Resources Institute

STREAM WATER QUALITY AND OXYGEN RELATIONSHIPS.......Dougal

7th Annual Water Resources
Design Conference,
Iowa State University
January 23-24, 1969

7th Annual
Water Resources Design Conference
Iowa State University
January 23-24, 1969

STREAM WATER QUALITY AND OXYGEN RELATIONSHIPS

by Merwin D. Dougal
Assistant Professor, Civil Engineering
Iowa State University

I. STREAM WATER QUALITY CONCEPTS

A. Purposes of Treatment

1. To protect the receiving stream, in relation to selected or recognized beneficial uses made of the stream and its flow. As indicated in a new text "Water and Waste Water Engineering," Volume I, by Fair, Geyer, and Okun:

> "Quality management of receiving waters is becoming more difficult while public demand for clean lakes and streams is becoming more persuasive."

2. Therefore, waste treatment systems must be designed to remove or reduce to an acceptable level those constituents which would adversely affect water quality in the stream. The adverse effect must be stated in defined and quantitative terms, if at all possible. This requires considerable knowledge of the receiving waters, streams or lakes, in addition to data concerning waste loads, treatment facilities and efficiencies, and the quality of the effluent discharged to the stream. Therefore, water quality criteria and stream behavior concepts have been introduced, developed, and improved in recent years.

B. Response of the Stream

1. In receiving, transporting and assimilating waste discharges or effluents, a stream will endeavor to cleanse itself through self-purification. The basic processes are <u>physical</u>, <u>chemical</u>, or <u>biological</u>. Additional processes include dilution, dispersion, sedimentation, reduction, oxidation, and the effect of sunlight. Biological processes are of more interest and concern today, in view of treatment requirements which include at least primary treatment. They are also the most difficult to predict.

2. Historically, four zones of self-purification are recognized for the reach downstream

of a point of waste discharge. These are

1. Zone of degradation
2. Zone of active decomposition
3. Zone of recovery
4. Zone of cleaner water.

In terms of oxygen content, these zones describe the oxygen-sag curve in qualitative terms.

C. Water Quality Standards

1. Two types of standards:

    a. Stream standards. --establish the limits on particular parameters of water quality, as measured in the stream. Wastes must be treated sufficiently so as not to exceed the established standards for the stream.

    b. Effluent standards. --specify the amount of wastes, as reflected in selected parameters of water quality, which can be discharged to the receiving stream. Accomplished by one of two methods:

        (a) specify degree of treatment, e.g., percent removal of BOD, suspended solids, etc.

        (b) specify maximum concentration or total waste load permitted to be discharged, e.g., lbs of BOD_5 per day, or concentration of substance, 30 mg/l of BOD_5, etc.

2. Both types are essential in programs for water quality improvement. Stream standards indicate what is desired or needed in the stream; effluent standards guide managers of individual waste treatment plants. Especially true when there are several waste discharge points in a short reach of the stream.

D. Concepts of Stream Classification

1. Purpose of classification---designate for each stream, or portions thereof, the beneficial uses of water and streams which are being protected, and the standards which apply.

2. Advantages:

    a. Public as well as private individuals then are informed of the quality status to be expected in each stream.

    b. Additional guide for design of treatment systems, as well as for additional urban and/or industrial developments.

3. Disadvantages:

   a. Suggested permanency to classification; may be difficult to raise stream to a higher classification, if so desired.

   b. Some states have used very low classifications to encourage industrial expansion, e.g., streams classified for waste discharge only.

4. A typical classification system is that of State of New York (1965).

Class	Description for Best Usage
AA	Source of water supply for drinking, culinary or food processing purposes and any other usages (and which would require disinfection only).
A	Source of water supply for drinking, culinary or food processing purposes and any other usage (but might require coagulation, sedimentation, filtration, and disinfection).
B	Bathing and any other usages except as sources of water supply for drinking, culinary, or food processing purposes.
C	Fishing and any other usages except those given in AA, A, & B.
D	Agricultural or source of industrial cooling or process water supply and any other usages except for AA, A, B, or C.
E	Sewage or industrial wastes or other wastes disposal and transportation, except for AA, A, B, C, or D.
F	For only sewage or industrial wastes or other wastes disposal.

The classification system includes conditions related to best usage and quality standards for each class. New York has additional classes for salt water areas, international border waters, etc.

E. Water Quality Standards in Iowa

1. Classification concept.
   a. Public Water Supply Use
   b. Aquatic Life Use
   c. Recreation Use
2. Designated points or reaches
   a. Natural Rivers or Lakes
   b. Recreational Impoundments
   c. Water Supply Impoundments
   d. Aquatic Life Use, warm water areas
   e. Aquatic Life Use, cold water areas
   f. Designated recreation areas on Iowa streams

3. General Criteria

   Minimum conditions applicable to all surface waters at all places and at all times.

   a. Free from substances attributable to municipal, industrial or other discharges that will settle to form putrescent or otherwise objectionable sludge deposits.

   b. Free from floating debris, oil, scum and other floating materials attributable to municipal, industrial or other discharges in amounts sufficient to be unsightly or deleterious.

   c. Free from materials attributable to municipal, industrial or other discharges producing color, odor or other conditions in such degree as to be detrimental to legitimate uses of the water.

   d. Free from substances attributable to municipal, industrial or other discharges in concentrations or combinations which are detrimental to human, animal, industrial, agricultural, recreational, aquatic or other legitimate uses of the water.

4. Specific criteria for stream standards.

   a. Seven-day, ten-year low-flow discharge for regulatory control purposes.

   b. Stream criteria for aquatic life

      i. warm water areas:

         Dissolved oxygen: not less than 5.0 mg/l during at least 16 hours of any 24-hour period and not less than 4.0 mg/l at any time during the 24-hour period; pH, 6.8-9.0; Temp., not to exceed 93°F, May-Nov, or 73°F Dec-April; Ammonia Nitrogen, as N, not greater than 2.0 mg/l; other specific constituents also.

      ii. cold water areas:

         Dissolved oxygen, 7.0 for 16 of 24 hours, and 5.0 mg/l minimum.

      iii. Recreation - general bacteriological considerations by sanitary survey

      iv. Public water supply

         Several criteria

5. Effluent standards, through rules and regulations, and permit conditions.

   a. All communities to effectively remove floatable and settleable solids as minimum degree of treatment.

   b. Industries for example, such as milk and cheese processing plants, permitted to discharge a maximum load of X lbs of 5-day BOD to the streams etc. through permit conditions.

   c. Control of feed lot operations.

II. GENERAL HYDROLOGIC CHARACTERISTICS OF IOWA STREAMS

A. Data Availability

1. Drainage Areas
    - a. Larimer, O.J., 1957, Drainage Areas of Iowa Streams, Bulletin No. 7, Iowa Highway Research Board, Ames, Iowa.
2. Basic Streamflow
    - a. U.S. Geological Survey, yearly to 1960, Water Supply papers:
        - i. Part 5, Hudson Bay and Upper Mississippi River Basins.
        - ii. Part 6-A, Missouri River Basin above Sioux City.
        - iii. Part 6-B, Missouri River Basin below Sioux City.

        (Summarized by Iowa Geological Survey in Bulletins 1, 2, 3, 6, 8; and compilation reports for each U.S.G.S. area, through 1950 and 1950-1960, WSP's 1308, 1309, 1310, 1728, 1729 and 1730.)
    - b. U.S. Geological Survey, 1961 to date, Surface Water Records of Iowa.
3. River basin inventories in Iowa.
    - a. Iowa Natural Resources Council, an Inventory of Water Resources and Water Problems:

Bulletin No. 1.	Des Moines River Basin, 1953.
Bulletin No. 2.	Nishnabotna River Basin, 1955.
Bulletin No. 3.	Iowa-Cedar River Basin, 1955.
Bulletin No. 4.	Floyd-Big Sioux River Basins, 1956.
Bulletin No. 5.	Skunk River Basin, 1957.
Bulletin No. 6.	Southern Iowa River Basins, 1958
Bulletin No. 7.	Northwestern Iowa River Basins, 1958.
Bulletin No. 8.	Western Iowa River Basins, 1959.

4. Low-Flow Studies, for flow-duration, low-flow frequency, net storage requirement, maximum periods of deficient discharge.
    - a. Schwob, H. H., 1958, Low-Flow Characteristics of Iowa Streams, Bulletin No. 9, Iowa Natural Resources Council, Des Moines, Iowa.
5. Additional studies of recession characteristics.
    - a. Saboe, C. W., 1966, Summer Base-Flow Recession Curves for Iowa streams, Open File Report, U.S.G.S., Iowa City, Iowa.
    - b. Howe, J. W., 1966, Recession characteristics of Iowa streams, Part I, Temporal and Areal Distribution of Recession Constants, Iowa State Water Resources Research Institute, Ames, Iowa.

c. Howe, J. W., 1968, Recession characteristics of Iowa Streams, Bulletin 43, Studies in Engineering, University of Iowa, Iowa City, Iowa.

B. General Rainfall and Stream Runoff Characteristics

Review Figures i, 2, 3.

1. Precipitation, mean annual for normal period 1931-60.
   ----25 inches to 35 inches, NW Iowa to SE Iowa
2. Average annual runoff of Iowa streams
   ---2 inches, NW Iowa to 8-9 inches, SE Iowa.
3. Minimum year runoff mid-1950's, at Iowa gaging stations
   ---0.14 inches to 2.87 inches
   ---many below 0.5 inches

C. Regional Division of Iowa into Three Low-Flow Regions

1. Stream variability
   a. Iowa streams exhibit wide variability in discharge
   b. Northeast Iowa has streams with best low flow characteristics.
   c. as move to southwest Iowa and western Iowa, have streams with very poor low flow characteristics.

2. Regional grouping.
   a. Region I. Ideal low-flow characteristics. Streams of almost all sizes have well-sustained low-flow discharges, with possible exception of very small streams in upland areas.
   (Northeast Iowa, through Turkey and Maquoketa River basins)
   b. Region II. Good low-flow characteristics. Large streams have good low flow characteristics. Intermediate and small drainage areas have fair to poor low-flow characteristics, with a large difference in unit area discharge values, between small and large basins.
   (Eastern Iowa streams, such as Wapsipinicon, Iowa and Cedar River basins)
   c. Region III. Poor low-flow characteristics. With few exceptions, low-flow characteristics of all streams are poor to very poor. Major streams may have fair values of low-flow discharges, intermediate streams exhibit poor conditions and small streams have very poor characteristics, with zero flow frequently being experienced.
   (Remainder of state, including Skunk, Des Moines and all southern and western Iowa streams, with few exceptions).

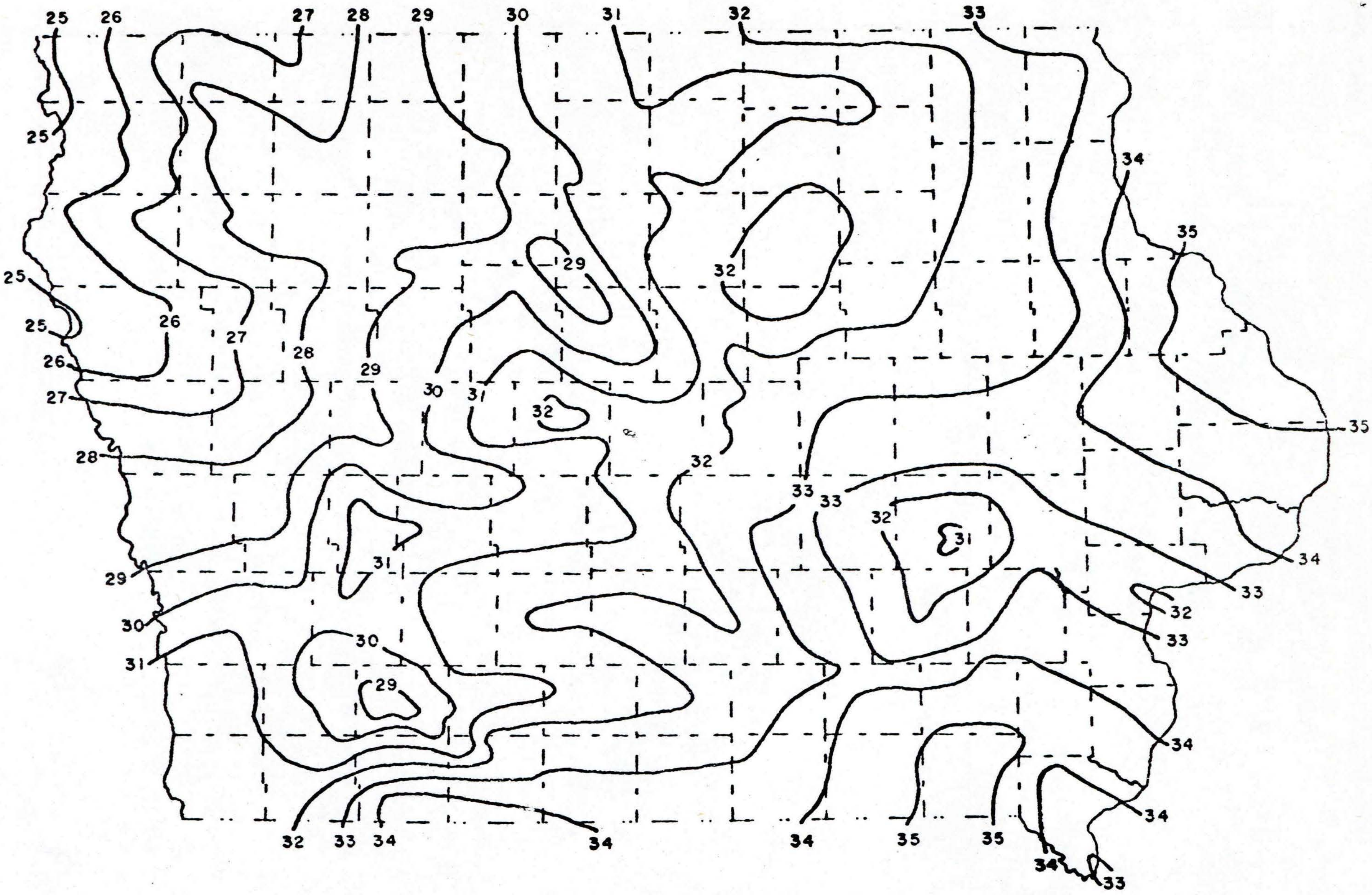

Figure 1. Isohyets of normal annual precipitation based on the period 1931-1960.

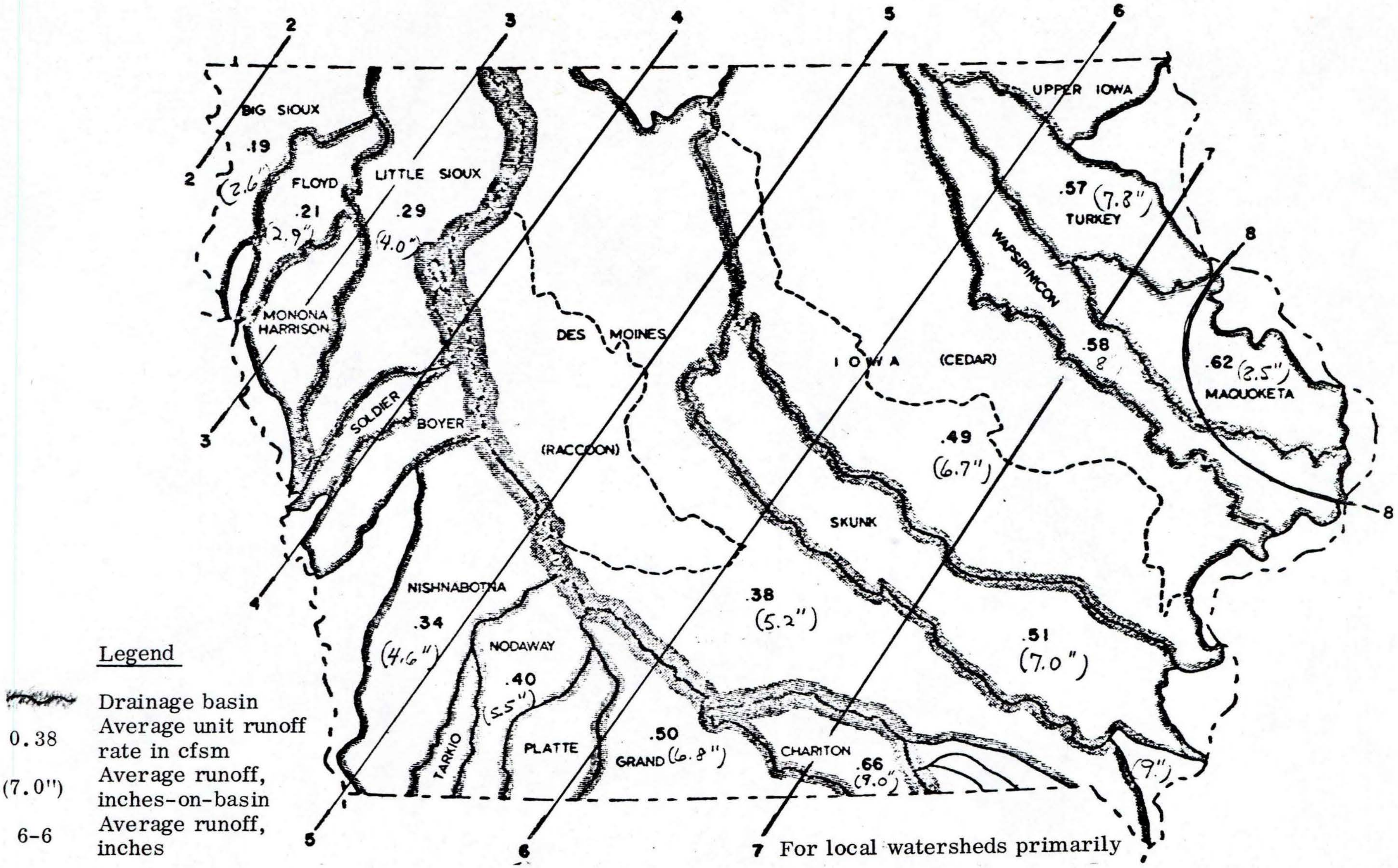

Figure 2. Average annual discharge for Iowa streams in unit runoff and in inches.

Precipitation totals for the 1956 water year are shown as 19.05, etc. in each division.

EQUIVALENTS

1" of runoff from 1 square mile
is equivalent to
53.33 acre-feet
47,610 gallons per day per year

U. S. Geological Survey
-1964-

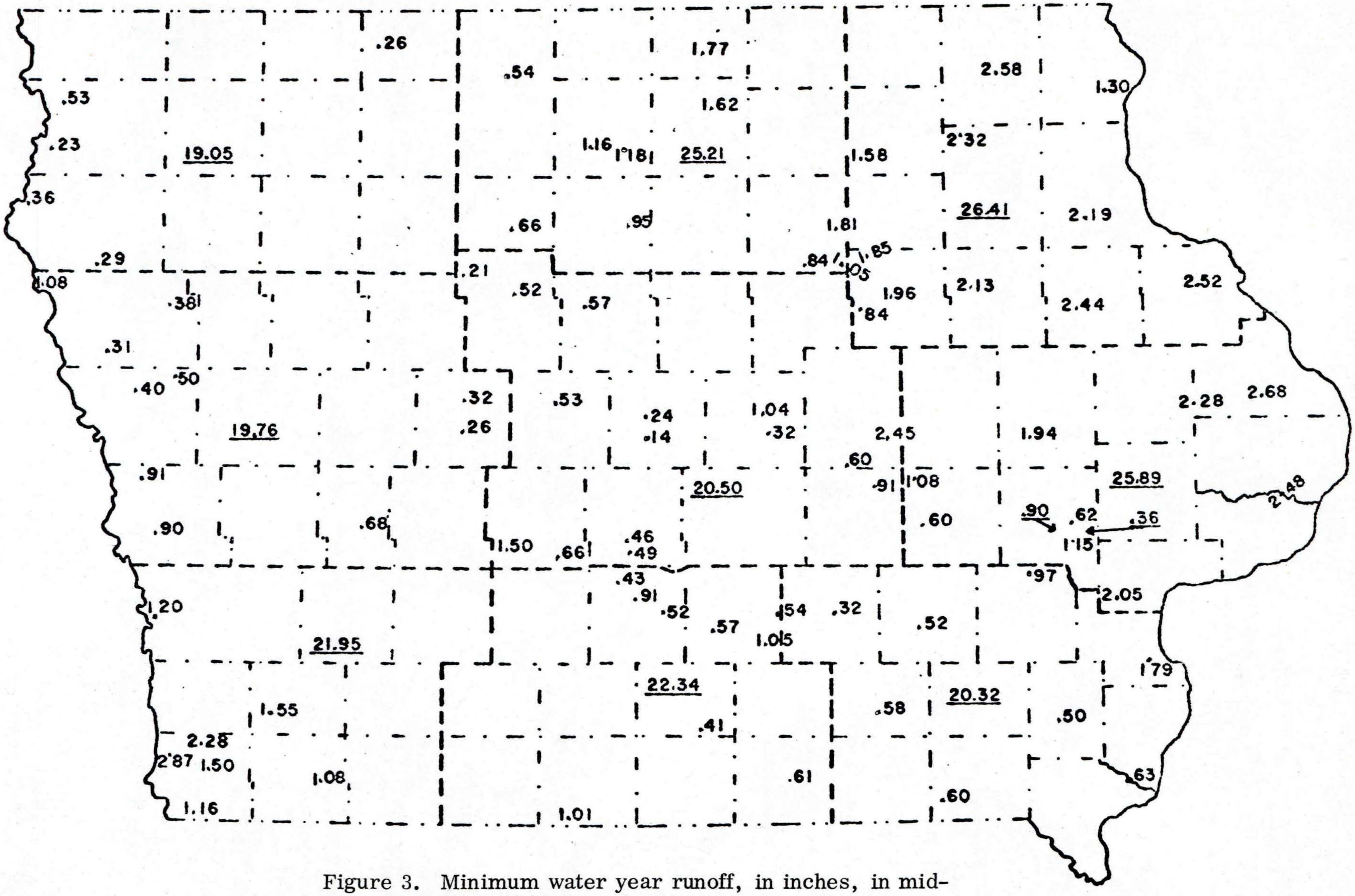

Figure 3. Minimum water year runoff, in inches, in mid-1950's at selected streamgaging stations.

Note: Large streams, 1000 sq. mi. or larger, Intermediate size streams, 100-1000 sq. mi., Small streams, less than 100 sq. miles.

Table 1

Classification of Iowa Streams by Low Flow Characteristics

Region	Size of Stream	Range of Magnitude of Low Flow, cfs/sq. mi.	
		90% duration value cfs/sq. mi.	7-day, 10-year low flow cfs/ sq. mi.
I. Ideal	all	0.085-0.170	0.04 - 0.10
II. Good	Large	0.03-0.10	0.01 - 0.06
	Intermediate	0.01 - 0.07	0.003-0.02
	Small	0 - 0.03	0 -0.006
III Poor	Large	0.004-0.03	0.002-0.01
	Intermediate	0.001-0.025	0.0001-0.008
	Small	0 -0.01	0 - 0.003

Note: See Figures 4, 5, and 6 also

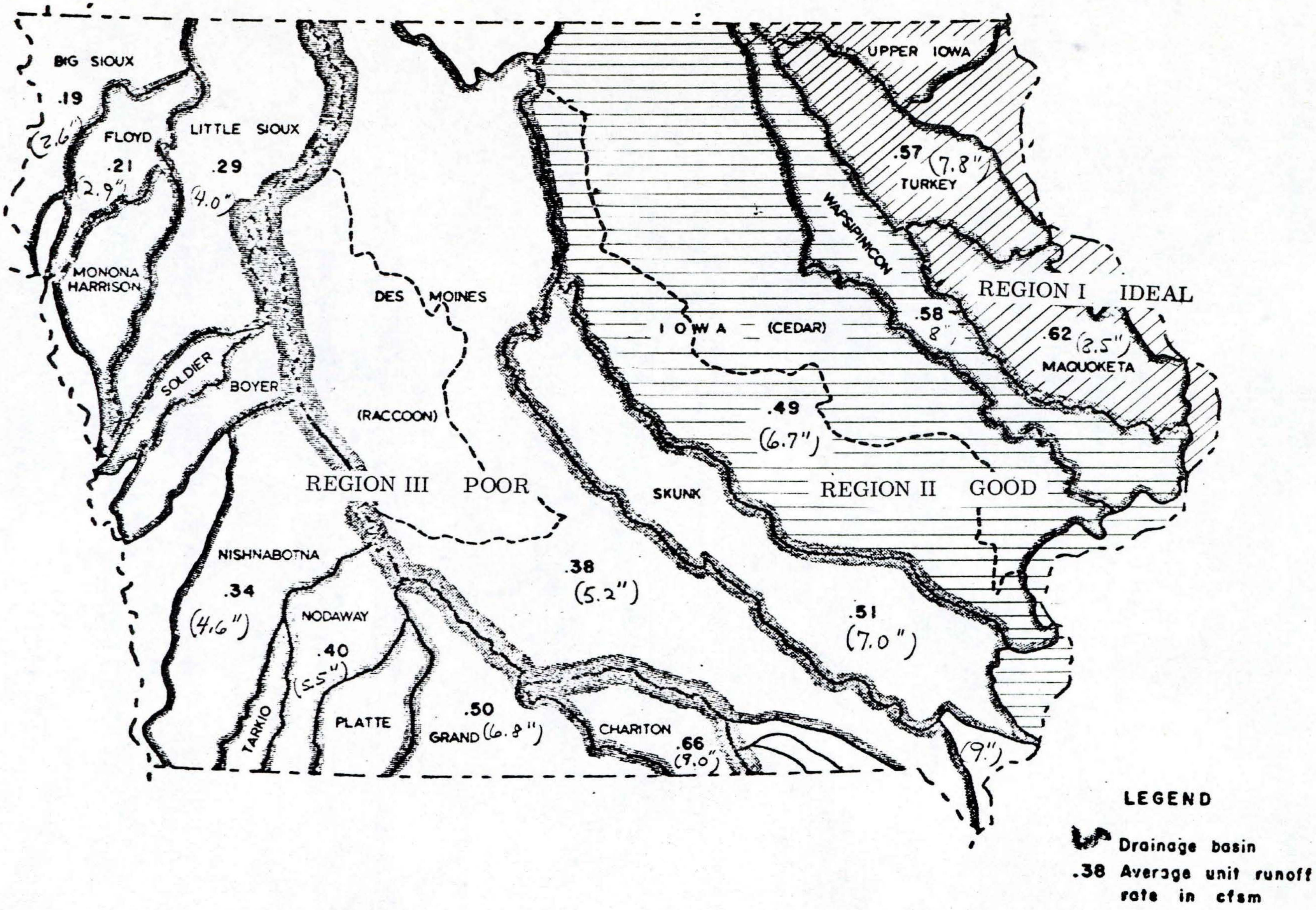

Figure 4. Division of Iowa into three regions according to low-flow characteristics.

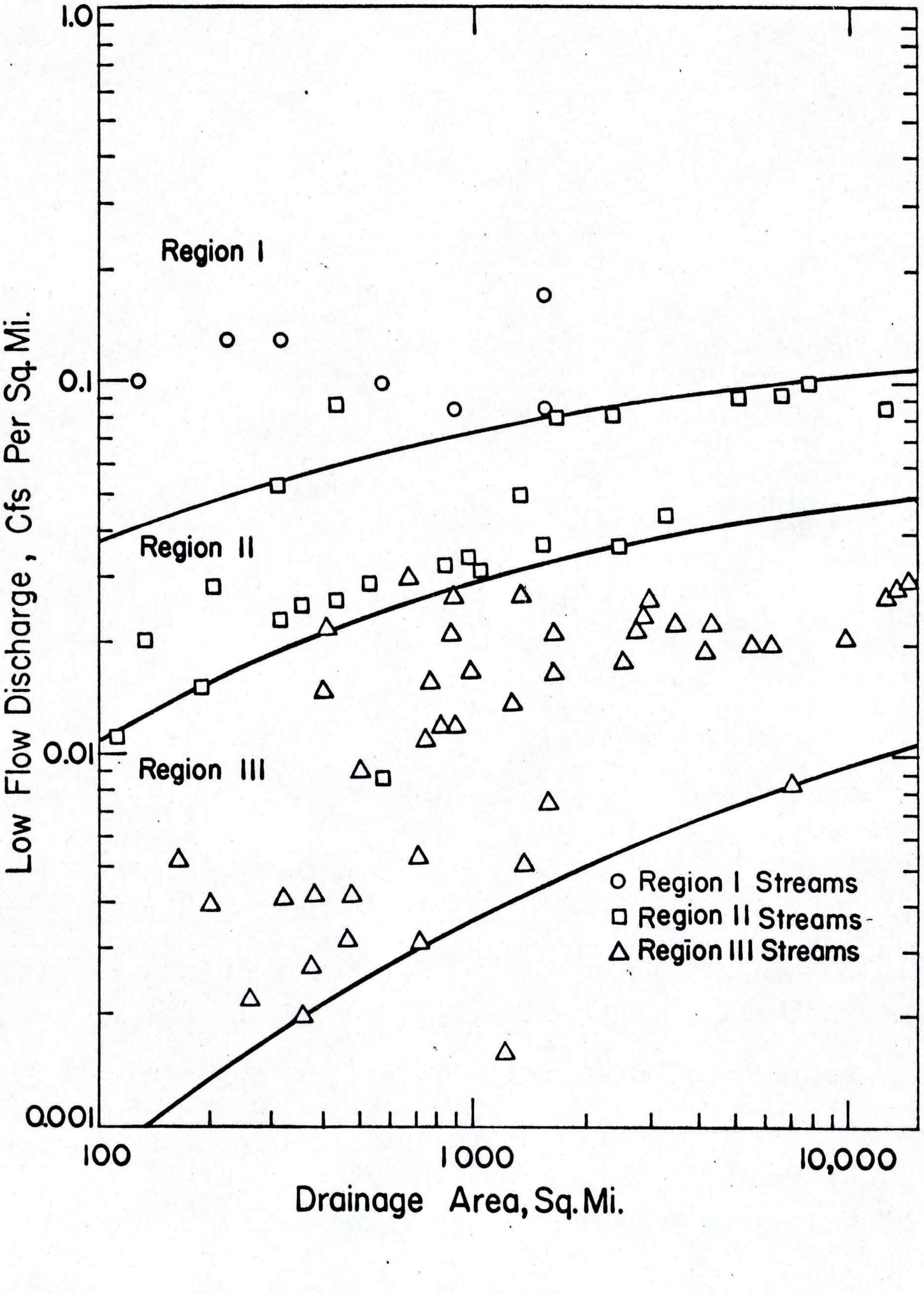

Figure 5. Low flow discharges of Iowa streams at U. S. G. S. gaging stations, for 90 percent duration value.

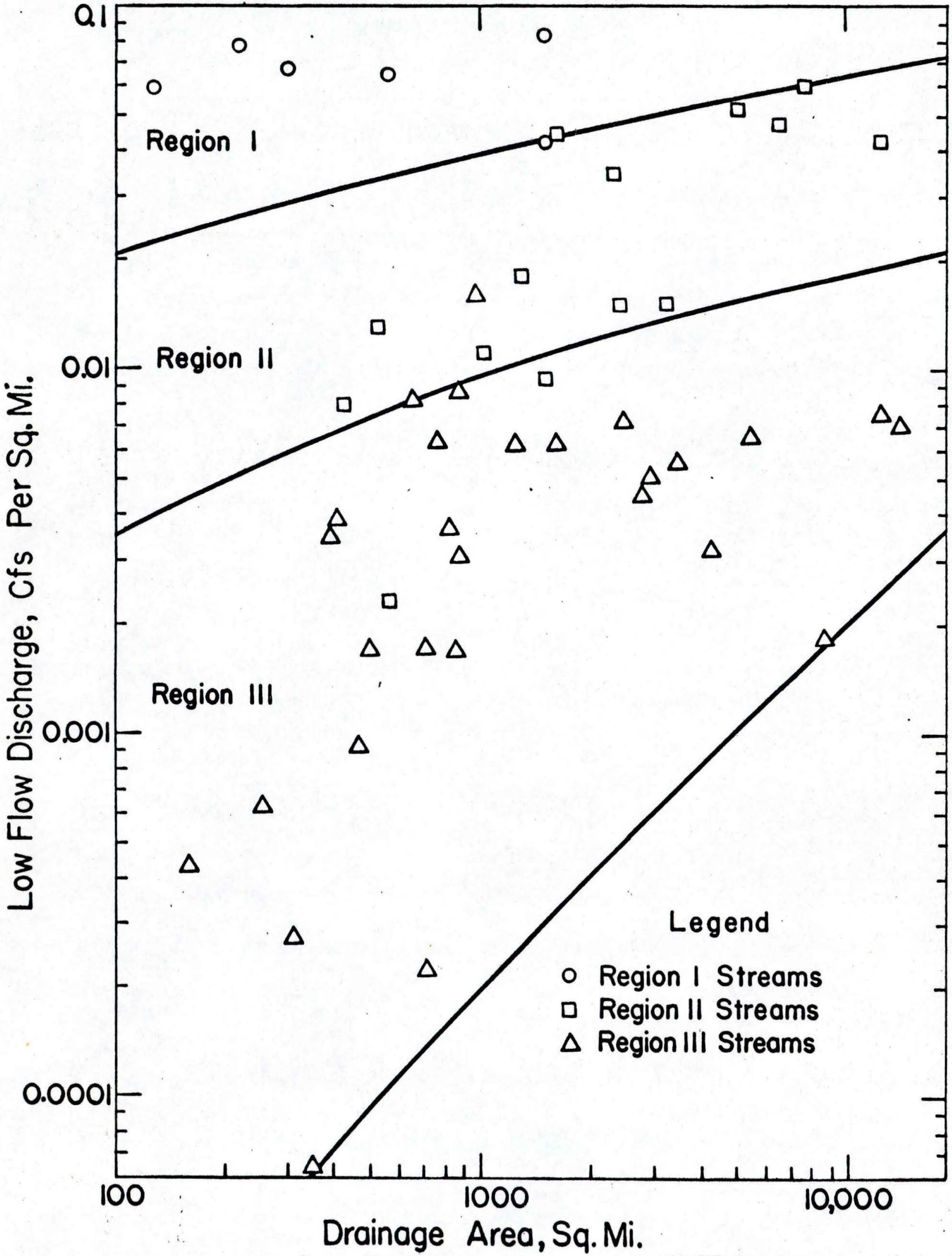

Figure 6. Low flow discharges of Iowa streams at U. S. G. S. gaging stations, for 7-day, 10-year recurrence interval.

D. Examples of Differences

Region	Stream	D. A. sq. mi.	Low Flow Discharge, cfs 90% duration	7-day, 10-year, low flow
II	Cedar River at Waterloo	5146	473	267
III	Des Moines River at Boone	5511	110	36
I	Upper Iowa at Decorah	568	56.8	36.3
III	Skunk River at Ames	556	2.3	0.15

E. General Capability of Iowa Streams to Assimilate Effluents

1. Some typical results for summer conditions using self-purification values, f, of 2.0 and 4.0

Waste Treatment Level, percent	Approximate Dilution Requirement, cfs/1000 P. E. for indicated value of f			
	Standard	Region		
	20°C	I 22°C	II 27°C	III 32°C
f =	4 2	4 2	4 2	4 2
70	0.46-0.76	0.54-0.87	0.79-1.2	1.1 -1.7
80	0.31-0.51	0.36-0.57	0.53-0.82	0.74-1.2
85	0.23-0.39	0.26-0.43	0.39-0.62	0.56-0.87
90	0.16-0.25	0.17-0.28	0.26-0.41	0.37-0.57
95	0.08-0.12	0.09-0.14	0.12-0.20	0.19-0.29

Note: Based upon self purification value of $f = \frac{r}{k}$ of 2.0 and 4.0 in Streeter-Phelps oxygen-sag formula, with no initial oxygen deficit. See Part IV. Temperatures selected to show effect of water temperature variations across Iowa.

2. Some typical results for population equivalents which could be accomodated per square mile of drainage area at 85 percent treatment level for large streams.

Region	Stream	Population Equivalents per sq. mile.	
		Lower Discharge value	Higher Discharge value
	f =	2 4	2 4
I	Large	90-150	210-350
II	Large	16-25	95-155
III	Large	2-4	11-18

Note: Combining dilution requirements with low flow discharges for 7-day, 10-year low flow discharge range previously given in Table 1.

III. HYDRAULIC CHARACTERISTICS OF IOWA STREAMS

A. General concepts

1. Deposition, scouring and transport capacity depends upon channel alignment, degree of meandering, stream slope, depth-surface area relationships, construction of low-head dams, major reservoirs, etc.

2. Many Iowa streams have been straightened:
   a. Large streams in southern, central, western Iowa.
   b. Small streams in central and northern Iowa.

B. Velocity or Time-of-travel Determination

Required for mathematical analysis of river behavior.

1. Methods:
   a. Miscellaneous stream discharge measurements
      ----current meter measurement
      ----frequently must use narrow section with maximum velocity
      ----not representative of flow time through pool-riffle-pool sequence.
   b. River surveys
      ----cross-sections every 500 feet or so.
      ----know or measure discharge at certain points.
      ----compute velocity from area-volume-discharge relationships.
      ----best for large streams
   c. Use of fluorescent dyes for tracers
      ----fluorescent techniques
         —measure at parts per billion level
         —water appears clear at 0.5 ppb., still can measure quantitatively,
         —Turner Model III Fluorometer at ISU; also Beckman instrument available on market.
      ----characteristics of Rhodamine dyes
         —low adsorption purportedly
         —not harmful to biological organisms, etc. at low concentrations
         —Rhodamine B used in ISU studies. 40% by weight, 250 lbs in 55 gal drum, about $2./lb. (can order partial drum)
      ----Dosages
         —usually want less than 10-50 ppb after initial mixing in river, if water supply intakes are involved.

—Roughly compute dosage needed by equivalent of 1 ppb for total volume in reach, Volume $=\frac{Q}{V}L$. Q = discharge, cfs; L = feet in reach; V = estimated velocity, fps.

—ISU studies, used about 1 gallon per 50-100 cfs, or approx. 5 lbs dye per 100 cfs of stream flow, recorded max. of 1-1.5 ppm at $\frac{1}{4}$-1 mile downstream, less than 5 ppb at 5-10 miles.

----concentration hydrograph analysis

—time of first appearance.

—time of peak concentration

—centroid value of time

—half of hydrograph area.

----Time of travel curves

----Relationship of time-of-travel to velocity and to discharge, $T = aQ^{-b}$.

2. Dispersion phenomena

----longitudinal mixing or dispersion illustrated by concentration hydrographs changing shape at successive sampling stations.

----Means that waste discharge slugs are rapidly dispersed longitudinally.

3. Reaeration or reoxygenation characteristics

a.

$$\frac{dD}{dt} = - rD$$

$$= -2.3K_2D$$

D = oxygen deficit

t = time

r = coefficient of reoxygenation, base e

K_2 = coefficient of reoxygenation, base 10

b. r, or K_2 varies with

i temperature

ii velocity

iii mean depth of flow

iv turbulence, scale and intensity

v energy slope

vi resistance coefficient

vii fluid characteristics of water or waste and water mixture

c. Tennessee Valley Authority

Research indicated that K_2 was adequately described by equation of form

$$K_2 = \frac{aV^b}{R^c}$$

in which V = average stream velocity, fps

R = mean depth of flow, feet

K_2 = coefficient of reoxygenation, per day

a, b, c = constants

d. For Tennesee Rivers

$$K_2 = 5.026\ V^{0.969} / R^{1.673} = 5V/R^{5/3}$$

e. Temperature effects

ASCE and TVA studies

$$K_2\ (T^{o}) = K_2\ (20^{o}) \times 1.0241^{\ (T-20)}$$

Coefficient of 1.0241 replaces formerly accepted value of 1.0159

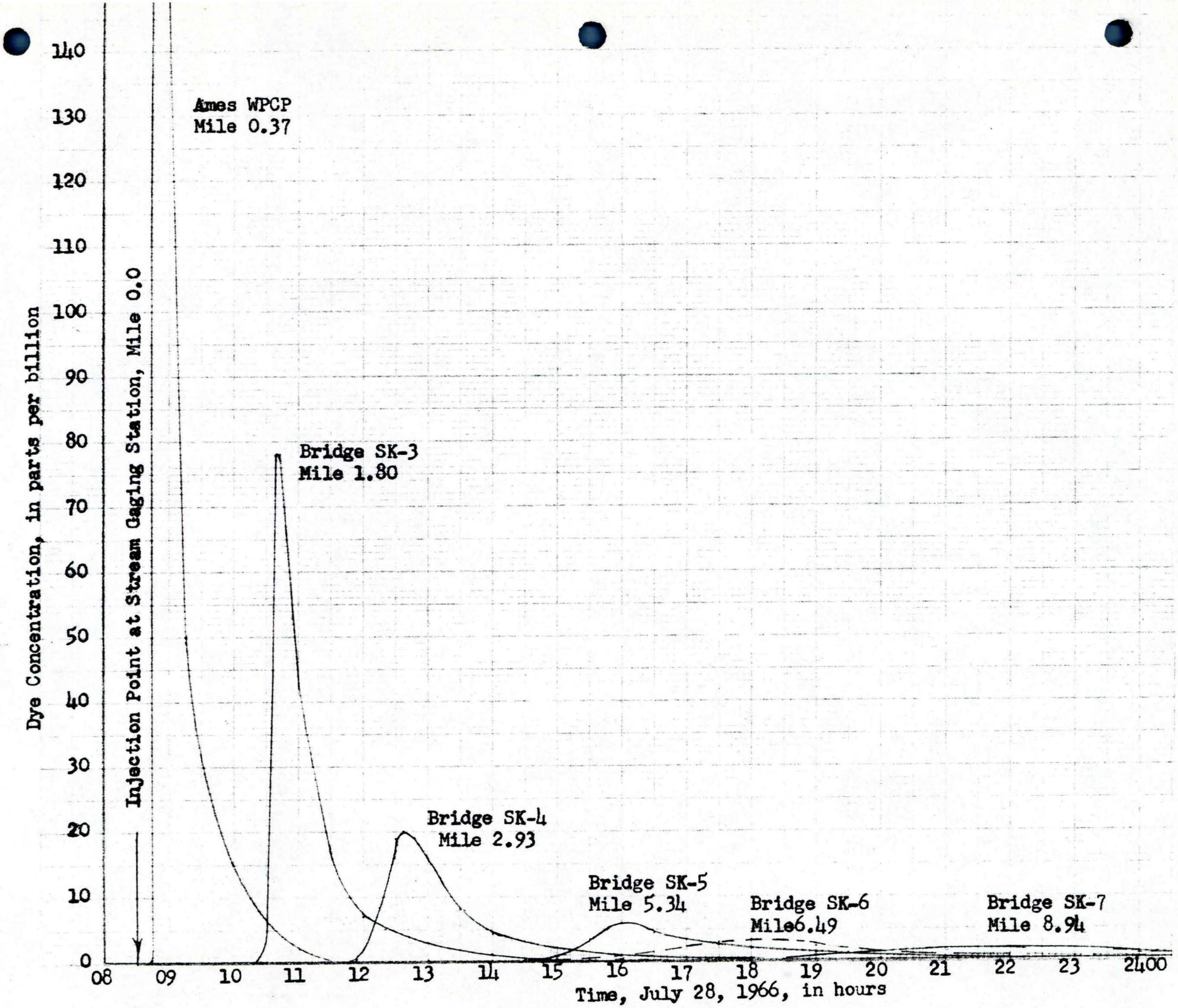

Figure 7. Time concentration curves illustrating passage of dye cloud in Skunk River downstream of Ames, Iowa, July 28, 1966.

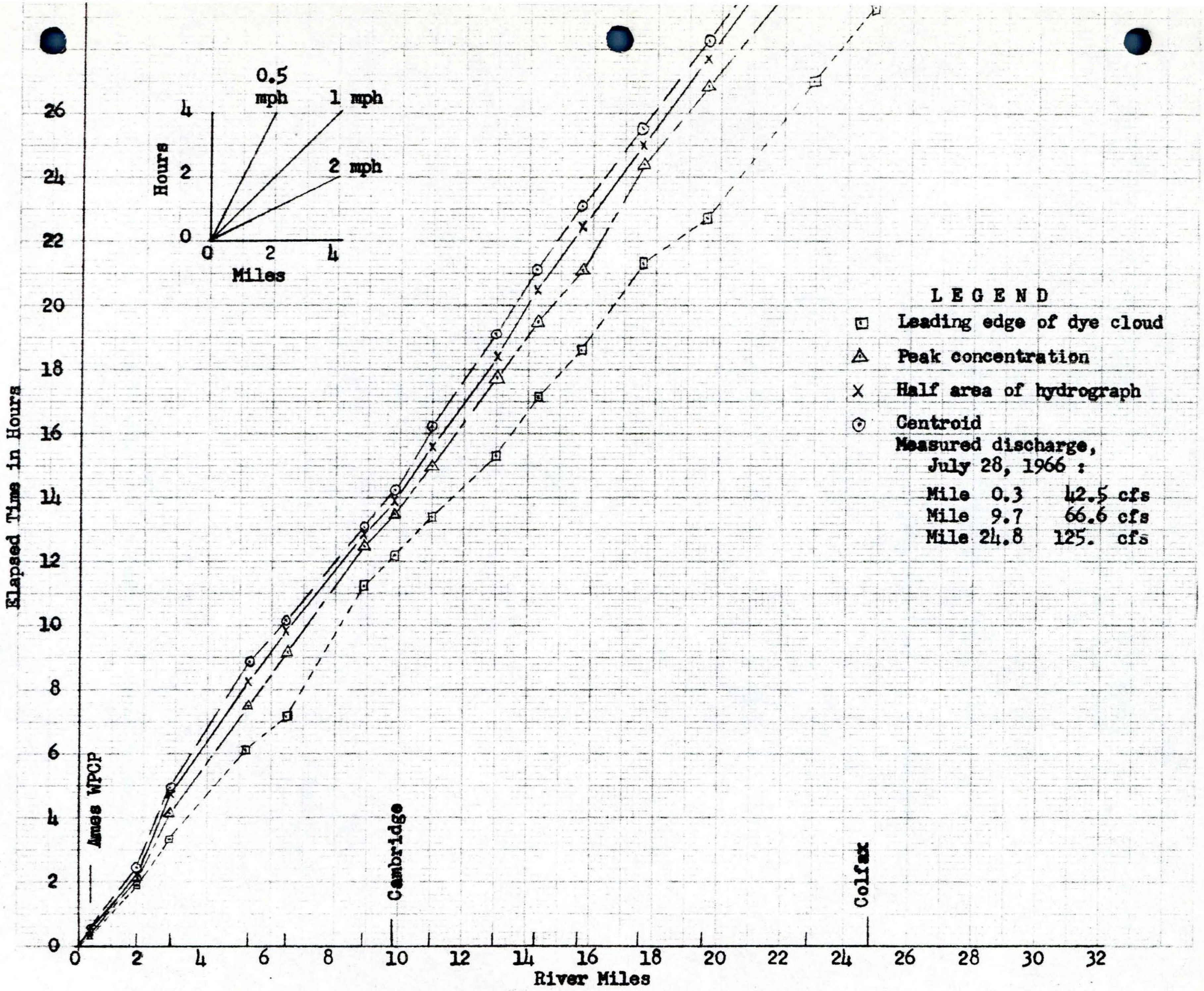

Figure 8. Cumulative traveltime and longitudinal dispersion characteristics of the Skunk River between Ames and Colfax, Iowa, as determined through dye tracer studies.

IV. STREETER-PHELPS OXYGEN-SAG EQUATION

A. Background and history

1. Developed during studies in Ohio River in early 1920's.

2. Based upon first-order biochemical reactions for deoxygenation of carbonaceous organic material and reoxygenation phenomena

3. Differential equation for oxygen deficit

$$\frac{dD}{dt} = kL - rD \qquad \text{(base e)}$$

$$= 2.3K_1 L - 2.3K_2 D \qquad \text{(base 10)}$$

Initial conditions

$t = 0,\ L = L_a,\ D = D_a$

L = oxygen demand of organic material, mg/l

D = oxygen saturation deficit, mg/l

t = time in days

L_a = initial oxygen demand, ultimate BOD, mg/l

D_a = initial saturation deficit, mg/l

$k = 2.3K_1$ = coefficient of deoxygenation, per day

$r = 2.3K_2$ = coefficient of reoxygenation, per day

B. Integrated equation, $r \neq k$

1. Natural logs

$$D = \frac{k}{r-k} L_a \left(e^{-kt} - e^{-rt}\right) + D_a e^{-rt}$$

2. Base 10

$$D = \frac{K_1}{K_2 - K_1} L_a \left(10^{-K_1 t} - 10^{-K_2 t}\right) + D_a 10^{-K_2 t}$$

3. If substitute $f = \frac{r}{k} = \frac{K_2}{K_1}$

f = rate of self purification

$$D = \frac{L_a}{f-1} e^{-kt} \left\{ 1 - e^{-(f-1)kt} \left[1 - (f-1) \frac{D_a}{L_a} \right] \right\}$$

C. For point of maximum deficit, the critical point

$$t_c = \frac{1}{k(f-1)} \log_e \left\{ f \left[1 - (f-1)\frac{D_a}{L_a} \right] \right\}$$

$$D_c = \frac{L_a e^{-kt_c}}{f}$$

D. Miscellaneous equations needed for use in stream studies.

1. Computing characteristics of mixtures

$$C_m = \frac{C_s Q_s + C_w Q_w}{Q_s + Q_w}$$

2. Temperature effects

$$K_1\ (T^o) = K_1\ (20^o) \times 1.047^{(T-20)}$$

Note: review of literature by R. L. Johnson indicates coefficient of 1.035 may be preferred to 1.047 commonly accepted.

$$K_2\ (T^o) = K_2\ (20^o) \times 1.024^{(T-20)}$$

$$L_a\ (T^o) = L_a\ (20^o) \times (0.02T + 0.6)$$

3. Ultimate, first stage (carbonaceous) BOD, L_a

$$BOD = L_a\ (1-10^{-K_1 t}) = L_a\ (1-e^{-kt})$$

4. Values of f (Fair and Geyer), $f = \frac{K_2}{K_1} = \frac{r}{k}$ (based upon $K_1 = 0.10$)

Stream type	f(20°C)
Small ponds and back waters	0.5 - 1.0
Sluggish streams and large lakes or impoundments	1.0 - 1.5
Large streams of low velocity	1.5 - 2.0
Large streams of moderate velocity	2.0 - 3.0
Swift streams	3.0 - 5.0
Rapids and Waterfalls	About 5.0
Reaeration under ice	approaches zero

5. Actual dissolved oxygen level, DO

DO = saturated DO — DO deficit

so need saturated DO versus temperature relationship, $^{\circ}$C.

$$\begin{aligned} DO(sat.) = {} & 14.652 \\ & -0.41022T \\ & +0.0079910T^2 \\ & -0.000077774T^3 \end{aligned}$$

by TVA and ASCE studies (at 20°C, DO = 9.02 mg/l)

6. For $f = \frac{r}{k} = 1$, or $r = k$

$$D = (ktL_a + D_a)\, e^{-kt}$$

$$t_c = \frac{1}{k}\left(1 - \frac{D_a}{L_a}\right)$$

E. Boundary Equations

Fair & Geyer

Can determine maximum loading on a river more easily by boundary equations, for given values of k, f, D_a, and D_c, the critical deficit. Especially since D_c is established by water quality criteria. Recognize that: $D_c = DO(sat) - DO_{min}$

1. For $D_a = \overset{0}{0}$ and $D_c \leqq$ DO (sat)

$$L'_a/D_c = f^{(f/f-1)} = f\, e^{kt'c} \qquad t'_c = (\log_e f)/\left[\,k\,(f-1)\,\right]$$

2. For $D_a = D_c \overset{=}{<}$ DO (sat.)

$$t''_c = 0$$

$$L''_a / D_c = f$$

3. In 1, if f = 1

$$t'_c = 1/k$$

$$L'_a / D_c = e = 2.718$$

4. Allowable loadings as computed in stream, for any other D_a value will be between L'_a and L''_a .

F. Determining K_1 for river

1. Equation

$$BOD = L_a\,(1 - 10^{-K_1 t})$$

2. Sample river at selected sites.
   a. Use grab, temporal, or composite sampling

3. Use 5-day BOD or, better, determine daily BOD and compute ultimate BOD at each station.

4. Plot BOD versus time-of-travel between stations,
   log BOD versus time.

5. Slope of line gives value of K_1.

$$K_1 = \frac{\text{log BOD (upstream station) - log BOD (downstream station)}}{\text{t (time of travel)}}$$

6. Note — see later section on experienced differences between laboratory determined K_1 for BOD analysis at a station and river K between stations.

F. Sample Problem #1

For Skunk River at Ames, and for summer conditions.

Includes nitrification, with results for carbonaceous organic loading in right hand two columns. Computer solution on following pages.

```
                OXYGEN BALANCE IN SURFACE WATERS

       DEPLETION CAUSED BY WASTE EFFLUENTS AT A POINT SOURCE
     OXYGEN DEMAND FOR CARBONACEOUS AND NITRIFICATION DEMANDS
                        BOD-C   AND   BOD-N



    SOLUTION FOR DOUGAL, M.D.,  CE 524, AMES RES.

       NAME OF STREAM **    SKUNK RIVER

        DOWNSTREAM OF ** AMES, IOWA

        CALCULATIONS ARE FOR ** SUMMER    ** CONDITIONS

    COEFFICIENTS AT 20 DEG. CENTIGRADE ARE
                                         RIVER      EFFLUENT
    1. DEOXYGENATION, BOD-C               0.200      0.200
    2. NITRIFICATION, BOD-N               0.200
    3. REOXYGENATION                      0.500
    4. RIVER VELOCITY, V =  0.10*Q**0.50

  MINIMUM DISSOLVED OXYGEN LEVEL FOR AQUATIC LIFE IS      4.00 MG/L
    CALCULATIONS FOR THIS ANALYSIS BEGIN WITH:

             INITIAL RIVER DISCHARGE  100.00 CFS
             INCREMENT OF INCREASE     10.00 CFS
             MAXIMUM DISCHARGE        200.00 CFS
             INCREMENT OF TIME          0.10 DAYS
             MAXIMUM TIME OF TRAVEL    10.00 DAYS
```

```
          RESULTS OF OXYGEN DEPLETION STUDY                        PAGE  1

   SOLUTION FOR DOUGAL, M.D.,  CE 524, AMES RES.

       NAME OF STREAM **    SKUNK RIVER

        DOWNSTREAM OF ** AMES, IOWA

        CALCULATIONS ARE FOR ** SUMMER    ** CONDITIONS


   BASIC DATA FOR THE RIVER, EFFLUENT, AND COMBINED MIXTURE ARE

               BOD-C    ULT    AMMON.    ULT    PER-   INIT.  TEMP.  DESIGN
               5-DAY   BOD-C   NH4-N    BOD-N   CENT    DO    DEG.   FLOW
               20DEG   20DEG                    SAT.          CENT.
     FOR       MG/L    MG/L     MG/L     MG/L    DO    MG/L           CFS

    RIVER       4.00    4.44     0.05     0.23  90.00   6.57  29.40 100.00

   EFFLUENT    20.00   22.22    10.00    45.69  75.00   6.80  18.30  15.00

   MIXTURE      6.09    6.76     1.35     6.16  87.98   6.60  27.95 115.00
                                   ×4.59

   COMBINED DISCHARGE IS   115.00 CFS

   VELOCITY IS    1.07 MPH OR   25.74 MPD

   TEMPERATURE OF COMBINED FLOW IS  27.95 DEG. C. OR  82.31 DEG. F.

       COEFFICIENTS AT THIS TEMPERATURE ARE

            KD= 0.288       KN= 0.288       KR= 0.567

   LA=    7.84 MG/L,   INITIAL DO=    6.60 MG/L

   DO, SATURATION=    7.50 MG/L,   INITIAL DO DEFICIT=    0.90 MG/L


   RESULTS FOR CARBONACEOUS DEMAND ONLY

        RIVER DISCHARGE  =      100.00 CFS
        COMBINED DISCHARGE =    115.00 CFS

        MINIMUM DISSOLVED OXYGEN LEVEL =      5.26 MG/L

        OCCURS AT MILE    22.39 DOWNSTREAM OF DISCHARGE POINT
        AT CRITICAL TIME OF    0.87 DAYS
```

```
                                                                              PAGE  2
RIVER DISCHARGE IS    100.00 CFS
COMBINED FLOW IS      115.00 CFS
D.O. AT SATURATION IS    7.50 MG/L

 TIME    DISTANCE    RESULTS OF COMBINED C-N DEMANDS       CARBONACEOUS
  OF      DOWN-     OXYGEN     DO     LA     NH4-N          DEMAND ONLY
TRAVEL   STREAM,    DEFICIT   LEVEL  LEVEL   LEVEL          OXY.     DO
 DAYS     MILES      MG/L     MG/L   MG/L    MG/L          DEFICIT  LEVEL
                                                             MG/L    MG/L

 0.10      2.57      1.63     5.87   7.34    1.26           1.26    6.24
 0.20      5.15      2.22     5.28   6.86    1.18           1.55    5.95
 0.30      7.72      2.69     4.81   6.42    1.10           1.77    5.73
 0.40     10.29      3.05     4.45   6.01    1.03           1.94    5.56
 0.50     12.87      3.32     4.18   5.63    0.97           2.07    5.43
 0.60     15.44      3.52     3.98   5.26    0.91           2.15    5.35
 0.70     18.02      3.65     3.85   4.93    0.85           2.20    5.29
 0.80     20.59      3.73     3.76   4.61    0.79           2.23    5.27
 0.90     23.16      3.77     3.73   4.31    0.74           2.23    5.26
 1.00     25.74      3.77     3.73   4.04    0.69           2.22    5.28
 1.10     28.31      3.74     3.75   3.78    0.65           2.19    5.31
 1.20     30.88      3.69     3.81   3.54    0.61           2.15    5.35
 1.30     33.46      3.62     3.88   3.31    0.57           2.10    5.40
 1.40     36.03      3.53     3.97   3.10    0.53           2.04    5.46
 1.50     38.61      3.43     4.07   2.90    0.50           1.98    5.52
 1.60     41.18      3.32     4.18   2.71    0.47           1.91    5.59
 1.70     43.75      3.21     4.29   2.54    0.44           1.84    5.66
 1.80     46.33      3.09     4.41   2.37    0.41           1.77    5.73
 1.90     48.90      2.96     4.53   2.22    0.38           1.69    5.81
 2.00     51.47      2.84     4.66   2.08    0.36           1.62    5.88
 2.10     54.05      2.71     4.78   1.95    0.33           1.55    5.95
 2.20     56.62      2.59     4.91   1.82    0.31           1.47    6.02
 2.30     59.20      2.47     5.03   1.70    0.29           1.40    6.10
 2.40     61.77      2.35     5.15   1.59    0.27           1.33    6.17
 2.50     64.34      2.23     5.26   1.49    0.26           1.27    6.23
 2.60     66.92      2.12     5.38   1.40    0.24           1.20    6.30
 2.70     69.49      2.01     5.49   1.31    0.22           1.14    6.36
 2.80     72.06      1.90     5.59   1.22    0.21           1.08    6.42
 2.90     74.64      1.80     5.70   1.14    0.20           1.02    6.48
 3.00     77.21      1.71     5.79   1.07    0.18           0.96    6.54
 3.10     79.78      1.61     5.89   1.00    0.17           0.91    6.59
 3.20     82.36      1.52     5.98   0.94    0.16           0.86    6.64
 3.30     84.93      1.44     6.06   0.88    0.15           0.81    6.69
 3.40     87.51      1.35     6.14   0.82    0.14           0.76    6.74
 3.50     90.08      1.28     6.22   0.77    0.13           0.72    6.78
 3.60     92.65      1.20     6.30   0.72    0.12           0.68    6.82
 3.70     95.23      1.13     6.37   0.67    0.12           0.64    6.86
 3.80     97.80      1.07     6.43   0.63    0.11           0.60    6.90
 3.90    100.37      1.00     6.50   0.59    0.10           0.56    6.93
 4.00    102.95      0.94     6.55   0.55    0.09           0.53    6.97
```

```
RIVER DISCHARGE IS     100.00 CFS
COMBINED FLOW IS       115.00 CFS
D.O. AT SATURATION IS    7.50 MG/L

 TIME     DISTANCE    RESULTS OF COMBINED C-N DEMANDS         CARBONACEOUS
  OF       DOWN-      OXYGEN     DO     LA      NH4-N         DEMAND ONLY
TRAVEL    STREAM,     DEFICIT  LEVEL  LEVEL    LEVEL          OXY.     DO
 DAYS      MILES       MG/L     MG/L   MG/L     MG/L         DEFICIT  LEVEL
                                                              MG/L     MG/L

 4.10     105.52       0.89     6.61   0.52     0.09          0.50    7.00
 4.20     108.10       0.83     6.66   0.48     0.08          0.47    7.03
 4.30     110.67       0.78     6.71   0.45     0.08          0.44    7.06
 4.40     113.24       0.74     6.76   0.42     0.07          0.41    7.08
 4.50     115.82       0.69     6.81   0.40     0.07          0.39    7.11
 4.60     118.39       0.65     6.85   0.37     0.06          0.36    7.13
 4.70     120.96       0.61     6.89   0.35     0.06          0.34    7.16
 4.80     123.54       0.57     6.93   0.32     0.06          0.32    7.18
 4.90     126.11       0.54     6.96   0.30     0.05          0.30    7.20
 5.00     128.69       0.50     6.99   0.28     0.05          0.28    7.22
 5.10     131.26       0.47     7.03   0.27     0.05          0.27    7.23
 5.20     133.83       0.44     7.06   0.25     0.04          0.25    7.25
 5.30     136.41       0.42     7.08   0.23     0.04          0.23    7.27
 5.40     138.98       0.39     7.11   0.22     0.04          0.22    7.28
 5.50     141.55       0.37     7.13   0.20     0.04          0.21    7.29
 5.60     144.13       0.34     7.16   0.19     0.03          0.19    7.31
 5.70     146.70       0.32     7.18   0.18     0.03          0.18    7.32
 5.80     149.27       0.30     7.20   0.17     0.03          0.17    7.33
 5.90     151.85       0.28     7.22   0.16     0.03          0.16    7.34
 6.00     154.42       0.26     7.23   0.15     0.03          0.15    7.35
 6.10     157.00       0.25     7.25   0.14     0.02          0.14    7.36
 6.20     159.57       0.23     7.27   0.13     0.02          0.13    7.37
 6.30     162.14       0.22     7.28   0.12     0.02          0.12    7.38
 6.40     164.72       0.20     7.29   0.11     0.02          0.11    7.38
 6.50     167.29       0.19     7.31   0.10     0.02          0.11    7.39
 6.60     169.86       0.18     7.32   0.10     0.02          0.10    7.40
 6.70     172.44       0.17     7.33   0.09     0.02          0.09    7.40
 6.80     175.01       0.16     7.34   0.09     0.01          0.09    7.41
 6.90     177.59       0.15     7.35   0.08     0.01          0.08    7.42
 7.00     180.16       0.14     7.36   0.08     0.01          0.08    7.42
 7.10     182.73       0.13     7.37   0.07     0.01          0.07    7.43
 7.20     185.31       0.12     7.38   0.07     0.01          0.07    7.43
 7.30     187.88       0.11     7.39   0.06     0.01          0.06    7.44
 7.40     190.45       0.11     7.39   0.06     0.00          0.06    7.44
 7.50     193.03       0.10     7.40   0.05     0.00          0.06    7.44
 7.60     195.60       0.09     7.41   0.05     0.00          0.05    7.45
 7.70     198.17       0.09     7.41   0.05     0.00          0.05    7.45
 7.80     200.75       0.08     7.42   0.04     0.00          0.05    7.45
 7.90     203.32       0.08     7.42   0.04     0.00          0.04    7.46
 8.00     205.90       0.07     7.43   0.04     0.00          0.04    7.46
```

```
                                                                    PAGE   4
  RIVER DISCHARGE IS    100.00 CFS
  COMBINED FLOW IS      115.00 CFS
  D.O. AT SATURATION IS    7.50 MG/L

  TIME    DISTANCE   RESULTS OF COMBINED C-N DEMANDS     CARBONACEOUS
   OF      DOWN-     OXYGEN     DO     LA     NH4-N      DEMAND ONLY
 TRAVEL   STREAM,    DEFICIT  LEVEL  LEVEL   LEVEL      OXY.     DO
  DAYS     MILES      MG/L     MG/L   MG/L    MG/L      DEFICIT  LEVEL
                                                          MG/L    MG/L
  8.10    208.47      0.07    7.43   0.04    0.00       0.04    7.46
  8.20    211.04      0.06    7.44   0.03    0.00       0.03    7.46
  8.30    213.62      0.06    7.44   0.03    0.00       0.03    7.47
  8.40    216.19      0.05    7.44   0.03    0.00       0.03    7.47
  8.50    218.76      0.05    7.45   0.03    0.00       0.03    7.47
  8.60    221.34      0.05    7.45   0.03    0.00       0.03    7.47
  8.70    223.91      0.04    7.45   0.02    0.00       0.03    7.47
  8.80    226.49      0.04    7.46   0.02    0.00       0.02    7.48
  8.90    229.06      0.04    7.46   0.02    0.00       0.02    7.48
  9.00    231.63      0.04    7.46   0.02    0.00       0.02    7.48
  9.10    234.21      0.03    7.46   0.02    0.00       0.02    7.48
  9.20    236.78      0.03    7.47   0.02    0.00       0.02    7.48
  9.30    239.35      0.03    7.47   0.02    0.00       0.02    7.48
  9.40    241.93      0.03    7.47   0.02    0.00       0.02    7.48
  9.50    244.50      0.03    7.47   0.01    0.00       0.01    7.48
  9.60    247.08      0.02    7.47   0.01    0.00       0.01    7.48
  9.70    249.65      0.02    7.48   0.01    0.00       0.01    7.49
  9.80    252.22      0.02    7.48   0.01    0.00       0.01    7.49
  9.90    254.80      0.02    7.48   0.01    0.00       0.01    7.49

   MINIMUM DISSOLVED OXYGEN LEVEL =    3.73 MG/L
 OCCURS AT MILE    25.74 DOWNSTREAM OF DISCHARGE POINT
 AT CRITICAL TRAVEL TIME OF    1.00 DAYS
 MINIMUM DO FOR AQUATIC HABITAT IS    4.00 MG/L
```

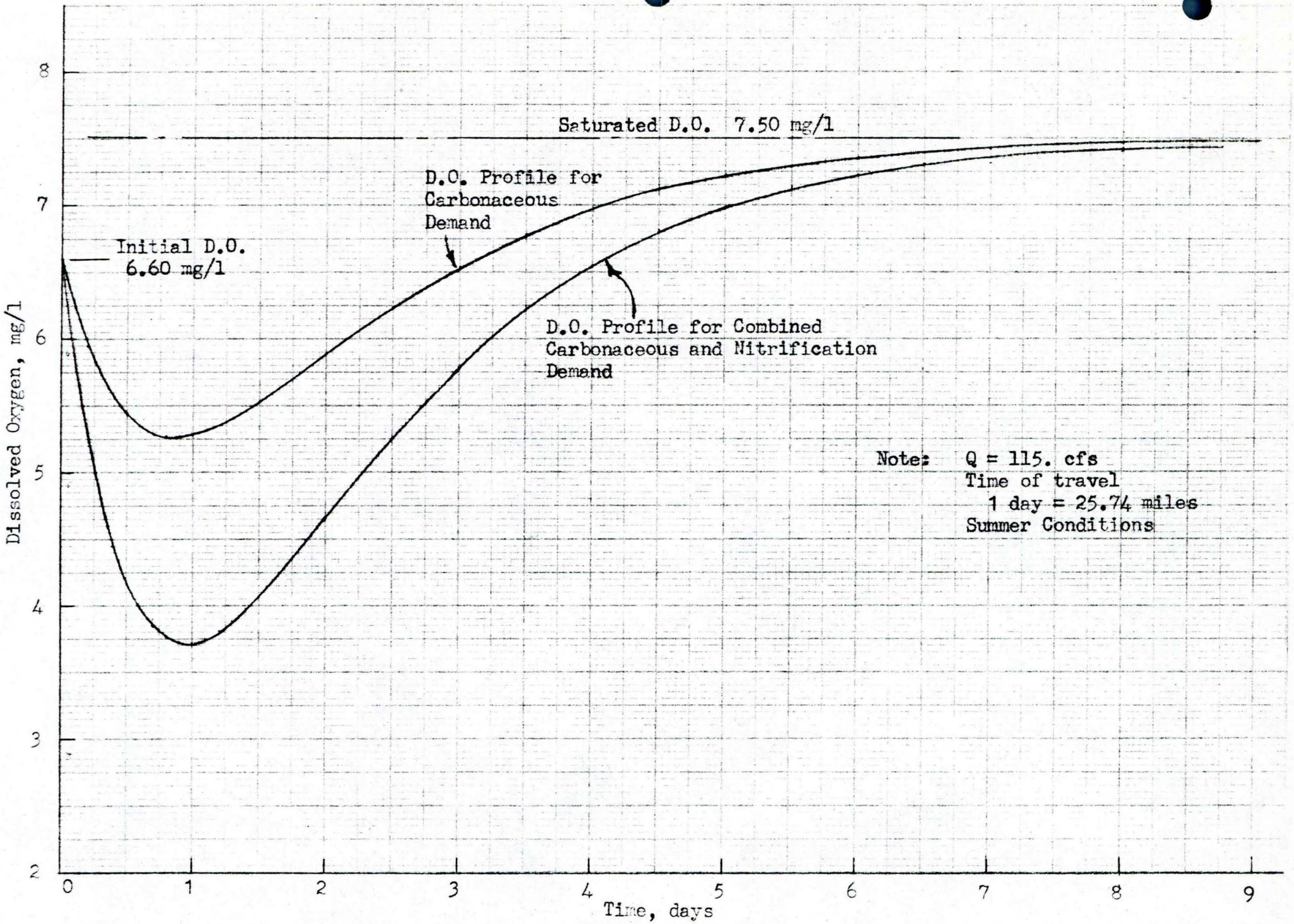

Figure 9. Dissolved oxygen profiles for sample problem no. 1, Skunk River at Ames, Iowa.

G. Sample Problem #2

For Skunk River at Ames, and for winter conditions.

Includes nitrification, with results for carbonaceous organic loading in right hand two columns. Computer solution on following pages.

```
            OXYGEN BALANCE IN SURFACE WATERS

        DEPLETION CAUSED BY WASTE EFFLUENTS AT A POINT SOURCE
      OXYGEN DEMAND FOR CARBONACEOUS AND NITRIFICATION DEMANDS
                       BOD-C  AND  BOD-N



      SOLUTION FOR  DOUGAL, M.D., CE 524, AMES RES.

        NAME OF STREAM **   SKUNK RIVER

         DOWNSTREAM OF ** AMES, IOWA

         CALCULATIONS ARE FOR ** WINTER   ** CONDITIONS

      COEFFICIENTS AT 20 DEG. CENTIGRADE ARE
                                         RIVER     EFFLUENT
      1. DEOXYGENATION, BOD-C            0.100     0.100
      2. NITRIFICATION, BOD-N            0.100
      3. REOXYGENATION                   0.050
      4. RIVER VELOCITY, V =   0.10*Q**0.50

    MINIMUM DISSOLVED OXYGEN LEVEL FOR AQUATIC LIFE IS        4.00 MG/L
      CALCULATIONS FOR THIS ANALYSIS BEGIN WITH

               INITIAL RIVER DISCHARGE    50.00 CFS
               INCREMENT OF INCREASE      10.00 CFS
               MAXIMUM DISCHARGE         150.00 CFS
               INCREMENT OF TIME           0.20 DAYS
               MAXIMUM TIME OF TRAVEL     20.00 DAYS
```

```
          RESULTS OF OXYGEN DEPLETION STUDY                      PAGE  1

   SOLUTION FOR  DOUGAL, M.D., CE 524, AMES RES.

      NAME OF STREAM **    SKUNK RIVER

       DOWNSTREAM OF ** AMES, IOWA

       CALCULATIONS ARE FOR ** WINTER    ** CONDITIONS


   BASIC DATA FOR THE RIVER, EFFLUENT, AND COMBINED MIXTURE ARE

              BOD-C   ULT   AMMON.   ULT   PER-  INIT.  TEMP.  DESIGN
              5-DAY  BOD-C  NH4-N   BOD-N  CENT   DO    DEG.   FLOW
              20DEG  20DEG                 SAT.         CENT.
     FOR      MG/L   MG/L    MG/L   MG/L    DO   MG/L           CFS

    RIVER      2.00   2.92   0.01    0.05 90.00  12.44   1.00 120.00

   EFFLUENT   60.00  87.75  25.00  114.23 50.00   5.47  10.00  15.00

   MIXTURE     8.44  12.35   2.79   12.73 86.75  11.67   2.00 135.00


   COMBINED DISCHARGE IS   135.00 CFS

   VELOCITY IS   1.16 MPH OR  27.89 MPD

   TEMPERATURE OF COMBINED FLOW IS   2.00 DEG. C. OR  35.60 DEG. F.

      COEFFICIENTS AT THIS TEMPERATURE ARE

            KD= 0.044      KN= 0.044      KR= 0.038

   LA=   7.90 MG/L,  INITIAL DO=  11.67 MG/L

   DO, SATURATION=  13.45 MG/L,  INITIAL DO DEFICIT=   1.78 MG/L


   RESULTS FOR CARBONACEOUS DEMAND ONLY

         RIVER DISCHARGE =        120.00 CFS
         COMBINED DISCHARGE =    135.00 CFS

         MINIMUM DISSOLVED OXYGEN LEVEL =     9.54 MG/L

         OCCURS AT MILE  236.98 DOWNSTREAM OF DISCHARGE POINT
         AT CRITICAL  TIME OF    8.50 DAYS
```

```
                                                                        PAGE   2
  RIVER DISCHARGE IS     120.00 CFS
  COMBINED FLOW IS       135.00 CFS
  D.C. AT SATURATION IS   13.45 MG/L

  TIME    DISTANCE    RESULTS OF COMBINED C-N DEMANDS        CARBONACEOUS
   OF      DOWN-      OXYGEN      DO      LA      NH4-N      DEMAND ONLY
 TRAVEL,  STREAM,     DEFICIT   LEVEL   LEVEL    LEVEL        OXY.     DO
  DAYS     MILES       MG/L      MG/L    MG/L     MG/L       DEFICIT  LEVEL
                                                               MG/L    MG/L
   0.20      5.58      2.16    11.29    7.75     2.73          1.91   11.54
   0.40     11.15      2.52    10.92    7.59     2.68          2.03   11.42
   0.60     16.73      2.87    10.58    7.44     2.62          2.14   11.30
   0.80     22.31      3.21    10.24    7.29     2.57          2.25   11.19
   1.00     27.89      3.53     9.92    7.15     2.52          2.36   11.09
   1.20     33.46      3.84     9.61    7.00     2.47          2.46   10.99
   1.40     39.04      4.13     9.32    6.86     2.42          2.56   10.89
   1.60     44.62      4.41     9.03    6.73     2.37          2.65   10.80
   1.80     50.19      4.69     8.76    6.59     2.32          2.74   10.71
   2.00     55.77      4.95     8.50    6.46     2.28          2.82   10.63
   2.20     61.35      5.20     8.25    6.33     2.23          2.90   10.55
   2.40     66.93      5.43     8.01    6.21     2.19          2.97   10.47
   2.60     72.50      5.66     7.79    6.08     2.14          3.05   10.40
   2.80     78.08      5.88     7.57    5.96     2.10          3.11   10.33
   3.00     83.66      6.08     7.36    5.84     2.06          3.18   10.27
   3.20     89.23      6.28     7.17    5.73     2.02          3.24   10.21
   3.40     94.81      6.47     6.98    5.61     1.98          3.30   10.15
   3.60    100.39      6.65     6.80    5.50     1.94          3.35   10.10
   3.80    105.96      6.82     6.63    5.39     1.90          3.40   10.04
   4.00    111.54      6.98     6.47    5.28     1.86          3.45   10.00
   4.20    117.12      7.13     6.31    5.18     1.83          3.50    9.95
   4.40    122.70      7.28     6.17    5.07     1.79          3.54    9.91
   4.60    128.27      7.41     6.03    4.97     1.75          3.58    9.87
   4.80    133.85      7.54     5.90    4.87     1.72          3.62    9.83
   5.00    139.43      7.67     5.78    4.78     1.68          3.65    9.80
   5.20    145.00      7.78     5.67    4.68     1.65          3.68    9.77
   5.40    150.58      7.89     5.56    4.59     1.62          3.71    9.74
   5.60    156.16      7.99     5.46    4.50     1.59          3.74    9.71
   5.80    161.74      8.09     5.36    4.41     1.55          3.76    9.68
   6.00    167.31      8.17     5.27    4.32     1.52          3.79    9.66
   6.20    172.89      8.26     5.19    4.23     1.49          3.81    9.64
   6.40    178.47      8.33     5.11    4.15     1.46          3.82    9.62
   6.60    184.04      8.41     5.04    4.07     1.43          3.84    9.61
   6.80    189.62      8.47     4.98    3.98     1.40          3.85    9.59
   7.00    195.20      8.53     4.92    3.90     1.38          3.87    9.58
   7.20    200.78      8.59     4.86    3.83     1.35          3.88    9.57
   7.40    206.35      8.64     4.81    3.75     1.32          3.89    9.56
   7.60    211.93      8.68     4.76    3.68     1.30          3.90    9.55
   7.80    217.51      8.72     4.72    3.60     1.27          3.90    9.55
   8.00    223.08      8.76     4.69    3.53     1.24          3.91    9.54
```

```
                                                                    PAGE  3
RIVER DISCHARGE IS     120.00 CFS
COMBINED FLOW IS       135.00 CFS
D.O. AT SATURATION IS   13.45 MG/L

 TIME     DISTANCE    RESULTS OF COMBINED C-N DEMANDS          CARBONACEOUS
  OF       DOWN-      OXYGEN      DO       LA      NH4-N        DEMAND ONLY
TRAVEL,   STREAM,     DEFICIT   LEVEL    LEVEL    LEVEL         OXY.     DO
 DAYS      MILES       MG/L      MG/L     MG/L     MG/L         DEFICIT  LEVEL
                                                                 MG/L    MG/L

  8.20    228.66       8.79      4.66     3.46     1.22          3.91    9.54
  8.40    234.24       8.82      4.63     3.39     1.20          3.91    9.54
  8.60    239.81       8.84      4.60     3.32     1.17          3.91    9.54
  8.80    245.39       8.86      4.58     3.26     1.15          3.91    9.54
  9.00    250.97       8.88      4.57     3.19     1.13          3.91    9.54
  9.20    256.55       8.89      4.56     3.13     1.10          3.90    9.55
  9.40    262.12       8.90      4.55     3.07     1.08          3.90    9.55
  9.60    267.70       8.91      4.54     3.01     1.06          3.89    9.56
  9.80    273.28       8.91      4.54     2.95     1.04          3.88    9.56
 10.00    278.85       8.91      4.54     2.89     1.02          3.87    9.57
 10.20    284.43       8.90      4.54     2.83     1.00          3.87    9.58
 10.40    290.01       8.90      4.55     2.77     0.98          3.85    9.59
 10.60    295.59       8.89      4.56     2.72     0.96          3.84    9.60
 10.80    301.16       8.88      4.57     2.66     0.94          3.83    9.62
 11.00    306.74       8.86      4.59     2.61     0.92          3.82    9.63
 11.20    312.32       8.84      4.60     2.56     0.90          3.80    9.64
 11.40    317.89       8.82      4.62     2.51     0.88          3.79    9.66
 11.60    323.47       8.80      4.65     2.46     0.87          3.77    9.67
 11.80    329.05       8.78      4.67     2.41     0.85          3.76    9.69
 12.00    334.63       8.75      4.70     2.36     0.83          3.74    9.71
 12.20    340.20       8.72      4.72     2.31     0.82          3.72    9.72
 12.40    345.78       8.69      4.75     2.27     0.80          3.71    9.74
 12.60    351.36       8.66      4.79     2.22     0.78          3.69    9.76
 12.80    356.93       8.63      4.82     2.18     0.77          3.67    9.78
 13.00    362.51       8.59      4.86     2.13     0.75          3.65    9.80
 13.20    368.09       8.55      4.89     2.09     0.74          3.63    9.82
 13.40    373.66       8.52      4.93     2.05     0.72          3.61    9.84
 13.60    379.24       8.47      4.97     2.01     0.71          3.58    9.86
 13.80    384.82       8.43      5.01     1.97     0.69          3.56    9.88
 14.00    390.40       8.39      5.06     1.93     0.68          3.54    9.91
 14.20    395.97       8.35      5.10     1.89     0.67          3.52    9.93
 14.40    401.55       8.30      5.15     1.85     0.65          3.50    9.95
 14.60    407.13       8.25      5.19     1.82     0.64          3.47    9.97
 14.80    412.70       8.21      5.24     1.78     0.63          3.45   10.00
 15.00    418.28       8.16      5.29     1.74     0.61          3.42   10.02
 15.20    423.86       8.11      5.34     1.71     0.60          3.40   10.05
 15.40    429.44       8.06      5.39     1.68     0.59          3.38   10.07
 15.60    435.01       8.00      5.44     1.64     0.58          3.35   10.10
 15.80    440.59       7.95      5.50     1.61     0.57          3.33   10.12
 16.00    446.17       7.90      5.55     1.58     0.56          3.30   10.15
```

```
                                                                   PAGE  4
     RIVER DISCHARGE IS     120.00 CFS
     COMBINED FLOW IS       135.00 CFS
     D.O. AT SATURATION IS  13.45 MG/L

     TIME    DISTANCE     RESULTS OF COMBINED C-N DEMANDS      CARBONACEOUS
      OF      DOWN-       OXYGEN     DO     LA     NH4-N       DEMAND ONLY
    TRAVEL,  STREAM,      DEFICIT  LEVEL  LEVEL   LEVEL        OXY.     DO
     DAYS     MILES        MG/L     MG/L   MG/L    MG/L        DEFICIT LEVEL
                                                                MG/L   MG/L
     16.20   451.74        7.84    5.60   1.55    0.54          3.28  10.17
     16.40   457.32        7.79    5.66   1.51    0.53          3.25  10.20
     16.60   462.90        7.73    5.71   1.48    0.52          3.22  10.22
     16.80   468.47        7.68    5.77   1.46    0.51          3.20  10.25
     17.00   474.05        7.62    5.83   1.43    0.50          3.17  10.28
     17.20   479.63        7.56    5.88   1.40    0.49          3.15  10.30
     17.40   485.21        7.51    5.94   1.37    0.48          3.12  10.33
     17.60   490.78        7.45    6.00   1.34    0.47          3.09  10.35
     17.80   496.36        7.39    6.06   1.32    0.46          3.07  10.38
     18.00   501.94        7.33    6.12   1.29    0.45          3.04  10.41
     18.20   507.51        7.27    6.17   1.26    0.45          3.01  10.43
     18.40   513.09        7.21    6.23   1.24    0.44          2.99  10.46
     18.60   518.67        7.15    6.29   1.21    0.43          2.96  10.49
     18.80   524.25        7.09    6.35   1.19    0.42          2.93  10.51
     19.00   529.82        7.03    6.41   1.17    0.41          2.91  10.54
     19.20   535.40        6.97    6.47   1.14    0.40          2.88  10.57
     19.40   540.98        6.91    6.54   1.12    0.39          2.85  10.59
     19.60   546.55        6.85    6.60   1.10    0.39          2.83  10.62
     19.80   552.13        6.79    6.66   1.08    0.38          2.80  10.65
     20.00   557.71        6.73    6.72   1.05    0.37          2.77  10.67

       MINIMUM DISSOLVED OXYGEN LEVEL =    4.54 MG/L
     OCCURS AT MILE  273.28 DOWNSTREAM OF DISCHARGE POINT
     AT CRITICAL TRAVEL TIME OF    9.80 DAYS
     MINIMUM DO FOR AQUATIC HABITAT IS    4.00 MG/L

       REQUIRED RIVER DISCHARGE TO MEET DO STANDARD
           IS  120.00 CFS, OR COMBINED Q OF  135.00 CFS
```

V. ADDITIONAL FACTORS INFLUENCING DEOXYGENATION AND REOXYGENATION, AND THE OXYGEN RELATIONSHIP

A. River "k" versus laboratory "k" as coefficient of deoxygenation.

1. Additional romoval of BOD in river by

   a. Adsorption on attached acquatic plants, and related biological activity (rocks, growths, etc. act as trickling filter).

   b. Sedimentation — (or scour during periods of increasing discharge)

   c. Flocculation

   d. Volatilization of organic acids

   e. Longitudinal mixing

2. River analysis yields

$$K_r = \frac{\log L_A - \log L_B}{t}$$

L_A = ultimate, 1st stage BOD at downstream station

t = time of travel

K_r = coefficient of deoxygenation, base 10, for river

3. Let $K_3 = K_r - K_1$

   a. Then explain or correlate K_3 to other river variables.

   b. can modify equations for $K_1 + K_3$, etc.

B. Nitrification of Ammonia.

1. Effluents have 20-30 mg/l total nitrogen, as N-Nitrogen, and 1/3 to 2/3 or more can be as ammonia nitrogen.
2. Metabolic breakdown is: organic nitrogen to ammonia to nitrites to nitrates.
3. Basic problem - nitrification of ammonia to nitrates by stream biota.
4. Overall reaction for nitrification

$$NH_4OH + 2O_2 \longrightarrow HNO_3 + 2H_2O$$

$\underline{14}$-N $\underline{64}$-O (Molecular weight ratio)

5. Requires 4.569 mg/l oxygen for each mg/l ammonia, as N-nitrogen.
6. If use first order reaction, remaining ammonia nitrogen is:

$$N = N_a 10^{-K_n t}$$

where N = ammonia nitrogen at time, t,

N_a = initial amount of ammonia nitrogen

K_n = coefficient of nitrification.

7. Major problem — how much ammonia nitrified by bacteria, how much used directly by algae.

C. Sludge deposits

1. Was major problem with raw sewage discharged to river
2. Should be minor problem <u>with</u> secondary treatment.
3. Streeter developed equation:

$$L_d = \frac{p_d}{(1-e^{-k'})}\ (1 - e^{-k't})$$

$$= \frac{p_d}{2.3\,'}\ (1 - 10^{-K't})$$

L_d = cumulative BOD in pounds (or same units as p_d)

p_d = BOD added to deposit in pounds per day, or possibly mg/l

$k' = 2.3K'$ = specific rate of oxidation of the deposit

K' = 0.03 to 0.05 according to Streeter, at 25°C.

4. Application best made by subdividing waste discharge into
   a. BOD of suspended, colloidal, and dissolved material.
   b. BOD of settleable solids.
   c. Use "truck load" approach developed by Velz. See USHEW, PHS Report W58-2: 47-61, 1958.

D. Background ~~on~~ or boundary addition of organic material along river.

1. Material washing in from adjacent lands, air, or river boundary, including perhaps dying algae.
2. Can accomodate it in mathematical models if considerate uniform addition.

E. Influence of Algae on Stream Environment

1. Can be of major importance in many rivers, especially with heavy nutrient loads being discharged to stream.
2. Diurnal cycle to algae effects.
   a. Photo-synthesis in daytime, in addition to continuous respiration rate.
      i. contributes oxygen to water body
      .i. Can experience super-saturation of dissolved oxygen, in excess of 20-30 mg/l.

   b. Respiration only at night.
      i. exerts additional oxygen demand upon stream

3. Equation for conversion to protoplasm.

$$6CO_2 + 6H_2O + 672\text{ K Cal.} \underset{\text{respiration}}{\overset{\text{sunlight \& chlorophyl}}{\rightleftarrows}} C_6H_{12}O_6 + 6O_2$$

4. Have two major types to consider
   a. Planktonic forms moving with streams
   b. Fixed algae or attached aquatic plants
5. Parameters
   a. P = photosynthesis
      R = respiration
      P - R = instantaneous production rate
      P/R = ratio of P to R at anytime
   b. Other parameters
      light intensities
      nutrients
      temperature
      stream boundary and flow characteristics
6. Evaluation
   a. Light and dark bottle technique (BOD battle) for planktonic forms of algae.
   b. River evaluation for fixed forms of algae or algal chamber method using area sample of fixed algae from river.
7. Typical oxygen production values
   a. Ohio River P = 57 lbs per acre per day
      R = 45 lbs per acre per day
      P/R = 1.3
   b. Sewage Pond, S. Dakota P = 183 lbs/ac/day
      R = 130 lbs/ac/day
      P/R = 1.4
   c. Truckee River at Reno Nevada
      i. Peak values P = 126 lbs/ac/day
         R = 115 lbs/ac/day
         P/R = 1.1

ii Average values P =72.5 lb/ac/day

R = 64.5 lb/ac/day

P/R = 1.1

or P = 21 mg/l/gay

R = 20 mg/l/day

with max. P of 2.4 mg/l/hour

d. TVA studies, typical results

   i. P/R values, 1.4 to as high as 6.0---many around 2 to 4

   ii Typical max. daily P rate P = 0.72 mg/l per hour

   iii. Average value for R R = 0.15 - 0.18 mg/l per hour

e. Ohio River

   i. Photosynthesis, P = 1.4 mg/l/hour maximum during day, at 0.5 ft. depth.

   ii. Respiration — 0.3 - 0.5 mg/l/hour

8. How to include in oxygen-sag equations??

   a. O'Connel & Thomas

$$\frac{dD}{dt} = kL - rD - (P-R)$$

   using (P-R) as a mg/l per day average.

   b. Actually, should have

   P-R = f (time)

   c. Possible use of sine or cosine functions

      i. half-wave or full-wave

      ii. complicates mathematics

F. Additional points of effluent discharge

   1. Recompute mixture values, then reapply oxygen-sag equation.

   2. Use differential equation form and successive computational steps down the river.

G. Additional tributary and ground water inflow into river, and miscellaneous effects.

   1. Tributary inflow at known point but must know stream quantity and quality characteristics.

   2. Ground water contribution usually adds increment of discharge for each mile of stream, or general increase in Q as Drainage area, D.A., increases.

3. Miscellaneous effects.
   a. Diurnal temperature pattern in air and water will affect saturated D. O. values.
   b. Dispersion concepts and influences

      Slugs rapidly dispersed in most streams with good velocity, or with riffle and pool sequence.

H. Combining some of these additional influences, for computing oxygen deficit.
1. River behavior mathematical model

$$D = D_a e^{-rt} \qquad \text{(a)}$$

$$+ \frac{k}{r-k} L_a (e^{-kt} - e^{-rt}) \qquad \text{(b)}$$

$$+ \frac{k}{r} P (1-e^{-rt}) - \frac{k}{r-k} P (e^{-kt} - e^{-rt}) \qquad \text{(c)}$$

$$+4.57 \frac{n}{r-n} N_a (e^{-nt} - e^{-rt}) \qquad \text{(d)}$$

$\pm$ Algae effects (daytime O_2 contribution, night-time respiration) (e)

(Need modifications if $r = k$, $r = n$, $k = n$, or $r = k = n$)

2. Explanation of items in (1)
   a. removing initial oxygen deficit
   b. oxygen demand of remaining carbonaceous material

      $$L = L_a e^{-kt}$$

   c. uniform contribution to stream of carbonaceous organic material, per day.

      $P = \frac{p}{(1-e^{-k})}$, p in mg/l

      This can be converted to per mile basis using discharge vs. velocity vs. time relationship

   d. Nitrification of ammonia by bacteria. $N = N_a e^{-nt}$ for decrease in ammonia nitrogen, and oxygen demand

      $(O_2)_N = N_a (1-e^{-nt})$ (4.57)

e. Evaluate effect of algae
  i. Some approaches make use of P/R ratios
  ii Envelope curve approach at I. S. U., using trigonometric functions
    ---daytime photosynthesis envelope curve
    ---nighttime respiration envelope curve
  iii. Note — Algae may have a substantial effect in Dissolved Oxygen levels, FWPCA desires to sample river just before daylight, evaluate this as critical condition.

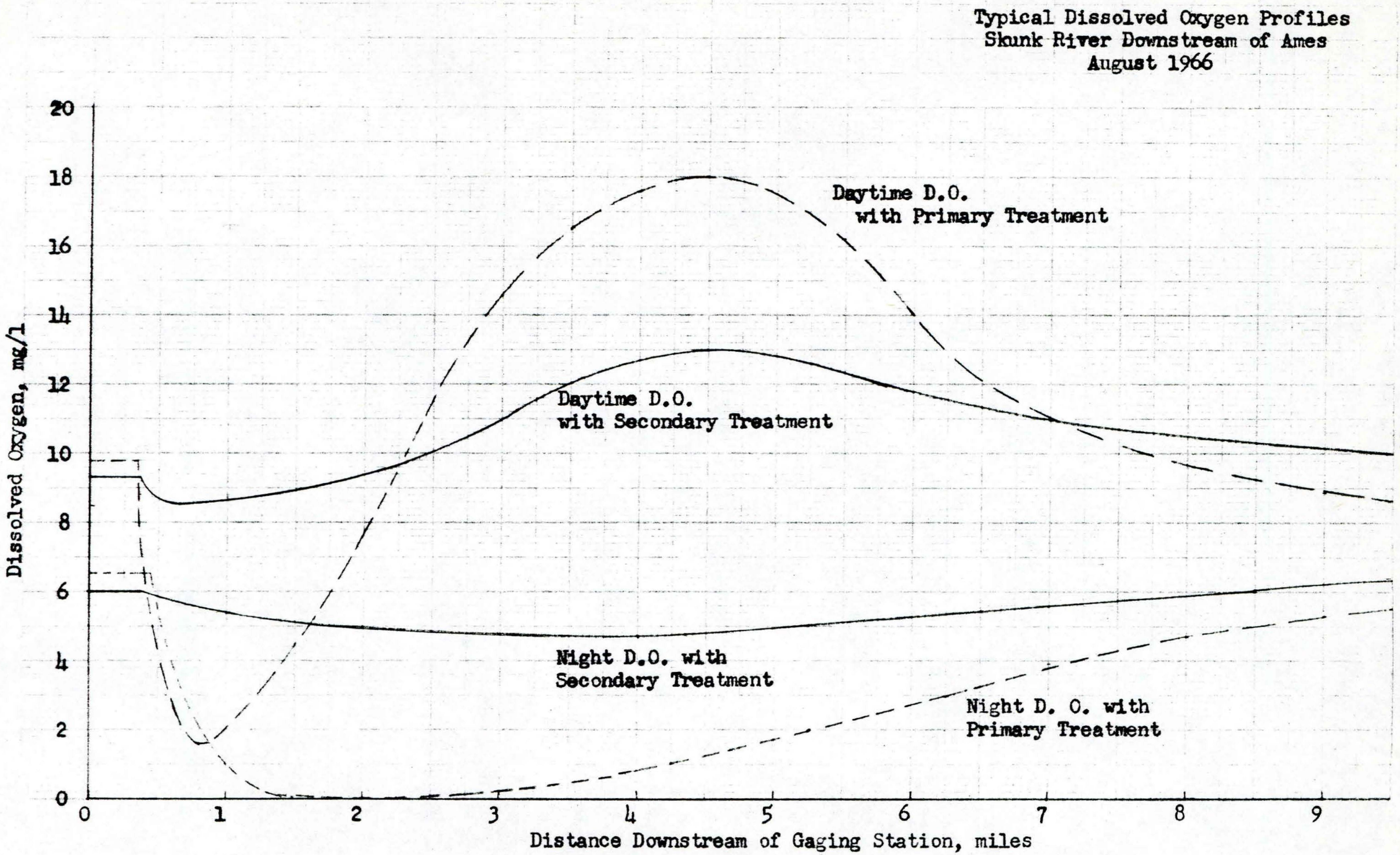

Figure 10. Typical dissolved oxygen profiles for daytime and nighttime, illustrating D.O. envelope curves for the reach downstream of Ames, Iowa.

VI. STATEWIDE NEEDS FOR FUTURE DESIGN DATA

1. Consider in standards and in design the low-flow variability in several regions.
2. Study, determine time-of-travel data for Iowa streams.
3. Additional waste assimilation and river behavior studies.
4. Expanded river sampling network, continuous monitoring stations.
5. Use of probability concepts versus absolute limits on water quality parameters.
6. Other considerations.

60
30