

MODELING OF WATER QUALITY OF BINDARE STREAM IN ZARIA-NIGERIA USING MATLAB

BY

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NIGERIA

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DECLERATION

I declare that the work in the thesis entitled "Modeling of Water Quality of Bindare Stream Zaria-Nigeria Using MATLAB" has been performed by me in the Department of Water Resources & Environmental Engineering under the supervision of Prof. C.A. Okuofu and. Engr (Dr) D.B. Adie. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

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Name of student	Signature	Date

CERTIFICATION

This thesis titled "MODELING OF WATER QUALITY OF BINDARE STREAM IN ZARIA-NIGERIA USING MATLAB" by Sanni, Mohammed Ismaila meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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ACKNOWLEDGMENT

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ABSTRACT

The objective of this study was to develop a MATLAB based simulation modeling using SIMULINK tools that produced dissolved oxygen sag curve, and applied it to Bindare stream in Zaria, Kaduna State-Nigeria, in order to assess the stream dissolved oxygen level and its self-purification capacity as a mitigation measure in stream pollution control.. Laboratory test of selected water quality parameters which includes Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), *p*H, Total Dissolved Oxygen (TDS), alkalinity, Electrical Conductivity (EC) and temperature was carried out in four sections of the stream as stipulated by "Standard Method" along the 6 kilometer stream stretch. Results generated by the model simulation included critical dissolved oxygen deficit D_c, critical time t_c of travel by the stream to attain D_c. The stream mean dissolved oxygen DO of 6.4mg/L was obtained which was within the range Stipulated by APHA, AWWA, and WEF 1995. .Determination Coefficient R^2 (found to be 0.86) was applied to check correlation between simulated and theoretical calculated results using Streeter-Phelps dissolved oxygen sag formula. It was therefore concluded that the Dissolved Oxygen Sag generated using MATLAB Simulink is a time saving calculation tool for DO studies, user friendly and can be applied to any stream/river of known required input parameters.

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ABBREVIATIONS

BOD	Biochemical Oxygen Demand
DO	Dissolved Oxygen
DO_{sat}	DO saturation values
D_O	The initial concentration of DO deficit in the stream measured in mg/L
D_C	Dissolved Oxygen Deficit at t_c
K_1	De-oxidation rate constant
K_2	Re-oxidation rate constants
L_a	Ultimate BOD
SA	Station A
SB	Station B
SC	Station C
SD	Station D
t_c	The critical time of travel
x	Simulated value
y	Calculated value
$S_x = \sum_{i=1}^{n} x_i$	The sum of the x_i's

$\overline{x} = S_x/n$ The mean value of the x_i's

$SS_x = \sum_{i=1}^{n} x_i^2$ The sum of the squares of the x_i's

$SSE_x = \sum_{i=1}^{n}(x_i - \overline{x})^2$ The sum the squares of the errors

$SP_{xy} = \sum_{i=1}^{n} x_i y_i$ The sum of the products $x_i y_i$

$S_y = \sum_{i=1}^{n} y_i$ The sum of the x_i's

$\overline{y} = S_y/n$ The mean value of the x_i's

$SS_y = \sum_{i=1}^{n} y_i^2$ The sum of the squares of the x_i's

$SPE_{xy} = \sum_{i=1}^{n} SP_{xy} - S_x S_y/n = (x_i - \overline{x})(y_i - \overline{y})$ The sum of the products of the errors

$SSR = SSE_y - SPE^2{}_{xy}/SSE_x$ The sum of the square of the residuals

$R^2 = 1 - SSR/SSE_y$ The determination coefficient

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Water quality directly affects virtually all water uses, fish survival, diversity and growth; recreational activities, municipal, industrial, and private water supplies, agricultural uses, waste disposal, and general aesthetics-all are affected by the physical, chemical, biological, and microbiological conditions. Water quality impairment is often a trigger for conflict in a watershed, simply because degraded water quality means that desired uses are not possible or not safe (Heathcote, 1998).

Water quality can be defined as the physical, chemical, biological composition of water as related to its intended use for such purpose as drinking, recreation, irrigation, and fisheries. Major rivers in developing countries serve multiple functions as ecosystem, economic basis, water resource and receiving water body, thus providing a livelihood basis for people living in the surroundings of its banks. Many of these rivers suffer increasingly severe pollution problems. By developing tools to effectively address river water pollution, such global core problems as inadequate availability of freshwater and pollution and overuse of renewable natural resources (Hurni *et al*., 2004) are addressed.

Broadly, the pollution in a river occurs due to the disposal of untreated point and nonpoint source pollutants. The point-source pollution refers to the pollutants discharged to the river from one discrete location or point, such as industrial or municipal wastewater. However, the nonpoint source pollution enters the receiving surface water diffusely at intermittent intervals. The extent of nonpoint source pollution is mainly related

to infiltration and storage characteristics of the basin, the permeability of soils, geographic, geological and land use/land cover conditions, and other hydrological parameters.

In Nigeria, rivers are receiving threats to their aquatic life and the environment due to the entry of pollutants from point as well as nonpoint sources. In many cases, effluents from municipal and industrial wastes are discharged into the river without prior treatment, which in turn causes exponential increase in pollutant concentrations and reduction in waste assimilative capacity of the river. It is understood that the most important consideration in determining the waste assimilation capacity of a river is its ability to maintain an adequate dissolved oxygen (DO) concentration. Also, the existence of the aquatic ecosystem flora and fauna depend on the presence of DO in the water. The main process that affects the oxygen content of water is the oxygen consumption of microorganisms living in the water, while they decompose biodegradable organic matter. This means that the presence of biodegradable organic matter is the one that mostly affects the fate of oxygen in the water.

There are internal and external sources of such biodegradable organic matter. Internal sources include organic matter that stem from the death and decaying of living organisms, aquatic plants, and animals also termed “detritus,” or dead organic matter. Among external sources, anthropogenic ones are of major concern and this includes wastewater, sewage discharges and runoff.

In the models biodegradable organic matter is taken into consideration by a parameter termed biochemical oxygen demand (BOD). BOD is defined as the mass of oxygen

consumed from a unit volume of water by microorganisms, while they decompose organic matter, during a specified period of time generally 5 days incubation time at $20^{\circ}C$. Another main process in the streams is the process of re-aeration that results in the uptakes of oxygen across the water surface due to the turbulent motion of water and due to the molecular diffusion. This process reduces the "oxygen deficit" (*D)* of water, which is defined as the difference between saturation oxygen content and the actual dissolved oxygen level.

To assess the changes in water quality e.g., BOD, DO, temperature, etc., water quality modeling of a river is required which has progressed from the pioneering work of Streeter and Phelps (1925), who developed the relationship between the decay of an organic waste measured by the BOD and DO resources of the river, producing the classic dissolved oxygen sag model. These two counteracting processes, BOD and DO, are considered in the traditional BOD–DO model of Streeter and Phelps (1925) in mathematical form. Subsequent to Streeter and Phelps (1925), several BOD–DO models and several concepts were introduced by Theriault (1927); Fair (1939); Thomas (1948); Li (1962, 1972); Camp (1963); Gundelach and Castillo (1976); Van Genuchten and Alves (1982); Bhargava (1983); Thomann and Muller (1987); Ambrose *et al*. (1996); Jolankai (1997); Yu *et al*. (1991); Adrian *et al*. (1994). Most of these models have gradually increased in terms of the number of variables representing the variation of BOD as well as DO concentrations. However, some of the models are different in functional forms and do not transform to the widely used Streeter and Phelps model. Further, these approaches assumed that the substances present in the water decay according to a first-order reaction, which is the rate of loss of the substance, are

proportional to its concentration at any time. In general river water quality models, and thus the BOD–DO models equations, can be derived as presented in the ensuing chapters.

1.2 STUDY AREA

Bindare stream flows in a West-East direction along a gully situated to the East of Sabon-gari and Chikaji industrial area, Zaria. Bindare stream which is about $6km$ long, took its source from Kwangila hills and empties in to River Galma. The stream has a catchment area of about $30.122km^2$. Most part of the gully contains water throughout the year because it cuts through a perched aquifer. The gully also receives various industrial effluents. The nature of Bindare stream channel varies considerable both from station to station and from time to time. Attempts to conserve the stream water include construction of earth/sand barrages and artificially enlarging and deepening of pools. Heaps of refuse, human feces and cattle dung are found on the slopes of its valley. Municipal and industrial effluents are channeled into the same drains and subsequently into the stream irrespective of their qualities.

Chikaji Industrial Estate is located in Sabon-gari, Zaria L.G.A. Zaria, situated in the northern guinea savanna zone, it possesses a tropical continental climate with distinct wet and dry seasons and rainy period that last from May to October. According to smith (1975), Zaria accounted for 9% of manufacturing plants in the former Northern Region of Nigeria.

Chikaji Industrial Estate which is almost encompassed by the Bindare Stream has the following industries: - (i) Electricity Meter Company of Nigeria (EMCON) which produces meter and circuit breakage, (ii) U.A.C. Pharmaceuticals and Personal Product Company, (iii) Kaduna Chalk Manufacturing Company, (iv) John Holt Agricultural

Industry, (v) Harco Textile Company, (vi) U.A.C. Seed Company and Pioneer Seed Company, both of which produces different seed hybrids,(vii) Comrade Bicycle Company and (viii) several warehouses (John, 2000).

Below is a portion of the land used map of the studied area

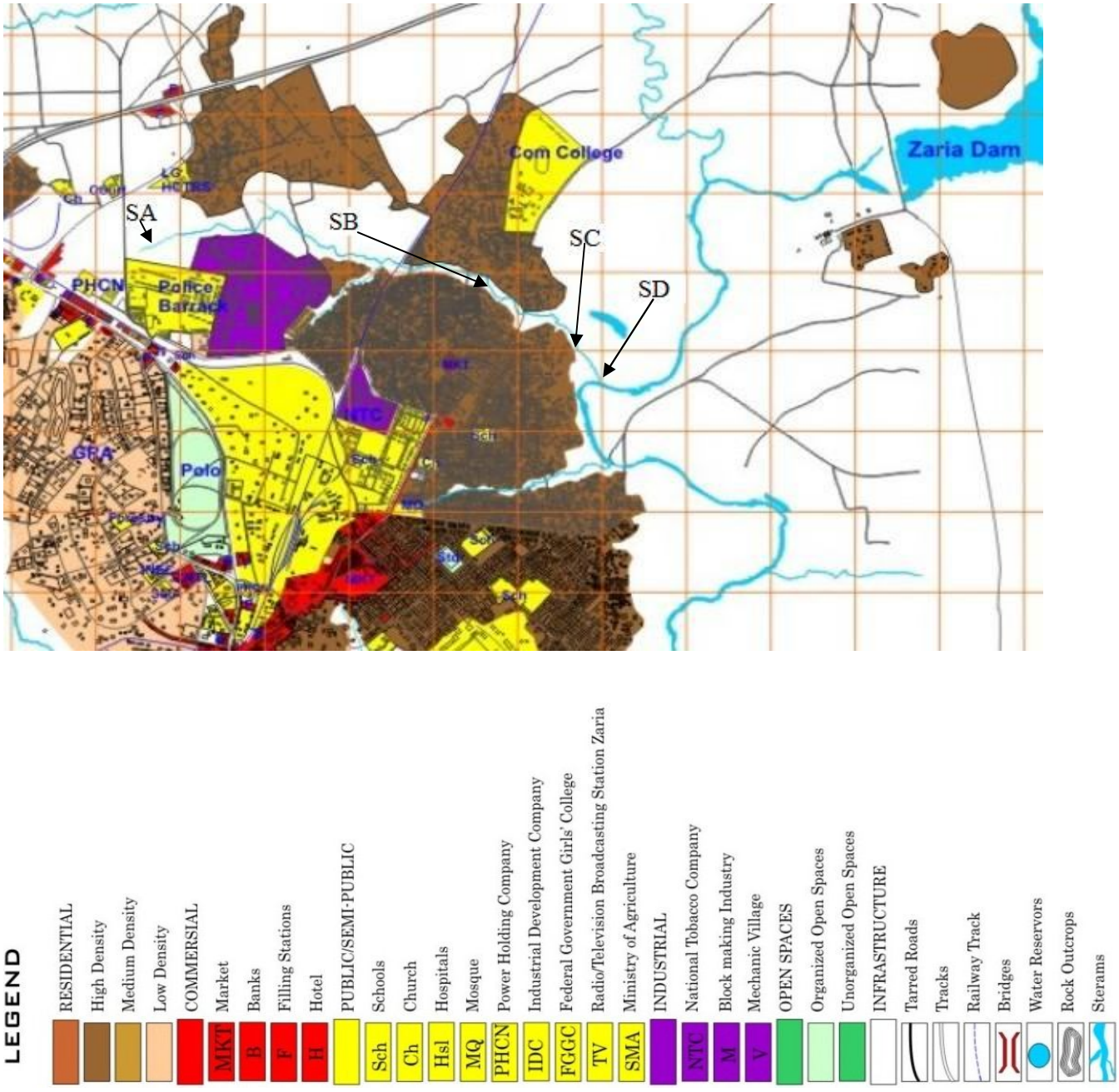


Figure 1.1: land used map for the studied area.

1.3 STATEMENT OF THE PROBLEM

Agricultural practices and increasing population along the Bindare stream has lead to the increase in number of pollutants and the amount of wastewater that pollutes the stream, with associated problems of odour, which has made the water not potable for human consumptions and other unaesthetic nuisances.

On the contrary, the need for water of satisfying quality continuously grows which call for some mitigation measures. Among some of the mitigation measures to curtail stream pollution is model prediction, using some selected water quality parameters such as BOD, DO, rate of stream re-aeration and rate of de-oxidation constant.

Model prediction of the changes in water quality for the Bindare stream is then required to assess the extent of environmental impact of the waste discharged and self-purification capacity of the stream.

1.4 AIM AND OBJECTIVES OF THE RESEARCH

The aim of this study was to develop a MATLAB based simulation modeling using SIMULINK tools that produced dissolved oxygen sag curve, and applied it to Bindare stream in order to assess the stream dissolved oxygen level and its self-purification capacity as a mitigation measure in stream pollution control.

This aim will be achieved through the following objectives:

1. By developing a model flow chart using 2010 MATLAB software that will simulate Bindare stream water quality with regards to the stream dissolved oxygen that can

be used to predict the dissolved oxygen deficit D_c, critical time of flow to attain D_c, and amount of dissolved oxygen level in the stream.

2. By checking the validity of the model simulation by comparing the results obtained with Streeter-Phelps mathematical water quality model formula using the same data collected and also using determination coefficient R^2 to verify the correlation.
3. By assessing the stream water quality parameter by the analysis of the results obtained with regards to the stream dissolved oxygen.

1.5 SIGNIFICANCE OF THE STUDY

The more water quality becomes a limiting factor in water resources use, the more important is water quality modeling for planning and operation of resources system.

The significance of this research is to assess the level of the Bindare Stream pollution, verify its assimilative capability and, to predict the consequence of waste discharged into the stream using simulation models based on Streeter-Phelps first order equation and the future effects of a change in the stream system.

The model holds the promise of predicting the environmental impact of waste discharged into stream, and evaluate water management intervention strategies, structured understanding, research, education, and improved communication (e.g. between wastewater engineers and receiving water quality experts); and regulatory applications including catchment planning.

Water quality modeling is a useful tool to water and environmental engineers, institutional training that deals with water pollution control and integrated water management because it helps in the advancement of scientific knowledge by testing their understanding in natural system.

CHAPTER TWO

LITERATURE REVIEW

2.1 PREAMBLE

Biological decomposition of organic matter is a complex Phenomenon and laboratory BOD results do not necessary fit actual stream conditions. BOD reaction rate is influence by immediate demand, stream dynamic environment, nitrification, sludge deposit, types and concentration of microbes in water. Therefore, laboratory BOD analyses and stream surveys are generally conducted for raw and treated wastewaters and stream water to determine BOD reaction rate.

2.2 MATHEMATICAL MODEL FOR THE BOD CURVE

It is desirable to represent the BOD curve by a mathematical model from kinetic considerations to portray the rate of oxygen utilization given by the first order reaction. Such curve reveals that the rate of oxygen utilization given by the tangent to the curve at a given incubation time, decreases as concentration of organic matter remaining un-oxidized becomes gradually smaller. Since there is proportionality between the rate of oxygen utilization and that of destruction of organic matter by biological oxidation, rate equation is then written in terms of organic matter concentration with the basic assumption of Streeter and Phelps model below;

1. The de-oxygenation and re-aeration are first order reaction
2. The reaction rate are constant

3. The net change of the oxygen deficit is a function only of the bacterial de-oxygenation and atmospheric re-aeration by gas absorption through a liquid air interface. (Shun, 2007)

2.2.1 First Order Reaction.

Phelps law states that the rate of biochemical oxidation of organic matter is proportional to the remaining concentration of un-oxidized substance.

$$-\frac{dL_t}{dt} = K_1 L_t \quad (2.1)$$

$$\frac{dL_t}{L_t} = -K_1 dt \quad (2.2)$$

By integrating

$$\int_{L_a}^{L_t} \frac{dL_t}{L_a} = -K_1 \int_0^t dt_1, \gg y = L_a(1-10^{-tk_t}) \quad (2.3)$$

Where L_t = BOD remaining after time t days, mg/L

L_a = first stage BOD, mg/L

K_1 = deoxygenation rate, base on e, K_1= 2.303k_1, per day

k_1 = deoxygenation rate, base on 10, k_1= 0.4343K_1, per day

Oxygen demand exerted up to time t, y, is a first-order reaction.

$$y = L_a - L_t \quad (2.4)$$

2.3 DETERMINATION OF PARAMETER K_1 AND L_a

In application of equation 2.4 usually with available series of BOD measurement y at a sequence (n=1, 2, 3… x) days. It is desired to determine the optimum values of the parameters K_1 and L_a which satisfy equation for the set of data, Several methods for calculating the parameters has been proposed by the followings;

2.3.1 Slope Method

The Slope Method (Thomas, 1937) for many years was the most used procedure for calculating the constants of the BOD curve via the least-squares treatment of the basic form of the first-order equation. Laboratory BOD analyses and stream surveys are generally conducted for river water to determine BOD reaction rate as follows.

$$\frac{dy}{dt} = K_1(L_a - y) \tag{2.5}$$

Where dy = increase in BOD per unit time at time t

K_1 = de-oxygenation constant, per day,

L_a = first stage ultimate BOD, mg/L

y = BOD exerted in time t, mg/L

The two normal equations for finding K_1 and L_a are

$$na + b\sum y - \sum y' = 0 \tag{2.6}$$

$$a\sum y + b\sum y^2 - \sum yy' = 0 \tag{2.7}$$

Solving this simultaneously yields values of a and b, from which K_1 and L_a be determined directly by following relations:

$$K_1 = -b \tag{2.8}$$

$$L_a = -a/b \tag{2.9}$$

The calculations include first determinations of y',$y'y$ and y^2 for each value of y.The summation of these gives the quantities of $\sum y'$,$\sum y'y$, and $\sum y^2$ which are used for the two normal equations. The values of the slopes are calculated from the given data of y and t as follows:

$$\frac{dy_i}{dt} = y'_i = \frac{(y_i - y_{i-1})\left(\frac{t_{i+1} - t_i}{t_i - t_{i-1}}\right) + (y_{i+1} - y_i)\left(\frac{t_i - t_{i-1}}{t_{i+1} - t_i}\right)}{t_{i+1} - t_{i-1}} \tag{2.10}$$

Solving this simultaneously yields values of a and b, from which K_1 and L_a can be determined directly by following relations:

Special case for equal time increments, $t_{i+1} - t_i = t_3 - t_2 = t_2 - t_1 = \Delta t$,

y' Becomes $\frac{dy_i}{dt} = \frac{y_{i+1} - y_{i-1}}{2\Delta t}$ (2.11)

A minimum of six observations of y and t are usually required to give consistent results, this method with six number of observations was used in this work.

2.3.2 Moment Method

Moore *el at.* (1950) developed the "moment" method that was simple, reliable, and accurate to analyze BOD data; this soon became the most widely used technique for computing the BOD constants. This method requires that BOD measurements must be a series of regularly spaced time intervals. Calculations are needed for the sum of the BOD values, Σy, accumulated to the end of a series of time intervals and the sum of the product of time and observed BOD values, Σty, accumulated to the end of the time series.

The rate constant K_1 and the ultimate BOD L_a can then be easily read from a prepared graph by entering values of $\Sigma y/\Sigma ty$ on the appropriate scale. The authors (Moore *et al*., 1950) presented three graphs for 3, 5 and 7-day sequences (Figs. 2.1, 2.2, and 2.3) with daily intervals for BOD value without lag phase.

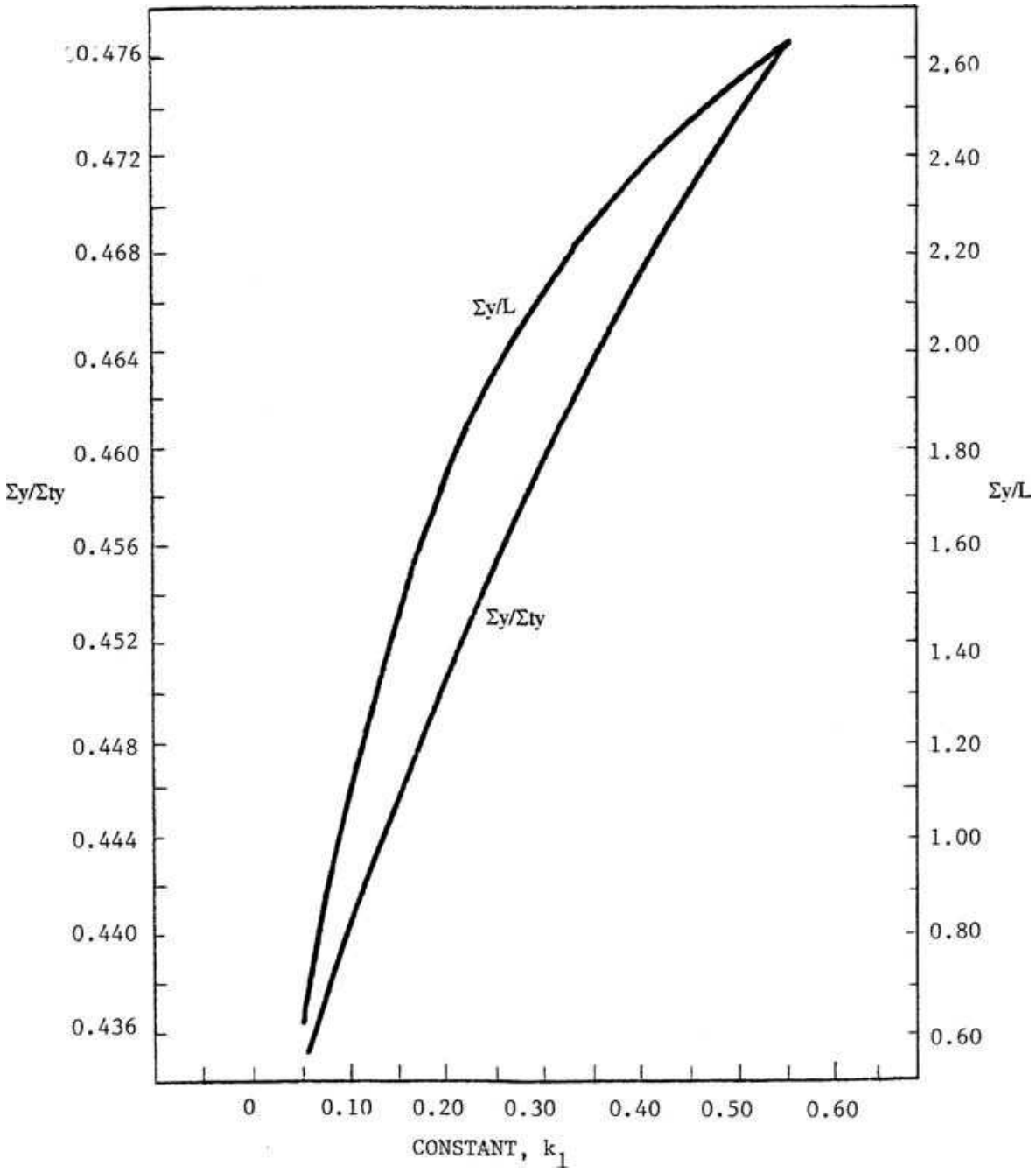


Figure 2.1: $\Sigma y/L$ and $\Sigma y/\Sigma ty$ for various values of K_1 in a 3-day sequence.

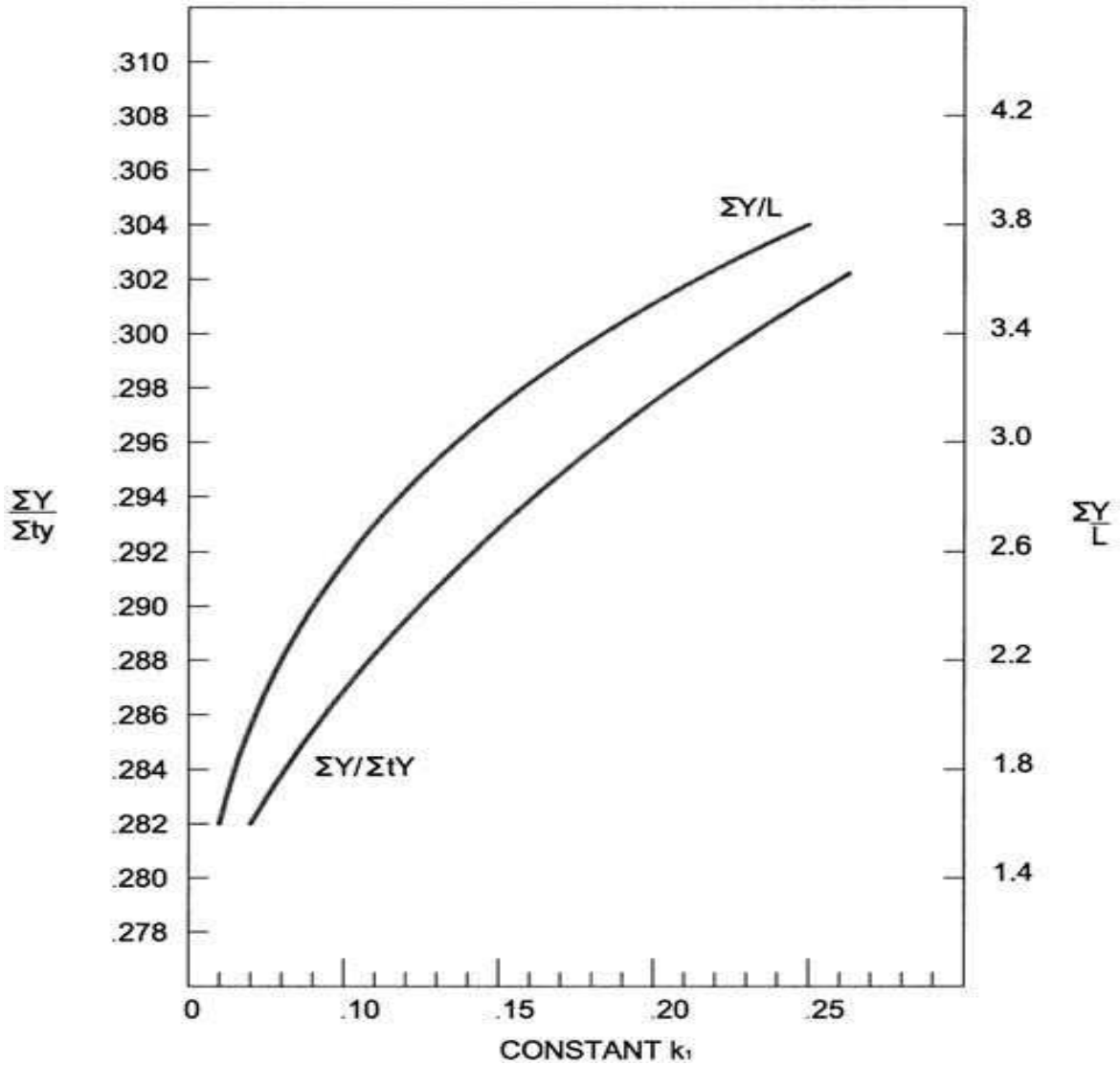


Figure 2.2: $\Sigma y/L$ and $\Sigma y/\Sigma ty$ for various values of K_1 in a 5-day sequence

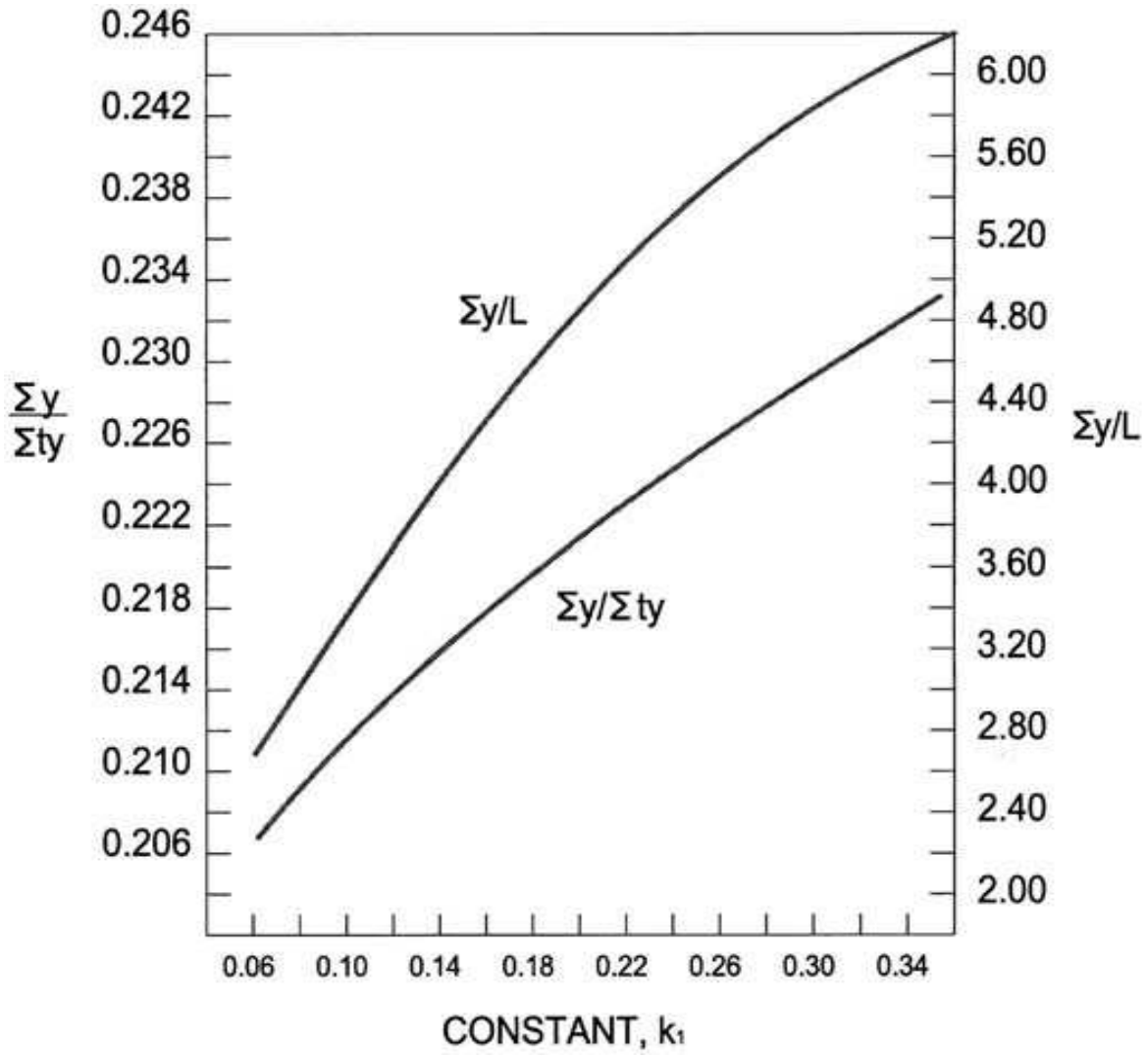


Figure 2.3: $\Sigma y/L$ and $\Sigma y/\Sigma ty$ for various values of K_1 in a 7-day sequence

2.3.3 Logarithmic Formula

Orford and Ingram (1953) reported that there is a relationship between the observed BOD from domestic sewage and the logarithm of time of observation. If the BOD data are plotted against the logarithm of time, the resultant curve is approximately a straight line. The general equation is expressed as

$$y_t = m \log t + b \tag{2.12}$$

Where m is the slope of the line and b is a constant (intercept).

The general equation can be transformed by dividing each side by the 5-day BOD_5 intercept of line to give

$$\frac{y_t}{s}=\frac{m}{s}\log t+\frac{b}{s} \quad (2.13)$$

$$\frac{y_t}{s}=M\log t+B \quad (2.14)$$

$$y_t=s(M+\log t+B) \quad (2.15)$$

Where s= BOD5 intercept of the line

$M=m/s$, BOD rate parameter

$B=b/s$, BOD rate parameter

For domestic sewage oxidation of 20^{o}C, the straight line through the observed plotted points, when extrapolated to the log$t$ axis, intercepts the log$t$ axis at 0.333days. The general equation is

$$y_t = S(\log t + 0.41) \quad (2.16)$$

Where 0.41 is the BOD rate parameter for domestic sewage, for any observed BOD curve with different oxidation time, the above equation may be generalized as

$$y_t = S(\log at + 0.41) \quad (2.17)$$

where S= BOD intercept (y-axis) of the line at 5/a days

S = 5-day BOD at the standardized domestic sewage oxidation rate, when a=1

S =strength factor

a =log$t$ at x-axis intercept of normal domestic sewage BOD curve divided by the x-axis intercept

$$a=\frac{0.333}{x-axis\ intercept} \quad (2.18)$$

a = 1 for a standardized domestic sewage BOD_5 curve

The oxidation rate

$$\frac{dy}{dx} = \frac{0.85S}{t} = K_1(L_a - y_t) \quad (2.19)$$

$$\frac{dy}{dx} = \frac{0.85S}{2.303t} = k_1 (L_a - y_t) \quad (2.20)$$

For the logarithmic formula method, you need to determine the two constant S and a. observed BOD data are plotted on semi-logarithmic graph paper. Time in days is plotted on a logarithmic scale on the x-axis and percent of 5-day BOD on a regular scale on the y-axis. The straight line f the best fix is drawn through the plotted points. The time value of the x-axis intercept is then read, x_1 (for a standardized domestic sewage sample, this is 0.333). The a value can be calculated by

$$a = 0.333/x_1 \quad (2.21)$$

2.3.4 Rapid Methods

Sheehy (l960) developed two rapid methods for solving first-order BOD equations. The first method, using the "BOD slide rule," is applicable to the ratios of observations on whole day intervals, from l to 8 days, to the 5-day BOD. The second method, the graphical method, can be used with whole or fractional day BOD values.

The BOD slide rule consists of scales A and B for multiplication and division. Scales C and D are the values of $1-10^{-k_1 t}$ and $10^{-k_1 t}$ plotted in relation to values of $k_1 t$ on the B scale. From given BOD values, the k_1 value is easily determined from the BOD slide rule. Unfortunately, the BOD slide rule is not on the market.

The graphical method is based on the same principles as the BOD slide rule method. Two figures are used to determine k_1 values directly. One figure contains k_1 values based on the ratios of BOD at time t (BOD_t) to the 5-day BOD for t less than 5 days. The other figure

contains k_1 values based on the ratio of BOD_t to BOD_5 at times t greater than 5 days. The value of k_1 is determined easily from any one of these figures based on the ratio of BOD_t to BOD_5.

2.4 STREETER–PHELPS OXYGEN SAG FORMULA

The most widely used oxygen sag formula for assessing the oxygen resources in streams and rivers subjected to effluent discharges is the Streeter-Phelps oxygen sag formula that was developed for the use on the Ohio River in 1914. The well-known formula is defined as follows (Streeter and Phelps, 1925):

$$t_c = \frac{1}{K_2 - K_1} In \frac{K_2}{K_1}\left(1 - D_o \left(\frac{K_2 - K_1}{L_0 K_1}\right)\right) \quad (2.22)$$

t_c = the critical time of travel (time during which particle arrives at the point of lowest dissolved oxygen concentration in the stream) measured in day

K_2= rate of re-aeration, the rate at which oxygen is dissolved in water measured in per day (day^{-1})

K_1= rate of biochemical decomposition of organic matter BOD (day^{-1})

D_O= the initial concentration of DO deficit in the stream measured in mg/L

L_a= initial concentration of BOD in the stream measured in mg/L

$$D_O = DO_{sat} - DO, \quad (2.23)$$

Where DO_{sat} = dissolved oxygen saturation, DO = initial dissolved oxygen at day one

$$D_C = \frac{K_1}{K_2} \times L_a e^{-K_1 t_c}, \quad (2.24)$$

D_C= dissolved oxygen deficit at t_c the value obtained is divided by 100 the dilution factor to give the dissolved oxygen in mg/L

2.4.1 Standard Methods of Analysis

Concurrent with the evaluation of environmental engineering practice, analytical methods have been developed to obtain the factual information required for the resolution and solution of problems. In many cases different methods have been proposed for the same determination, and

many of them were modified in some manner. As a result, analytical data obtained by analysis were often in disagreement.

In an attempt to bring order out of chaos, the American Public Health Association appointed a committee to study the various analytical methods available and published the recommendation of the committee as "Standard Methods of Water Analysis" in 1905.

"Standard Methods" as published today is the product of the untiring effort of hundreds of individuals who serve on committees, testing and improving analytical procedures for the purpose of selecting those best suited for inclusion in "Standard Methods", which is now available as "Standard methods for the examination of water and waste water".(APHA, 1995).

2.4.2 Sample Collection Method

Polypropylene bottles four liters each was used to transport the sample from the stream site to the laboratory for water quality parameter analysis. Prior to sample collection, at laboratory all bottles were washed with dilute acid followed by distilled water and dried, at each sampling location before collecting the sample into the bottles for analysis, bottles were rinsed three times with the water to be collected and the sample bottles were labeled with date and sample point.

Sample bottles were held near the base and plunged below the water surface with the neck facing upstream. To avoid contamination, care was taken to avoid contact between the stream bed and the collection bottle. Sample bottles were filled to the bottle neck, and caped. Several water quality parameters were sampled, measured and recorded. These include pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), temperature, Electrical Conductivity (EC), alkalinity, and Total Dissolved Solids (TDS).

2.4.3 Impact and Measurement of the Water Quality Parameters

*2.4.3.1 p*H

The pH of natural water can provide important information about many chemical and biological processes and provides indirect correlations to a number of different impairments. This is usually an indication of the amount of carbonates, and bicarbonates that shift the equilibrium producing [OH^-]. Other contributors to an alkaline *p*H include boron, phosphorous, nitrogen containing compounds and potassium. Changes in *p*H can be indicative of an industrial pollutant, photosynthesis or the respiration of algae that is feeding on a contaminant. Most ecosystems are sensitive to changes in *p*H and the monitoring of *p*H has been incorporated into the environmental laws of most industrialized countries. *p*H is typically monitored for assessments of aquatic ecosystem health, recreational waters, irrigation sources and discharges, live stock, drinking water sources, industrial discharges, intakes, and storm water runoff.

At extremely high or low *p*H levels (for example 9.6 or 4.5), the water becomes unsuitable for most organisms. Young fish and insects are also very sensitive to changes in *p*H. Most aquatic organisms adapt to a specific *p*H level and may die if the *p*H of the water changes even slightly.

The *p*H is the measurement of the acid/base activity in solution; specifically it is the negative common logarithm of the activity/concentration of hydrogen ions;

$$p\mathrm{H} = -\log[\mathrm{H}^+] \qquad (2.25)$$

In natural waters, the *p*H scale runs from 0 to 14. A *p*H value of 7 is neutral; a *p*H less than 7 is acidic and greater than 7 represents base saturation or alkalinity.

*p*H can be measured calorimetrically or electrometrically. Colorimetric method is used only for

rough estimation. It can be done either by using universal indicator or by using *p*H paper. The hydrogen electrode is the absolute standard for the measurement of *p*H. They range from portable battery operated units to highly precise instruments. But glass electrode is less subjected to interferences and is used in combination with a calomel reference electrode. This system is based on the fact that a change of 1 *p*H unit produces an electric charge of 59.1 mV at 25°C.

2.4.3.2 Procedure for pH determination using photometer

1. Follow the manufacturer's operating instructions.
2. Fill the cuvette with 10mL of unreacted sample (up to the mark) and replace the cap.
3. Place the cuvette into the holder and close the lid
4. Press the **ZERO** key. The display will show "-0-0-" when the meter reading is zeroed and ready for measurement.
5. Remove the cuvette and 5 drops of HI 93710-0 phenol Red indicator. Replace the cap and mix the solution.
6. Reinsert the cuvette into the instrument.
7. Press the **READ** key to start the reading. The instrument displays the *p*H value

2.4.3.3 Dissolved Oxygen (DO)

Dissolved Oxygen is the amount of oxygen dissolved in water, measured in milligrams per liter (mg/L).Oxygen is essential to the survival of all forms of aquatic life including the organisms that break down man-made pollutants. DO is measured using the azide modification of the Winkler method, DO present in the samples oxidizes divalent manganese under alkaline conditions. With acidification, the manganese will in turn oxidize iodide to iodine in an amount equivalent to the original oxygen content of the sample. The iodine is titrated with thio-sulfate and the end point is detected visually by

using starch.

The main reason DO levels might fall is due to any human activity that heats the water and the presence of organic waste. Organic waste comes from something living or that was once living. It comes from raw or poorly- treated sewage; runoff from farms and animal feedlots; and natural sources like decaying aquatic plants and animals and fallen leaves in water.

Microscopic organisms, called decomposers, break down the organic waste and use oxygen in the process. Two common types of decomposers are bacteria and protozoa. More waste means more decomposers and more oxygen being used.

The DO concentration of stream waters results from: (1) the diffusion of oxygen from the surrounding air, (2) the photosynthetic activity of algae and submerged plants, and (3) the respiratory activities of organisms in open water and the benthos. In freshwaters, the saturation level is determined by two variables: temperature and atmospheric pressure.

DO saturation (DO_{sat}) values for various water temperatures will be computed using the American Society of Civil Engineers, (1960) formula as below

$$\mathrm{DO_{sat}} = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \quad (2.26)$$

Where $\mathrm{DO_{sat}}$= dissolved oxygen saturation concentration, mg/L

T = water temperature, ℃

Where DO_{sat}= dissolved oxygen saturation concentration, mg/L, T = water temperature °C.

The DO saturation concentration generated by the formula in equation 2.26 above must be corrected for differences in air pressure caused by air temperature changes and for elevation above the mean sea level (MSL), the correction factor can be calculated as

$$F = \frac{2116.8 - (0.08 - 0.000115 \times A) \times E}{2116.8} \quad (2.27)$$

F = corrected factor for above MSL,

A = air temperature, ^{o}C,

E = elevation of the site above MSL

2.5.3.4 Determination of Dissolved Oxygen (DO)

The BOD dilution method requires determinations of the amount of dissolved oxygen. These determinations are performed by either titration or instrumental (DO analyzer) methods. The basic titration method is that of Winkler. Wastewaters may contain several ions and compounds which interfere with the original DO determination. Description of the azide modification of Winkler, which effectively removes the interference caused by nitrate, is presented as follows:

Winkler's method is based on oxidation of iodide ion (I^-), which is contained in the alkali-iodide-azide reagent, to iodide (I_2) by dissolved oxygen of the sample, and titration of the iodine by sodium thio-sulfate ($Na_2S_2O_3$), utilizing starch as indicator. Oxidation is performed in acid medium (H_2SO_4) in the presence of manganese sulfate ($MnSO_4$). The alkali-iodide-azide reagent is a solution of NaOH, NaI, and NaN_3 (sodium azide).

Below were the chemical equations involved in the reactions:

$$2I^- \rightarrow I_2 + 2e \qquad (2.28)$$

Interference of nitrates is due to their oxidation to NO with formation of I_2

$$2NO_2^- + 2I^- + 4H^+ \rightarrow 2NO + I_2 + 2H_2O \qquad (2.29)$$

Titration of I_2 by thiosulfate corresponds to to equation (3.5) [thiosulfate ($S_2O_3^{2-}$) is oxidized to tetrathionate ($S_4O_6^{2)^-}$].

$$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^- \qquad (2.30)$$

Starch yields a blue colour in the presence of iodine. Titration with sodium thiosulfate continued until the blue colour disappears.

2.4.3.5 Procedure for the Laboratory Experimental Determination of DO

i. To the sample as collected in a 300-mL B.O.D. bottle add 2mL of Manganese Sulphate solution
ii. Add 2mL alkali-iodide-azide regent, well below the surface of the liquid.
iii. Stopper with care to exclude air bubbles and mix by inverting the bottle several times
iv. Shake again after the precipitate has settle and left a clear supernatant above the floc
v. When settling produces 100mL of supernatant add 2mL of conc.H_2SO_4
vi. Re-stopper and mix by gentle inversion several time
vii. Remove 200mL into a conical flask for titration
viii. Titrate with 0.025N $Na_2S_2O_3.5H_2O$ to a pale straw colour
ix. Add 1-2mL starch solution as indicator
x. Titrate to the first disappearance of the blue colour, and read the titrate which gives the amount of dissolved oxygen in the sample analyzed

DO content of the sample was determined for the day-one (the very day the sample was collected) before incubating the sample at a temperature of 21°C and the DO for day-two (next day) after incubation for 24hour was again determined at a temperature of 21^{o}C. If DO for the day-one was 'A' and DO for day-two was 'B' then the DO is (A-B) gave the amount of oxygen utilized by the micro-organism while consuming the waste at the second day.

2.4.3.6 Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand (B.O.D.) of sewage or of polluted water is the amount of oxygen required for the biological decomposition of dissolved organic matter to occur under aerobic condition and at the standardized time and temperature. Usually, the time is taken as 5 days and the temperature 20°C as per the global standard.

The B.O.D. test is among the most important method in sanitary analysis to determine the polluting power, or strength of sewage, industrial wastes or polluted water. It serves as a measure of the amount of clean diluting water required for the successful disposal of sewage by dilution. The test has its widest application in measuring waste loading to treatment plants and in evaluating the efficiency of such treatment systems.

The test consists in taking the given sample in suitable concentrations in dilute water in B.O.D. bottles. Two bottles are taken for each concentration and three concentrations are used for each sample. One set of bottles is incubated in a B.O.D. incubator for 5 days at 20°C; the dissolved oxygen (initial) content (D_1) in the other set of bottles will be determined immediately. At the end of 5 days, the dissolved oxygen content (D_2) in the incubated set of bottles is determined.

$$\text{BOD mg/}L=\frac{(D_1-D_2)}{P} \qquad (2.31)$$

P = decimal fraction of sample used.

D_1 = dissolved oxygen of diluted sample (mg/L), immediately after preparation.

D_2 = dissolved oxygen of diluted sample (mg/L), at the end of 5 days incubation.

Among the three values of B.O.D. obtained for a sample select that dilution showing the residual dissolved oxygen of at least 1 mg/L and a depletion of at least 2 mg/L. If two or more dilutions are showing the same condition then select the B.O.D. value obtained by that dilution in which the maximum dissolved oxygen depletion was obtained.

Aerobic decomposition of organic material by micro-organisms, particularly bacterial, is an

oxidation process which leads consumption of DO and hence its removal from the water. The quantity of DO needed by the bacterial is the biochemical oxygen demand (BOD). This process can be represented in term of DO by:

$$\frac{dDO}{dt} = -K_1 L \qquad (2.31)$$

Where K_1 is the kinetic constant for BOD decay and L is the BOD remaining to be consumed. Both K_1 and L_o (ultimate BOD), vary with temperature. (Chadwick *et al*)

2.4.3.7 Temperature

Temperature is an important water quality parameter since it directly influences the amount of dissolved oxygen that is available to aquatic organisms and is relatively easy to measure using thermometer. Water bodies will naturally show changes in temperature seasonally and daily; however, man made changes to stream water temperature will affect fish's ability to reproduce.

Environmental polices require the monitoring of stream water temperature. In most urban and industrial locations, environmental permits are required to help minimize the temperature loading to streams.

Water temperature tells many things about the health of a river. Temperature affects:

1) *Dissolved oxygen levels in water* – Cold water holds more oxygen than warm water.

2) *Photosynthesis* – As temperature goes up, the rate of photosynthesis and plant growth also goes up. More plants grow and more plants die. When plants die, decomposers eat them and use oxygen. So when the rate of photosynthesis increases, the amount of oxygen needed by aquatic organisms increases.

3) *Animal survival* – Many animals need certain temperatures to live. For example,

stonefly nymphs and trout need cool temperatures. Dragonfly nymphs and carp can live in warmer water. If water temperatures change too much, many organisms can no longer survive.

4) *Sensitivity to toxic wastes and disease* – Wastes often raise water temperatures. This leads to lower oxygen levels and weakens many fish and insects. Weakened animals get sick and die more easily.

2.4.3.8 Electrical Conductivity (EC)

Conductivity is the ability of a substance to conduct electricity. The conductivity of water is a more-or-less linear function of the concentration of dissolved ions. Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems. If the conductivity of a stream suddenly increases, it indicates that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems and the source of EC may be an abundance of dissolved salts due to poor irrigation management, minerals from rain water runoff, or other discharges. EC is also the measure of the water quality parameter "Total Dissolved Solids" (TDS) or salinity.

An apparatus called a conductivity meter that consists of conductivity cell and meter measures conductivity. The conductivity cell consists of two electrodes (platinum plates) rigidly held at a constant distance from each other and are connected by cables to the meter.

2.4.3.9 Alkalinity

The alkalinity of water is a measure of its buffering capacity. The higher the value, the more acid can be neutralized (*i.e.*, the more the water can resist a change in pH).

Alkalinity of natural waters is primarily the result of bicarbonates (HCO_3^-), but is expressed in terms of calcium carbonate ($CaCO_3$). Carbonates (CO_3^{2-}) and bicarbonates are common to most waters since they are abundant in nature. However, if the bedrock of watersheds is lacking in carbonates and other buffering minerals, as in granite bedrock, alkalinity values will be low.

Decreasing alkalinity over a period of years can have serious effects on the stream ecosystem, as well as downstream lakes and ponds. Gradual lowering of the pH can result in the disappearance of some aquatic species and a decline in the condition and reproductive rate of fish. In large quantities, it imparts a bitter taste to water and it precipitate when it reacts can foul pipes and other water-systems appurtenances.

Alkalinity is measured commonly by titration using burette. The sample is titrated with an acid solution, which neutralizes the alkaline species present. The endpoint is determined by observing a color change, using a pH electrode as an indicator. The volume of titrant required to change the color to reach the endpoint is then used to calculatetotal alkalinity.

Using the indicator method, the experimental procedure to determine the stream sample Alkalinity is as follows:

2.4.3.10 Experimental Procedure for the Determination of Alkalinity

"Standard Methods" recommends the following experimental procedure in the determination of alkalinity:-

1. Pipette 50 mL of sample into a clean Erlenmeyer flask (V).
2. Add one drop of sodium thiosulphate solution, if residual chlorine is present.
3. Add two drops of phenolphthalein indicator; if the pH is above 8.3, colour of solution becomes pink.

4. Titrate against standard sulphuric acid in the burette, till the colour just disappears. Note down the volume (V_1).

5. Then add two drops of methyl orange indicator, the colour turns yellow.

6. Again titrate against acid, until the colour turns to orange yellow. Note down the total volume (V_2).

Alkalinity, mg/L $CaCO_3$=$\frac{A \times N \times 50000}{mL\ sample}$ (2.32)

A= ml of titration for sample to reach phenolphthalein end point

N=Normality of acid (0.02N)

2.4.3.10 Total Dissolved Solids (TDS)

It is the measure of the amount of particulate solids that are in solution after filtration. TDS is an indicator of nonpoint source pollution problems associated with various land use practices, dissolved solids due to the dissolution, weathering of rock and soil. The TDS measurement could be obtained with the conductivity meter and is expressed in (mg/L). Dissolved solids are determined by evaporating a known volume of water and weighing the residue. It is determine as follows

1. Filter a measured portion of the mixed sample (50 or 100 mL) through a filter paper and collect the filtrate in a previously prepared and weighed evaporating dish.

2. Pour a measured portion (50 to 100 mL) of the well-mixed sample into the dish and evaporate the contents by placing the dish on a steam bath.

3. Transfer the dish to an oven maintained at either 103–105°C or 179–181°C and dry it for 1 hour.

4. Allow the dish to cool briefly in air before placing it, while still warm in a desiccator to complete cooling in a dry atmosphere.

5. Weight of dissolved solids = ($W_2 - W_1$) mg

W_1 = Weight of empty evaporating dish in mg.

W_2 = Weight of empty evaporating dish in mg + Residue left after evaporating the filtrate in mg

$$mg/\text{L total dissolved solids} = \frac{mg \text{ of total dissolved solids} \times 1000}{\text{mL of sample}} \quad (2.33)$$

2.4.4 Determination of Re-oxygenation Rate Constant(K_2)

Re-oxidation is the physical process of transfer of oxygen from the atmosphere through the air-water interface into the water. The rate at which this process takes place is proportional to the oxygen deficit, the difference between the saturation DO concentrations (DO_{sat} which is close 9 mg/L at 20°C) and the actual DO in the water. This process is represented in water quality models by:

$$\frac{dDO}{dt} = K_2(DO_{sat} - DO) \quad (2.34)$$

The value of the re-oxidation coefficient K_2 depends, eventually, on the hydraulic parameters of the stream (Chadwick *et al*). There are many formulations for K_2 and it is up to the modeler to select the most appropriate formula for the situation been modeled. For the purpose of this study O'Connor-Dobbin (1958) was used because it gives more consistent result. U = stream velocity(m/s), H = stream depth (m)

$$K_2 = 13 \frac{U^{0.5}}{H^{1.5}} \quad (2.35)$$

2.5 WATER QUALITY MODELS

Water quality modeling is an attempt to relate specific water conditions to natural processes using mathematical relationships. It usually consists of a set of mathematical

expressions relating one or more water quality parameters to one or more natural processes.

There is an extensive variety of water quality modeling software used by experts whose model parameters are based on Streeter and Phleps. Water quality models have been developed during the past four decades. Jørgensen (1996) states that 4000 models have been used in aquatic researches focused on environmental management. QUAL2E/UNCAS (Brown and Barnwell, 1987), WASP (Ambrose *et al*., 1993), CE-QUAL-RIV1 (Environmental Laboratory, 1995), CE-QUAL-W2 (Cole and Wells, 2002), and EPD-RIV1 (Martin and Wool, 2002) are examples of models, which have been applied to various streams in water quality studies (Erturk *et al*., 2004).

Those models are relatively comprehensive tools and can produce practical results that are important for water pollution control, study of eutrophication and assessment of the effects of point and diffuse pollution management questions such as estimation of total maximum daily loads (TMDL) and decisions on waste load allocation by degree of wastewater treatment and application of best management practices for nutrient control in watersheds. However, they are usually complex, include many processes and represent the aquatic ecosystems from moderate to high detail. A study conducted by Gurel *et al.* (2007) indicates that those models usually contain 40 to several hundreds of kinetic and stochiometric coefficients for model calibration. Considering the recent development in aquatic ecology and information technologies, application of such models may seem feasible for various studies. However, those models are generally not easy to learn during classical academic training. Therefore, difficulties arise during most of the water quality modeling courses/trainings when practical applications of models are

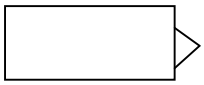
needed to be illustrated to the students/trainees (hereinafter referred to as users) who are usually inexperienced in water quality modeling. Several authors (Musselman, 1993; Salt, 1993; Robinson, 1994; Pegden *et al*., 1995; Pidd, 1996), who are experts in computer science and general simulation approaches reinforce the idea to use simple models (Chwif and Paul, 2000). However, there may be the cases, where the simple models are not the most appropriate ones for the solution of the problem and hence "to apply the simplest possible model is not always the best idea" (Erturk *et al*., 2006).

2.6 DESCRIPTION OF MATLAB MODEL

The MATLAB software provides a computing environment which combines numerical computation facilities with an array of graphical functions. SIMULINK operates as an additional module within the MATLAB and is used for simulating dynamic system; the Math works (1994). For this modeling, SIMULINK is used to simulate the interactions between selected water quality processes occurring in the stream. The input data required for the simulation includes K_1, K_2 and DO_{sat}.. The model simulated the Bindare stream water quality with regards to dissolved oxygen by a one-dimensional mass balance analysis based on first order equation. (Chadwick *et al*).

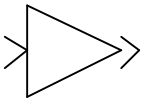
It provides an interactive graphical environment and a customizable set of block libraries that let you accurately design, simulate, implement, and test control, signal processing, communications, and other time-varying systems.

2.6.1 Simulink Library

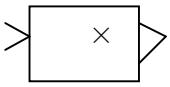


2.6.1.1 Constant Block: The constant block generates real or complex constant values. The

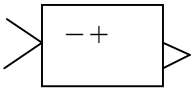
block generates scalar, vector, or matrix output, depending on the dimensionality of the constant value parameter and the setting. The output of the block has the same dimensions and elements as the constant value parameters.



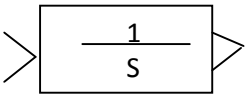
2.6.1.2 Gain Block: The gain block multiplies the input by a constant value (gain). The input and the gain can each be a scalar, vector, or matrix. The block accepts a real or complex scalar, vector or matrix of any numerical data type that simulink supports. If the input is real the output will be real, if complex the output is complex.



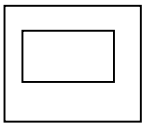
2.6.1.3 Multiplication Block: by default, the product block outputs the result of multiplying two input, two scalars, a scalar and non scalar that have the same dimensions.



2.6.1.4 Sum Block: The sum block performs addition or subtraction on its inputs. This block can add or subtract scalar, vector, or matrix inputs.

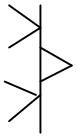


2.6.1.5 The Integrator Block: this outputs the integral of its input at the current time step, the output of the block is limited based on the upper and lower saturation limits, simulink treats the integral block as a dynamics system with one state, its output.



2.6.1.6 Scope Block: the block displays its input with respect to simulation, when simulation is written to connected scope. As a result, you open the scope after a simulation,

the scope output the signals or signals will be displayed by double clinking on it.



2.6.1.7 Mux Block: It combines inputs into a single vector output. An input can be scalar, vector signal. All input must be of the same data type and numeric type.

2.7 DETERMINATION COEFFICIENT R^2

In order to investigate how well the model with the estimated parameters describes the actual observations, the determination coefficient shall be applied as below.

$$R^2 = \frac{SSE_y - SSR}{SSE_y} \tag{2.36}$$

R^2 lies in the interval [0 1] and measures the part of variation of the y_i's which the model describes as a linear function of the x_i's. The greater the determination coefficient R^2 is, the better the model describes the observations.

2.8 DESCRIPTION OF THE TRADITIONAL OXYGEN SAG CURVE

A complete mathematical model to describe DO concentrations within the stream would include all significant factors. Natural streams cannot presently be expressed mathematically with absolute certainty, but reasonably accurate predictions can be made through realistic assumptions concerning the re-aeration phenomenon and de-oxygenation caused by carbonaceous and nitrogenous biochemical oxygen demands (BOD) (User's Manual for Modified Iowa DEQ Model, June 1983).

The main process that depletes the oxygen content of water is the oxygen consumption of microorganisms, living in the water, while they decompose biodegradable organic matter. This means that the presence of biodegradable organic matter is the one that mostly affect the fate of oxygen in the water. There are internal and external sources include organic

matter that stem from the decay (death) of living organisms. Among external sources anthropogenic ones are major concern and this include wastewater discharges and runoff induced non-point source.

In this model biodegradable organic matter is taken into consideration by a parameter termed “Biochemical Oxygen Demand, BOD”. BOD is defined as the quantity of oxygen consumed from a unity volume of water by microorganisms, while they decompose organic matter, during a specified period of time. Thus BOD_5 is the five day biochemical oxygen demand that is the amount of oxygen that was used up by micro-organism in a unity volume of water during five days “incubation” time in the respective laboratory experiment, thus in thesis ten days incubation was used.

Another main process in the oxygen household of stream is the process of re-aeration, the uptake of oxygen across the water surface due to the turbulent motion of water and to molecular diffusion. This process reduces the “oxygen deficit” of water, which is defined as the difference between saturation oxygen content and the actual dissolved oxygen level.

These two counteracting processes are considered in the traditional BOD-DO model (Streeter and Phelps, 1925) in the mathematical form that you can see in “Graph Window” at the appendix.

In this model the decomposition of biodegrable organic matter is expressed as the “first order” decay of BOD in function of time where time is the time of travel.

The oxygen line, the oxygen sag curve, is written for the oxygen deficit D is such a way that oxygen consumed by microorganism adds to the oxygen deficit, while the process of re-aeration reduces this deficit.

The oxygen sag curve has a critical point where the dissolved oxygen content of water is the lowest, which is when the oxygen deficit is the highest. The time of travel is expressed by finding the minimum of the sag curve. Thus the critical dissolved oxygen concentration is obtained as the difference between saturation oxygen concentration and the critical oxygen deficit.

Most of the available water quality models are too comprehensive and not appropriate tools for the inexperienced users that are just learning the basic concepts of water quality modeling. Therefore the aim of this study is to design, develop and easy to use simple stream water quality modeling using MATLAB software that is optimized for basic educational/training purposes.

The analysis of the collected sample from the site for modeling Bindare Stream was carried out in Water Resources and Environmental Engineering Laboratory using Standard Method.

CHAPTER THREE

MATERIAL AND METHODS

Field and laboratory test were conducted according to Standard Method (APHA, 1995) the water sample collected for a period of four weeks (26 November to 24 December 2010 at all stations) to monitor the water quality parameters. The 6 kilometer Bindare stream was divided into at four stations (SA, SB, SC and SD).

3.1 Material

The apparatus and reagents in table 3.1 were used in the analysis of the stream parameters in the Water Resources and Environmental Engineering Laboratory ABU Zaria.

TABLE: 3.1: MATERIALS

Parameter analyzed	Apparatus	Reagents
1. *P*H	Photometer.	Buffer solutions.
2.Dissolved Oxygen DO (mg/L)	BOD bottle, conical flask, burette, pipette, retort stand, measuring cylinder.	Manganese sulphate, conc. HSO_4, alkalide iodide azide reagent, starch solution, sodium thiosulphate.
3. Biochemical Oxygen Demand BOD (mg/L)	BOD bottle, conical flask, burette, pipette, retort stand, measuring cylinder.	Manganese sulphate, conc. HSO_4, alkalide iodide azide reagent, starch solution, sodium thiosulphate.
4.Stream Temperature (°C)	Thermometer.	
5.Electrical Conductivity EC	Electrical conductivity meter, cell.	
6. Alkalinity (mg/L) as $CaCO_3$	Conical flask, measuring cylinder, burette, pipette.	Phenolphthalein indictor, methyl orange indictor $0.02NH_2SO_4$.
7. Total Dissolved Solid TDS (mg/L)	Petri dish, measuring cylinder, wash bath, funnel, oven, weighing balance.	
8. Stream Velocity V (cm/s)	Current Meter	
9. Stream depth H (cm)	5m length of measuring tape	
10. Site Elevation E (m)	GPRS General Packet Radio Service (GPRS)	

3.2 METHODS

The field work was conducted during the period of 4 weeks (November to December 2010). The stream stretch was divided into four stations-SA, SB, SC and SD- (fig.1). Water samples were collected weekly from the site at four stations along the stream stretch and taken to the Water Resources and Environmental Engineering Laboratory ABU Zaria for analysis according to APHA-AWWA-WPCF, (1995). Some selected water quality parameter which includes BOD, DO, *p*H, electrical conductivity, total dissolved solids, and alkalinity were determined as prescribed by "Standard Method" adopted by American Public Health Association in 1995. Stream hydraulics parameters; temperature, stream depth, flow velocity were measured insitu at the four stations. The DO laboratory test results allowed the calculations of the stream rate of de-oxidation constants K_1 and ultimate BOD L_a given by "Slope Method".

Applying the O' Connor-Dobbin (1958) formula the stream rate of re-oxidation constant K_2 was obtained.

Streeter-Phelps combined the processes of re-oxidation and de-oxidation rate constant in equations 2.31 and 2.34 to yield the classical solution known as the oxygen sag curve displayed in figure 2. The required data input into figure1 generated figure 2 when simulated.

3.2.1 Experimental Determination of DO and BOD

Detail procedures for the experimental determination of DO and BOD was as outlined in pages 23 and 24 in chapter two. In this study an 8-day incubation period was used during the BOD determination.

Calculations to obtain the rate of stream de-oxidation rate constant K_1 and ultimate BOD L_a were presented in detail in chapter four of this work.

3.2.2 Experimental Determination of *p*H, Total Dissolved Solids, Alkalinity, Electrical Conductivity

The detail experimental procedures for the determination of *p*H, total dissolved solids, alkalinity, and electrical conductivity of the stream stipulated by "standard method" was as outline in chapter two.

The laboratory results obtained for the parameters were presented in table 4.43 to table 4.46. These parameters were not included in the SIMULINK model simulation but gave information about the quality level of the stream.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 PREPARATION OF INPUT DATA FOR THE MODEL SIMULATION

In Table 4.1, the first day stream DO was determined using "Standard Method" which was found to be 8.7 mg/L while the second day DO value was 7.6mg/L. The difference in DO (8.7-7.6)mg/L divided by the dilution factor of 1:100 (1/100), gave the first BOD value. To obtain the second BOD value, the third day DO value was also subtracted from the 8.7 mg/L and likewise for remaining readings. The laboratory test was carried out for an 8-day BOD incubation period at a constant temperature of 21.5^{o}C. It was observed that the sample DO level decreases as the day progresses due to the activities of the micro-organisms decomposing the organic waste in the water sample using the available sample dissolved oxygen.

TABLE 4.1:STATION SA FIRST WEEK (WEEK1) BOD VALUE

Date	Time t(day)	DO (mg/L)	BOD (mg/L)
26/11/2010	0	8.7	
27/11/2010	1	7.6	(8.7-7.6)×100 =110
28/11/2010	2	7.2	(8.7-7.2)×100 =150
29/11/2010	3	7.0	(8.7-7.0)×100=170
30/11/2010	4	6.6	(8.7-6.6)×100=210
01/12/2010	5	6.3	(9.3-6.3)×100=240
02/12/2010	6	6.0	(9.3-6.0)×100=270
03/12/2010	7	5.8	(9.3-5.8)×100=290

Applying the Slope Method given in equation 2.11, table 4.2 was obtained.

TABLE 4.2: SA SLOPE VALUE

t	Y	y'	yy'	y^2
0	0			
1	110	75	8250	12100
2	150	30	4500	22500
3	170	30	5100	28900
4	210	35	7350	44100
5	240	30	7200	57600
6	270	25	6750	72900
7	290			
Sum	1150	225	39150	238100

1150 is the sum of the first six observations (n=6), $\frac{dy_i}{dt}=y'_i=\frac{y_3-y_1}{t_2-t_1}=\frac{150-0}{2-0}=75$

The Matlab expression for determining a, b, was given equation 4.1

[a,b]=solve('6*a+b*Σy=Σy' ','a*Σy+b*Σy^2=Σyy'') (4.1)

From table 4.2,

Σy=1150, Σy'=225, Σyy'=39150, Σy^2=238100.

a=85500/1061=80.584

b=-477/2122=-0.225

From equation 2.29,

K_1 =-*b*, K_1=-(-0.225)

K_1=0.225 per day.

From equation 2.30,

La=-a/b, La=-(-80.584/0.225)

La=358.49mg/L

The same procedure was repeated for the rest of the stations whose tables obtained were presented in table 4.3 to table 4.32 at appendix.

K_2=13 $\frac{U^{0.5}}{H^{1.5}}$,

The stream parameters which includes velocity, stream depth, temperature as measured insitu and values of K_2, DO_{sat}, K_1 and L_a were presented in table 4.33 at station SA

Therefore K_2=13×$\frac{7.08^{0.5}}{33.3^{1.5}}$ =0.180 per day.

This procedure was followed step wise to fill out Table 4.33 to Table 4.36 for different sampling dates.

TABLE 4.33: STREAM HYDRAULIC PARAMETERS ON 26/11/2010

Stream Parameter	S A	SB	SC	SD
Velocity (V), cm/s	7.08	6.44	9.46	1.76
Depth (H) cm	33.3	27.4	28.7	15.6
Re-oxidation Rate K_2 (per day)	0.18	0.23	0.26	0.28
Temperature °C	18.0	18.2	18.0	18.1
DO_{sat} (mg/L)	9.1842	9.1457	9.1842	9.1649
De-oxidation Rate K_1 (per day)	0.225	1.011	0.559	0.443
L_a, ultimate BOD mg/L	358.49	503.58	458.19	414.39

TABLE 4.34: STREAM HYDRAULIC PARAMETERS ON 03/12/2010

Stream Parameter	SA	SB	SC	SD
Velocity (V), cm/s	6.15	3.97	8.03	0.82
Depth (H) cm	33.0	25.6	27.9	12.7
Re-oxidation Rate K_2 (per day)	0.17	0.20	0.25	0.26
Temperature °C	17.0	17.3	17.1	17.0
DO_{sat} (mg/L)	9.3802	9.3202	9.3601	9.3802
De-oxidation Rate K_1 (mg/L)	0.288	1.097	0.919	0.605
L_a, ultimate BOD mg/L	319.34	545.47	524.33	453.16

TABLE 4.35: STREAM HYDRAULIC PARAMETERS ON 10/12/2010

Stream Parameter	SA	SB	SC	SD
Velocity (V cm/s	4.00	3.03	5.76	0.35
Depth (H) cm	31.1	25.1	27.2	10.4
Re-oxidation Rate K_2 (per day)	0.15	0.18	0.22	0.23
Temperature °C	17.1	17.5	17.0	17.0
DO_{sat} (mg/L)	9.3601	9.2806	9.3802	9.3802
De-oxidation Rate K_1 (mg/L)	0.244	1.104	0.994	0.643
L_a, ultimate BOD mg/L	392.82	621.89	552.05	512.95

TABLE 4.36: STREAM HYDRAULIC PARAMETERS ON 17/12/2010

Stream Parameter	SA	SB	SC	SD
Velocity (V), cm/s	2.21	1.91	4.86	0.28
Depth (H) cm	29.6	24.3	26.5	9.60
Re-oxidation Rate K_2 (per day)	0.12	0.15	0.21	0.23
Temperature °C	16.4	16.9	16.6	16.3
$DO_{sa}t$ (mg/L)	9.5016	9.3997	9.4606	9.5223
De-oxidation Rate K_1 (per day)	0.325	1.324	1.094	0.663
L_a, ultimate BOD mg/L	331.26	654.74	598.67	531.31

4.2 SIMULINK: Block Diagram

Figure 4.1, presented the diagrammatical presentation of the SIMULINK model for the simulation. The actual SIMULINK model that can be simulated with the required input data was made available in MATLAB environment. Running time for the model simulation was twenty days in order to generate an easily read and smooth curve. Input into the SIMULINK model generated the expected oxygen sag curve in figure 4.2 by double clicking the graph block. The with the respective values presented in tables 4.37 to 4.40.

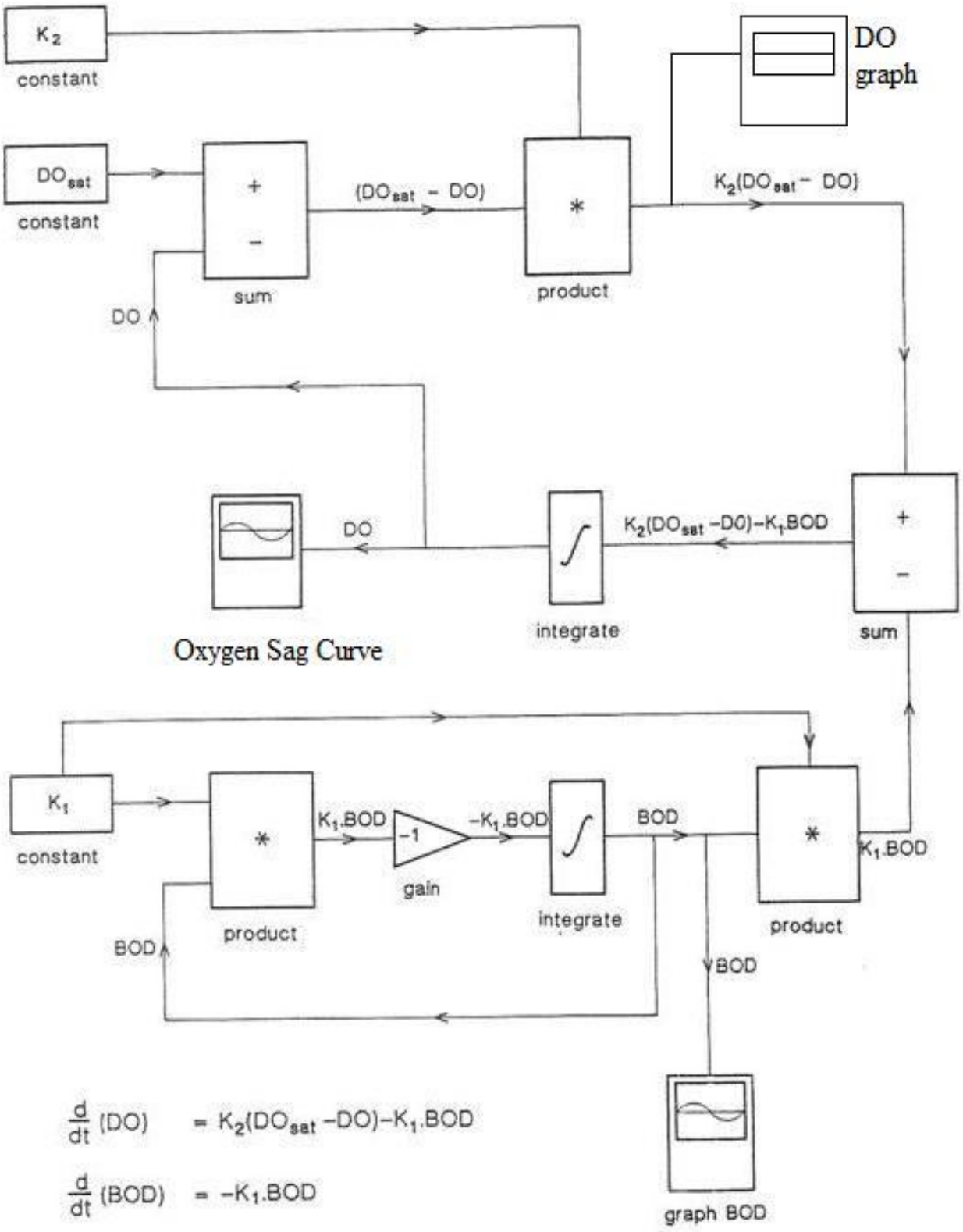


Figure 4.1: SIMULINK Block Diagram for Streeter-Phelps Dissolved Oxygen Sag curve

4.2.1 Streeter-Phelps Dissolved Oxygen Sag Curve

Streeter-Phelps combined the processes of re-oxidation and de-oxidation rate constant in equations 2.31 and 2.34 to yield the classical solution known as the oxygen sag curve displayed in figure 4.2. The required data input into figure 4.1 generated figure 4.2 when simulated.

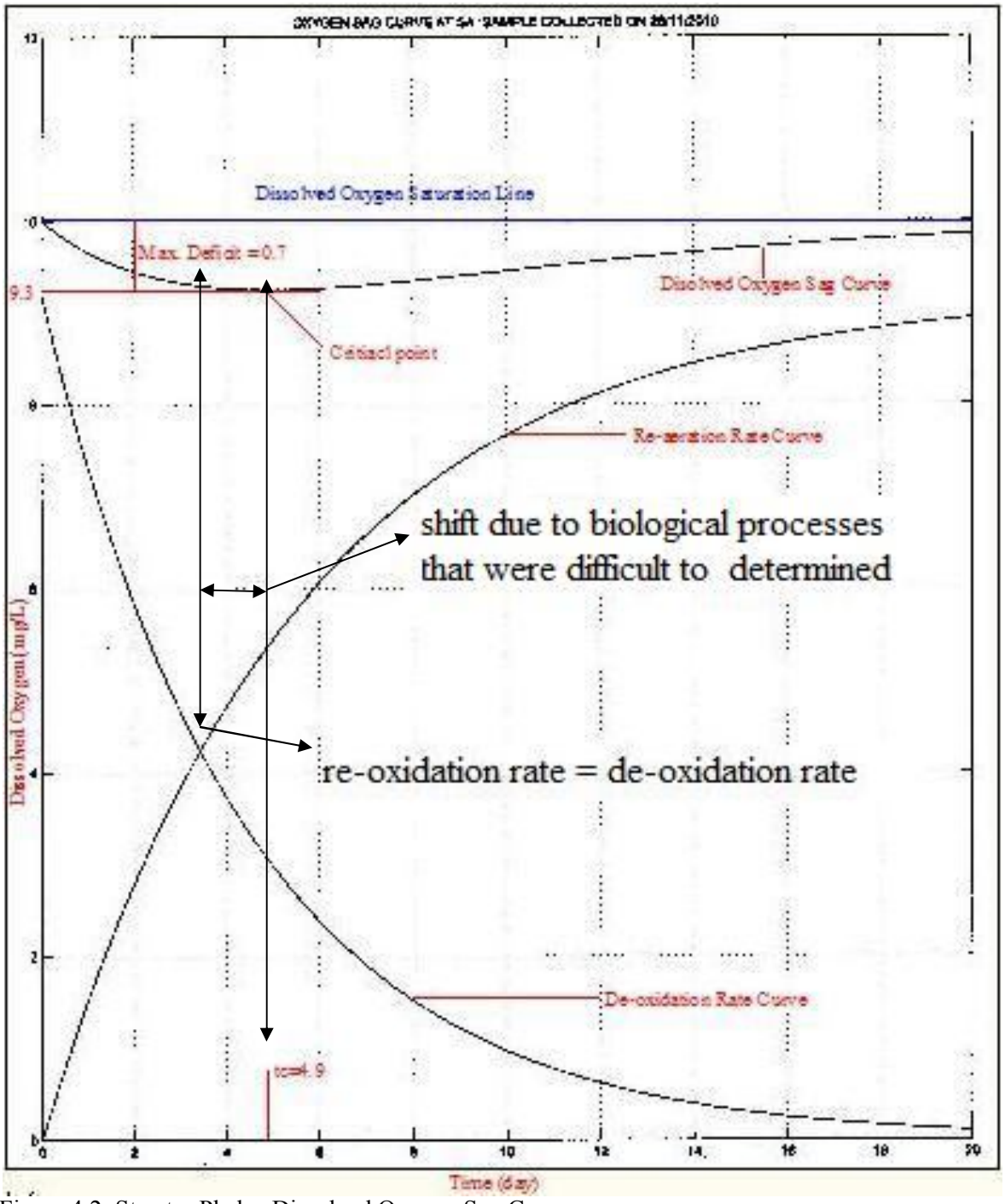


Figure 4.2: Streeter Phelps Dissolved Oxygen Sag Curve

TABLE 4.37: STATION SA SIMULATION RESULTS

Date (week)	First week	Second week	Third week	Fourth week
Max. Critical deficit D_c (mg/L)	0.7	1.8	1.6	3.4
Critical time t_c (day)	4.9	4.5	5.0	5.0
Dissolved oxygen *DO* mg/L	9.3	8.2	8.4	6.6

TABLE 4.38: STATION SB SIMULATION RESULTS

Date (week)	First week	Second week	Third week	Fourth week
Max. Critical deficit D_c (mg/L)	4.6	5.2	5.4	6.3
Critical time t_c (day)	2.0	2.0	2.0	1.9
Dissolved oxygen *DO* mg/L	3.4	4.8	4.6	3.7

TABLE 4.39: STATION SC SIMULATION RESULTS

Date (week)	First week	Second week	Third week	Fourth week
Max. Critical deficit D_c (mg/L)	2.5	4.2	4.8	5.2
Critical time t_c (day)	7.6	2.0	2.0	2.0
Dissolved oxygen *DO* mg/L	7.5	5.8	5.2	4.8

TABLE 4.40: STATION SD SIMULATION RESULTS

Date (week)	First week	Second week	Third week	Fourth week
Max. Critical deficit D_c (mg/L)	1.5	2.9	3.4	3.6
Critical time t_c (day)	2.9	2.4	2.6	2.4
Dissolved oxygen *DO* mg/L	8.5	7.1	6.6	6.4

4.2.2 Variation of Dissolved Oxygen Level Down Bindare Stream

Taking the first week amount of dissolved oxygen of each station obtained from the simulation and plotted against the station as presented in table 4.37 to 4.40, the dissolved oxygen level down the stream (self-purification capacity) was as shown in figure 4.4.

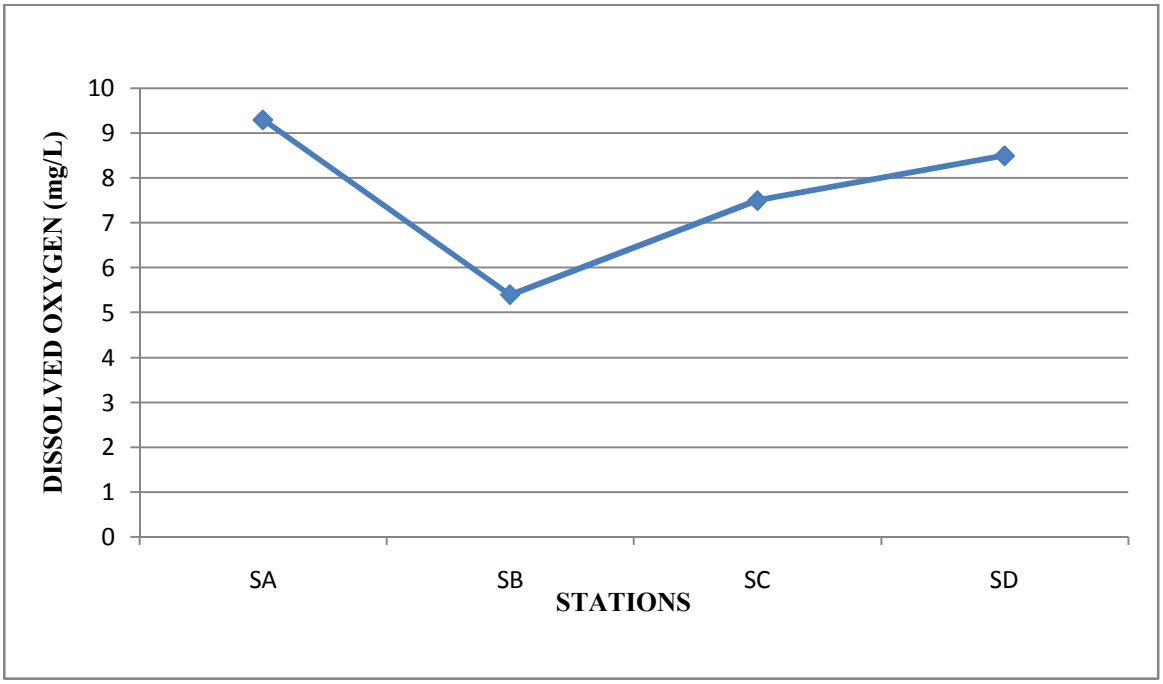


Figure 4.3: Graph of First Week simulated Dissolved Oxygen level down the Stations

SA was the upstream with the highest dissolved oxygen and SB showed the point of lowest dissolved oxygen indicating maximum waste discharged into the Bindare stream body, which was evident in the concentration of the population around the station SB, check map for clearance.

4.2.3 Stream Dissolved Oxygen and Stream Depth Comparison

Figure 4.4 presented the amount of dissolved oxygen at station SA against its depth for the period of the study.

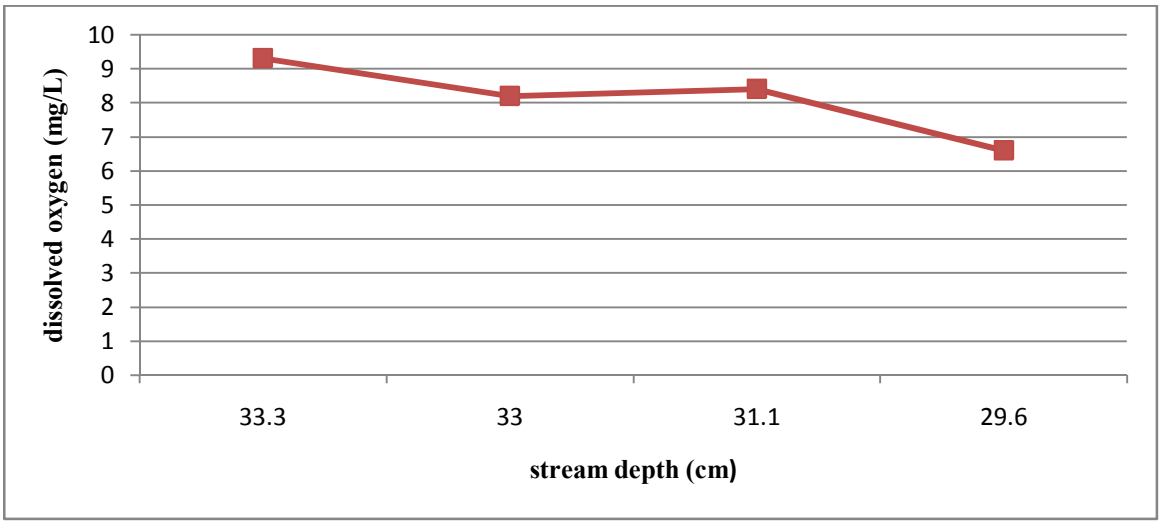


Figure 4.4: Graph of Simulated Dissolved Oxygen (mg/L) against it respective Depth (cm)

Form figure 4.4 it was shown that as stream flow reduces with respect to the depth, the amount of dissolved oxygen in the water body also reduces there by amplifying the stream odour and the potency of waste discharged into the stream became pronounced.

4.3 RESULTS COMPARISON

To validate the simulation model flow chart, the following calculations were carried out.

4.3.1 Calculation Using Streeter-Phelps First Order Equation

The theoretical Streeter-Phelps dissolved oxygen sag formulae were used to check the validity of the simulation model result was as outlined below, taken SA

$$t_c = \frac{1}{K_2 - K_1} In \frac{K_2}{K_1}\left(1\text{-}D_o\left(\frac{K_2 - K_1}{L_a K_1}\right)\right) \quad (4.6)$$

t_c = the critical time of travel (time during which particle arrives at the point of lowest dissolved oxygen concentration in the stream) measured in day

K_2= rate of re-aeration, the rate at which oxygen is dissolved in water measured in per day

K_1= rate of biochemical decomposition of organic matter BOD (day^{-1})

D_O= the initial concentration of DO deficit in the stream measured in mg/L

L_a= initial concentration of BOD in the stream measured in mg/L

D_O=DO_{sat} – DO,

Where DO_{sat} = dissolved oxygen saturation,

DO = initial dissolved oxygen at day one, from table 4.3,

K_2=0.18day^{-1};
K_1=0.225day^{-1};
L_a=358.49mg/L;
DO_{sat}=9.1842mg/L ,

D_O=9.1842-8.7=0.48mg/L. substitute this values into equation 4.7

t_c=$\frac{1}{0.180-0.225} In \frac{0.18}{0.225}(1 - 0.48 \times \frac{(0.180-0.225)}{358.49\times 0.225})$=4.95≈5.0. These steps were followed for the rest of the stations

D_C=$\frac{K_1}{K_2}\times L_a e^{-K_1 t_c}$, (4.7)

Substitute for K_1, K_2, L_a, and t_c in equation 4.7, Dc=145.48mg/L

This value obtained divided by the dilution factor (P=100), then Dc = 1.45mg/L, to obtain dissolved oxygen level of the stream, 1.45mg/L was subtracted from the value of Dissolved Oxygen Saturation Line (10 mg/L) from the graph. From SA graph titled "OXYGEN SAG CURVE AT SA: SAMPLE COLLECTED ON 26/11/2010" the dissolved oxygen level at Dc=1.45 was 10-1.45=8.55mg/L. Following this procedure, table 4.41 was obtained

TABLE 4.41 RESULTS COMPARISONS

STATION	DATE (WEEK)	DO stimulated mg/L	DO calculated mg/L
SA	First week	9.30	8.55
	Second week	8.20	8.52
	Third week	8.40	8.20
	Fourth week	6.60	8.18
SB	First week	5.40	6.76
	Second week	4.80	6.66
	Third week	4.60	5.32
	Fourth week	3.70	4.67
SC	First week	7.50	7.56
	Second week	5.80	6.64
	Third week	5.20	6.23
	Fourth week	4.80	6.10
SD	First week	8.50	8.10
	Second week	7.10	7.53
	Third week	6.60	7.13
	Fourth week	6.40	6.88

4.3.2 The Determination Coefficient R^2

In order to investigate how well the model with the estimated parameters describes the actual observations, the determination coefficient was applied.

$$R^2 = \frac{SSE_y - SSR}{SSE_y}$$

R^2 lies in the interval [0 1] and measures the part of variation of the y_i's which the model describes as a linear function of the x_i's. The greater the determination coefficient R^2 is, the better the model describes the observations.

TABLE 4.42: RESULTS CORRELATION

parameter	*x*	Parameter	*Y*
	9.30		8.55
	8.20		8.52
	8.40		8.20
	6.60		8.18
	5.40		6.76
	4.80		6.66
	4.60		5.32
	3.70		4.67
	7.50		7.56
	5.80		6.64
	5.20		6.23
	4.80		6.10
	8.50		8.10
	7.10		7.53
	6.60		7.13
	6.40		6.88
$S_x = \sum_{i=1}^{n} x_i$	102.9	$S_y = \sum_{i=1}^{n} y_i$	113.03
$\overline{x} = S_x/n$	6.43125	$\bar{y} = S_y/n$	7.064375
$SS_x = \sum_{i=1}^{n} {x_i}^2$	702.05	$SS_y = \sum_{i=1}^{n} {y_i}^2$	817.76
$SSE_x = \sum_{i=1}^{n} (x_i - \overline{x})^2$	40.27438	$SSE_y = \sum_{i=1}^{n} (y_i - \bar{y})^2$	19.27179
$SP_{xy} = \sum_{i=1}^{n} x_i y_i$	752.761		
$SPE_{xy} = \sum_{i=1}^{n} SP_{xy} - S_x S_y/n$	25.83681		
$SSR = SSE_y - SPE^2{}_{xy}/SSE_x$	2.696966		
$R^2 = 1 - SSR/SSE_y$	0.860056		

R^2 value 0.86 obtained suggested that the simulated results obtained agreed with the Streeter-Phelps theoretical dissolved oxygen saturation formula.

4.3.3 The Stream Water Quality Level in terms of *p*H, Total Dissolved Solids, Alkalinity, Electrical Conductivity.

Table 4.43 to 4.46 presented some of the stream water quality parameters that were not included in the simulation.

TABLE 4.43: WATER QUALITY READING FOR SAMPLE AT STATION SA

Date	*p*H	Alkalinity mg/L CaCO3	Electrical conductivity mS/m ($\times 10^3$)	Total Dissolved solid mg/L
26/11/2010	6.7	259	0.24	460
03/12/2010	6.8	263	0.22	410
10/12/2010	6.7	253	0.21	390
17/12/2010	6.7	258	0.21	430

TABLE 4.44: WATER QUALITY READING FOR SAMPLE AT STATION SB

Date	*p*H	Alkalinity mg/L CaCO3	Electrical conductivity mS/m ($\times 10^3$)	Total Dissolved solid mg/L
26/11/2010	6.7	320	0.54	500
03/12/2010	6.8	346	0.49	480
10/12/2010	7.1	362	0.56	520
17/12/2010	6.9	356	0.71	720

TABLE 4.45: WATER QUALITY READING FOR SAMPLE AT STATION SC

Date	*p*H	Alkalinity mg/L CaCO3	Electrical conductivity mS/m ($\times 10^3$)	Total Dissolved solid mg/L
26/11/2010	6.8	343	1.53	800
03/12/2010	7.2	377	1.50	760
10/12/2010	6.6	345	1.05	790
17/12/2010	6.7	331	1.10	890

TABLE 4.46: WATER QUALITY READING FOR SAMPLE AT SD

Date	*p*H	Alkalinity mg/L CaCO3	Electrical conductivity mS/m ($\times 10^3$)	Total Dissolved solid mg/L
26/11/2010	6.7	338	1.53	800
03/12/2010	6.9	365	1.49	770
10/12/2010	7.2	386	1.02	810
17/12/2010	6.7	302	1.20	910

4.3.3.1 pH

*p*H, or the "potential of hydrogen", is a measure of the concentration of hydrogen ions in the water. This measurement indicates the acidity or alkalinity of the water. Naturally occurring fresh waters have a pH range between 6 and 8. The pH of the water is important because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms.

Chehalis River Council (CRC) 2009 stipulated that *p*H of range of 6.5-8.5 of a stream is acceptable. Bindare Stream *p*H value on the average was found to be 6.8 which fall within the acceptable limit as required by CRC.

4.3.3.2 Total Dissolved Solid (TDS)

Total dissolved solid is a measure of the amount of particulate solids that are in solution. This is an indicator of nonpoint source pollution problems associated with various land use practices. The TDS measurement was obtained with the conductivity meter expressed in (mg/L). It is general indicator of ion concentrations that affects taste and no state water quality standard for TDS of a stream/river as stated by Chehalis River Council (CRC) 2009. The stream mean TDS was found to be 652.5 mg/L.

4.3.3.3 Alkalinity

Aquatic organism benefit from a stable *p*H value in their optimal range, to maintain a fairly constant pH in water body, a higher alkalinity is preferable. Higher alkalinity means that the water body has the ability to neutralize acidic pollution from rainfall or basic inputs from wastewater. The stream mean alkalinity was found to be 325.25 mg/L and as stipulated by Chehalis River Council CRC 2009 there is no stated water quality standards for alkalinity.

4.3.3.4 Electrical conductivity

Conductivity is the ability of the water to conduct an electrical current, and is an indirect measure of the ion concentration. The more ions present, the more electricity can be conducted by the water. This measurement is expressed in microsiemens per centimeter

(uS/cm) at 25 degrees Celsius. The Stream mean conductivity was found to be 0.82×10^3 mS/m.According to CRC 2009 there was no stated water quality standards for conductivity of a stream/river.

4.4 MODEL LIMITATION

Dissolved oxygen (DO) concentrations in Bindaren Stream are controlled by many factors including atmospheric re-aeration, biochemical oxygen demands (carbonaceous and nitrogenous), algal photosynthesis and respiration, benthal oxygen demands, temperature, and the physical characteristics of the stream. Many of these factors are difficult, if not impossible, to accurately assess. As a result of this difficulty, limitations on the non inclusion of these controlling factors are discussed below.

1. Photosynthesis can produce large quantities of oxygen during the day by the presence of algae and other aquatic plants present in the stream, conversely, at night, algal respiration creates an oxygen demand.
2. Benthal oxygen demands result from anaerobic decomposition of settled organic material at the bottom of the stream. These reactions release carbonaceous and nitrogenous organic materials that create biochemical oxygen demands.

   The inclusion of benthal oxygen demands in the model requires extensive field surveys to determine the real extent of sludge deposits within a stream and coefficients that describe the release into the water. No data are available to accurately describe the sludge deposition.

The effect of these limitations is evident in the shift away of critical time from the point where rate of re-oxidation equals rate of de-oxidation in the dissolved oxygen sag curve in figure 4.3 page 56.

A complete mathematical model to describe DO concentrations within the stream would include all significant factors. Natural streams cannot presently be expressed mathematically with absolute certainty, but reasonably accurate predictions can be made through realistic assumptions concerning the re-oxidation phenomenon and de-oxidation caused by carbonaceous and nitrogenous biochemical oxygen demands (BOD).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSION

Increasing water scarcity in Dogarawa/Chikaji-Zaria provides a strong impetus for model in water quality remediation at the watershed as a means to increase water availability to the community. The application of stream water quality modeling, as a support tool to evaluate remediation options, is often limited by the availability of reliable data. Current proposals to use the river complex water quality model software are hampered by its relative complexity and large data requirements, with the result that use of such model is often not economically feasible, especially in developing countries. However, the basic Streeter-Phelps equation was used in conjunction with Slope Method in an attempt to better simulate the Bindare Stream oxygen sag curve by simplifying this model using SIMULINK to suit specific applications, the general water quality situation of the stream can still be predicted with limited data.

The finding of the study indicated that Bindare Stream assimilating capacity is yet to be exceeded and from the dissolved oxygen sag curve generated by the model, it can be inferred that;

1. A combination of re-oxidation and biodegradation can allow recovery of the stream pollution as shown in figure 4.2, page 45.
2. The Dissolved Oxygen Sag Curve based on Streeter-Phelps generated using MATLAB is a time saving calculation tool for DO studies

3. The breakdown of pollutants by bacteria creates an oxygen sag curve. Organisms that have a high oxygen demand like trout cannot survive at the critical point in the sag curve.
4. The amount of stream dissolved oxygen decreases progressively as the steam flow reduces, this was shown in figure 4.2, page 51
5. The high value of the determination coefficient R^2 0.86 obtained showed that the Model using MATLAB described the observations better.
6. Volume of the stream flow, rate of re-oxidation and de-oxidation all affect how great a sag curve is produced, as shown by the model graphs at the appendix
7. At station SB there was a significant high value of maximum dissolved oxygen deficit as presented in table 4.8, which clearly signified high contaminant at SB and reduces down the stream at SC and SD due to the stream self-purification processes.
8. The mean ultimate BOD 485.79 mg/L of the stream recorded as against 0 mg/L stipulated by Nigeria standard/ WHO (World Health Organization 2006), indicated that the stream is not fit for drinking except if subjected to the required treatment but can be used for such purposes like wetting of garden flowers, irrigation, washing of street e.tc.

5.2 RECOMMENDATION

Dissolved Oxygen Sag curve generated using MATLAB SIMULINK is recommended for use in stream pollution measures because it is a time saving calculation tool for DO studies, it is user friendly and can be applied to any stream/river of known required parameters.

There is a need for better and complete mathematical modeling software that will describe DO concentrations within the stream which would include all significant factors. When sufficient data are available, cautious assumptions made that tend to assure a high degree of protection for water quality without imposing unrealistically stringent effluent limitations. This will also help to improve the validity of the models and such data if made available allows a reasonably and accurate prediction of the impact of different wastewater loads or treatment arrangements upon the DO.

The high BOD mean value obtained of 485.79 mg/L at point SB showed that as population increases along the stretch of the stream, there is tendency that the stream will become depilated of dissolved oxygen if the community waste discharged into the stream is not handled.

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Plate 1 : PHOTOMETER

used for measuring water quality parameters like to mention afew *p*H,dissolved oxygen,nitrate,alkalinity,calcium,chlorine,sulfate,water colour e.t.c



Plate 2: DIGITAL CURRENT METER

TABLE 4.1:STATION SA FIRST WEEK (WEEK1) BOD VALUE

Date	Time t(day)	DO (mg/L)	BOD (mg/L)
26/11/2010	0	8.7	
27/11/2010	1	7.6	(8.7-7.6)×100 =110
28/11/2010	2	7.2	(8.7-7.2)×100 =150
29/11/2010	3	7.0	(8.7-7.0)×100=170
30/11/2010	4	6.6	(8.7-6.6)×100=210
01/12/2010	5	6.3	(9.3-6.3)×100=240
02/12/2010	6	6.0	(9.3-6.0)×100=270
03/12/2010	7	5.8	(9.3-5.8)×100=290

TABLE 4.1:STATION SA SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	110	75	8250	12100
2	150	30	4500	22500
3	170	30	5100	28900
4	210	35	7350	44100
5	240	30	7200	57600
6	270	25	6750	72900
7	290			
Sum	1150	225	39150	238100

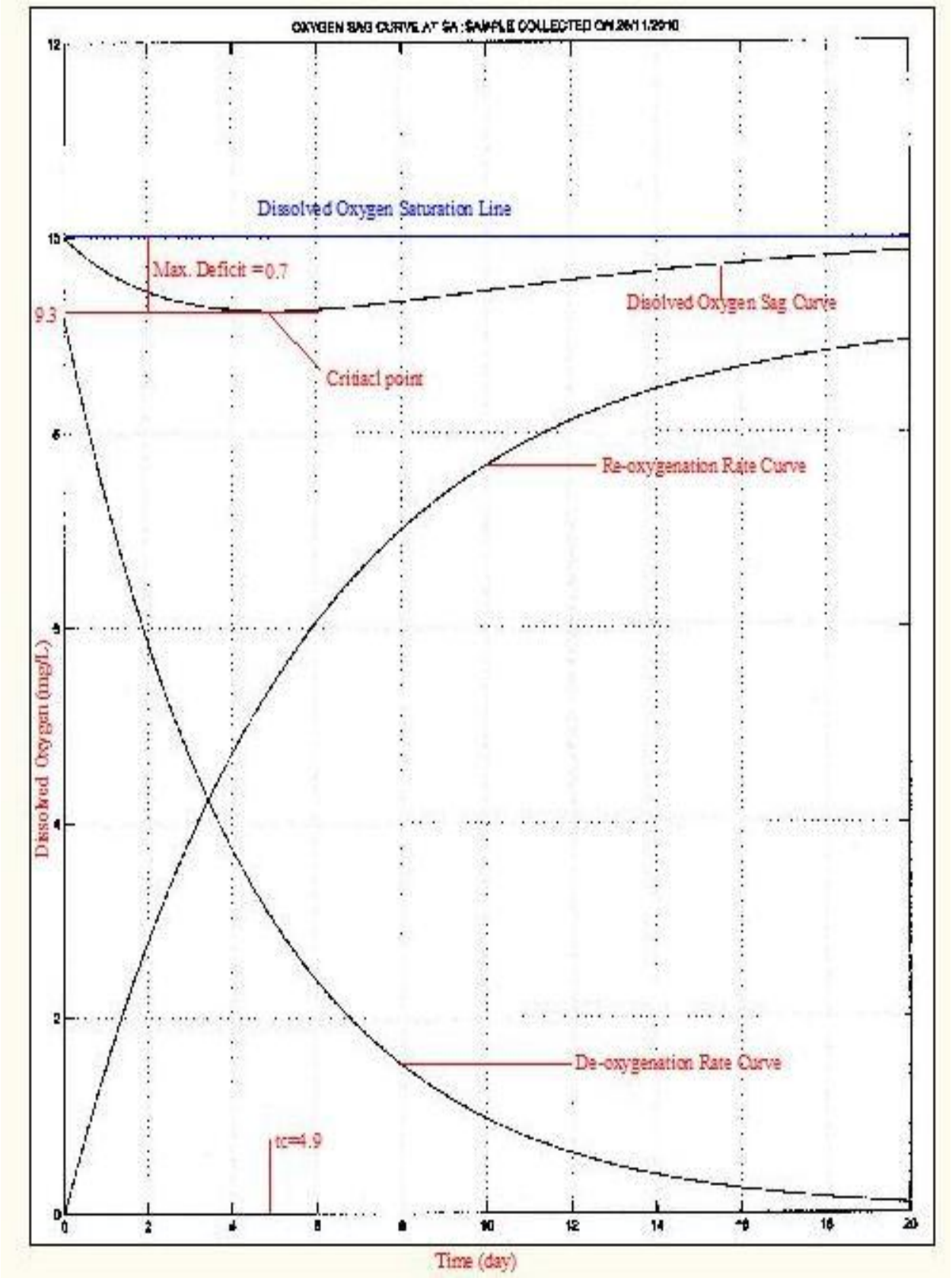

OXYGEN SAG CURVE AT SA : SAMPLE COLLECTED ON 26/11/2010
Dissolved Oxygen Saturation Line
Max. Deficit =0.7
9.3
Critical point
Dissolved Oxygen Sag Curve
Re-oxygenation Rate Curve
De-oxygenation Rate Curve
tc=4.9
Dissolved Oxygen (mg/L)
Time (day)
0
2
4
6
8
10
12
14
16
18
20

TABLE 4.3: SB WEEK1 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
26/11/2010	0	8.3	
27/11/2010	1	4.6	370
28/11/2010	2	4.2	410
29/11/2010	3	4.0	430
30/11/2010	4	3.6	470
01/12/2010	5	3.3	500
02/12/2010	6	3.2	510
03/12/2010	7	3.0	530

TABLE 4.4: SB SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	370	205	75850	136900
2	410	30	12300	168100
3	430	30	12900	184900
4	470	35	16450	220900
5	500	20	10000	250000
6	510	15	7650	260100
7	530			
Σ	2690	335	135150	1220900

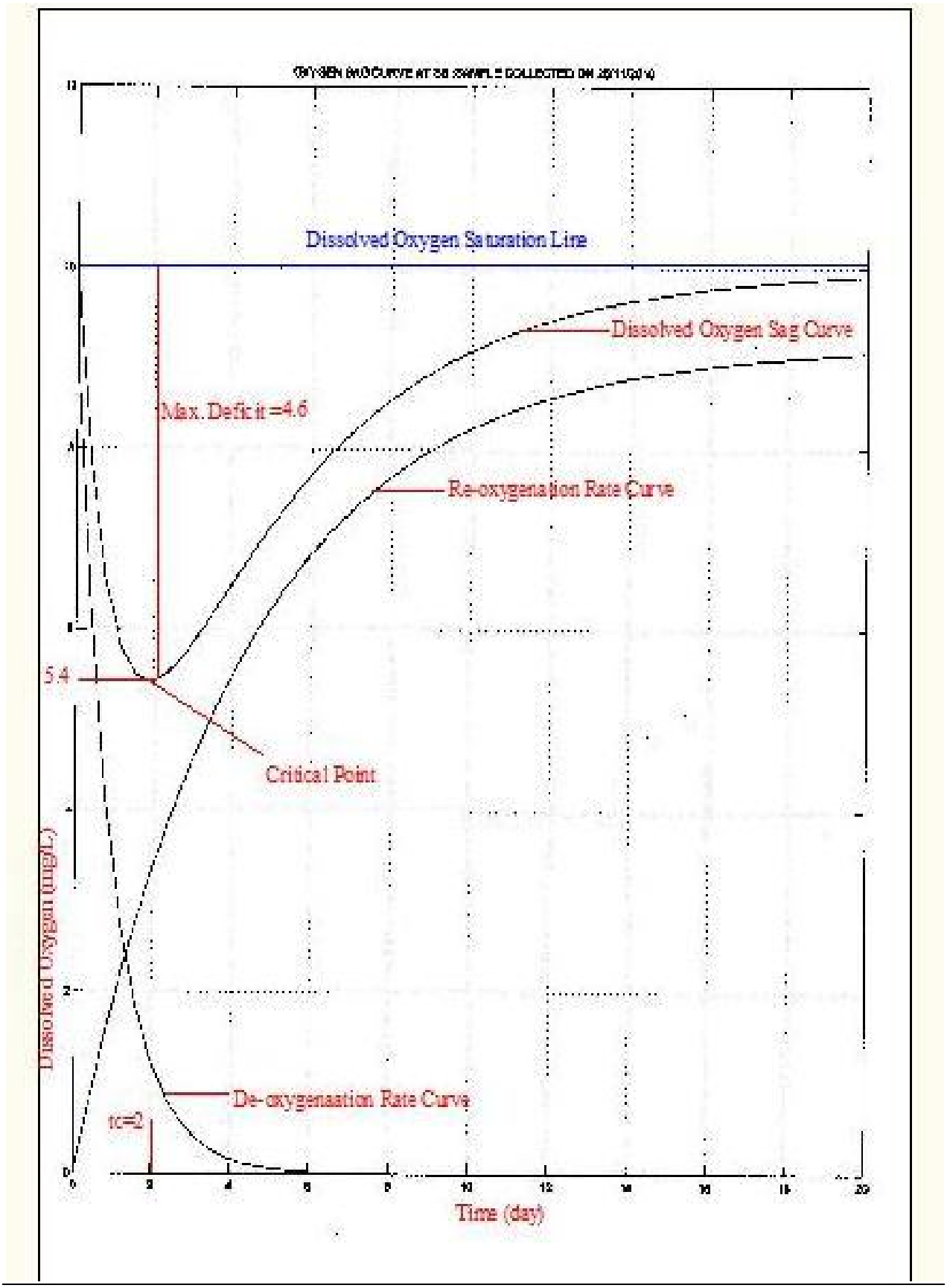

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit =4.6
Re-oxygenation Rate Curve
5.4
Critical Point
De- oxygenation Rate Curve
tc=2
Time (day)

TABLE 4.5: SC WEEK1 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
26/11/2010	0	7.4	
27/11/2010	1	4.8	260
28/11/2010	2	4.3	310
29/11/2010	3	3.8	360
30/11/2010	4	3.6	380
01/12/2010	5	3.2	420
02/12/2010	6	2.9	450
03/12/2010	7	2.6	480

TABLE 4.6: SC SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	260	155	40300	67600
2	310	50	15500	96100
3	360	35	12600	129600
4	380	30	11400	144400
5	420	35	14700	176400
6	450	30	13500	202500
7	480			
Σ	2180	335	108000	816600

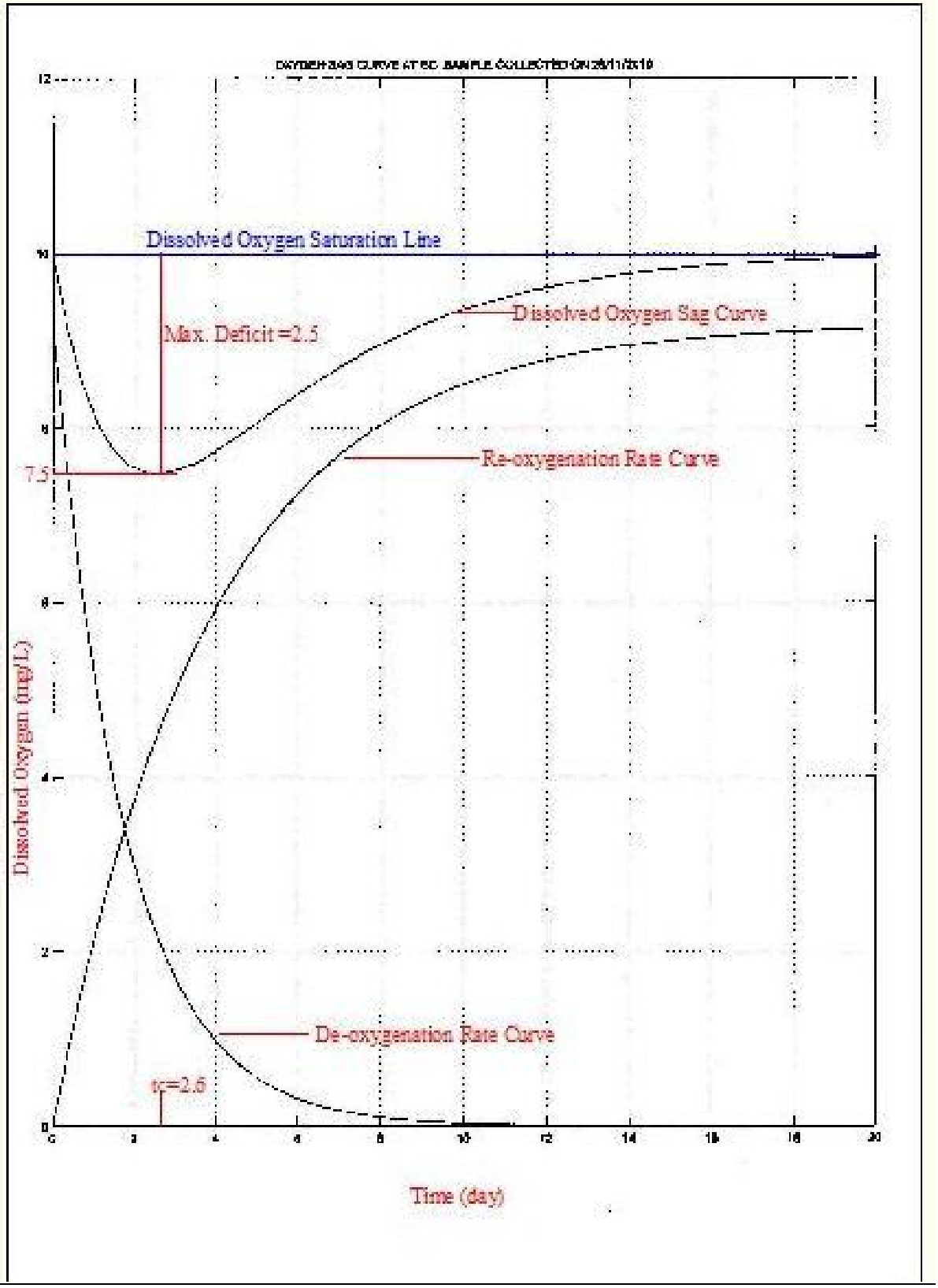

Dissolved Oxygen Saturation Line
Max. Deficit =2.5
Dissolved Oxygen Sag Curve
Re-oxygenation Rate Curve
7.5
De-oxygenation Rate Curve
tc=2.6
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.7: SD WEEK1 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
26/11/2010	0	8.3	
27/11/2010	1	6.2	210
28/11/2010	2	5.7	260
29/11/2010	3	5.4	290
30/11/2010	4	5.2	310
01/12/2010	5	4.7	360
02/12/2010	6	4.4	390
03/12/2010	7	4.2	410

TABLE 4.8: SD SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	210	130	27300	44100
2	260	40	10400	67600
3	290	25	7250	84100
4	310	35	10850	96100
5	360	40	14400	129600
6	390	25	9750	152100
7	410			
Σ	1820	5295	79950	573600

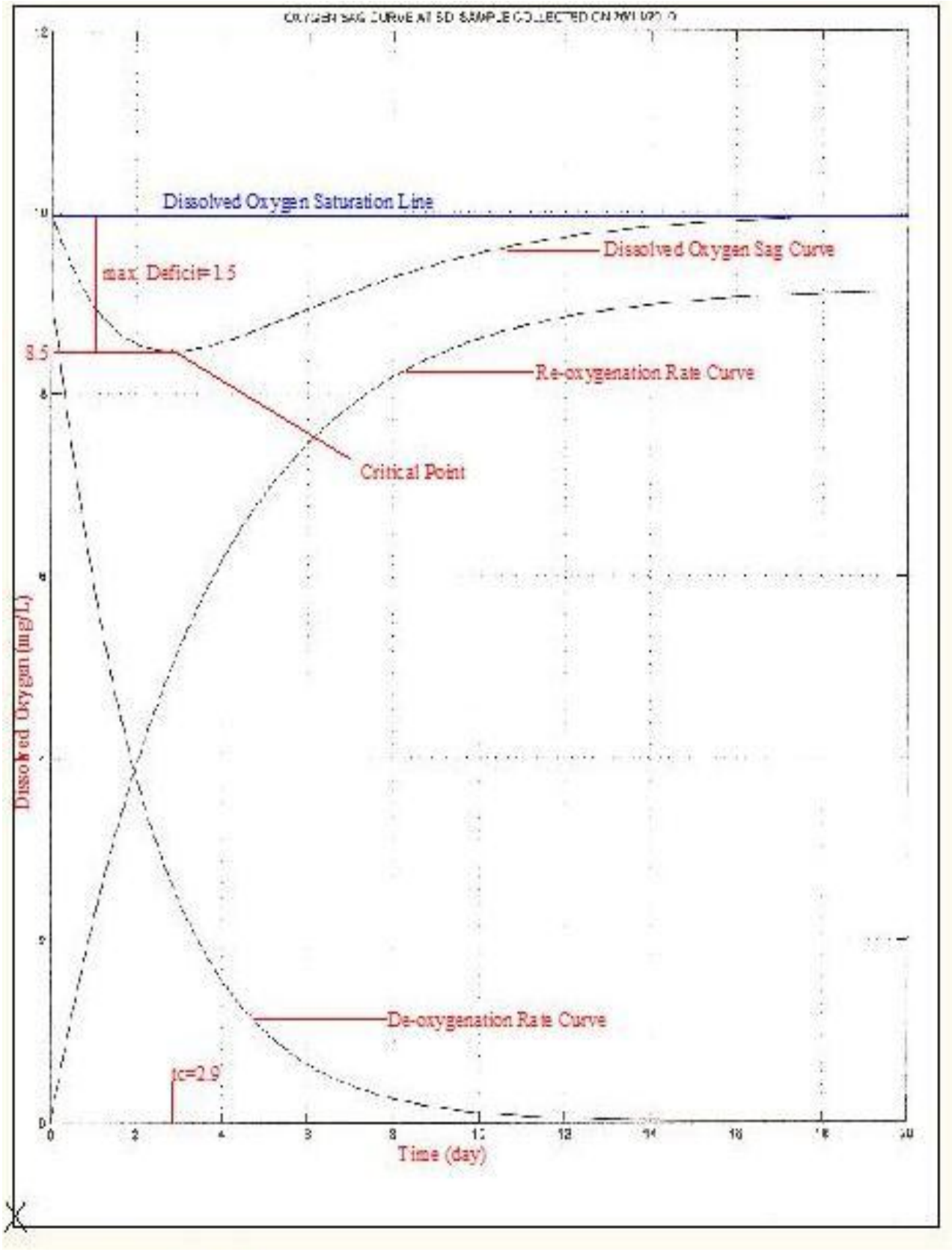

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
max. Deficit=1.5
8.5
Re-oxygenation Rate Curve
Critical Point
De-oxygenation Rate Curve
tc=2.9
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.9: SA WEEK2 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
03/12/2010	0	8.6	
04/12/2010	1	7.3	130
05/12/2010	2	6.9	170
06/12/2010	3	6.8	180
07/12/2010	4	6.5	210
08/12/2010	5	6.4	220
09/12/2010	6	6.0	260
10/12/2010	7	5.6	300

TABLE 4.10: SA SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	130	85	11050	16900
2	170	25	4250	28900
3	180	20	3600	32400
4	210	20	4200	44100
5	220	25	5500	48400
6	260	40	10400	67600
7	300			
Σ	1170	215	39000	238300

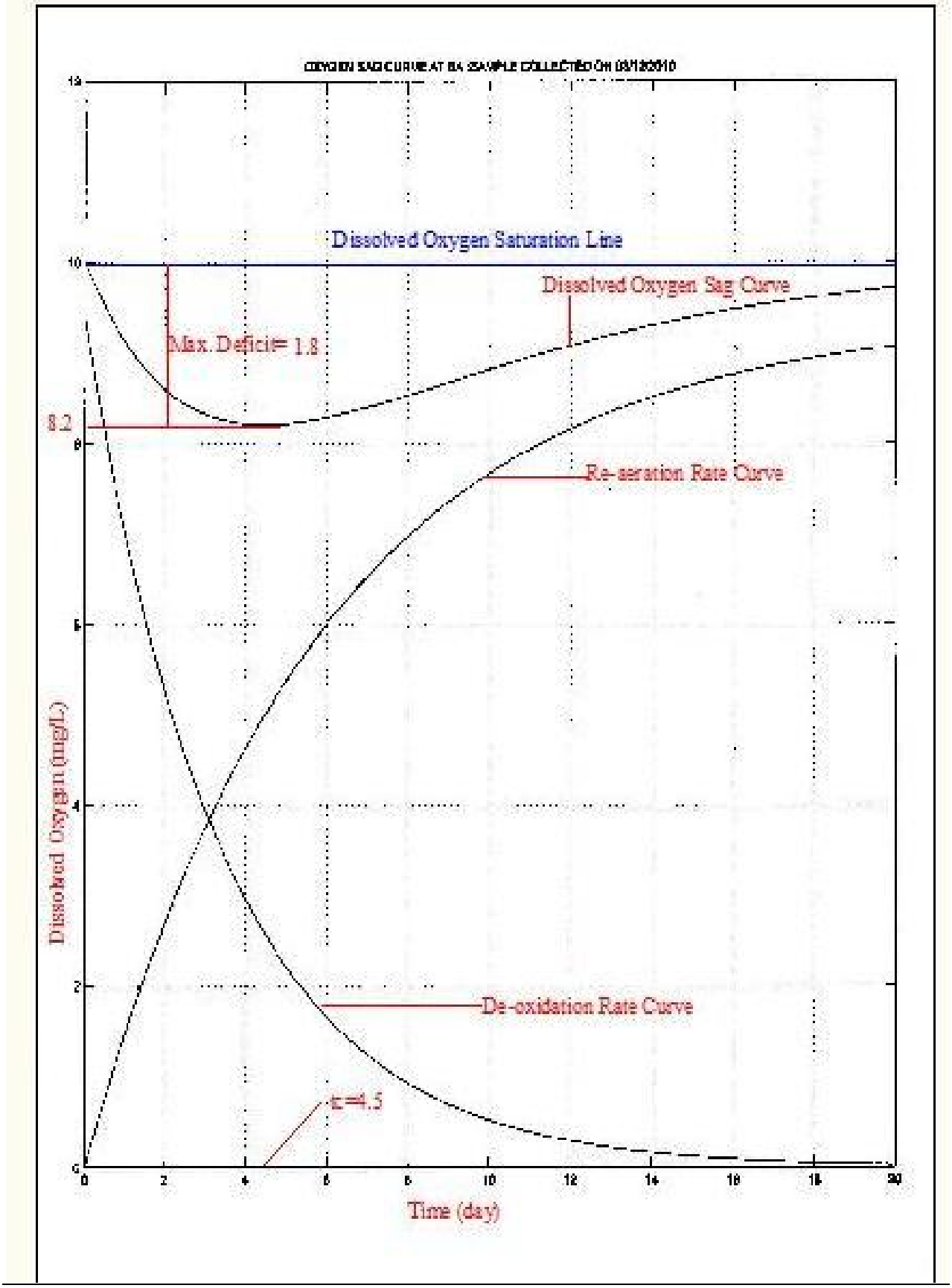

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit= 1.8
8.2
Re-aeration Rate Curve
De-oxidation Rate Curve
tc=4.5
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.11: SB WEEK2 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
03/12/2010	0	7.8	
04/12/2010	1	3.7	410
05/12/2010	2	3.3	450
06/12/2010	3	3.0	480
07/12/2010	4	2.7	510
08/12/2010	5	2.5	530
09/12/2010	6	2.2	560
10/12/2010	7	2.0	580

TABLE 4.12: SB SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	410	225	92250	168100
2	450	35	15750	202500
3	480	30	14400	230400
4	510	25	12750	260100
5	530	25	13250	280900
6	560	25	14000	313600
7	580			
Σ	2940	365	162400	1455600

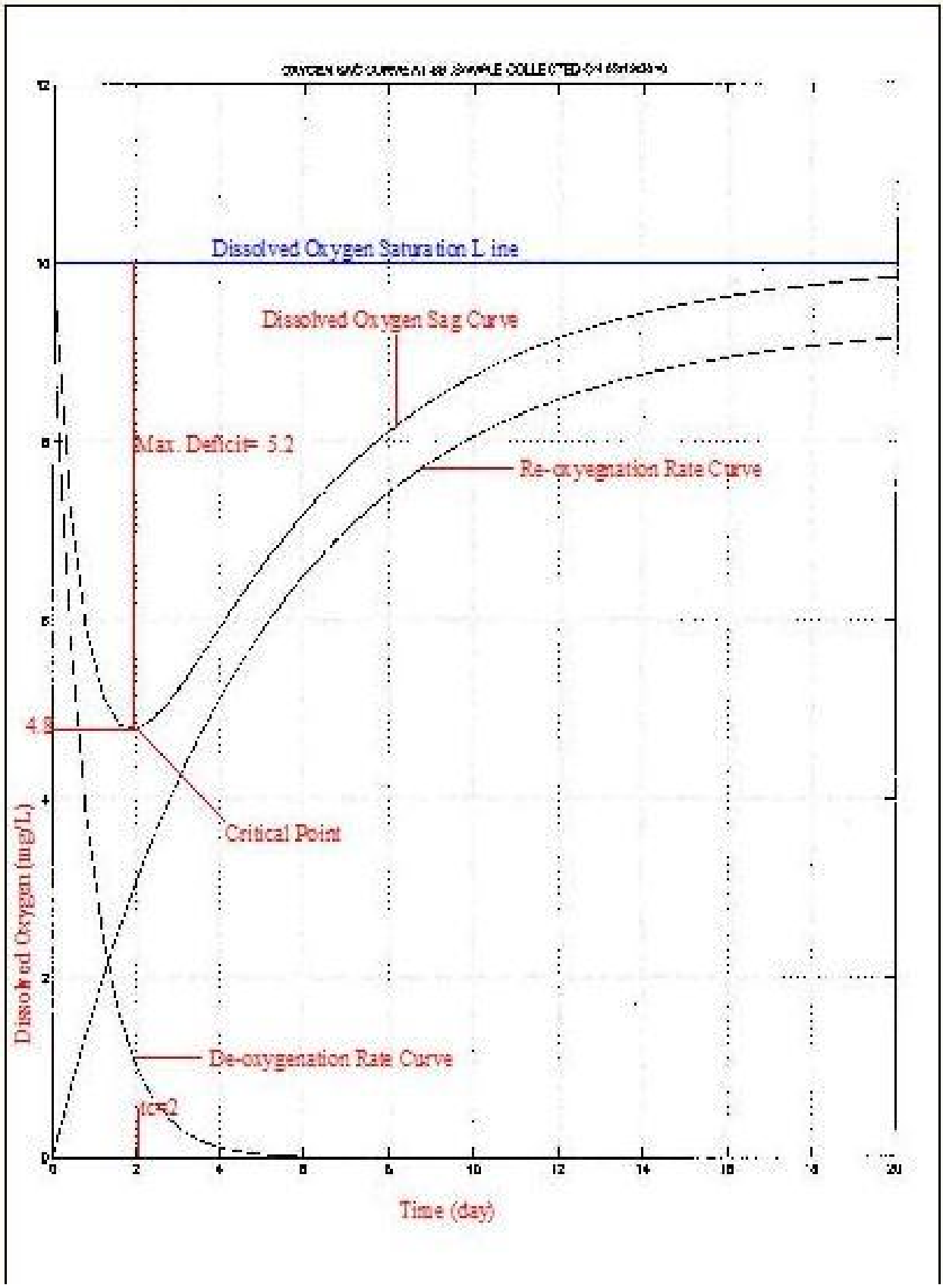

Dissolved Oxygen Saturation L ine
Dissolved Oxygen Sag Curve
Max. Deficit= 5.2
Re-oxygenation Rate Curve
4.8
Critical Point
De-oxygenation Rate Curve
tc=2
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.13: SC WEEK2 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
03/12/2010	0	6.7	
04/12/2010	1	2.9	380
05/12/2010	2	2.5	420
06/12/2010	3	2.3	440
07/12/2010	4	1.9	480
08/12/2010	5	1.6	510
09/12/2010	6	1.4	530
10/12/2010	7	1.1	560

TABLE 4.14: SC SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	380	210	79800	144400
2	420	30	12600	176400
3	440	30	13200	193600
4	480	35	16800	230400
5	510	25	12750	260100
6	530	25	13250	280900
7	560			
Σ	2760	355	148400	1285800

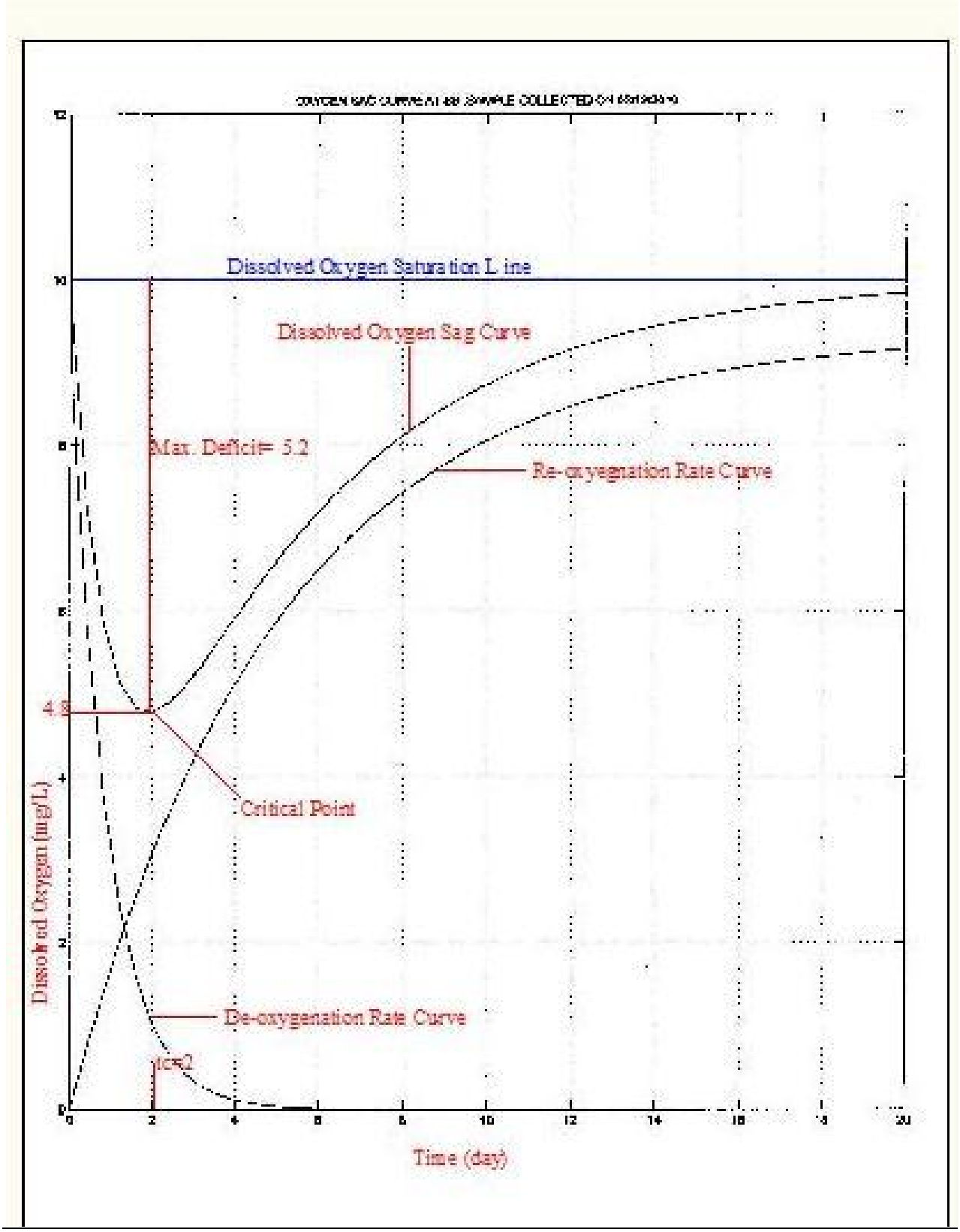

Dissolved Oxygen Saturation L ine
Dissolved Oxygen Sag Curve
Max. Deficit= 5.2
Re-oxygenation Rate Curve
4.8
Critical Point
De-oxygenation Rate Curve
tc=2
Dissolved Oxygen (mg/L)
Time (day)
0
2
4
6
8
10
12
14
16
18
20

TABLE 4.15: SD WEEK2 BOD VALUE

Date	Time t, (day)	DO mg/L	BOD mg/L
26/11/2010	0	8.6	
27/11/2010	1	6.5	210
28/11/2010	2	6.0	260
29/11/2010	3	5.7	290
30/11/2010	4	5.5	310
01/12/2010	5	5.0	360
02/12/2010	6	4.7	390
03/12/2010	7	4.5	410

TABLE 4.16: SD SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	210	130	27300	44100
2	260	40	10400	67600
3	290	25	7250	84100
4	310	35	10850	96100
5	360	40	14400	129600
6	390	25	9750	152100
7	410			
Σ	1820	295	79950	573600

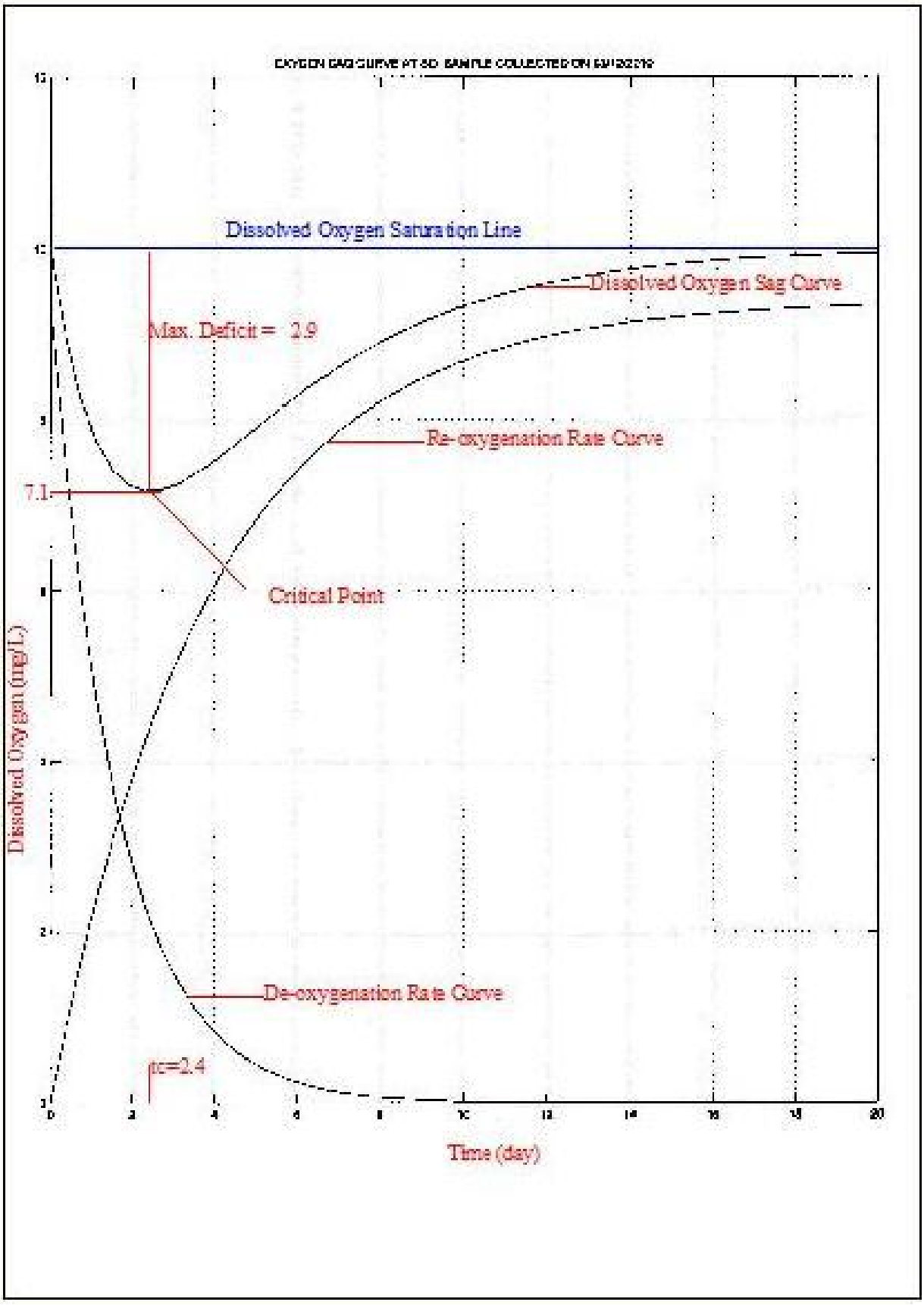

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit = 2.9
Re-oxygenation Rate Curve
7.1
Critical Point
De-oxygenation Rate Curve
tc=2.4
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.17: SA WEEK3 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
10/12/2010	0	7.8	
11/12/2010	1	6.6	120
12/12/2010	2	6.2	160
13/12/2010	3	6.0	180
14/12/2010	4	5.7	210
15/12/2010	5	5.4	240
16/12/2010	6	5.0	280
17/12/2010	7	4.9	290

TABLE 4.18: SA SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	120	80	9600	14400
2	160	30	4800	25600
3	180	25	4500	32400
4	210	30	6300	44100
5	240	35	8400	57600
6	280	25	7000	78400
7	290			
Σ	1190	225	40600	252500

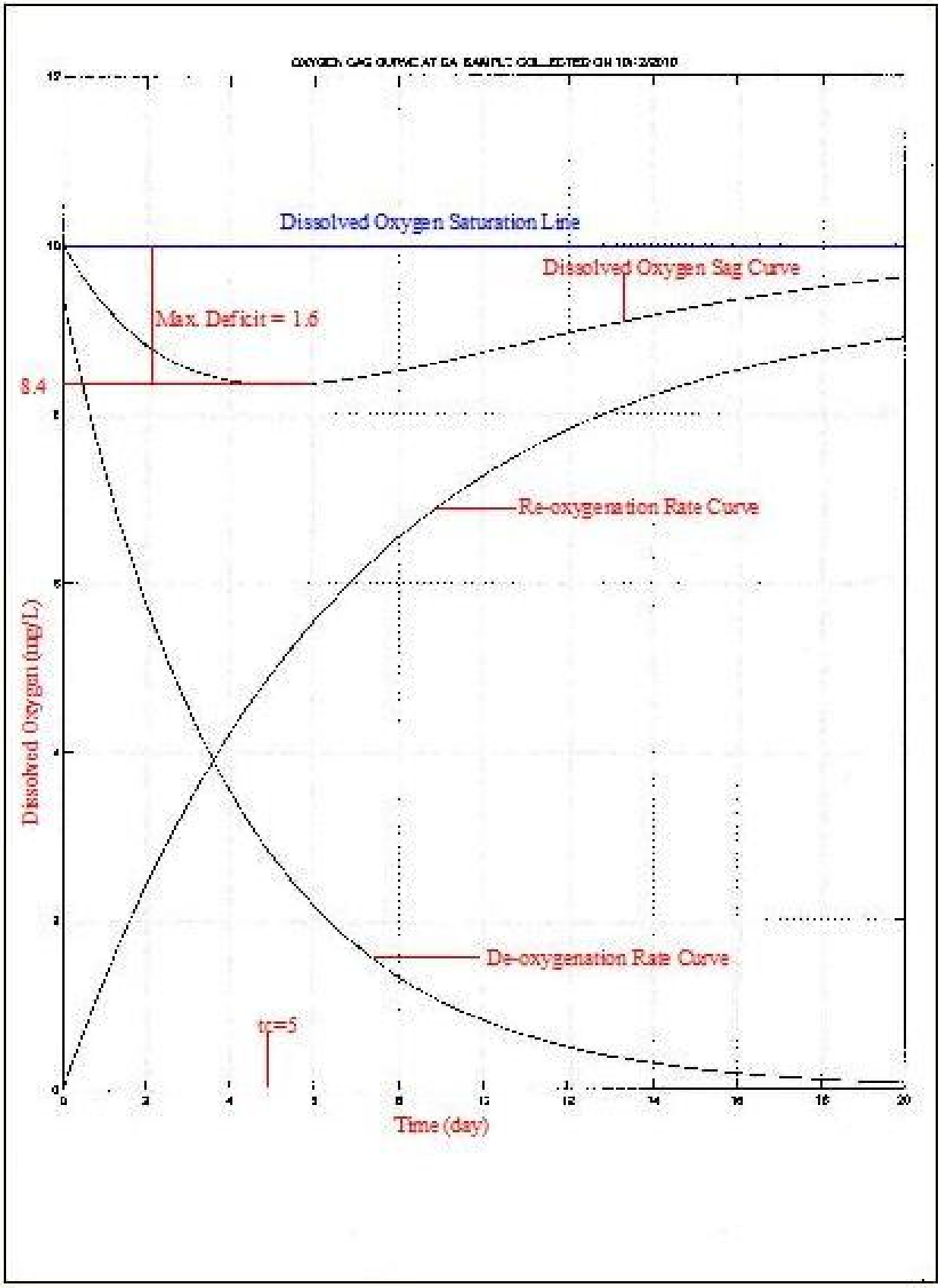

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit = 1.6
8.4
Re-oxygenation Rate Curve
De-oxygenation Rate Curve
tc=5
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.19: SB WEEK3 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
17/12/2010	0	7.1	
18/12/2010	1	1.9	520
19/12/2010	2	1.4	570
20/12/2010	3	1.2	590
21/12/2010	4	1.0	610
22/12/2010	5	0.8	630
23/12/2010	6	0.3	680
24/12/2010	7	0.0	710

TABLE 4.20: SB SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	520	285	148200	270400
2	570	35	19950	324900
3	590	20	11800	348100
4	610	20	12200	372100
5	630	35	22050	396900
6	680	40	27200	462400
7	710			
Σ	3600	435	241400	2174800

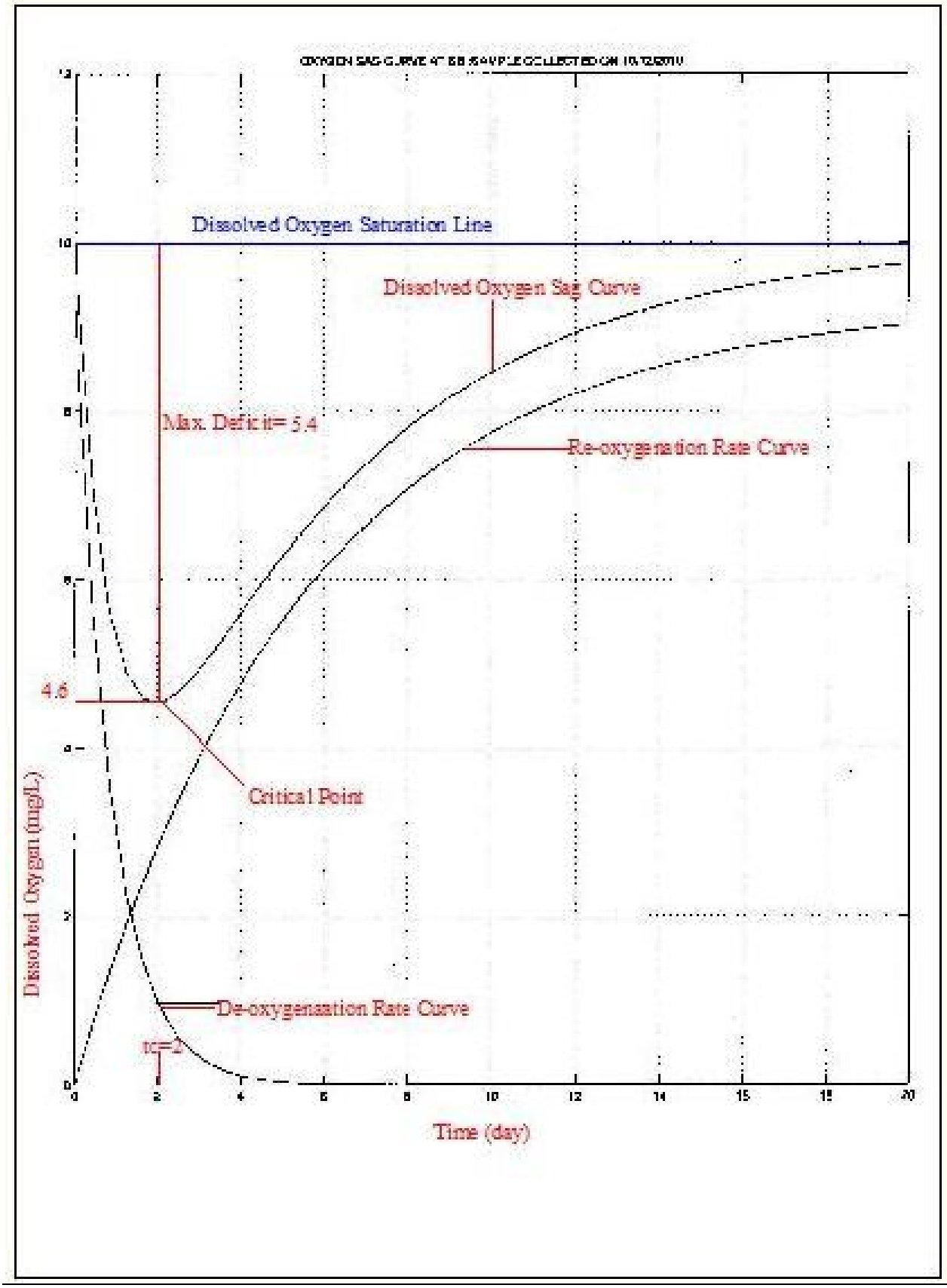

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit= 5.4
Re-oxygenation Rate Curve
4.6
Critical Point
De-oxygenation Rate Curve
tc=2
Dissolved Oxygen (mg/L)
Time (day)
0
2
4
6
8
10
12
14
16
18
20

TABLE 4.21: SC WEEK3 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
10/12/2010	0	8.7	
11/12/2010	1	4.6	410
12/12/2010	2	4.2	450
13/12/2010	3	4.0	470
14/12/2010	4	3.6	510
15/12/2010	5	3.3	540
16/12/2010	6	3.1	560
17/12/2010	7	2.8	590

TABLE 4.22: SC SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	410	225	92250	168100
2	450	30	13500	202500
3	470	30	14100	220900
4	510	35	17850	260100
5	540	25	13500	291600
6	560	25	14000	313600
7	590			
Σ	2940	370	165200	1456800

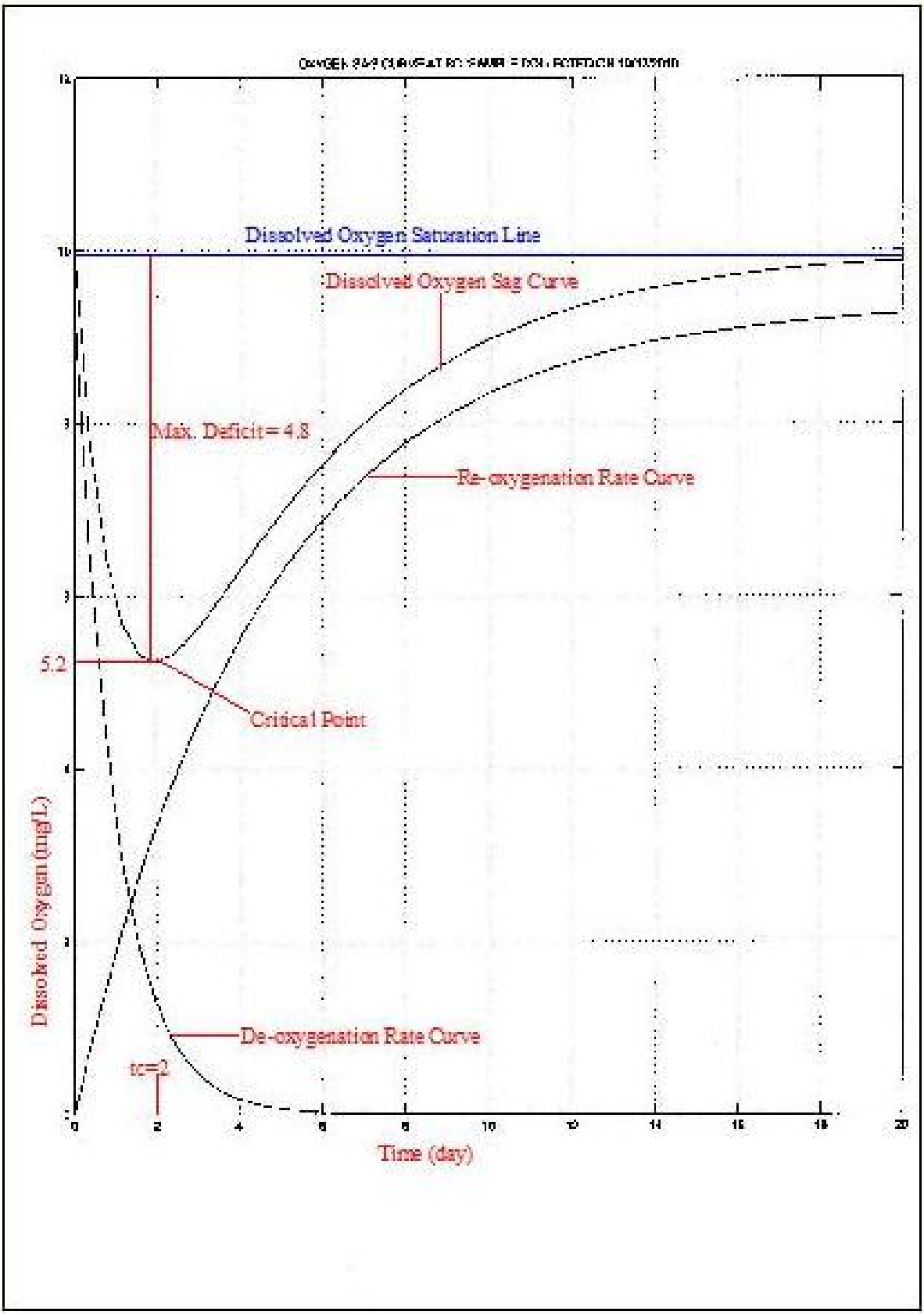

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit = 4.8
Re-oxygenation Rate Curve
5.2
Critical Point
De-oxygenation Rate Curve
tc=2
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.23: SD WEEK3 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
10/12/2010	0	6.8	
11/12/2010	1	3.7	310
12/12/2010	2	3.2	360
13/12/2010	3	2.7	410
14/12/2010	4	2.2	450
15/12/2010	5	2.1	470
16/12/2010	6	1.7	510
17/12/2010	7	1.5	530

TABLE 4.24: SD SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	310	180	55800	96100
2	360	50	18000	129600
3	410	45	18450	168100
4	450	30	13500	202500
5	470	30	14100	220900
6	510	30	15300	260100
7	530			
Σ	2510	365	135150	1077300

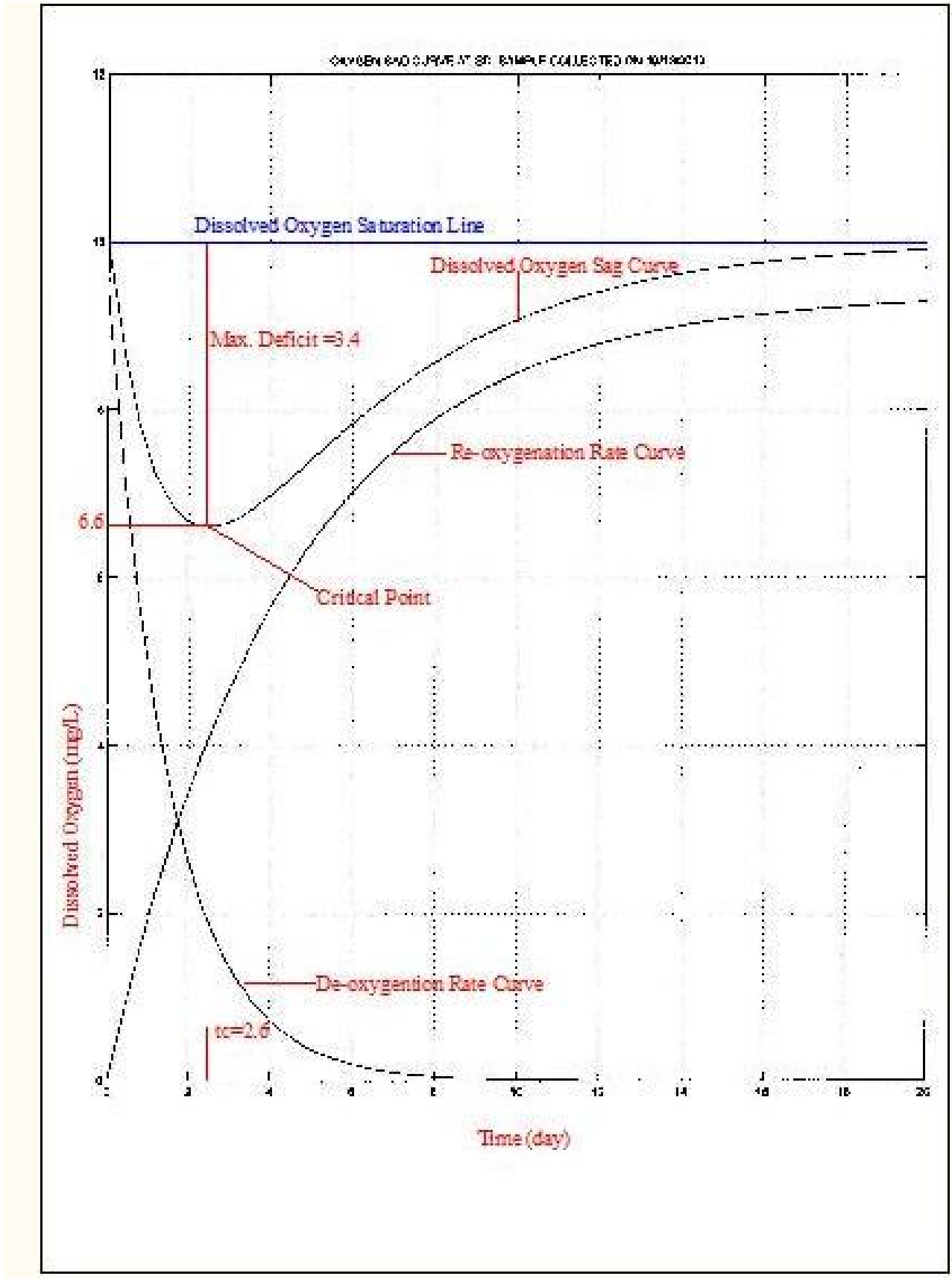

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit =3.4
Re-oxygenation Rate Curve
6.6
Critical Point
De-oxygention Rate Curve
tc=2.6
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.25: SA WEEK4 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
17/12/2010	0	8.9	
18/12/2010	1	7.8	110
19/12/2010	2	7.3	160
20/12/2010	3	6.8	210
21/12/2010	4	6.6	230
22/12/2010	5	6.3	260
23/12/2010	6	6.1	280
24/12/2010	7	5.8	310

TABLE 4.26: SA SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	110	80	8800	12100
2	160	50	8000	25600
3	210	35	7350	44100
4	230	25	5750	52900
5	260	25	6500	67600
6	280	25	7000	78400
7	310			
Σ	1250	240	43400	280700

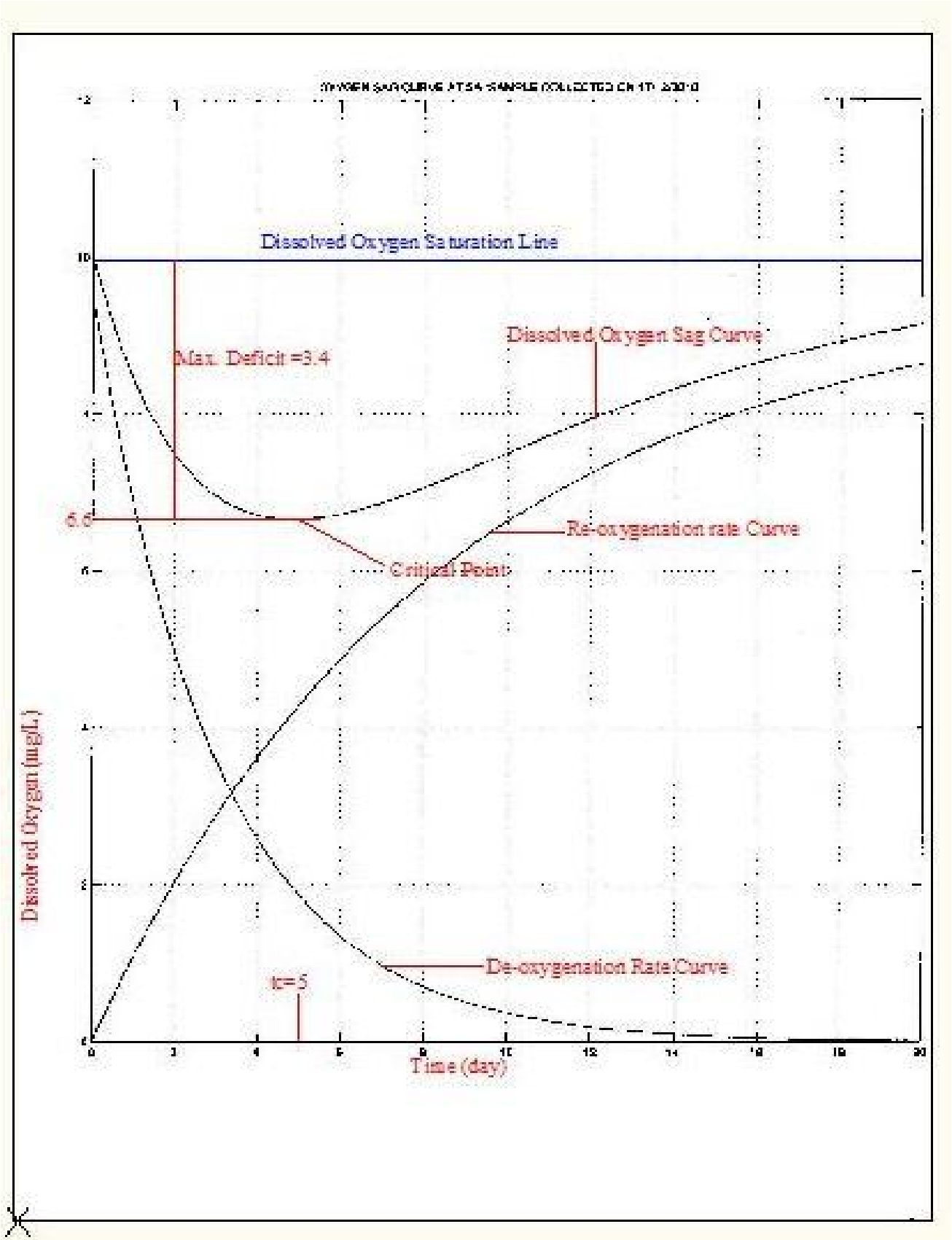

Dissolved Oxygen Saturation Line
Max. Deficit =3.4
Dissolved Oxygen Sag Curve
6.6
Re-oxygenation rate Curve
Critical Point
De-oxygenation Rate Curve
tc=5
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.27: SB WEEK4 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
17/12/2010	0	7.1	
18/12/2010	1	1.9	520
19/12/2010	2	1.4	570
20/12/2010	3	1.2	590
21/12/2010	4	1.0	610
22/12/2010	5	0.8	630
23/12/2010	6	0.3	680
24/12/2010	7	0.0	710

TABLE 4.28: SB SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	520	285	148200	270400
2	570	35	19950	324900
3	590	20	11800	348100
4	610	20	12200	372100
5	630	35	22050	396900
6	680	40	27200	462400
7	710			
Σ	3600	435	241400	2174800

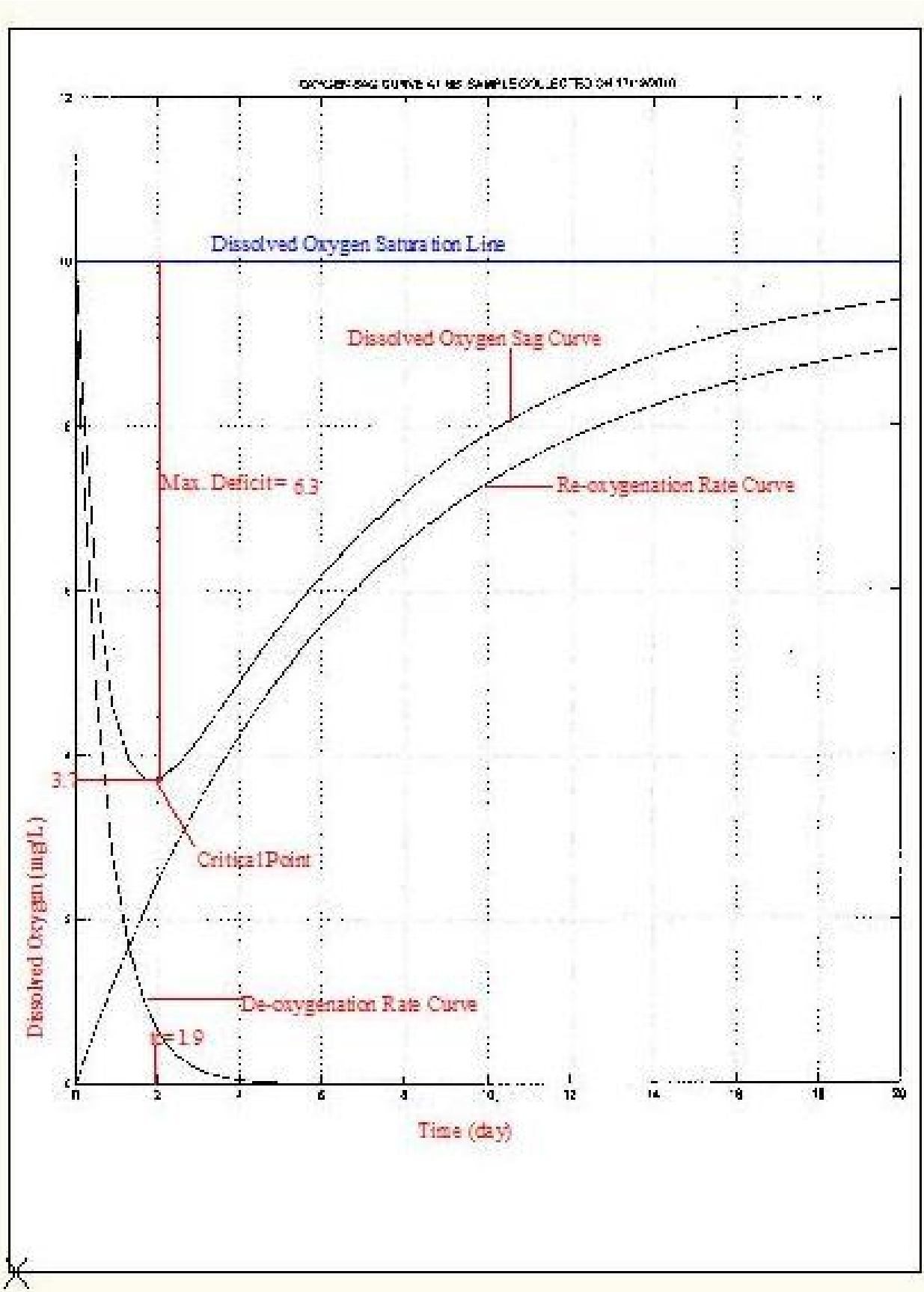

Dissolved Oxygen Saturation Line
Dissolved Oxygen Sag Curve
Max. Deficit= 6.3
Re-oxygenation Rate Curve
3.7
Critical Point
De-oxygenation Rate Curve
t=1.9
Dissolved Oxygen (mg/L)
Time (day)

TABLE 4.29: SC WEEK4 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
17/12/2010	0	8.7	
18/12/2010	1	4.0	470
19/12/2010	2	3.8	490
20/12/2010	3	3.4	530
21/12/2010	4	3.1	560
22/12/2010	5	2.9	580
23/12/2010	6	2.6	610
24/12/2010	7	2.4	630

TABLE 4.30: SC SLOPE VALUE

t	y	y'	yy'	y^2
0	0			
1	470	245	115150	220900
2	490	30	14700	240100
3	530	35	18550	280900
4	560	25	14000	313600
5	580	25	14500	336400
6	610	25	15250	372100
7	630			
Σ	3240	385	192150	1764000

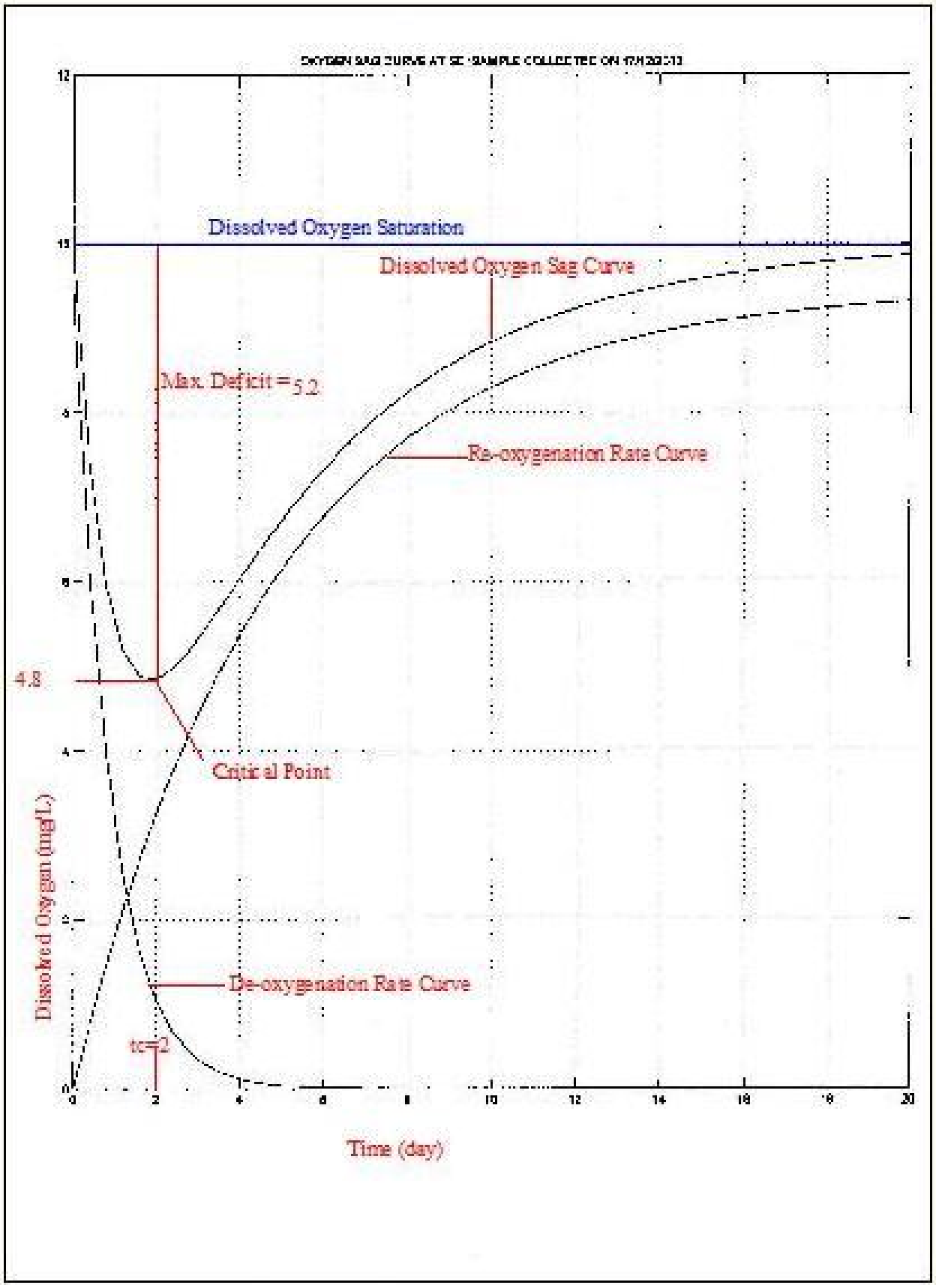
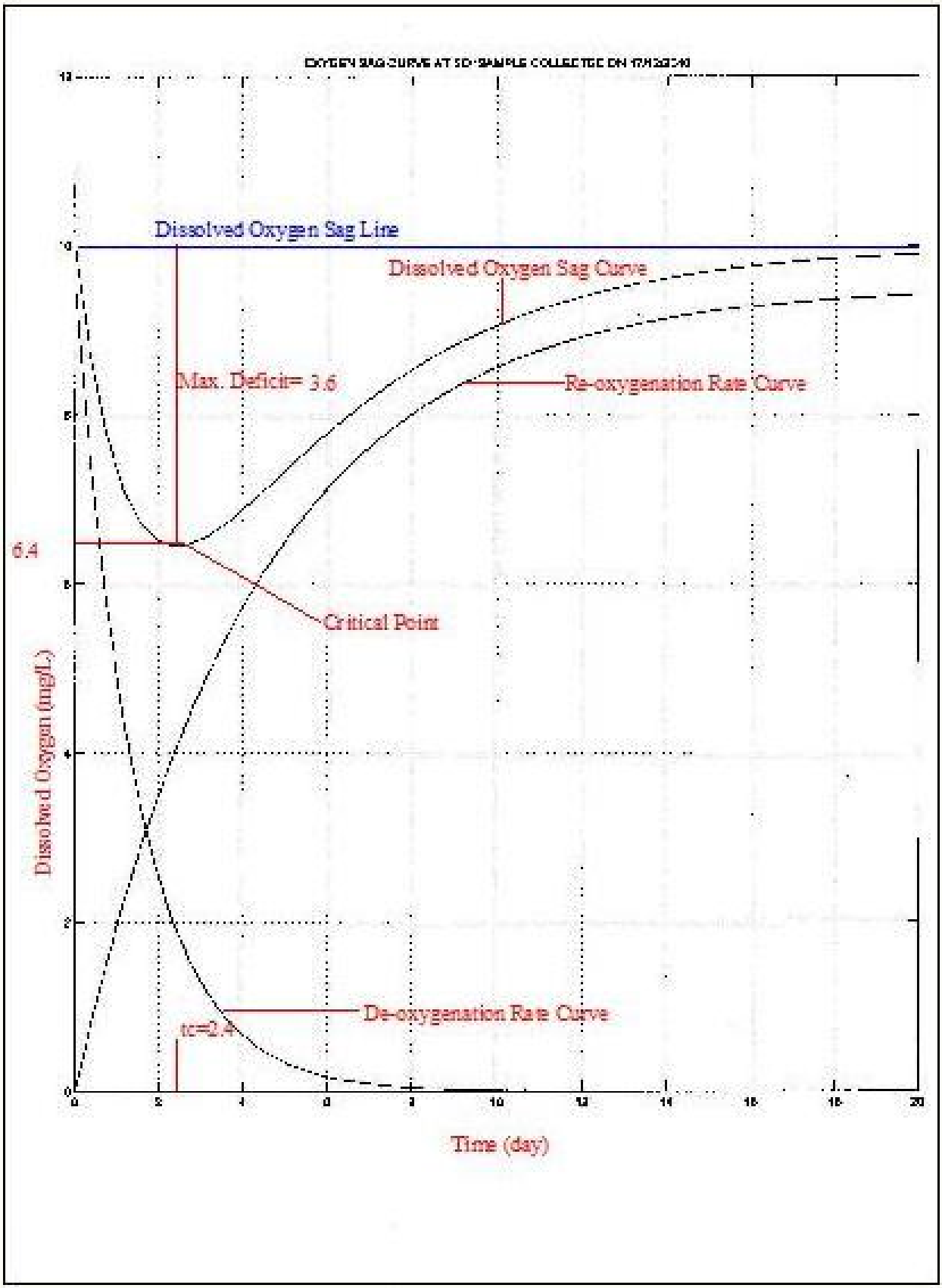

Dissolved Oxygen Saturation
Dissolved Oxygen Sag Curve
Max. Deficit = 5.2
Re-oxygenation Rate Curve
4.8
Critical Point
De-oxygenation Rate Curve
tc=2
Dissolved Oxygen (mg/L)
Time (day)

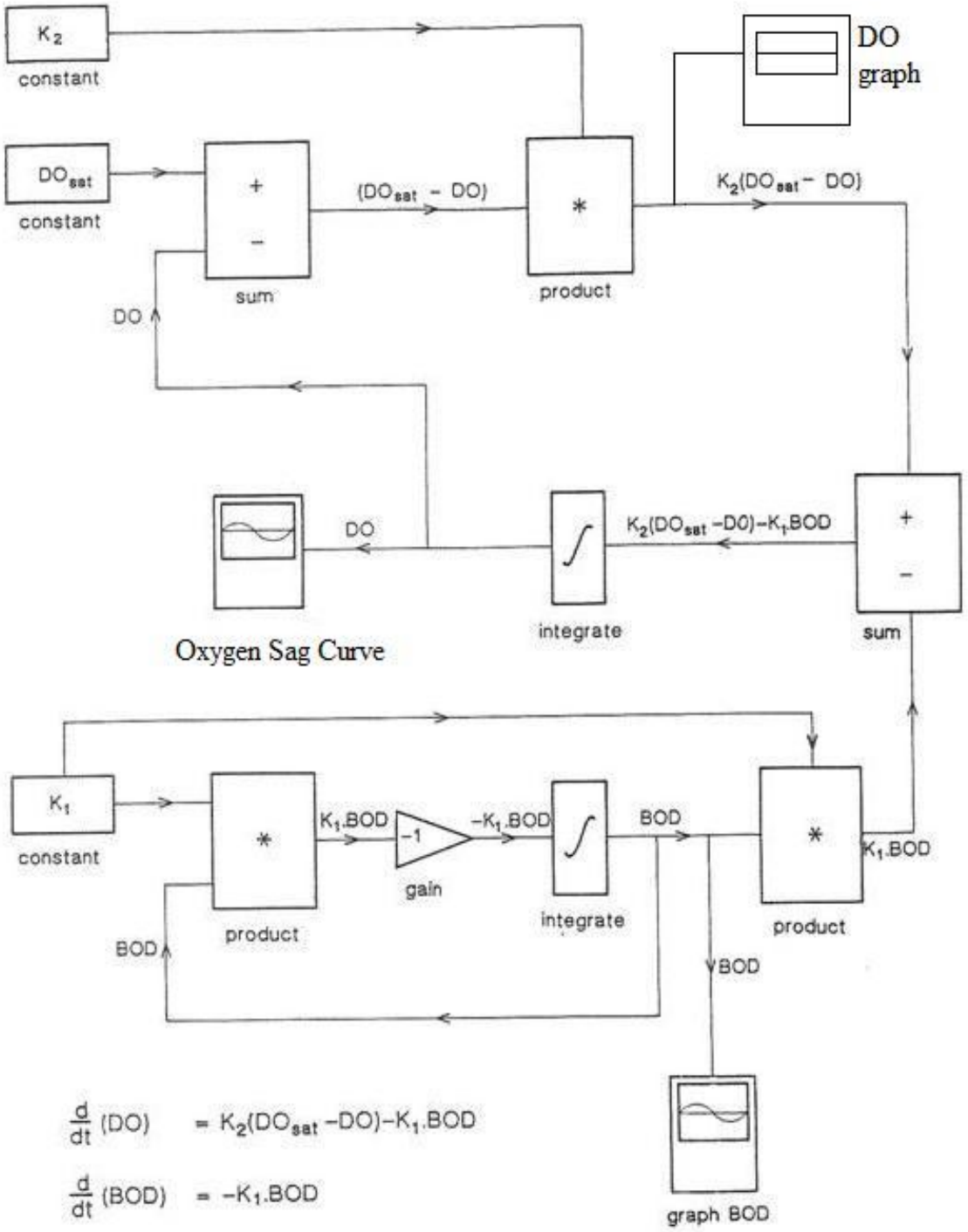
TABLE 4.31: SD WEEK4 BOD VALUE

Date	Time t(per day)	DO (mg/L)	BOD (mg/L)
17/12/2010	0	8.7	
18/12/2010	1	5.2	350
19/12/2010	2	4.9	380
20/12/2010	3	4.4	430
21/12/2010	4	4.1	460
22/12/2010	5	3.8	490
23/12/2010	6	3.5	520
24/12/2010	7	3.0	570

TABLE 4.32: SD SLOPE VALUE

T	y	y'	yy'	y^2
0	0			
1	350	190	66500	122500
2	380	40	15200	144400
3	430	40	17200	184900
4	460	30	13800	211600
5	490	30	14700	240100
6	520	40	20800	270400
7	570			
Σ	2630	370	148200	1173900


Dissolved Oxygen Sag Line
Dissolved Oxygen Sag Curve
Max. Deficit= 3.6
Re-oxygenation Rate Curve
6.4
Critical Point
De-oxygenation Rate Curve
tc=2.4
Dissolved Oxygen (mg/L)
Time (day)


K2
constant
DO
graph
DOsat
constant
+
−
sum
(DOsat − DO)
*
product
K2(DOsat − DO)
DO
DO
integrate
K2(DOsat −DO)−K1.BOD
+
−
sum
Oxygen Sag Curve
K1
constant
*
product
K1.BOD
−1
gain
−K1.BOD
integrate
BOD
*
product
K1.BOD
BOD
BOD
graph BOD
d/dt (DO) = K2(DOsat −DO)−K1.BOD
d/dt (BOD) = −K1.BOD