained titrimetrically as described by R.J. Beyers et al. (1963). The mathematical equation for this conversion was built into the computer program.
2. Offset the pH values for the downstream station by the average flow time. Flow times can be estimated readily using dyes, radionuclides or salts as tracking agents.
3. Accrual correction is to adjust the upstream or downstream CO₂ values to account for any addition of CO₂ to the study area. The mathematical expression

$$Ac = [S (F) + C]/F + 1.0$$

illustrates the correction where Ac = accrual corrected CO₂ values for the upstream station, S = the CO₂ concentration at the upstream site, C is the CO₂ level of the accrued component and F is the accrual factor. This factor is derived from the ratio of the volume of flow contributed by the two components; i.e., the accrued drainage and the flow into the study area. This value often is negligible and no correction is necessary (Odum 1956).

4. Millimoles CO₂/l are converted to gm CO₂/m²; i.e., millimoles * 44 * mean depth of study area.
5. Correct CO₂ values for diffusion. This correction is accomplished through a variety of methods, many of which have been discussed by Odum (1956). The method used in this program is

$$D = [\left(\frac{A+B}{2} \right) - C] (K)(F) + B$$

where D is the diffusion corrected CO₂ values for the downstream station, A is the accrual corrected upstream CO₂, B is the downstream CO₂, C = the saturation constant, K = the gas transfer coefficient and F is the flow time between the two sampling stations.

6. Subtract the downstream CO₂ data from the upstream values and divide by the average flow time between the two stations. This final step yields positive and negative values. The positive values represent gms per hour community respiration while the negatives are gms per hours net productivity.

This program was also written to integrate the respiration and productivity values to obtain subsequent daily values for productivity and respiration, average productivity and respiration per hour. A summary section of the program also permits the integration of the data over an annual period and total productivity of the stream discharge volume per hour.

The program was written for a UNIVAC 1108 computer using the FORTRAN level 5 language.

Data Card Format

The data form (page 6) is set up to record pH readings directly from a strip chart recorder with one day recorded per form. The time of the first reading is recorded and times of subsequent readings for each station are calculated based on the cycle time of the recorder. The program then interpolates between the readings of each station to obtain hourly values. Factors for the various corrections and conversions are read from cards in the STREAM2 program.

Output

The final report consists of a one page summary for each day presenting pH values, CO₂ values and integrated production. A typical report is presented on page 7.

Summary

The program, as reproduced here, represents the initial efforts by the authors. It has proven workable for the particular set of data for which it was developed, but is subject to revision and refinement, particularly if it is to be used at other sites under different conditions.

Program Description

<u>Routine</u>	<u>Page</u>	<u>Description</u>
STREAM1	9	Main program; sets constants, calls various subroutines to process data.
INPUT	10	Reads one day's set of data, checks for errors, calculates actual time of each pH reading, corrects for drift and calibration factors. Prints and punches data for each day.
HOURS	12	Interpolates between pH readings to obtain hourly readings for each station.
HAP0	15	Used to calculate consecutive days based on month, day, year.
STREAM2	16	Main program to read tables of factors and all various subroutines to calculate stream productivity.
READ	18	Reads punched cards from STREAM2.
CONVRT	19	Subroutine to convert hourly pH readings to stream productivity. These are converted to CO ₂ values from conversion curves based on laboratory data. CO ₂ values are adjusted for accrual and diffusion characteristics of the stream. Productivity measurements are obtained as final step.

Program Description (continued)

<u>Column</u>	<u>Format</u>	<u>Item</u>
1	A1	File - Distinguishes computer user group
2-4	A3	Location
5-8	I5	Sample Number
10	A1	Sample Type
11-16	3I2	Date of Sample (Month, day, year)
17-20	I4	Time (24-hour) of first pH reading
21-23	I3	Form Number (200)
24-25	A2	Editing Tag
26-27	I2	Card Number
28-29	I2	Time Period (not necessarily hours)
30-53	6F4.2	pH readings at various stations
54-58	F5.0	Correction factor for meter drift for each day. If meter drifts high, a negative value would be entered to reduce each of the observed pH readings.
59-80	3A6,A4	Comments

Control Card Format

The control cards define the calculation procedure and output options. Data for all stations are processed for each day with no limit to the number of days that can be processed during a run.

<u>Column</u>	<u>Format</u>	<u>Item</u>
1-25		Same identification as with data cards except the form number is 201.
26-27	I2	Card 01
28-29	I2	Plots hourly CO ₂ values for each day all stations if IPL0T=1.
30-31	I2	Calculates total production for each station for each day, compares stations and punches summary card if IPROD=1.
32-37	2I3	KTIME(2) Start and stop hours of production (0-24)
38-39	I2	KCODE Production sequence code. 1 = light off-on or on-off-on. 2 = light on-off or off-on-off.
40-41	I2	NSTAT is number of stations
42-46	F5.0	Cycle time (minutes) of pH strip recorder
47-77	6F5.0	Depth of each station (meters)
1-25		Same as on first card
26-27	I2	Card 02
28-58	6F5.0	Corrections for resistance in connections from each station to recorder. If reduction in signal causes readings to be low, a positive correction would be added to each observed reading.
59-80	3A6,A4	General title or remarks

K. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

54 - - - 58

59 - - 62

R e m a r k s

[illegible]

Intermediate Stream Calculations for 11/1/69

Week 1 constants recorded 10/31/69 depth .21 flow rates 2.6 2.7 volumes 55.0 53.0

Hour	Station 1			Station 4			Station 5			REACH 1-4		REACH 4-5	
	pH	CO2	CORR CO2	pH	CO2	CORR CO2	pH	CO2	CORR CO2	CO2 DIFF	CO2 / M	CO2 DIFF	CO2 / M
1	7.59	4.15	4.26	7.61	4.07	4.87	7.96	3.10	3.79	.609	.234	-1.081	-.400
2	7.59	4.15	4.26	7.59	4.15	4.95	7.93	3.18	3.88	.692	.266	-1.072	-.397
3	7.54	4.33	4.39	7.59	4.15	4.96	7.91	3.21	3.91	.579	.223	-1.055	-.391
4	7.52	4.42	4.44	7.60	4.11	4.93	7.89	3.27	3.98	.487	.187	-.952	-.353
5	7.54	4.33	4.39	7.60	4.11	4.92	7.92	3.20	3.89	.538	.207	-1.029	-.381
6	7.56	4.26	4.33	7.55	4.30	5.12	7.97	3.08	3.78	.788	.303	-1.341	-.497
7	7.56	4.26	4.33	7.50	4.50	5.35	8.03	2.95	3.66	1.014	.390	-1.688	-.625
8	7.57	4.21	4.30	7.50	4.50	5.35	8.05	2.91	3.62	1.042	.401	-1.725	-.639
9	7.59	4.15	4.26	7.55	4.30	5.11	8.07	2.87	3.56	.856	.329	-1.559	-.578
10	7.65	3.95	4.12	7.57	4.21	5.01	8.09	2.84	3.50	.888	.341	-1.502	-.556
11	7.73	3.71	3.95	7.52	4.42	5.21	8.09	2.84	3.53	1.260	.485	-1.686	-.624
12	7.79	3.55	3.85	7.65	3.95	4.68	8.09	2.84	3.47	.832	.320	-1.205	-.446
13	7.77	3.59	3.88	7.76	3.62	4.32	8.07	2.87	3.48	.445	.171	-.845	-.313
14	7.73	3.71	3.95	7.82	3.48	4.18	8.04	2.93	3.52	.223	.086	-.654	-.242
15	7.73	3.71	3.95	7.81	3.50	4.20	7.98	3.06	3.67	.243	.094	-.528	-.195
16	7.65	3.95	4.12	7.75	3.62	4.35	7.95	3.13	3.77	.230	.089	-.583	-.216
17	7.59	4.15	4.26	7.67	3.88	4.65	7.94	3.15	3.82	.394	.151	-.836	-.310
18	7.58	4.18	4.28	7.66	3.91	4.69	7.93	3.18	3.85	.408	.157	-.835	-.309
19	7.59	4.15	4.26	7.64	3.97	4.75	7.96	3.10	3.78	.496	.191	-.979	-.363
20	7.61	4.07	4.21	7.62	4.04	4.82	8.01	2.98	3.65	.613	.236	-1.172	-.434
21	7.62	4.04	4.18	7.62	4.04	4.82	7.95	3.13	3.81	.636	.245	-1.004	-.372
22	7.61	4.07	4.21	7.64	3.97	4.75	7.95	3.13	3.81	.542	.208	-.943	-.349
23	7.63	4.91	4.16	7.64	3.97	4.74	7.94	3.15	3.83	.581	.223	-.917	-.340
24	7.65	3.95	4.12	7.66	3.91	4.67	7.91	3.21	3.88	.549	.211	-.786	-.291

		G/M**2 /TIME	G/M**2 /HOUR	Gram /Hour	No. Hours
Reach 1-4	Net photosynthesis	.000	.000	.000	.0
	Night respiration	5.748	.239	62.724	24.0
	Gross photosynthesis	5.748	.239	62.724	24.0
Reach 4-5	Net photosynthesis	9.621	.401	101.172	24.0
	Night respiration	.000	.000	.000	.0
	Gross photosynthesis	9.621	.401	101.172	24.0

Program Deck Set-Up (Specific for UNIVAC 1108 Computer)

1. Standard Run Card
2. FORTRAN program decks
3. Execute card
 - ▽ NAP XQT STREAM
4. Control cards; Form 201, Cards 01 and 02
5. Data cards; Form 200 arranged by date, no limit on number of days that can be processed in a run.
6. End of run
 - ▽ EOF
 - ▽ FIN

▽ = 7/8 punch in Column 1.

```

C-----
C      PROGRAM STREAM1
C---MAIN PROGRAM TO READ RAW PH VALUES AND CONVERT TO HOURLY READINGS,
C---RATTLESNAKE SPRINGS STUDY  CONDUCTED BY ED WOLF
C---WRITTEN  FORTRAN 5  FOR  UNIVAC 1108,   RJ OLSON           1969
C
C      DIMENSION,COMMON AND TYPE STATEMENTS (SAME FOR EACH SUBROUTINE)
COMMON /BLOCK1 / IPLOT,IPROD,KTIME(2),KCODE,NSTAT,CYCLE,DEPTHS(6),
1 RESIST(6),REMARK(4),IDATE(25),ITIME(25),PERIOD(25),PHREAD(25,6),
2 DRIFT(25),REMRKS(25,4),TIME(25,6),NTIME,JTIME(25),MTIME,NREAD(6),
3 MREAD,IREAD,JREAD,MINPH,MAXPH,MAXDIF,IERR,IEND,FILE,LOCAT,TAG
COMMON /BLOCK2/ PHCRT(25,6),CO2(25,6),CHANGE(24,6),PRODT(6),
1 NPROD(6),PROD5(6),PROD6(6),PRODMM(6),RESPT(6),NRESP(6),RESP5(6),
2 RESP6(6),RESPMM(6),RATIOS(6),REMRKD(25,4)
COMMON /BLOCK3 / PHC(84),PHT(84)
INTEGER FILE,LOCAT,TAG
INTEGER DATE,CARD1,FILE2,LOCAT2,DATE2,FORM2,CARD2,TAG2,FORM
REAL MINPH,MAXPH,MAXDIF
100 FORMAT (A1,A3,6X,A6,4X,I3,A2,I2,2I2,2I3,2I2,7F5.0, / A1,A3,
1 6X,A6,4X,I3,A2,I2,6F5.0,3A6,A4)
110 FORMAT (1H1, /// "      RUN TERMINATED DUE TO ERROR IN PARAMETER "
1 "CARDS -- CHECK INPUT DECK," )
C      SET VALUES FOR CHECKING DATA AND COUNTING READINGS
NSTAT = 3
MREAD = 12
IREAD = 5
JREAD = 20
MINPH = 5.0
MAXPH = 11.0
MAXDIF = 4.5
C-----SET HOURS OF INTEREST
MTIME = 25
DO 1 I=1,MTIME
1 JTIME(I) = ABS (I - 1)
C
C---BRANCH TO "INPUT" ROUTINE TO PROCESS DATA
CALL INPUT
C
STOP
END

```

```

C-----
      SUBROUTINE INPUT
C---ROUTINE TO READ RAW PH VALUES RECORDED ON 87 MINUTE CYCLE FOR 6
C---STATIONS IN RATTLESNAKE SPRINGS STUDY
C
C      DIMENSION,COMMON AND TYPE STATEMENTS (SAME FOR EACH SUBROUTINE)
      COMMON /BLOCK1 / IPLOT,IPROD,KTIME(2),KCODE,NSTAT,CYCLE,DEPTHS(6),
1 RESIST(6),REMARK(4),IDATE(25),ITIME(25),PERIOD(25),PHREAD(25,6),
2 DRIFT(25),REMRKS(25,4),TIME(25,6),NTIME,JTIME(25),MTIME,NREAD(6),
3 MREAD,IREAD,JREAD,MINPH,MAXPH,MAXDIF,IERR,IEND,FILE,LOCAT,TAG
      COMMON /BLOCK2/ PHCRT(25,6),CO2(25,6),CHANGE(24,6),PRODT(6),
1 NPROD(6),PROD5(6),PROD6(6),PRODMM(6),RESPT(6),NRESP(6),RESP5(6),
2 RESP6(6),RESPMM(6),RATIOS(6),REMRKD(25,4)
      COMMON /BLOCK3 / PHC(84),PHT(84)
      INTEGER FILE,LOCAT,TAG
      REAL MINPH,MAXPH,MAXDIF
      DIMENSION IPHCRT(25),IDAY(3),JDAY(3),CYCLET(6)
100 FORMAT (10X,3I2,I4,7X,F2,0,F5,2,10X,2F5,2)
C---SET CYCLE TIMES
      CYCLE = 87.0
      CYCLET(1) = 0.0
      CYCLET(2) = 30.0
      CYCLET(3) = 49.0
C---START FIRST DAY
1 CONTINUE
  I = 1
  LU = 5
  READ(LU,100,END=50) (JDAY(J),J=1,3),ITIME(I),PERIOD(I),
1 (RESIST(J),J=1,3)
  IF (PERIOD(1) .GT. 0.0) GO TO 1
  TIME1 = MOD(ITIME(I),100) + INT(ITIME(I)/100)*60
  IF (TIME1 .GT. 1200.) TIME1 = TIME1 - 1440
  I = 0
  GO TO 15
C---NEW DAY, SAVE PREVIOUS DAY'S LAST VALUES, REREAD FIRST CARD OF NEW
5 CONTINUE
  LU = -4
  I = 0
C---RESET DAYS
  DO 41 J = 1,3
41 JDAY(J) = IDAY(J)
  CALL HAPO (IDAY(2),IDAY(1),IDAY(3),IHAPO)
  I = 0
6 CONTINUE
  GO TO 15
C---NEW CORRECTION FACTORS AND START TIME FOR DAY
10 CONTINUE
  LU = 5
  DO 11 J = 1,3
  RESIST(J) = PHREAD(I,J)
11 CONTINUE
  TIME1 = MOD(ITIME(I),100) + INT(ITIME(I)/100)*60
  IF (TIME1 .GT. 1200.) TIME1 = TIME1 - 1440
  I = I + 1

```

```

C---READ CARDS
  15 CONTINUE
    I = I + 1
    READ(LU,100,END=50) (IDAY(J),J=1,3),ITIME(I),PERIOD(I),
      1 (PHREAD(I,J),J=1,3)
    LU = 5
C---CHECK IF SAME DAY
  IF (IDAY(1) ,EQ. JDAY(1) ,AND. IDAY(2) ,EQ. JDAY(2) ,AND.
    1 IDAY(3) ,EQ. JDAY(3)) GO TO 20
C---END OF DAY, FINISH OLD, PUNCH PH VALUES, START NEW
  NTIME = I - 1
  CALL HAPO (JDAY(2),JDAY(1),JDAY(3),JHAPO)
  CALL HOURS
  CALL OUTPUT
  GO TO 5
C---IF SAME DAY, CHECK FOR CORRECTION FACTORS (CARD NO. 00)
  20 CONTINUE
  IF (PERIOD(I) ,LE. 0.0) GO TO 10
C---ADD OTHERS TO ARRAY
  25 CONTINUE
C---CORRECT PH FOR RESISTANCE AND DRIFT, CONVERT TIMES TO MINUTES TO HOURS
  DO 30 J = 1,3
    PHREAD(I,J) = PHREAD(I,J) + RESIST(J)
    TIME(I,J) = (CYCLE * (PERIOD(I)-1.0) + CYCLET(J) + TIME1) / 60.0
  30 CONTINUE
  GO TO 15
  50 CONTINUE
  CALL HOURS
  CALL OUTPUT
  RETURN

C
C-----
C
  SUBROUTINE OUTPUT
C---INTERNAL SUBROUTINE TO PRINT AND PUNCH HOURLY READINGS
  505 FORMAT (/2X,I2,"/",I2,"/",I2)
  506 FORMAT (1X,I1,I3,25F5.2)
  507 FORMAT (I4,I1,25I3)
  WRITE(6,505) (JDAY(L),L=1,3)
  K = 1
C---LOOP FOR 3 SELECTED STATIONS
  DO 40 J = 1,3
    IF (J ,GT. 1) K = J + 2
C---LOOP FOR HOURS OF DAY TO CONVERT TO INTEGERS *100 (DROP DECIMAL POINT)
  DO 39 L = 1,25
    39 IPHCRT(L) = PHCRT(L,J) * 100
    IF (NREAD(J) ,LT. MREAD) GO TO 37
    WRITE(6,506) K,NREAD(J),(PHCRT(L,J),L=1,25)
    PUNCH 507, JHAPO,K,(IPHCRT(L),L=1,25)
  37 CONTINUE
  40 CONTINUE
  RETURN
  END

```

```

C-----
      SUBROUTINE HOURS
C-----ROUTINE CHECKS PH READINGS FOR EXTREMS -- DELETES,
C      INTERPOLATES BETWEEN TIMES TO GIVE HOURLY PH VALUES FOR ANALYSIS,
C      CHECKS THAT THERE IS ENOUGH READINGS , SETS COUNTER,
C
C      DIMENSION,COMMON AND TYPE STATEMENTS (SAME FOR EACH SUBROUTINE)
      COMMON /BLOCK1 / IPLOT,IPROD,KTIME(2),KCODE,NSTAT,CYCLE,DEPTHS(6),
1 RESIST(6),REMARK(4),IDATE(25),ITIME(25),PERIOD(25),PHREAD(25,6),
2 DRIFT(25),REMRKS(25,4),TIME(25,6),NTIME,JTIME(25),MTIME,NREAD(6),
3 MREAD,IREAD,JREAD,MINPH,MAXPH,MAXDIF,IERR,IEND,FILE,LOCAT,TAG
      COMMON /BLOCK2/ PHCRT(25,6),CO2(25,6),CHANGE(24,6),PRODT(6),
1 NPROD(6),PROD5(6),PROD6(6),PRODDMM(6),RESPT(6),NRESP(6),RESP5(6),
2 RESP6(6),RESPMM(6),RATIOS(6),REMRKD(25,4)
      INTEGER FILE,LOCAT,TAG
      REAL MINPH,MAXPH,MAXDIF
      DATA BLANK / 6H /
      LOGICAL CHECK, CHECKD
C-----CLEAR PH ARRAY
      DO 77 I = 1,25
      DO 77 J = 1,6
100 PHCRT(I,J) = 0,0
C-----LOOP FOR EACH STATION
      DO 80 J = 1,NSTAT
      NREAD(J) = 0
C
C-----FIND FIRST AND LAST GOOD PH READINGS
      DO 5 I = 1,NTIME
      JS = I
      CHECKD = CHECK(PHREAD(I,J))
5 IF (CHECKD) GO TO 6
6 CONTINUE
      DO 7 I = NTIME, 1,-1
      JT = I
      CHECKD = CHECK(PHREAD(I,J))
7 IF (CHECKD) GO TO 8
8 CONTINUE
C-----CHECK IF ENOUGH GOOD READINGS
      IF ((JT - JS + 1) .LT. MREAD) GO TO 90
C
C-----FIND FIRST HOUR WITH PH READINGS BEFORE, SET EARLIER HOURS TO
C      FIRST READING,
      DO 10 I = 1,MTIME
      IS = I
      IF (JTIME(I) .GT. TIME(JS,J)) GO TO 11
      PHCRT(I,J) = PHREAD(JS,J)
10 CONTINUE
11 CONTINUE

```

```

C-----FIND LAST HOUR WITH READING AFTER, SET LATER HOURS TO LAST READING.
      DO 15 I = MTIME, 1,-1
        IT = I
        IF (JTIME(I) ,LT. TIME(JT,J)) GO TO 16
        PHCRT(I,J) = PHREAD(JT,J)
      15 CONTINUE
      16 CONTINUE
C-----CHECK THAT THERE ARE READINGS BEFORE IREAD AND AFTER JREAD
      IF (IS ,GE. IREAD ,OR. IT ,LE. JREAD) GO TO 91
C
C-----FILL IN HOURLY VALUES BY INTERPOLATION
      NREAD(J) = 1
      K = JS
      KL = 1
C-----LOOP FOR HOURS
      DO 60 I = IS,IT
C
        GO TO (64,63),KL
      64 L = K
C-----FIND NEXT GOOD VALUE ABOVE HOUR
      65 L = L + 1
        IF (L ,GT. JT) GO TO 93
        CHECKD = ,NOT, (CHECK(PHREAD(L,J)))
        IF (CHECKD) GO TO 65
C-----COUNT NUMBER OF GOOD READINGS THE FIRST TIME A VALUE IS CHECKED
        NREAD(J) = NREAD(J) + 1
        IF (TIME(L,J) ,LT. JTIME(I)) GO TO 65
C-----IF READING TAKEN WITHIN 3 MINUTES OF HOUR, DO NOT INTERPOLATE
        IF (ABS(TIME(K,J) - JTIME(I)) ,LT. 0,05) GO TO 67
C-----CHECK TO SEE THAT READINGS ARE CLOSE ENOUGH TO HOUR
      63 CONTINUE
        IF ((JTIME(I) - TIME(K,J)) ,GT. MAXDIF) GO TO 92
        IF ((TIME(L,J) - JTIME(I)) ,GT. MAXDIF) GO TO 92
C-----INTERPOLATE FOR HOUR
        PHCRT(I,J) = PHREAD(K,J) + (PHREAD(L,J) - PHREAD(K,J)) * (JTIME(I)
      1      - TIME(K,J)) / (TIME(L,J) - TIME(K,J))
C-----CHECK IF K VALUE IS STILL CLOSEST TO NEXT HOUR
        KL = 1
        IF (TIME(L,J) ,GT. JTIME(I+1)) KL = 2
        GO TO (66,60),KL
C-----ASSUME L VALUE IS CLOSER
      66 K = L
        GO TO 60
C
C-----SET TO PH READING AS IS
      67 CONTINUE
        KL = 1
        PHCRT(I,J) = PHREAD(K,J)
C
      60 CONTINUE
        GO TO 80

```


C-----SET COUNTERS TO INDICATE NOT ENOUGH READINGS

90 NREAD(J) = JT - JS + 1

GO TO 95

91 NREAD(J) = -1

GO TO 80

92 NREAD(J) = -2

GO TO 80

93 NREAD(J) = -3

C

C-----RETURN FOR NEXT STATION

95 CONTINUE

80 CONTINUE

C

RETURN

C

C-----

FUNCTION CHECK(PH)

C-----CHECK THAT PH READING IS WITHIN ACCEPTABLE RANGE

CHECK = (PH ,GT, MINPH) ,AND, (PH ,LT, MAXPH)

END

```
C-----
C      SUBROUTINE HAPO (L,M,N,NHD)
C -- ROUTINE TO CALCULATE CONSECUTIVE DAYS SINCE JULY 1, 1944
C INPUT PARAMETERS -- DAY,MONTH,YEAR (YEAR AS 2 DIGIT VALUE, 1944 = 44)
C OUTPUT PARAMETERS -- HAPO DATE, SET TO -1 IF ERROR IN INPUT
C
C      DIMENSION MTABLE(12)
C      MTABLE(1)=0
C      MTABLE(2)=31
C      MTABLE(3)=59
C      MTABLE(4)=90
C      MTABLE(5)=120
C      MTABLE(6)=151
C      MTABLE(7)=181
C      MTABLE(8)=212
C      MTABLE(9)=243
C      MTABLE(10)=273
C      MTABLE(11)=304
C      MTABLE(12)=334
C      IBASE=268
C      K=MTABLE(M)
C      KY=N-44
C      IF (KY)10,20,30
10  NHD=-1
C      GO TO 60
20  NHD=L+K-IBASE
C      IF (NHD)10,10,60
30  J=KY/4
C      LL=MOD(KY,4)
C      IF (LL)45,45,50
40  NHD=L+K-IBASE+365*KY+J-1
C      GO TO 60
45  IF (M-3)40,50,50
50  NHD=L+K-IBASE+365*KY+J
60  RETURN
C      END
```

```

C-----
C   PROGRAM STREAM2
C---MAIN PROGRAM TO TAKE HOURLY PH VALUES AND CONVERT TO PRODUCTIVITY
C---READS PH READINGS, 25 VALUES PER CARD, AND STORES FOR PROCESSING
C---MUST HAVE ALL 3 STATIONS TO PROCESS A DAY
C---WRITTEN FORTRAN 5 FOR UNIVAC 1108, RJ OLSON FEB, 1973
C---RATTLESNAKE SPRINGS STUDY CONDUCTED BY ED WOLF
C
      COMMON IDAY,IWK,NWK,KDATE(2),IPAGE,IDATE(3),JDATE(3),FACTS(100,16)
      1 ,PHREAD(50,3),TABLE(25,13),PHOTO(2,3,4),PHCO2(25,10)
100  FORMAT (3I2,2F2.0,11F5.0)
101  FORMAT (10X,10F5.0)
      LOGICAL BAD, NEXT
      CALL DOY (KDATE)
      NWK = 1
C---READ IN TABLES OF FACTORS NEEDED FOR VARIOUS CORRECTIONS
      1 CONTINUE
      READ(5,100,END=2) ID,IM,IY,(FACTS(NWK,I),I=5,16)
      CALL HAPO (ID,IM,IY,IH)
      FACTS(NWK,1) = IM
      FACTS(NWK,2) = ID
      FACTS(NWK,3) = IY
      FACTS(NWK,4) = IH
      NWK = NWK + 1
      GO TO 1
      2 CONTINUE
C---GET TABLE OF CONVERSION DATA PH TO CO2 VALUES -- NEW DATA 02/73
      DO 45 I = 1,22
      READ(5,101,END=50) (PHCO2(I,J),J=10,1,-1)
      45 CONTINUE
      50 CONTINUE
      LU5 = 5
      5 CONTINUE
      IDAY = 0
C---READ FIRST CARD
      CALL READ (IDAY, 1, 0, BAD, LU5)
      IF (BAD) GO TO 5
C---READ CARD 2 (STATION 4)
      CALL READ (IDAY, 4, 0, BAD, LU5)
      IF (BAD) GO TO 5
C---CARD 3 (STATION 5)
      CALL READ (IDAY, 5, 0, BAD, LU5)
      IF (BAD) GO TO 5
C--- READ NEXT DAY
      10 CONTINUE
      NEXT = .TRUE.
      CALL READ (IDAY+1, 1, 25, BAD, LU5)
      IF (BAD) GO TO 15
      CALL READ (IDAY+1, 4, 25, BAD, LU5)
      IF (BAD) GO TO 15
      CALL READ (IDAY+1, 5, 25, BAD, LU5)
      IF (BAD) GO TO 15
      GO TO 20

```

```
C---IF NEXT DAY NOT AVAILABLE, USE 2400 READINGS
  15 CONTINUE
    NEXT = ,FALSE,
    DO 16 I = 1,3
    DO 16 J = 26,35
  16 PHREAD(J,I) = PHREAD(25,I)
C
C---PROCESS DAY
  20 CONTINUE
    CALL CONVRT
C
    IF (LU5 .EQ. 99) GO TO 30
C---IF NEXT DAY ALREADY IN ARRAY, MOVE TO BEGINNING OF ARRAY
C---IF NOT STORED, START FRESH
    IF (,NOT, NEXT) GO TO 5
    DO 25 I = 1,3
    DO 25 J = 1,25
  25 PHREAD(J,I) = PHREAD(J+25,I)
    IDAY = IDAY + 1
    GO TO 10
C
C---END
  30 CONTINUE
    STOP
    END
```

```

C-----
      SUBROUTINE READ (KDAY, KSTAT, KINDEX, BAD, LU)
C---ROUTINE TO READ CARDS, CHECK DAY (HAPO), AND STATION ...,SETS BAD TO
C---.FALSE, IF DOES NOT MATCH, STORES IN ARRAY ACCORDING TO KINDEX IF OK
C
      COMMON IDAY,IWK,NWK,KDATE(2),IPAGE,IDATE(3),JDATE(3),FACTS(100,16)
      1 ,PHREAD(50,3),TABLE(25,13),PHOTO(2,3,4),PHC02(25,10)
      LOGICAL BAD
      DIMENSION PH(25)
      BAD = .FALSE.
      101 FORMAT (//////5X, "## INPUT DATA MISSING OR IN ERROR ## DAY",15,
      1 " STATION",13," DATE SKIPPED,")
      100 FORMAT (I4,I1,25F3,2)
C
C---READ DATA FROM INPUT CARDS
      READ(LU,100,END=20) JDAY,JSTAT,(PH(I),I=1,25)
      IF (KDAY .EQ. 0) KDAY = JDAY
      IF (JDAY .NE. KDAY) BAD = .TRUE.
      IF (JSTAT .NE. KSTAT) BAD = .TRUE.
      IF (BAD) GO TO 10
C---ADD TO ARRAY
      IS = 1
      IF (KSTAT .GT. 1) IS = KSTAT - 2
      DO 5 IT = 1,25
      5 PHREAD(IT+KINDEX,IS) = PH(IT)
      LU = 5
      RETURN
C---WRITE MESSAGE AND RETURN
      10 CONTINUE
      WRITE(6,101) KDAY,KSTAT
      IF (JSTAT .EQ. 1) LU = -4
      RETURN
C
C---END OF DATA
      20 CONTINUE
      BAD = .TRUE.
      LU = 99
      RETURN
      END

```

```

C-----
      SUBROUTINE CONVRT
C---ROUTINE TO DO CALCULATIONS FOR STREAM PRODUCTIVITY AND PRINT TABLE
C
      COMMON IDAY,IWK,NWK,KDATE(2),IPAGE,IDATE(3),JDATE(3),FACTS(100,16)
      1 ,PHREAD(50,3),TABLE(25,13),PHOTO(2,3,4),PHCO2(25,10)
      DIMENSION TITLE(6,6), TOTAL(3)
      DATA ((TITLE(I,J),J=1,5),I=1,6)/
      1 30HREACH 1-4 NET PHOTOSYNTHESIS ,
      2 30H          NIGHT RESPIRATION ,
      3 30H          GROSS PHOTOSYNTHESIS,
      1 30HREACH 4-5 NET PHOTOSYNTHESIS ,
      2 30H          NIGHT RESPIRATION ,
      3 30H          GROSS PHOTOSYNTHESIS, /
100 FORMAT (1H1,/ T85,A6,A3,5X,"PAGE ",I3, //
      1 T20,"INTERMEDIATE STREAM CALCULATIONS FOR ",I2,"/",I2,"/",I2, /)
101 FORMAT (T5,"HOUR *      STATION 1      **      STATION 4      **",
      1 "      STATION 5      ** REACH 1-4 ** REACH 4-5 **",/
      3 "      T5,"      * PH * CO2 * CORR ** PH * CO2 * CORR **",
      4 " PH * CO2 * CORR ** CO2 * CO2 ** CO2 * CO2 **", /
      5 "      T5,"      *      *      * CO2 **      *      * CO2 **",
      6 "      *      * CO2 ** DIFF * / M ** DIFF * / M **",/
      7 "      T5,"-----**",
      8 "-----**", /)
102 FORMAT (T5,I3,6F7.2,3F7.2,2(1X,2F7.3) )
103 FORMAT (/T45,"G/M**2      G/M**2      GRAMS      NO,"/,
      1 "      T45,"/TIME      /HOUR      / HOUR      HOURS", )
104 FORMAT (T11,5A6,2F10.3,F10.3,F7.1)
105 FORMAT (I4,4(F7.3,F7.3,F3.0), T74,"99RJ059" )
106 FORMAT ( )
110 FORMAT (// 5X, "NO INFORMATION FOR HAPO DAY ",I4," , DAY SKIPPED.")
120 FORMAT (1H+, T81,"G/M**2/DAY ",T93,F8,3)
121 FORMAT (/ T11,"REACH 1-5 GROSS PHOTOSYNTHESIS", T81,"G/M**2/DAY ",
      1 T93,F8,3)
122 FORMAT(5X,"WEEK",I3,3X,"CONSTANTS RECORDED ",I2,"/",I2,"/",I2,
      1 3X,"DEPTH ",F4,2,3X,"FLOW RATES",2F4,1,3X,"VOLUMES",
      2 2F5,1 /)
C---DETERMINE INDEX FOR CONSTANTS
      DO 5 I = 1,NWK
      IWK = I
      IF (IDAY .GE. FACTS(I,4) ,AND. IDAY .LT. FACTS(I+1,4)) GO TO 6
      5 CONTINUE
C---WRITE ERROR IF NO MATCH
      WRITE (6,110) IDAY
      RETURN
      6 CONTINUE
C---SHIFT HOURS
      IS = FACTS(IWK,5)
      JS = FACTS(IWK,5) + FACTS(IWK,6)
      DO 10 IH = 1,25
      TABLE(IH,1) = PHREAD(IH,1)
      TABLE(IH,4) = PHREAD(IH+IS,2)
      10 TABLE(IH,7) = PHREAD(IH+JS,3)

```

C---CONVERT TO CO2 VALUES

DO 20 J = 1,3

IS = J

IF (J, EQ, 2) IS = 4

IF (J, EQ, 3) IS = 7

C---LOOK UP PH IN TABLE OF CO2 VALUES

DO 20 IH = 1,25

P = TABLE(IH,IS)

IF (P, LT, 6.8) P = 6.8

IF (P, GT, 9.1) P = 9.1

IP = INT((P - 6.81) * 10.) + 1

IF (IP, LT, 1) IP = 1

IF (IP, GT, 22) IP = 22

IQ = P*100. - IP*10. - 669.

IF (IQ, LT, 1) IQ = 1

IF (IQ, GT, 10) IQ = 10

C = PHCO2(IP,IQ)

20 TABLE(IH,IS+1) = C

DO 30 IH = 1,25

C---ACCURAL

TABLE(IH,3) = (TABLE(IH,2)*FACTS(IWK,7) + 0.487)/(FACTS(IWK,7)+1.)

C---CONVERT FROM MMOLES TO G OF CO2

TABLE(IH,2) = TABLE(IH,2) * 44. * FACTS(IWK,8)

TABLE(IH,3) = TABLE(IH,3) * 44. * FACTS(IWK,8)

TABLE(IH,5) = TABLE(IH,5) * 44. * FACTS(IWK,8)

TABLE(IH,8) = TABLE(IH,8) * 44. * FACTS(IWK,8)

30 CONTINUE

C---DIFFUSION CORRECTION

DO 40 IH = 1,25

TABLE(IH,6) = ((TABLE(IH,3) + TABLE(IH,5))/2.0 - FACTS(IWK,12)) *
1 FACTS(IWK,9) * FACTS(IWK,10) + TABLE(IH,5)TABLE(IH,9) = ((TABLE(IH,5) + TABLE(IH,8))/2.0 - FACTS(IWK,13)) *
1 FACTS(IWK,9) * FACTS(IWK,11) + TABLE(IH,8)

40 CONTINUE

C---DIFFERENCES BETWEEN STATIONS

DO 50 IH = 1,25

TABLE(IH,10) = TABLE(IH,6) - TABLE(IH,3)

TABLE(IH,11) = TABLE(IH,10) / FACTS(IWK,10)

TABLE(IH,12) = TABLE(IH,9) - TABLE(IH,5)

TABLE(IH,13) = TABLE(IH,12) / FACTS(IWK,11)

50 CONTINUE

C---SUMS

DO 80 I = 1,2

ZEROES = 0.0

DO 79 J = 1,3

DO 79 K = 1,4

79 PHOTO(I,J,K) = 0.0

IS = 2*I - 1

DO 75 IH = 1,24

IF (TABLE(IH,IS+10)) 71,72,73

C---NEGATIVE DIFFERENCE (RESP,)

71 PHOTO(I,1,1) = PHOTO(I,1,1) + ABS(TABLE(IH,IS+10))

PHOTO(I,1,4) = PHOTO(I,1,4) + 1.

GO TO 75

```

C---ZERO DIFFERENCE
  72 ZEROES = ZEROES + 1
    GO TO 75
C---POSITIVE DIFFERENCES ((PHOTO)
  73 PHOTO(I,2,1) = PHOTO(I,2,1) + TABLE(IH,IS+10)
    PHOTO(I,2,4) = PHOTO(I,2,4) + 1.
  75 CONTINUE
C---DISTRIBUTE ZEROES
  PHOTO(I,1,4) = PHOTO(I,1,4) + ZEROES / 2.
  PHOTO(I,2,4) = PHOTO(I,2,4) + ZEROES / 2.
  PHOTO(I,3,4) = 1.000
C---CONVERT TO PER HOUR BASIS
  DO 77 J = 1,2
    PHOTO(I,J,2) = PHOTO(I,J,1) / PHOTO(I,J,4)
    PHOTO(I,J,3) = PHOTO(I,J,2) * FACTS(IWK,13+I) / FACTS(IWK,8)
C---GROSS
  DO 77 K = 1,3
    PHOTO(I,3,K) = PHOTO(I,3,K) + PHOTO(I,J,K)
  77 CONTINUE
  PHOTO(I,3,4) = 24.0
C---RETURN FOR OTHER REACH OF STREAM
  80 CONTINUE
C---WRITE OUTPUT
  DO 81 I = 1,3
    81 JDATE(I) = FACTS(IWK,I)
    CALL DATEH (IDAY, IDATE(2), IDATE(1), IDATE(3))
    IPAGE = IPAGE + 1
    WRITE(6,100) KDATE, IPAGE, (IDATE(I), I=1,3)
    WRITE(6,122) IWK, JDATE, FACTS(IWK,8), FACTS(IWK,10), FACTS(IWK,11),
1 FACTS(IWK,14), FACTS(IWK,15)
    WRITE(6,101)
    DO 90 I = 1,24
      N = I
      WRITE(6,102) N, (TABLE(I,J), J=1,13)
    90 CONTINUE
    WRITE(6,103)
    M = 0
    DO 95 I = 1,2
      WRITE(6,106)
      DO 95 J = 1,3
        M = M + 1
        WRITE(6,104) (TITLE(M,N), N=1,5), (PHOTO(I,J,K), K=1,4)
    95 CONTINUE
C---PUNCH RESULTS
  PUNCH 105, IDAY, ((PHOTO(I,J,K), K=2,4), J=1,2), I=1,2)
  RETURN
  END

```


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