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A Study of Assimilative Capacities for Receiving Streams

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A STUDY OF ASSIMILATIVE
CAPACITIES FOR RECEIVING STREAMS

By

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RESEARCH REPORT

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A STUDY OF ASSIMILATIVE CAPACITIES
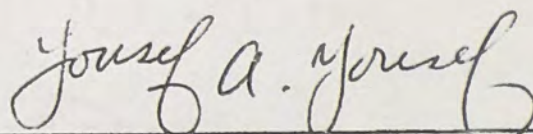## FOR RECEIVING STREAMS

by

Hadi Elmi

Abstract

Literature review on various stream processes which contribute to reoxygenation and deoxygenation was presented. These processes include atmospheric reaeration, photosynthesis-respiration, biochemical oxygen consumption, and benthic demand. Measuring these parameters in a selected stream is a complex and costly operation. On the other hand, prediction models developed are specific to particular location and environmental conditions and can only be applied to similar situations.

Computer models such as "RIVER" are available and could be used to predict dissolved oxygen concentrations along a waterway for a specified set of stream conditions. The model "RIVER" was calibrated by using the existing conditions of flow and water quality parameters along Phillippi Creek, Sarasota County, Florida. Also treatment requirements which could eliminate dissolved oxygen violations were predicted.

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Director of Research Report

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CHAPTER I

INTRODUCTION

Streams are one of our most important natural resources. Streams have life and economic values. Life values, consist of providing water and food for living beings, and beautification to our environment. The economic values are illustrated by their usage for drinking, industrial and irrigation water sources. Also they have many other benefits such as transportation, recreation, fish propagation, etc.; therefore, there is a great need to keep our streams pollution free.

The concentration of dissolved oxygen is one of the most important criteria in stream pollution control (1). The discharge of municipal and industrial waste into a natural body of running water presents a primary concern in this regard (2). The decomposition of waste by bacteria results in utilization of dissolved oxygen. Reaeration (2) by the atmosphere puts the oxygen back into the water; however, there is a limit (2) for reaeration.

A minimum dissolved oxygen of 4.0 to 5.0 mg/l should be maintained in streams as specified by Chapter 17-3, Florida State regulations. This dissolved oxygen concentration is influenced by oxygen sources and sinks. A delicate balance exists between the amount of oxygen being used and the amount of oxygen put into the system.

The basic oxygen balance relationship which includes dominant sources and sinks can be expressed as follows:

$$D = \frac{K_d L_i}{K_a - K_r} (e^{Jrx} - e^{Jax}) + \frac{K_n N_i}{K_a - K_n} (e^{Jnx} - e^{Jax}) + \frac{R-P}{K_a}$$

$$(1 - e^{Jax}) + \frac{S}{Ra} (1 - e^{Jax}) + \frac{B}{Ka} (1 - e^{Jax}) + D_i \, e^{Jax}$$

where:
D = dissolved oxygen deficit at x, mg/l

Di = dissolved oxygen deficit at x = 0, mg/l

Li = ultimate carbonaceous BOD (CUOD) at x = 0, mg/l

Ni = ultimate nitrogenous BOD (NUOD) at x = 0, mg/l

K_d = first order carbonaceous BOD oxygen utilization rate coefficient for segment, /day

K_n = nitrogenous BOD oxygen utilization rate coefficient for segment, /day

K_r = carbonaceous BOD removal rate coefficient for segment, /day

K_a = reaeration rate coefficient for segment, /day

P = photosynthetic oxygen production rate, mg/l/day

R = algal respiration rate, mg/l/day

S = benthic oxygen demand rate, mg/l/day

B = uniformly distributed background oxygen demand rate, mg/l/day

Jr = K_r A/Q

Jn = K_n A/Q

Ja = K_a A/Q

Q = freshwater stream flow, cfs

A = cross sectional area, ft^2

X = distance, ft

The theory and nomenclature used in the model are those used by O'Connor and the computer program "River" is used to develop the assimilative capacity of fresh water streams (3).

It should be noted that this model assumes first order decay kinetics for carbonaceous BOD and nitrogenous BOD. First order kinetics of carbonaceous BOD has been used extensively in stream oxygen analyses. Also, it has been established that the oxidation of nitrogenous BOD can be adequately represented by first order kinetics (4).

Other oxygen sources and sinks include algal photosynthesis and respiration and benthel demand for bottom deposits in streams. Photosynthesis-respiration effects may be ignored for the following reasons:

1. Photosynthesis generally exceeds respiration which results in a slight net gain of dissolved oxygen added to the water body. Therefore, neglecting those terms will reduce slightly the predicted dissolved oxygen.

2. It may be difficult to accurately define their effect for a particular stream reach without extensive and costly studies.

3. Stream water which contains high color intensity from swamp drainage would not support substantial photosynthetic activities.

Oxygen uptake by bottom sediments from different localities of fresh and brackish water has been studied by various investigators and is found to vary between 0.07 and 7.0 $gm/m^2/day$ at $20^{\circ}C$ (5,6,7). Some of these rates may exert a significant effect on the oxygen

deficit in streams, expecially at low flow conditions when the volume of water column per unit area is minimum. Detailed analysis for oxygen sources and sinks will be presented in the following chapters.

Objective and Scope

The broad objective of this research report is to study the assimilative capacities for receiving water bodies. The assimilative capacity will be based on the oxygen balance in streams.

Specifically, a literature review of oxygen source and sinks will be made. Factors such as hydrodynamic characteristics, deoxygenation, reaeration, photosynthesis-respiration processes and benthic demand for streams will be evaluated. The literature survey will aid in selection of input data for water bodies similar to the Sarasota County area. Particularly, the dissolved oxygen deficit for Phillippi Creek will be determined under various conditions using a computer model "RIVER." From the the existing water quality measurements along Phillippi Creek and effluent characteristics of wastewater treatment plants, it will be possible to calibrate the computer model "RIVER." After calibration of the model, types of treatment required to keep the dissolved oxygen at a minimum of 5 mg/l in Phillippi Creek will be developed.

CHAPTER II

DEOXYGENATION

Deoxygenation is the consumption of dissolved oxygen in natural streams resulting from biochemical oxygen demand (CBOD, NBOD), benthic oxygen demand (oxygen demanding material in the bottom mud of a stream), and respiratory requirements of aquatic plants. These oxygen sinks will be discussed as follows:

Biochemical Oxygen Demand

Biochemical oxygen demand is defined as the oxygen required for degradation of organic material by aerobic decomposition. It includes the biodegradation of carbonaceous matter (CBOD), and the nitrogeneous content (NBOD). CBOD could be represented by the following mathematical equation:

$$Y = L \left(1 - e^{K_d t}\right)$$

or

$$Y = L \left(1 - 10^{k_d t}\right)$$

where: Y = BOD satisfied at time t (mg/l)

L = ultimate first stage BOD (mg/l)

The nitrogeneous matter (NBOD) could be stochiometrically calculated from the following equation (8).

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + H_2O + 2H^+$$
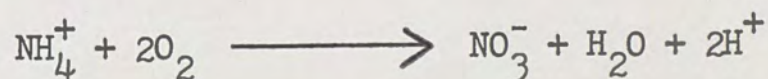
This equation indicates that 64 grams of oxygen are required to oxidize 17 grams of ammonia; therefore,

$$NBOD = 4.57 \ TON$$

where: TON = total organic nitrogen

Mathematically, the coefficient decay rate (k_d) can be calculated from laboratory and/or field measurements of the BOD values at various time intervals. Four different methods; namely, the least square method, the slope method, the moment method, and the logarithmic method are used in the calculation of k_d. The four methods are extensively explained and demonstrated in literature (9).

The organic matter in a natural stream is not oxidized in the same fashion as it is determined by a BOD test. In order to determine the reaction constant for a stream it is necessary to determine the BOD of stream samples at successive stations downstream from the source of pollution. Also the time of travel between the source of pollution and measuring station is required. Then it's possible to find the rate of removal of organic matter from a curve showing the 5-day BOD values versus time of flow along the stream. The rate of removal can be expressed as (10):

$$K_r = \frac{1}{t} \ \log \frac{L_A}{L_B} \tag{2-2}$$

where: K_r = rate of BOD removal in stream

      t = time of travel between stations

      L_A = BOD_5 upstream at point A

      L_B = BOD_5 downstream at point B

It should be noted that K_r is the rate of removal not necessarily the rate of oxidation. In considering the difference between laboratory and stream rate of removal, the following factors should be considered (10):

    a. Factors Effecting Rate of Removal in Stream:

        1. Sedimentation and flocculation: organic matter may settle at the bottom of a river which decreases the amount of BOD (benthal system).

        2. Scour: organic matter which settles down previously, may be resuspended by high velocity flow and add to the load which decreases the rate of removal.

        3. Volatilization: certain organic compounds may react with end products in the benthal system and escape as gases, i.e., H_2S, CO_2, CH_4.

    b. Factors Effecting Rate of Oxidation in Streams:

        1. Turbulence: turbulence increases the speed of many chemical reactions, therefore, this factor increases the rate of oxidation.

        2. Biological growth on stream bed: in rock type stream bed, this factor increases the rate of oxidation.

        3. Immediate demand: some wastes which contain reduced chemical compounds may require immediate oxygen demand.

        4. Nutrient: the amount of nutrient significantly affects the rate of bacterial growth in streams, which in turn affects the rate of oxidation.

Thomas (10) has proposed the following equation:

$$K_r(\text{river}) = K_3 + K_d(\text{laboratory})$$

When organic waste is removed by any of the above factors, K_3 is

positive and then when it is added to flowing water and measured at

a downstream station, K_3 would be negative.

Another method of predicting the rate of BOD removal, K_r,

is (11):

$$K_r = K_d + (V/D)n \qquad (2-3)$$

where: K_r = stream removal rate coefficient (base e)

K_d = bottle rate coefficient (base e)

n = coefficient of bed activity

V = stream velocity, ft/sec

D = stream depth, ft

The coefficient n is taken as a step function of stream slope and is

given in Table 2-1.

TABLE 2-1

CHANGES IN COEFFICIENT OF BED ACTIVITIES
BY STREAM SLOPE

Stream Slope (ft/mi)	n
2.5	.1
5.0	.15
10.0	.25
25.0	.4
50.0	.6

In Tables 2-2 and 2-3 some range values of BOD decay coeffi-

cient, removal coefficient, and deoxygenation coefficient are given.

The rate of deoxygenation has been found to be a function of

temperature. The formulation of temperature function is as follows:

TABLE 2-2

CARBONACEOUS AND NITROGENEOUS REMOVAL
RATES IN STREAMS (Base e) (5)

Variables	Coefficient	Values 1/day	Remark
CBOD	K_r	1.0-3.0	reflects settling and/ or shallow stream with high oxidation
CBOD	K_r	0.6-1.0	some settling
CBOD	K_d	0.1-0.6	normal BOD rates
NBOD	K_n	0.1-0.6	normal range

TABLE 2-3

DEOXYGENATION RATES FOR SOME SELECTED
RIVERS (10)

River	Flow (cfs)	Temp (^oC)	BOD_5 (mg/1)	K_d	K_r	Comments
Elk	5	12	52	3.0	3.0	shallow rocky stream
Hudson	620	22	13	0.15	1.7	bio & chem oxdation & rock bed
Wabash	2800	25	14	0.3	0.75	sedimentation of organic matter
Wilemette	3800	22	4	0.2	1.0	------------------

$$\frac{K_a}{K_b} = \theta^{(T_1 - T_2)} = e^{C(T_1 - T_2)} \qquad (2\text{-}4)$$

where: K_a, K_b = rate of velocity constant at temperature T_1 and T_2

θ = temperature coefficient

Streeter and Phelps found that $\theta = 1.047$ (9). Theriault found that for every degree centigrade increase in temperature after $20^{\circ}C$, the ultimate oxidizability is increased by two percent (9). Then Streeter and Phelps found that $1^{\circ}C$ increase not only increased the ratio of 1.047, but also increased the ultimate oxidizability (9).

Benthal Oxygen Demand

The discharge of settleable waste often results in sludge deposit formation. These deposits may build up, if the river velocities are too low. Also, if the depth of the river increases an anaerobic condition may occur. An anaerobic condition will produce CO_2, CH_4, and H_2S. If the gas production is considerably high, it will cause the floating of sludge which indeed causes aesthetic problems and the depletion of dissolved oxygen. Both organics and inorganics are deposited in bottom sediment, organics come from outside sources (waste) and also from primary production (dead plants) within estuaries. Inorganics including sand, silts, and clay are introduced to the stream from the ocean and upstream rivers as well as from scour and resuspension within the system (6).

Benthal decomposition is completed in three stages. The first stage is a period of fermentation in which there is rapid production of gases by anaerobic decomposition. The second stage is

a period of consolidation during which sediments subside, density
is increased and gas production is decreased. The third stage is a
period of stabilization during which an aerobic decomposition is ex-
hausted and benthal oxygen demand is very low (1).

Oxygen demand by bottom sediments of a stream could be
directly measured by an oxygen electrode in a bell jar. Edeberg
and Hofsten used this technique and the range of values between .3-
3.0 grams $O_2 m^{-2} day^{-1}$ were obtained at 19 different localities of
fresh and brackish water (lakes and rivers) in Sweden (7). Edeberg
and Hofsten also found that the lab measurement was consistently
lower than field measurement (7). Oxygen uptake of some wastes
by bottom sediment is given in Table 2-4 (5).

It has been reported that the oxygen consumption is a func-
tion of sediment depth as follows (6):

$$S = aD^{.485} \qquad (2-5)$$

where: S = oxygen uptake $(gO_2 m^{-2} day^{-1})$

D = sediment depth up to 20 cm

a = an empirical constant value

However, Fillos and Malof (7) showed that oxygen uptake is inde-
pendent of sediment depths greater than 10 cm. Educard and Ralley
(7) were unable to find any difference in oxygen uptake sediment
depths of 4 to 17 cm. Stein and Denison (7) also did not find any
evidence of higher oxygen uptake at increasing sediment depth (7).

Therefore, it could be generalized that the depth of sediment
does not effect the oxygen uptake since usually only the first few

TABLE 2-4

OXYGEN UPTAKE BY BOTTOM SEDIMENTS

Bottom Type and Location	Uptake (gmO_2/m^2day) at 20°C	
	Range	Approx. Average
Sphaerotilus (10gm dry wt/m^2)	----------	7
Municipal Sewage Sludge Out Fall Vicinity	2.00-10.0	4
Municipal Sewage Sludge Aged Down Stream Out Fall	1.00- 2.0	1.5
Cellulosic Fiber Sludge	4.00-10.0	7
Estuarine Mud	1.00- 2.0	1.5
Sandy Bottom	0.20- 1.0	0.5
Mineral Soils	0.05- 0.1	0.07

millimeter layers of sediment goes under aerobic decomposition and the rest of the layers at bottom are anaerobic. The benthal decomposition rate is very slow. Initial reaction rate (base e) for bottom sediments from Colorado River ranged from 0.0052 - 0.0061/day. (1).

Photosynthesis and Respiration

Photosynthesis is the process in which the chlorophyll containing plant utilizes radiant energy from the sun and converts water and carbon dioxide into glucose and oxygen. The photosynthesis reaction can be written as:

$$6CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

The production of oxygen is accomplished by the removal of hydrogen from the water forming a peroxide which is then broken down into water and hydrogen. The photosynthesis process could result in saturated oxygen as high as 150-200 percent of air saturation level.

The respiration process is accomplished by the use of oxygen and production of carbon dioxide at night time. A suggested relationship between respiration and chlorophyll is given as follows (5):

$$R \ (mg/l/hr) = .001 \ (Chlor. \ "a") \ mg/l$$

Some average values of gross photosynthetic production (P - R) of dissolved oxygen are shown in Table 2-5 (5).

TABLE 2-5

AVERAGE VALUE OF GROSS PHOTOSYNTHETIC
PRODUCTION OF DISSOLVED OXYGEN

Type of Water and Location	(P - R) (grams/m^2-day)
Truckee River - Bottom At-tached Algae	9
Tidal Creek - Diatom Bloom	6
Delaware Estuary - Summer	3-7
Duwamish River Estuary Seattle, Washington	.5-2.0
Neuse River System North Carolina	.3-2.4

CHAPTER III

REOXYGENATION

Reoxygenation in streams can be accomplished by the reaeration from the atmosphere, photosynthetic activities of aquatic plants, and man-induced aeration. Atmospheric aeration in streams is a physical process that involves the entry of oxygen molecules from the atmosphere into water. Reaeration pehnomena is the result of molecular diffusion of oxygen and physical mixing (dispersion) of the turbulent water. Diffusion takes place at the surface of water because of the inherent kinetic energy possessed by oxygen molecules. Then, this dissolved oxygen is distributed throughout the volume and depth by turbulent mixing till it reaches saturation.

The saturation concentration of oxygen in liquid is directly proportional to the partial pressure of oxygen in the atmosphere in contact with the liquid at constant temperature (Henry's Law):

$$C_s = K_s P \tag{3-1}$$

where: C_s = saturation concentration of oxygen (ml/l)

P = partial pressure (proportionality volume)

K_s = coefficient of absorption (ml/l)

The coefficient of absorption for O_2 is given in Table 3-1 (12).

The saturation concentration of oxygen in a stream can be predicted by the empirical formula (5):

TABLE 3-1

ABSORPTION COEFFICIENT OF OXYGEN IN WATER

Gas	Molecular Weight	Weight at 0C and 760mm Hg, g/1	K_s*			
			0C	10C	20C	30C
Oxygen, O_2	32	1.429	49.3	38.4	31.4	20.7

*(milliliter of gas, reduced to 0C and 760mm Hg, per liter of water when pressure of gas is 760 mm Hg)

$$C_s = 14.652 - .41022T + .0079910T^2 - .0007777T^3 \qquad (3\text{-}2)$$

where: $T = {}^{o}C$

It should be noted that C_s is a function of temperature, salinity and barametric pressure. Tables and nomographs have been established to present dissolved oxygen concentrations under various conditions of temperature, pressure and salinity (13).

Atmospheric Reaeration in Streams

Oxygen is transferred from the atmosphere to the water body through the gas-liquid interface. The rate of transfer of oxygen is a function of temperature and turbulence. Turbulence is a function of stream velocity and stream depth for any particular stream. Therefore, most of the equations proposed for reaeration coefficient, K_a, show a direct relationship to some power of velocity and inversely to some power of depth as follows.

Streeter-Phelps

Streeter and Phelps (9) after extensive study of the Ohio River proposed that K_a depends on velocity, depth, shape, and channel irregularity. He derived the following equation (9):

$$k_a = \frac{CV^n}{H^2} \qquad (3\text{-}3)$$

where: k_a = reaeration coefficient (day^{-1}) to base 10

   V = mean velocity (ft/sec)

   H = mean depth (ft)

   C,n = constants for particular river stretch depends on channel slope and roughness

Isaacs' Equation

Isaccs (14) in a simulated stream found K_a to be consistent with the Streeter-Phelps Equation. He found K_a was proportional to average stream velocity and inversely proportional to average stream depth raised to 3/2 power (14).

$$k_a = .06339 \frac{D_m^{1/2}}{\nu^{1/6} g^{1/6}} \times \frac{V}{H^{3/2}} \tag{3-4}$$

where: D_m = the molecular diffusivity of oxygen into water (ft^2/sec)

ν = kinematic viscosity (ft^2/sec)

g = acceleration due to gravity (ft/sec^2)

O'Connor-Dobbins

O'Connor-Dobbins (15) analyzed the reaeration data for the Elk, Clarion, Tennessee, Illinois, Ohio Rivers, and San Diego Bay in 1968. For those streams showing a pronounced vertical velocity gradient (high velocity) and nonisotropic turbulence,

$$k_a = \frac{480 \ D_m^{\frac{1}{2}} S^{\frac{1}{4}}}{H^{5/4}} \tag{3-5}$$

For deep channel turbulence which approaches isotropic conditions,

$$k_a = \frac{(D_m V)^{\frac{1}{2}}}{2.31 \ H^{3/2}} \tag{3-6}$$

where: D_m = the molecular diffusion coefficient (cm^2/sec)

The molecular diffusion coefficient, D_m, at $20^\circ C$ is .0019 ft^2/day. Table 3-2 shows changes in D_m at various temperatures.

O'Connor-Dobbins concluded that the isotropic condition is satisfied when Chezy's coefficient, C, is more than 17 and noniso-

TABLE 3-2

MOLECULAR DIFFUSION COEFFICIENT

D_m x 10^6 (ft^2/day)	Temperature (°C)
1464	10
1704	15
1944	20
2208	25
2544	30

tropic for value of "C" less than 17. O'Connor-Dobbins Equation
was developed for velocity range .19 - 4.2 ft/sec and depth range
1 - 10 ft (15).

Churchill Equation

Churchill, Elmore and Buckinham (16) made an extensive an-
alysis of the reaeration data for Clinch, Holston, French, Broad,
Watunga and Hiwassee Rivers in 1962; and they arrived at the empiri-
cal equation:

$$k_a = \frac{5.026 \; v^{.969}}{H^{1.673}}$$ (3-7)

The range of depth for the above equation was 2 - 11 ft and
velocity in range of 1.8 ft/sec to 5.0 ft/sec (16).

Langbein and Durrum Equation

Langbein and Durrum reworked Churchill's and O'Connor's data
and evaluated reaeration coefficients for the Kansas, Missouri, and
Mississippi Rivers (17). He developed the following equation:

$$K_a = \frac{17.5V}{H^{1.33}}$$ (3-8)

Edwards, et al. Equation

Edwards, et al., measured the reaeration coefficient rate in
several streams in England under controlled conditions where a sul-
fide dosing of the stream produced a transient, well-defined drop
in dissolved oxygen. The time rate of recovery is a measure of the
reaeration rate. They combined British data with that collected in

the Tennessee Valley streams (i.e., rivers studied by Churchill and others) to produce the equation:

$$k_a = \frac{9.4 \ V^{.67}}{H^{1.85}} \qquad (3-9)$$

The equation (3-9) was derived under velocity range from .1 to 5.0 ft/sec and depths from .4 to 11.0 ft. The value of K_a, computed from Equation (3-9), does not differ significantly from the O'Connor-Dobbins equation. In fact, Edwards, et al., concluded that the O'Connor-Dobbins equation adequately predicts reaeration for values K_a less than 11-12 per day (18).

Zake's Diagram

Zake's developed a straight line relationship between K_a and D_T in a semi-log scale as shown in Figure 3-1. The turbulent diffusion, D_T, has been determined by equation:

$$D_T = \frac{g \ x \ H \ x \ V \ x \ 10^{-5}}{37 \ n \ C^2} \qquad (3-10)$$

or approximately:

$$D_T = \frac{H \ V}{200}$$

where: D_T = turbulent diffusion (m^2/sec)

   V = velocity (m/sec)

   H = depth (m)

   n = roughness coefficient

   C = Chezy's coefficient
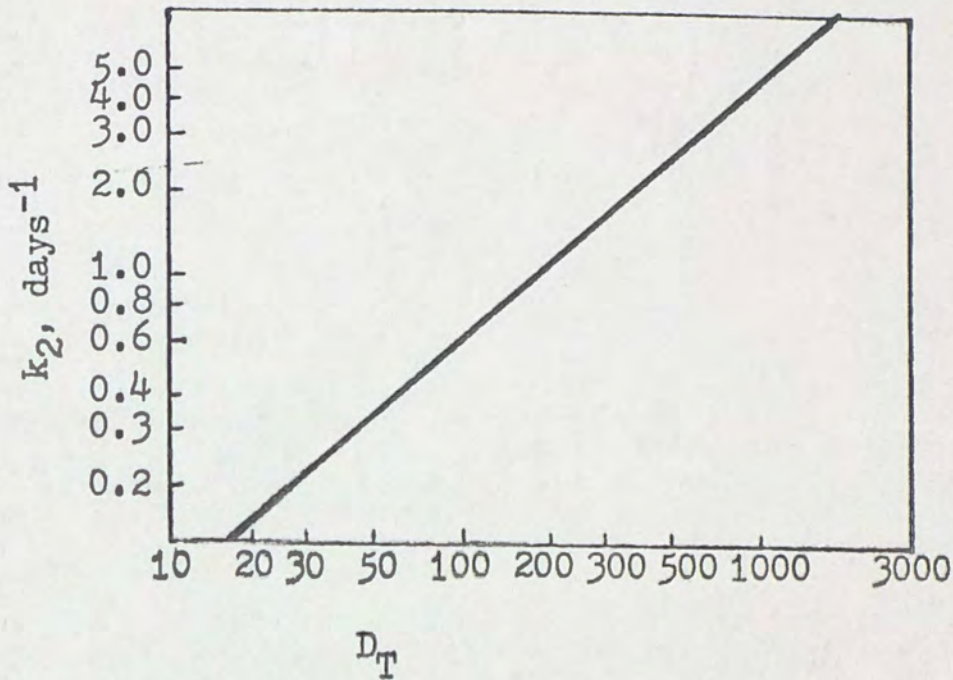
Fig. 3-1. Zake's Diagram

Krenkel and Orlob's Equation (1962)

Krenkel and Orlob, after observation on an artificial channel, developed the following equation (19):

$$k_a = (4.302 \times 10^{-5}) \, D_L^{1.150} \, H^{-1.95} \qquad (3-11)$$

where: D_L = longitudinal dispersion coefficient (ft^2) = 9.1 $U_x H$

U_x = overall bed shear velocity (ft/min)

H = mean depth (ft)

k_a = reaeration coefficient (1/min) to base 10

Thackson and Krenkel's Equation (1967)

Thackson and Krenkel examined the relationship between dispersion and reaeration coeffieicnt. Thackston's dispersion formula was derived from observation on the same streams used by Churchill and others (20).

$$k_a = .000015 \ D_L/H^2 \qquad (3\text{-}12)$$

where: $D_L = 7.25 \ HU_* \ (\bar{U}/U_x)^{\frac{1}{4}}$ or

$D_L = 5.82H \ U_x \ (\bar{U}/U_x)^{\frac{1}{4}}$

$U_x = \sqrt{\tau_o/\rho}$

τ_o = stress at boundary

ρ = fluid density

$\bar{U}/U_*$ = dimensionless measure of bottom roughness of the channel (range of $D_L = .1\text{-}.3 \ \text{ft}^2/\text{sec}$)

Negulescu and Rojanski's Equation (1969)

Negulescu and Rojanski derived the following equation (21):

$$k_a = 4.74 \ (V/H)^{.85} \qquad (3\text{-}13a)$$

$$k_a = .0153 \ D_L \ (V/H)^{1.63} \qquad (3\text{-}13b)$$

where: k_a = reaeration coefficient (day^{-1}) to base 10

V = velocity (cm/sec)

H = depth (cm)

$D_L = 310 \ (V/H)^{-.78} \ \text{cm}^2/\text{sec}$

Negulescu and Rojanski concluded that the equation (3-13b) is more

accurate. The equation (3-13) was derived under velocity variation

range of not more than 1.2 m/sec and depth not more than .5m.

Tsivoglov-Wallace Equation

Tsivolglov-Wallace (22) studied the direct measurement of

reaeration coefficient using a radioactive tracer gas for oxygen in

Flint, South, Chatahoochee, Patuxent and Jackson Rivers. These five

rivers are the combination of hydraulic features, such as water falls,

rapids and pools with flows ranging from 5 - 3000 cfs. Tsivoglov-Wallace arrived at a new model to provide dependable prediction of stream reaeration capacity:

$$K_a = C \ (\Delta h / t_f) \tag{3-14}$$

where: t_f = time of flow in a segment of stream (hr)

Δh = water surface elevation change through this segment (ft)

C = constant of proportionality

C average = .054 reported from field study

K_a = reaeration coefficient (1/hr) to base e

The range of length of river studied, flow, velocity, depth and K_a observed are shown in Table 3-3. Also they concluded that O'Connor and Churchill's equations will not adequately predict the value of K_a for these five rivers (22).

Bansal Method for Determination of K_a

Bansal noted that the reaeration coefficient is a function of pollutant dispersion in stream, mean depth, and mean velocity of stream. Furthermore, he found a linear relationship on log-log scale between K_a and Reynolds number.

As mentioned earlier in this chapter, Churchill, et al. (1962) made an extensive analysis of the reaeration data on the Clinch, Holston, French Board, Watunga, and Hiwassee Rivers. O'Connor and Dobbins analyzed the reaeration data for the Elk, Clarion, Tennessee, Illinois and Ohio Rivers and the San Diego Bay. Langbein and Durrum reworked the Churchill and O'Connor data and evaluated reaeration

coefficient for the Kansas, Missouri and Mississippi Rivers.

Bansal used this data and found a linear relationship between dimensionless $k_a H^2/\nu$ and Reynolds number on log-log plot as presented in Figure 3-2.
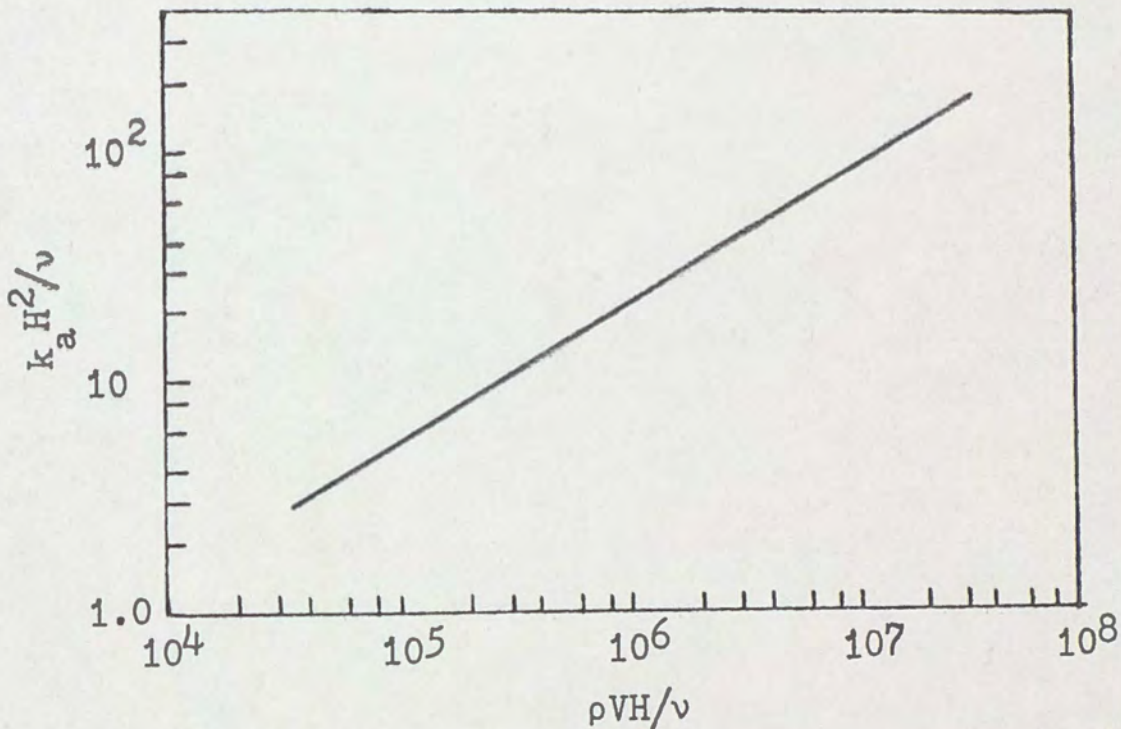
Fig. 3-2. Reaeration Parameters vs. Reynolds Number

The equation of the line of best fit is:

$$\text{Log } (k_a H^2/\nu) = -2.27 + .6 \text{ Log } (\rho VH/\mu) \qquad (3\text{-}15a)$$

or

$$k_a H^2/\nu = .0054 \, (\rho VH/\mu)^{.6} \qquad (3\text{-}15b)$$

The correlation coefficient of the points about the mean line is .934 and standard error is .131. Equation (3-15b) can be rewritten as (23):

TABLE 3-3

THE HYDRAULIC CHARACTERISTIC AND THE K_a VALUE OBSERVED BY TSIVOGLOV-WALLACE FOR FIVE RIVERS

River	Length Studied	Flow (cfs)	Velocity (ft/sec)	Depth (ft)	Elevation Change (ft)	k_2 Observed by gas tracer
Flint	9.9 mi.	5-27	.31-.88	.82-1.96	8.1-57.8	.101-.698/hr @ 25°C
South	18.3 mi.	47-207	.82-1.27	1.05-2.4	2.1-47.7	.125-.324/hr @ 25°C
Chatahoo-chee	120.0 mi.	1070-3300	1.72-2.45	3.62-7.66	1.2-17.8	.029-.061/hr @ 25°C
Patuxent	7.0 mi.	9.8-19.5	.22-.39	.8-1.1	4.8-29.6	.101-.199/hr @ 25°C
Jackson	--------	90-130	.321-.673	1.67-3.14	9.2-47.16	.07 -.364/hr @ 25°C

$$K_a = \frac{CV^a}{H^b}$$

where: $C = .0054 \ (v)^{.4}$

$C = .000054 \ sec^{-1}$ @ $20°C$

$a = .6$ constant

$b = -1.4$ constant

The reaeration coefficient K_a changes with temperature and pollutants present in streams.

Temperature Effect on K_a

The effect of temperature on the reaeration coefficient has been studied by various investigators and the general conclusion is that K_a varies inversely with the temperature.

$$K_a(T) = K_a(20°C) \ \theta^{(T-20)} \tag{3-16}$$

The value of θ has been found to vary with the reaeration systems as shown in Table 3-4.

Pollutant Effect on Reaeration

It should be noted that various pollutants alter the gas transfer rate of a stream. This change causes the rate of gas transfer to vary under the same hydraulic and environmental condition depending on the pollutant concentration. The percent amount alteration of gas transfer rate can be predicted by:

$$\alpha = \frac{K_a'}{K_a} \tag{3-17}$$

where: K_a' = the reaeration coefficient of polluted water

K_a = the reaeration coefficient of clean water

TABLE 3-4

TEMPERATURE EFFECTS ON REAERATION COEFFICIENTS

No. Investigators	Constant (θ)	Aeration System
1. Streeter, Wright and Kehr (1936)	1.047	Laboratory flow
2. Truesdale and Van Dyke (1958)	1.018	Laboratory flow
3. Dowing and Truesdale (1955)	1.024	Channel flow with mechanical aerator
4. Elmore and West (1961)	1.016	Channel flow with mechanical aerator
5. Streeter (1926)	1.016	Natural stream

α = percent change in the reaeration coefficient

K_a' and K_a can be measured in control pilot plan studies.

Pollutants are transferred through the stream by longitudinal, lateral, and vertical dispersion. The longitudinal dispersion parameter is of major interest and can be effectively meausred by injection of dyes in streams. A number of empirical formulas have been developed for prediction of dispersion as shown in Table 3-5 (24). These formulas were based on various assumptions as follows:

Equation 1 and 2 have been evaluated assuming that the diffusive transport in longitudinal direction is the main reason for causing dispersion. Equation 3 assumes that the velocity distribution in the vertical direction contributes to the longitudinal dispersion (fluid near the water surface travels faster than near the bottom). Equation 4 is based on the assumption that the velocity distribution in the lateral direction forms the basis for the convective spread of the pollutant in stream. Equation 5 explains the importance of dead zones present in stream that causes skewness of the time concentration curves. Equation 6 considers the effect of dead zones and the lateral velocity distribution.

TABLE 3-5

EMPIRICAL FORMULAS FOR PREDICTION OF LONGITUDINAL
DISPERSION (D_L) IN STREAMS

Investigators	Equation
1. Parker (1961)	$D_L = 14.28 \ (2gS)^{\frac{1}{2}} \ R^{3/2}$
2. Glover (1964)	$D_L = 500 \ V_* \ H$
3. Elder (1959)	$D_L = 5.93 \ V_* \ H$
4. Yotsuka and Fiering (1964)	$D_L = 13.0 \ V_* \ H$
5. Krenkel (1962)	$D_L = 9.1 \ V_* \ H$
6. Thackston (1966)	$D_L = 7.25 \ V_* \ H \ (\overline{V}/V_*)^{\frac{1}{4}}$

where: D_L = longitudinal dispersion coefficient, ft^2/sec

  g = acceleration due to gravity, ft/sec^2

  S = slope of energy grade line, ft/ft

  R = radius of pipe (channel flow), ft

  V_* = overall bed shear velocity, ft/sec

  H = depth, ft

CHAPTER IV

ESTUARINE ANALYSIS

In previous chapters, predictions of oxygen deficit in fresh
water streams has been discussed and tidally affected areas will be
considered through this chapter. Mixing of freshwater and salt water
under tidal action can be defined as an estuary. The Clean Water
Restoration Act of 1966 defines "estuarine zones" as "environmental
systems consisting of an estuary and those transitional areas which
are consistently influenced or affected by water from an estuary
such as but not limited to salt marshes, coastal, and intertidal
areas, bays, harbors, lagoons, in-shore waters and channel" and
"estuarine" as "all or part of the mouth of a navigable or inter-
state river or stream or body of water having an unimpaired natural
connection with the open sea and within which the sea water is mea-
sureably diluted with fresh water derived from land drainage" (9).

Mixing in an estuary depends on tide situation. As tides
rise and fall, it sets up tidal current. Also, in high tides the
depth of water increases significantly over low tides. The range
of tidal velocity in the Tampa Bay area is between approximately .4
- .9 ft/sec, and generally the height of tides reach about 2 ft (25).
Dissolved oxygen analysis in tidally influenced zones will be discussed
next.

Oxygen Balance in an Estuary

Dissolved oxygen modeling of an estuary has been extensively discussed by several investigators (26,27,28,29,30,31) and one, two and three dimensional models were proposed. A simplified model to predict oxygen deficit under steady state conditions is:

$$D = \frac{K_d L_i}{K_a - K_d} \left(e^{-x(K_d/E)^{.5}} - e^{-x(K_a/E)^{.5}} \right) + D_i \, e^{-x(K_a/E)^{.5}} \quad (4\text{-}1)$$

where: D = dissolved oxygen deficit at x, mg/l

D_i = dissolved oxygen at x = 0, mg/l

L_i = ultimate carbonaceous BOD (CUOD) at x = 0, mg/l

K_a = reaeration rate coefficient for segment, /day

K_d = first order carbonaceous BOD oxygen utilization rate coefficient for segment, /day

E = dispersion coefficient, mi^2/day

This equation is similar to the Streeter-Phelp's equation proposed for fresh water streams when benthic demand and photosynthesis-respiration activities are ignored. From equation (4-1), it can be shown that the important parameters that influence calculation of oxygen deficit in an estuary include E, K_a, and K_d. A discussion on these parameters will follow.

Dispersion Coefficient "E"

The variation in tidal current and the presence of chloride in an estuary cause the mixing between incoming waste and sea water. Dispersion coefficients can be measured based on the longitudinal chloride profile. It should be noted that the distribution and

extent of chloride in an estuary reflects the magnitude of dispersion. For conservative substances in steady state condition,

$$Ch = Ch_o \ e^{Ux/E} \qquad (4-2)$$

for x < 0 where: Ch = the chloride concentration

Cho = the concentration at x = 0, which is referred to as the mouth of the estuary.

The plot of Ch/Cho versus distance in semi-log paper would result in a straight line with the slope of U/E in which U is the net downstream velocity and E is the dispersion coefficient. Based on this approach and assuming a tide period of 12.4 hours and sinusoidal varying tidal current, Helting and O'Connel developed two equations as follows (27):

$$E = 5.2 \ (Umax)^{4/3} \qquad (4/3 \ Law) \qquad (4-3a)$$

$$E = 20.7 \ (Umax)^2 \qquad (Random \ Process) \qquad (4-3b)$$

in which Umax is the maximum tidal velocity in knots (obtained from tidal current tables) and E is in $mile^2/day$.

For small estuaries, Myrick and Leopold have developed power relationships (5):

$$H = a \ Q_T^{.13}$$
$$U = C \ Q_T^{.78} \qquad (4-4)$$
$$W = e \ Q_T^{.09}$$

where: H = depth, ft

U = velocity, ft/sec

W = width, ft

Q_T = total tidal flow, cfs

a,c,e = empirical constant (log-log plots of field data permit the determination of the constant)

The equation (4-4) is applicable for increasing velocity during flooding conditions in small estuaries.

Another method is the time-variable model approach. This model uses a finite difference approximation to the one dimensional model for chlorine. The equation is as follows:

$$\frac{\partial Ch}{\partial t} = \frac{1}{A} \frac{\partial}{\partial x} \left(E \frac{\partial Ch}{\partial x} \right) - \frac{Q}{A} \frac{\partial Ch}{\partial x} \tag{4-5}$$

where the chloride concentration at the ocean is a known function of time. For best value of E trial and error solution or analog computers are used.

Table 4-1 provides a summary of different techniques for the estimation of the longitudinal dispersion coefficient for several estuaries.

Reaeration Coefficient

The basic relationship for the reaeration coefficient in a stream is given by:

$$k_a = \frac{(D_m r)^{\frac{1}{2}}}{H} \tag{4-6}$$

where: D_m = the molecular diffusivity of oxygen

r = the rate of surface renewal

H = the average depth of station

TABLE 4-1

ESTIMATED LONGITUDINAL DISPERSION COEFFICIENT
FOR SOME ESTUARIES (5)

Estuary	E mi^2/day	Tracer	Estimation Method
Delaware	2-7	Chloride	Torresdale, P.A. to Reedy Island, Eq. (4-5) Analog Computer
	7-11	Chloride	Lower portion - Dela Bay Eq. (4-4)
Potomac	.2-.6	Dye	Upper 25 miles non-saline portion, Eq. (4-5) Analog Computer
Potomac	.6-6	Chloride	Middle 25 miles brackish portion, Eq. (4-5) Digital Computer
Potomac	6-10	Chloride	Lower 50 miles ch 3000 - 10,000 mg/l, Eq. (4-5) Digital Computer
Waccasassa (Cedar Key, Florida)	2-2.7	Chloride	Small Gulf of Mexico estuary; brackish portion Umax = .4 knots, Eq. (4-4) with variable area
	.4-.8	Dye	Upper non-saline portion
James	9-11	Sulfate	Non-saline portion, Eq. (4-4)
Hudson	8	Chloride	25-50 miles from Buttery, ch 1000, 5000 mg/l, Eq. (4-4)

O'Connor (28) derives a similar relationship for an estuary which follows:

$$k_a = \frac{(D_m U_o)^{\frac{1}{2}}}{H^{3/2}} \tag{4-7}$$

where: U_o = the mean tidal velocity over a complete tide cycle

H = the average depth in a particular section over a tide cycle

Also, a number of empirical formulas which were discussed in Chapter III might be adequate for an estuary, if the proper substitution is made for mean tide velocity.

Juliano (29), Bailey (30), and Krames (31) proved that predictive empirical equations will not adequately predict reaeration for California estuaries (Sacramento, San Joaquin estuary, and Suisun Bay) and the Houston ship channel. But they all concluded that these predictive equations could be used for the same types of situations under which they have been derived.

Deoxygenation Coefficient

The plot of log of BOD against an arithmetic scale of distance results in a straight line. The slope of the line is j_1. Then K_d can be calculated from the following equation:

$$j_1 = \frac{U}{2E} \left(1 - \sqrt{1 + 4K_d/U^2}\right) \tag{4-8}$$

Wind Effects

The effect of wind on the reaeration coefficient, K_a, has been investigated by Dowing, et al. (32), Juliano (29), and Eloubaidy (33). Dowing, et al., performed a laboratory study using a small

tank and fan to generate wind current. They stated that their "results were not in good agreement with estimates of the effect of wind obtained from the results of direct measurement of the reaeration in an estuary." This is due to the more turbulent nature of wind generated by a fan. However, their data indicated that wind velocity of about 7 mph did not have any effect on reaeration.

Juliano showed in two different experiments that the effect of wind is considerable in comparison to no wind on the reaeration coefficient. Juliano indicated oxygen transfer rate in a California estuary varied between 0.5 and 3.0 day^{-1}, depending upon wind velocity. However, the data were scattered probably because wind direction was not considered.

Eloubaidy indicated that reaeration rates increased significantly at a wind velocity of 1.6 mph to 2.5 mph. He arrived at:

$$k_a = 3.13 \times 10^{-8} R_{sh} U_c H_m \qquad (4\text{-}9)$$

where: $R_{sh} = U_s H/$ shear Reynolds number

$U_s = .0185 V_w$ surface shear velocity (ft/sec)

V_w = wind velocity measured 2 feet above the surface of water (ft/sec)

H = depth (ft)

ν = kinematic viscoeity (ft^2/sec)

$U_c = gHS_c$ = shear velocity (ft/sec)

g = acceleration due to gravity (ft/sec^2)

S_c = pressure adjusted channel slope approximately equal to slope of channel

H_m = mean depth of flow created by wind (ft)

The equation (4-9) was arrived in condition with mean water velocity of 1 ft/sec, wind velocity 5 mph - 25 mph, and channel depth of .385 ft.

CHAPTER V

PREDICTION OF OXYGEN DEFICIT
ALONG PHILLIPPI CREEK

Phillippi Creek runs for approximately 13 miles long in
Sarasota County, Southwest Florida, with its mouth located at Little
Sarasota Bay. Its water flows from wastewater treatment plant efflu-
ents during dry weather conditions and stream water runoff during
the rainy season. Effluent from five wastewater treatment plants,
as shown in Figure 5-1 and Table 5-1, flow to Phillippi Creek. Table
5-1 indicates the type of treatment, design capacity and wastewater
characteristics over a six month period from March to August, 1975.
Also, existing water quality characteristics for several stations
are available from STORET data supplied by the Florida Department
of Environmental Regulation. The available information will aid in
the prediction of oxygen deficits along the Phillippi Creek by ap-
plying the computer model "RIVER." In order to use the "RIVER"
program, the hydraulic characteristics, water quality characteristics,
reaeration, deoxygenation, photosynthesis-respiration, and benthic
demand along the stream should be evaluated. In the absence of mea-
sured parameters, values from literature based on sound engineering
judgment and reasoning will be made.

Hydraulics Characteristics

Forty-nine observations for width, velocity, and flow for

40

Fig. 5-1. Existing Wastewater Treatment Plants and Water Quality Stations
Along Phillippi Creek

TABLE 5-1

DOMESTIC WASTEWATER TREATMENT PLANT FACILITIES
DISCHARGING TO PHILLIPPI CREEK

Plant Code	Facility Name	Process	Design Capacity MGD	Flow, MGD				BOD$_5$	
				Min.	Max.	Avg.		In	Out
21	Southern Gulf	C/S W/PP	0.5	.186	.352	.240		258	12
33	Fla. Cities Gulf Gate	AWT	1.8	.315	.903	.525		244	22
47	Kensington Park	Modified T/F	0.56	.337	.565	.411		244	28
84	South Eastern	AWT W/PP	0.75	.038	.069	.047		167	1
85	Southeast Plaza	E/A	0.05	.039	.061	.048		234	16

Phillippi Creek from 1960 to 1967 were supplied by the USGS. Using this data and assuming rectangular cross sections, average depths were calculated. The data was analyzed using the regression analysis computer program and relationships between velocity, depth and flow were obtained as shown in Figures 5-2 and 5-3. These correlations were used in determining velocities, depth, and width at various flow conditions.

In order to use the "RIVER" model program, Phillippi Creek was divided into sections. A new section starts whenever there is a change in flow characteristics or water quality. The flow along Phillippi Creek during dry weather conditions is essentially from the wastewater treatment plant effluents which is reflected in the 7-day, 10-year minimum flow provided by the USGS as shown in Table 5-2. It must be noted that the summation of wastewater treatment plant effluents may exceed the 7-day, 10-year minimum flow at some sections along Phillippi Creek. The difference may exist due to evaporation and percolations.

Reaeration Coefficients

The reaeration coefficients were calculated by the use of O'Connor (15), Edwards (18), and Tsivoglov (22) empirical equations. The K_a values vary between 0.8 and 2.9 per day, from O'Connor, 0.53 to 2.99 per day from Edwards, and 0.017 to 0.23 per day from Tsivoglov. Also, K_a stagnation of 0.47 per day from Padden (1) was used.

$$Q = -394.5 + 287.36H$$

Correlation Coefficients = 0.9318
No. Observations = 49
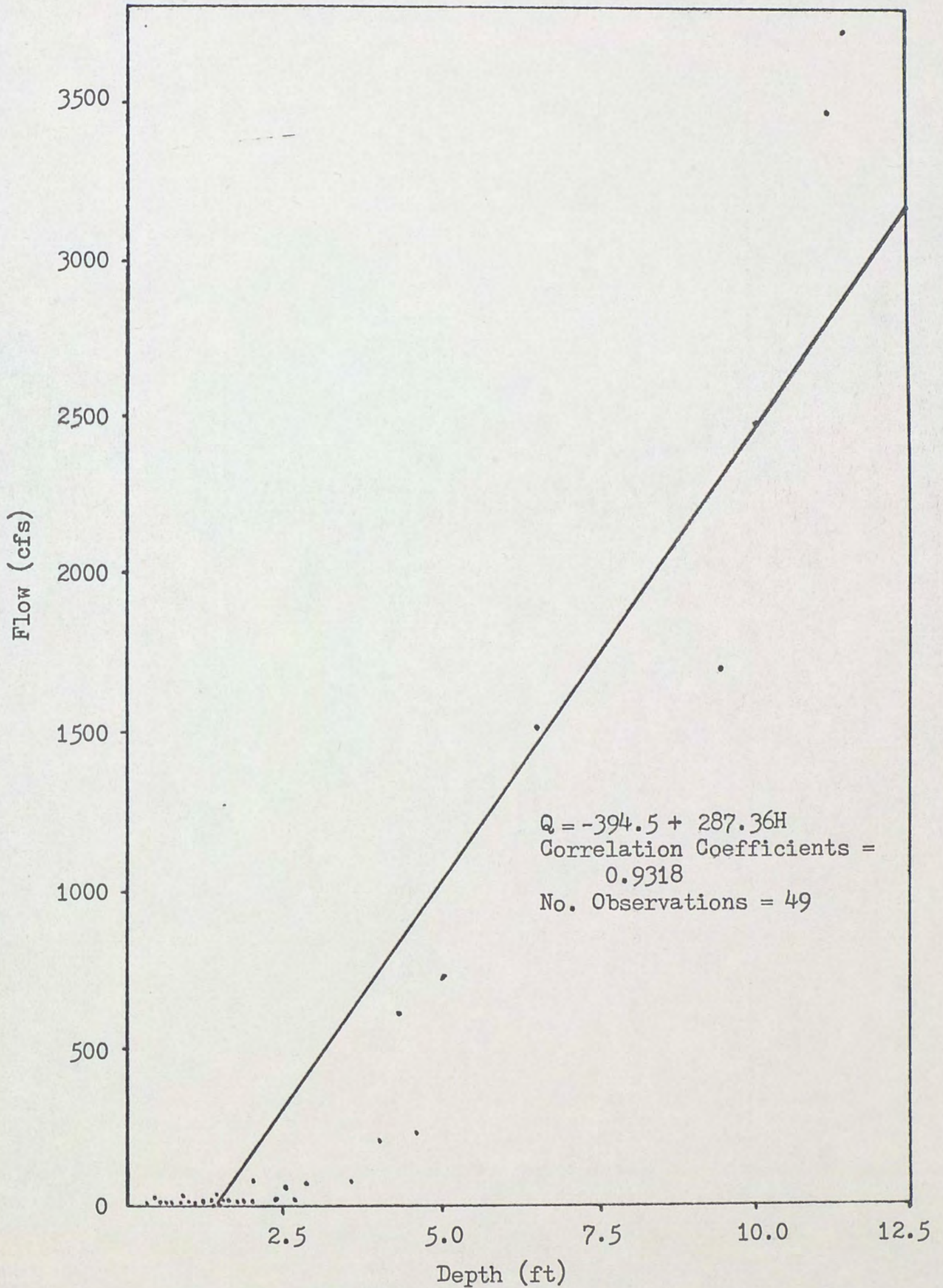
Fig. 5-2.   Straight Line Relationship, Flow vs. Depth
Along Phillippi Creek
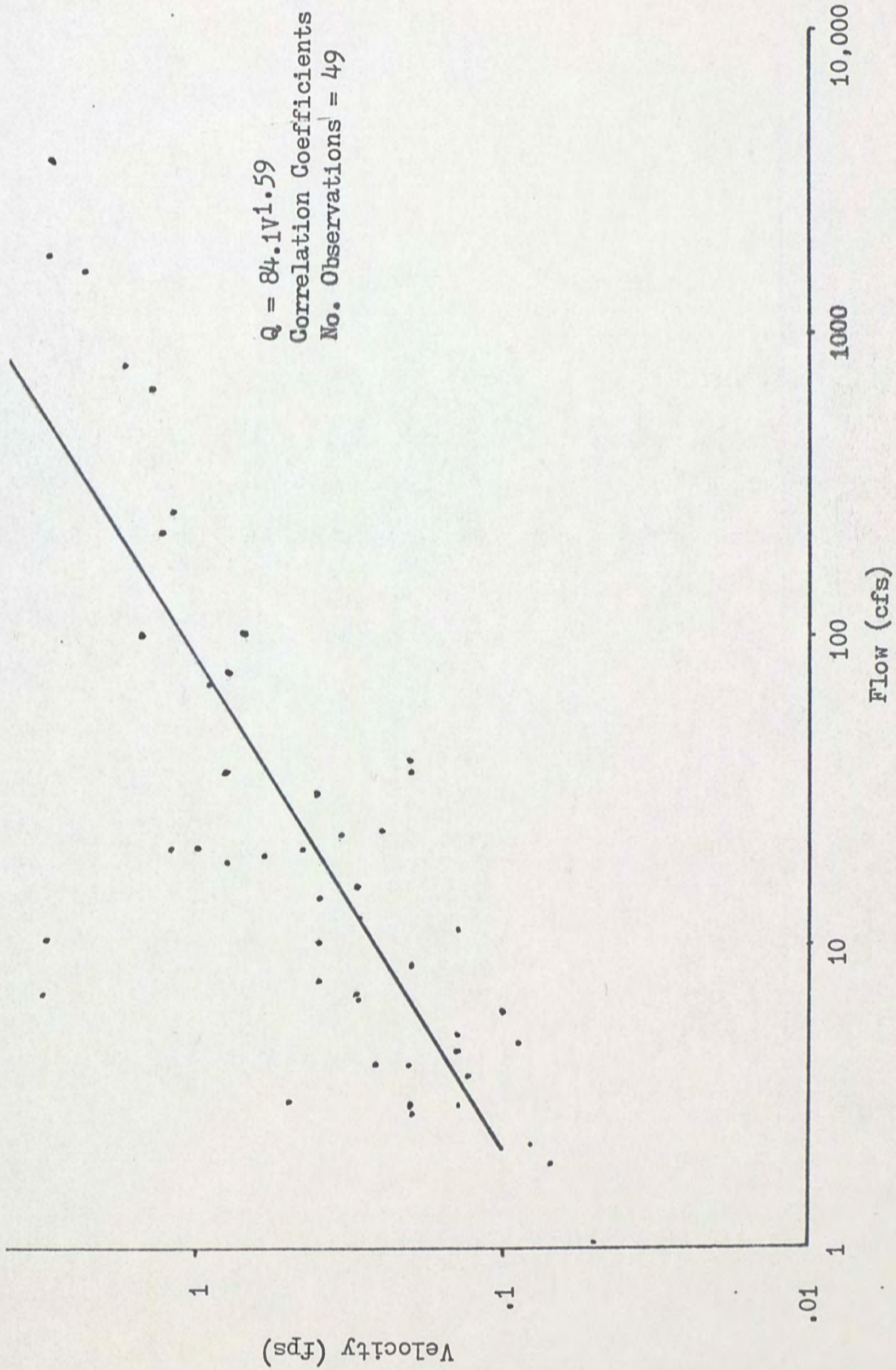
Fig. 5-3. Straight Line Relationship on Log-Log Scale, Flow vs. Velocity Along Phillippi Creek

$Q = 84.1V^{1.59}$

Correlation Coefficients = 85

No. Observations = 49

TABLE 5-2

SUMMARY OF 7 DAY, 10 YEAR MINIMUM FLOW
FOR PHILLIPPI CREEK

Site Name	Location	Drainage sq. mi.	7 Day, 10 Year Min. Flow (cfs)
Phillippi Creek Near Sarasota	Latitude 27°17'54" Longitude 82°31'08" @ State Rd 72	50.8	1.5
Phillippi Creek @ SCL RR	Latitude 27°19'34" Longitude 82°29'38" @ Sea Board Coast-line RR	36.8	1.1
Phillippi Creek @ N-S County Rd	Latitude 27°18'30" Longitude 82°27'05" @ Cattleman Rd	22.2	0.2

K_d, K_r, and K_N

The decay rate, K_d, and the deoxygenation rate, K_r, are considered to be constant at values of 0.23 per day. Also, K_N was considered to be constant in the range of 0.1 per day. These values are consistent with those values used in literature (1,4,5).

Water Quality Characteristics

The water quality characteristics for each section were estimated from the effluent quality from each plant and existing water quality stations along Phillippi Creek. The water quality characteristics from existing stations are shown in Table 5-3. Table 5-3 shows a much higher specific conductance at station 608 during January and May 1975 as compared to September 1975. This indicates that Phillippi Creek may be tidally influenced during dry weather conditions for a distance of about 1.9 miles from the mouth. The closest plant is about 3 miles from the mouth; therefore, Phillippi Creek could be treated as a fresh water stream between plant 33 and the end of the river. Also, the lowest dissolved oxygen concentration was measured at station 626 which is about 4.5 miles from the mouth. The existing oxygen deficit along the waterway is shown in Figure 5-4.

Calibration of the "RIVER" Model

The existing conditions of plant effluents and water characteristics during dry weather conditions were used to calibrate the computer model "RIVER." Two runs were made to simulate the existing

TABLE 5-3

CHARACTERISTICS OF WATER SAMPLES ALONG PHILLIPPI CREEK
SARASOTA COUNTY

| Sampling Location | Sampling | | | Temp oC | pH | DO mg/l | Tur- bid. JTU | Sp. Cond. mho /cm | Color JTU | Nitrogen mg/1-P | | Phosphorus mg/1-P | |
	Date	Time	Depth*							TKN	NO3	QP	TP
Sta. 608 (1.9 miles from mouth)	May 75	----	---	26	7.84	4.5	2.5	43000	20	-----	0.071	0.832	----
	Jan 75	1030	1.0	18	7.30	3.3	4.3	17000	---	-----	-----	----	----
	Sept 74	1200	1.0	25	7.18	3.9	5.0	500	225	-----	-----	----	----
Sta. 625 (3.5 miles from mouth)	May 75	----	---	26	6.79	4.6	5.3	4800	40	-----	0.345	0.345	3.471
	Jan 75	1100	1.0	17	7.60	2.9	1.9	800	---	-----	-----	----	----
	Sept 74	1230	1.0	25	7.20	4.7	5.0	430	225	-----	-----	----	----
Sta. 626 (4.5 miles from mouth)	May 75	----	---	24	7.28	1.0	5.7	1300	85	-----	0.154	6.788	----
	Jan 75	1000	1.0	16	7.40	1.8	----	640	5.7	-----	-----	----	----
	Sept 74	----	---	24	6.98	3.9	5.8	290	200	-----	-----	----	----
Sta. 628 (7.05 miles from mouth)	May 75	----	---	24	7.04	1.1	0.5	1300	20	-----	-----	0.471	1.909
	Jan 75	1130	1.0	16	7.20	8.8	1.5	800	---	-----	-----	----	----
	Sept 74	----	---	25	7.00	5.5	4.9	460	225	-----	-----	----	----
Sta. 629 (8.65 miles from mouth)	May 75	----	---	25	6.14	7.2	1.8	1200	30	-----	0.648	0.331	----
	Jan 75	----	---	--	----	---	---	----	---	-----	-----	----	----
	Sept 74	1545	2.0	28.5	7.60	7.5	----	720	---	-----	-----	----	----
Sta. 630 (12.2 miles from mouth	May 75	----	---	26	6.70	7.2	4.0	1400	10	-----	0.050	0.032	----
	Dec 74	----	---	11	7.26	2.9	4.0	900	80	-----	-----	----	----
	Nov 74	----	---	22	7.70	7.3	1.6	1300	40	-----	-----	0.130	0.160

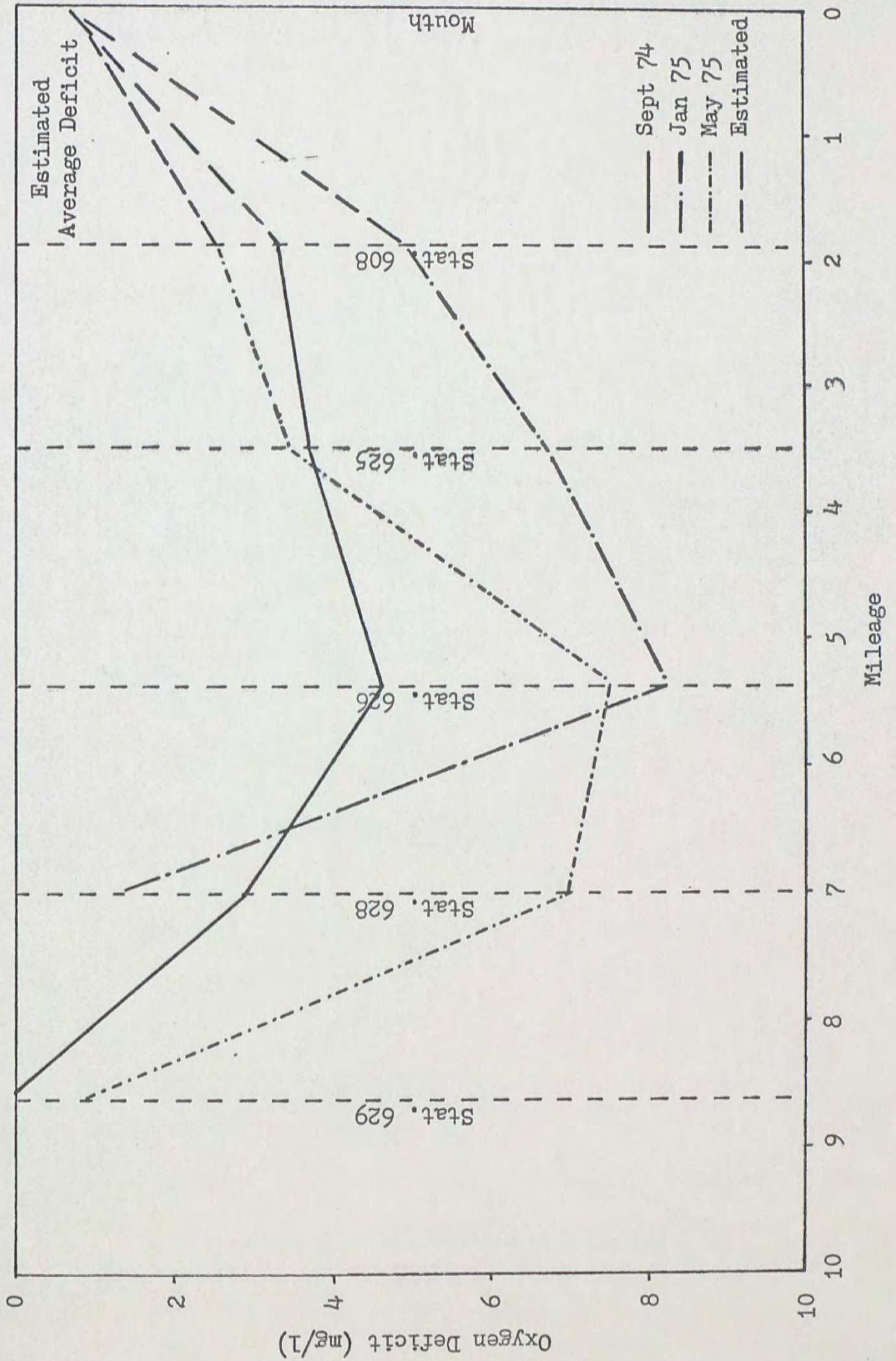*Depth measured in feet

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Fig. 5-4 . Dissolved Oxygen Sag Curves Along the Phillippi Creek

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conditions. Reaeration coefficients were read from the model and varied between 0.8 - 2.9 per day as predicted by O'Connor and used in the first run. Reaeration coefficients of 0.47 per day as for stagnant conditions were used in the second run. The other parameters were kept constant as shown in Table 5-4.

Data obtained from the previous runs are shown in Figure 5-5. Figure 5-5 also shows the measured dissolved oxygen concentration along Phillippi Creek during May 1975. A good agreement appears to exist between predicted and measured dissolved oxygen values. Calibration of the model was used as a tool to check the validity of assumed parameters under the existing conditions. Dissolved oxygen violations are most likely to be observed between junction main A and Branch AA and junction main A and source 33 as shown in in Figure 5-5. To prevent dissolved oxygen violations, it may be required to upgrade the plant effluent to advanced waste treatment (AWT) quality along the stream.

Two runs of the computer program "RIVER" were made utilizing AWT standards for wastewater plant effluent. The standards are 5 mg/l BOD_5, 5 mg/l S.S., 3 mg/l total nitrogen as N, and 1 mg/l total phosphorus as P. The other parameters used in calibration of the model which are shown in Table 5-4 were kept the same except benthic demand was increased to 0.5 $gm/day/m^2$. The results obtained are shown in Figure 5-6. Dissolved oxygen concentrations do not reflect any violation if reaeration coefficients predicted by O'Connor are used.
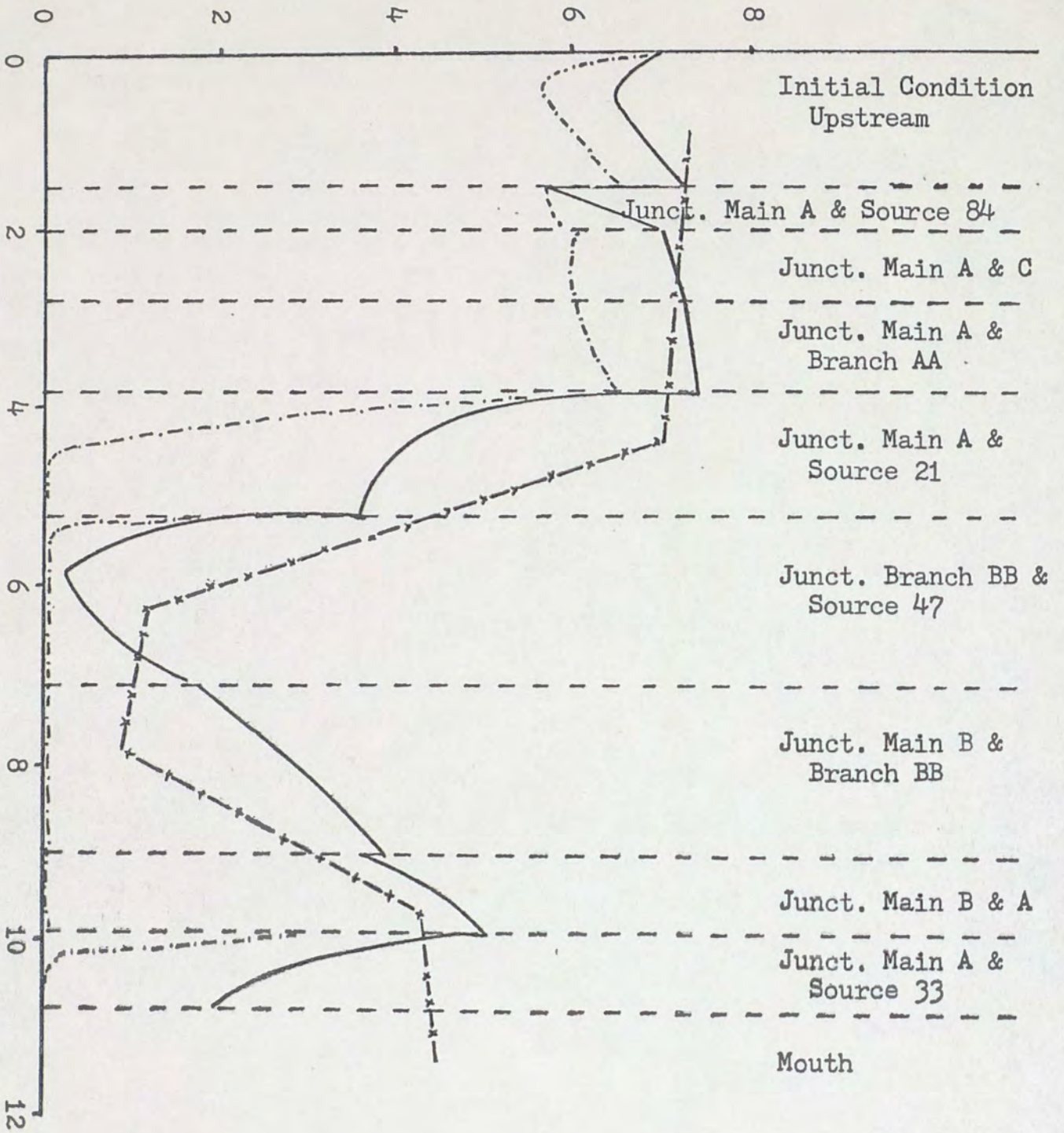
TABLE 5-4

SUMMARY OF PARAMETERS USED FOR THE
COMPUTER MODEL "RIVER"

	Q (cfs)	Area (ft²)	Length (miles)	Vel. (ft/sec)	Depth (ft)	Benthic Demand gm/m²/day	BOD$_y$ C (mg/l)	BOD$_y$ N (mg/l)
Extreme Upstream Conditions	0.1	6.0	1.5	0.01	1.37	0.3	3.0	4.51
Junction Main A & Source #84	0.2	8.3	0.5	0.02	1.37	0.3	1.96	6.85
Junction Main A & Main C	0.2	10.0	0.8	0.02	1.37	0.3	3.0	4.57
Junction Main A & Branch AA	---	10.0	1.0	0.02	1.37	0.3	----	----
Junction Main A & Source #21	1.0	16.3	1.4	0.02	1.37	0.3	18.5	68.55
Junction Main A & Source #85	1.05	16.3	0.2	0.06	1.37	0.3	3.0	4.57
Junction Branch BB & Source #47	0.9	17.3	1.9	0.05	1.37	0.3	33.0	68.55
Junction Main B & Branch BB 8	0.9	17.3	1.9	0.05	1.37	0.3	---	----
Junction Main B & Main A	1.85	20.5	0.9	0.09	1.37	0.3	---	----
Junction Main A & Source #33	3.25	24.5	0.9	0.13	1.38	0.3	64.7	68.55

Note: (1) Temperature assumed to be 26°.
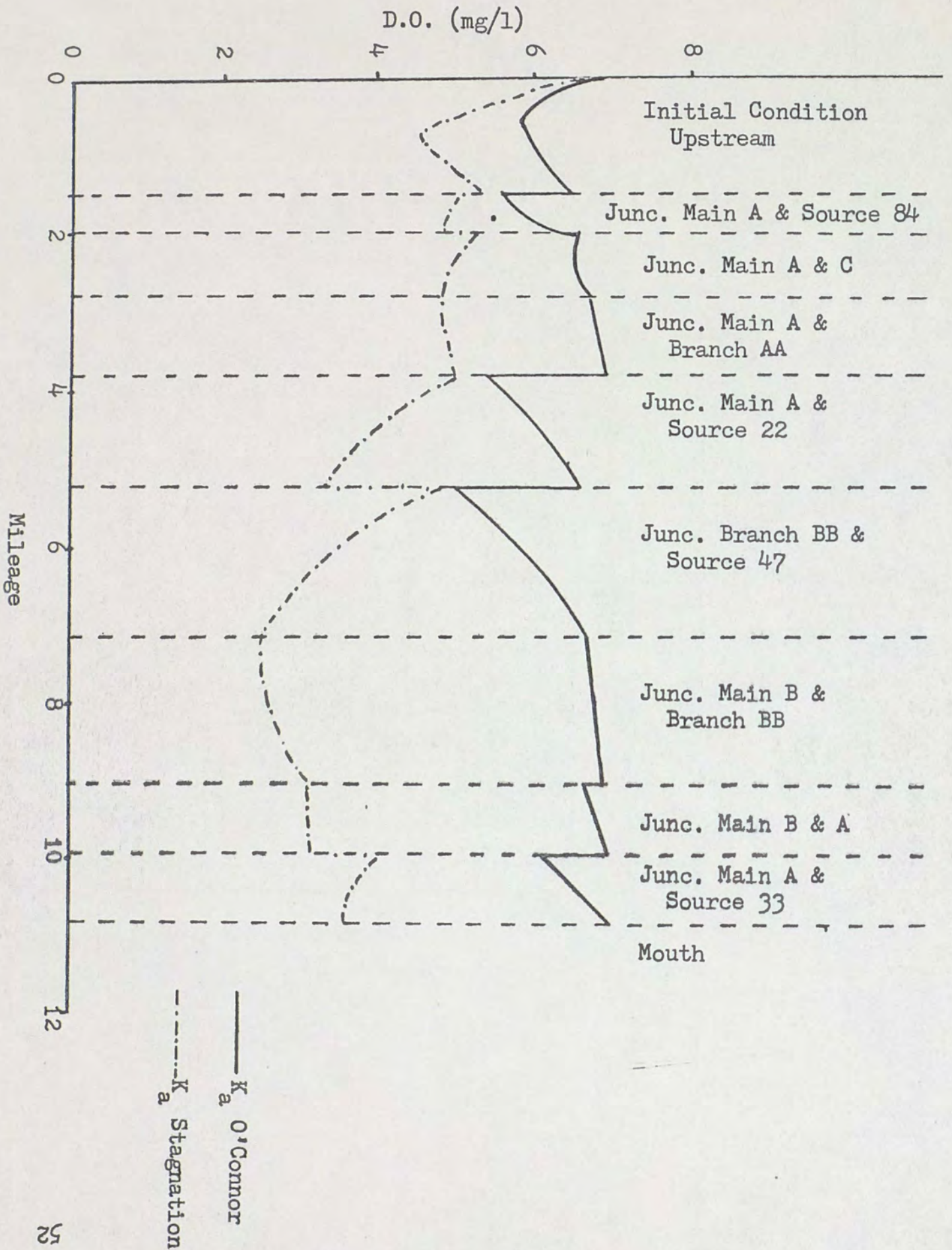(2) The net product of photosynthesis and respiration assumed to be zero.

Fig. 5-5. D.O. Profile Along Philippi Creek, Existing Conditions

Initial Condition
Upstream

Junct. Main A & Source 84

Junct. Main A & C

Junct. Main A &
Branch AA

Junct. Main A &
Source 21

Junct. Branch BB &
Source 47

Junct. Main B &
Branch BB

Junct. Main B & A

Junct. Main A &
Source 33

Mouth

—x—x—Actual

———K_A O'Connor

------K_A Stagnation

Conclusions

1. Streams are individualistic. The self-purification varies from one stream to another and from one reach to another along the stream. The stream self-purification can be evaluated by plotting the oxygen sag curve which reflects the composite effect of stream reaeration, deoxygenation, photosynthesis-respiration, and benthic demand.

2. Formulas developed for the prediction of reaeration coefficients in streams are only applicable for similar conditions under which they were developed. Reaeration coefficients for small streams with minimum flow conditions are difficult to predict since prediction models are scarce for such streams.

3. Studies to determine stream reaeration, deoxygenation, photosynthesis-respiration, and benthic demand on fresh water streams in the State of Florida are scarce or non-existent.

4. Reaeration coefficients for Phillippi Creek were developed using various models. Under dry weather conditions, the reaeration coefficients K_a values using O'Connor were the highest and varied between 0.8 and 2.9 per day. K_a value for stagnant conditions after Padden was 0.47 per day. Some models such as Tsivoglov predicts K_a values lower than those predicted under stagnant conditions. Others including Edwards and Rojanski K_a values were between those predicted by O'Connor and those predicted by Padden.

5. Computer models are available to predict dissolved oxygen concentrations along the streams. The model "RIVER" was

used along Phillippi Creek and good agreements were observed between predicted and measured dissolved oxygen concentrations.

6. Upgrading the effluent quality from wastewater treatment plants along Phillippi Creek to AWT may be required in order to eliminate dissolved oxygen violations during dry weather conditions. However, further studies should be made to test dissolved oxygen concentrations under wet weather conditions.

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