UNIVERSITY OF ALBERTA

ANALYSIS OF RESIDENCE TIME DISTRIBUTIONS IN WATER TREATMENT PROCESSES AS RELATED TO THE CT CONCEPT

BY

LEONARDUS E. LIEM ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE.**

IN

ENVIRONMENTAL ENGINEERING

DEPARTMENT OF **CIVIL ENGINEERING**

EDMONTON, ALBERTA
FALL, 1994

ISBN 0-315-95068-4

Name LEONARDUS EDWIN LIEM

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

ENGINEERING — CIVIL
SUBJECT TERM

0 5 4 3
SUBJECT CODE

U·M·I

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS

Architecture	0729
Art History	0377
Cinema	0900
Dance	0378
Fine Arts	0357
Information Science	0723
Journalism	0391
Library Science	0399
Mass Communications	0708
Music	0413
Speech Communication	0459
Theater	0465

EDUCATION

General	0515
Administration	0514
Adult and Continuing	0516
Agricultural	0517
Art	0273
Bilingual and Multicultural	0282
Business	0688
Community College	0275
Curriculum and Instruction	0727
Early Childhood	0518
Elementary	0524
Finance	0277
Guidance and Counseling	0519
Health	0680
Higher	0745
History of	0520
Home Economics	0278
Industrial	0521
Language and Literature	0279
Mathematics	0280
Music	0522
Philosophy of	0998
Physical	0523
Psychology	0525
Reading	0535
Religious	0527
Sciences	0714
Secondary	0533
Social Sciences	0534
Sociology of	0340
Special	0529
Teacher Training	0530
Technology	0710
Tests and Measurements	0288
Vocational	0747

LANGUAGE, LITERATURE AND LINGUISTICS

Language	
General	0679
Ancient	0289
Linguistics	0290
Modern	0291
Literature	
General	0401
Classical	0294
Comparative	0295
Medieval	0297
Modern	0298
African	0316
American	0591
Asian	0305
Canadian (English)	0352
Canadian (French)	0355
English	0593
Germanic	0311
Latin American	0312
Middle Eastern	0315
Romance	0313
Slavic and East European	0314

PHILOSOPHY, RELIGION AND THEOLOGY

Philosophy	0422
Religion	
General	0318
Biblical Studies	0321
Clergy	0319
History of	0320
Philosophy of	0322
Theology	0469

SOCIAL SCIENCES

American Studies	0323
Anthropology	
Archaeology	0324
Cultural	0326
Physical	0327
Business Administration	
General	0310
Accounting	0272
Banking	0770
Management	0454
Marketing	0338
Canadian Studies	0385
Economics	
General	0501
Agricultural	0503
Commerce-Business	0505
Finance	0508
History	0509
Labor	0510
Theory	0511
Folklore	0358
Geography	0366
Gerontology	0351
History	
General	0578
Ancient	0579
Medieval	0581
Modern	0582
Black	0328
African	0331
Asia, Australia and Oceania	0332
Canadian	0334
European	0335
Latin American	0336
Middle Eastern	0333
United States	0337
History of Science	0585
Law	0398
Political Science	
General	0615
International Law and Relations	0616
Public Administration	0617
Recreation	0814
Social Work	0452
Sociology	
General	0626
Criminology and Penology	0627
Demography	0938
Ethnic and Racial Studies	0631
Individual and Family Studies	0628
Industrial and Labor Relations	0629
Public and Social Welfare	0630
Social Structure and Development	0700
Theory and Methods	0344
Transportation	0709
Urban and Regional Planning	0999
Women's Studies	0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES

Agriculture	
General	0473
Agronomy	0285
Animal Culture and Nutrition	0475
Animal Pathology	0476
Food Science and Technology	0359
Forestry and Wildlife	0478
Plant Culture	0479
Plant Pathology	0480
Plant Physiology	0817
Range Management	0777
Wood Technology	0746
Biology	
General	0306
Anatomy	0287
Biostatistics	0308
Botany	0309
Cell	0379
Ecology	0329
Entomology	0353
Genetics	0369
Limnology	0793
Microbiology	0410
Molecular	0307
Neuroscience	0317
Oceanography	0416
Physiology	0433
Radiation	0821
Veterinary Science	0778
Zoology	0472
Biophysics	
General	0786
Medical	0760

EARTH SCIENCES

Biogeochemistry	0425
Geochemistry	0996
Geodesy	0370
Geology	0372
Geophysics	0373
Hydrology	0388
Mineralogy	0411
Paleobotany	0345
Paleoecology	0426
Paleontology	0418
Paleozoology	0985
Palynology	0427
Physical Geography	0368
Physical Oceanography	0415

HEALTH AND ENVIRONMENTAL SCIENCES

Environmental Sciences	0768
Health Sciences	
General	0566
Audiology	0300
Chemotherapy	0992
Dentistry	0567
Education	0350
Hospital Management	0769
Human Development	0758
Immunology	0982
Medicine and Surgery	0564
Mental Health	0347
Nursing	0569
Nutrition	0570
Obstetrics and Gynecology	0380
Occupational Health and Therapy	0354
Ophthalmology	0381
Pathology	0571
Pharmacology	0419
Pharmacy	0572
Physical Therapy	0382
Public Health	0573
Radiology	0574
Recreation	0575
Speech Pathology	0460
Toxicology	0383
Home Economics	0386

PHYSICAL SCIENCES

Pure Sciences

Chemistry	
General	0485
Agricultural	0749
Analytical	0486
Biochemistry	0487
Inorganic	0488
Nuclear	0738
Organic	0490
Pharmaceutical	0491
Physical	0494
Polymer	0495
Radiation	0754
Mathematics	0405
Physics	
General	0605
Acoustics	0986
Astronomy and Astrophysics	0606
Atmospheric Science	0608
Atomic	0748
Electronics and Electricity	0607
Elementary Particles and High Energy	0798
Fluid and Plasma	0759
Molecular	0609
Nuclear	0610
Optics	0752
Radiation	0756
Solid State	0611
Statistics	0463

Applied Sciences

Applied Mechanics	0346
Computer Science	0984
Engineering	
General	0537
Aerospace	0538
Agricultural	0539
Automotive	0540
Biomedical	0541
Chemical	0542
Civil	0543
Electronics and Electrical	0544
Heat and Thermodynamics	0348
Hydraulic	0545
Industrial	0546
Marine	0547
Materials Science	0794
Mechanical	0548
Metallurgy	0743
Mining	0551
Nuclear	0552
Packaging	0549
Petroleum	0765
Sanitary and Municipal	0554
System Science	0790
Geotechnology	0428
Operations Research	0796
Plastics Technology	0795
Textile Technology	0994

PSYCHOLOGY

General	0621
Behavioral	0384
Clinical	0622
Developmental	0620
Experimental	0623
Industrial	0624
Personality	0625
Physiological	0989
Psychobiology	0349
Psychometrics	0632
Social	0451

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: **Leonardus E. Liem**

TITLE OF THESES: **Analysis of Residence Time Distributions in Water Treatment Processes as Related to the CT Concept**

DEGREE: **Master of Science**

YEAR THIS DEGREE GRANTED: **1994**

4242 - 49 St
Vegreville, AB
T9C - 1B5

September 30, 1994

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **ANALYSIS OF RESIDENCE TIME DISTRIBUTIONS IN WATER TREATMENT PROCESSES AS RELATED TO THE CT CONCEPT** submitted by **LEONARDUS E. LIEM** in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **ENVIRONMENTAL ENGINEERING.**

D. W. Smith - Supervisor

S. J. Stanley - Co Supervisor

J. J. Leonard - Committee Member

Date: July 27, 1994.

ABSTRACT

The assessment of the disinfection practice in water treatment has moved away from total reliance on the analysis of microbial contaminants in the finished water to the incorporation of disinfection kinetics concept to determine the adequacy of the disinfection process. The movement is highlighted by the promulgation of the Surface Water Treatment Rule (SWTR) in 1989 in the United States. Among other things, the SWTR requires the assessment of disinfection process based on the CT concept (disinfectant concentration multiplied by effective contact time). For the effective contact time, the t_{10} (time for 10% of the water to pass through the process) is stipulated by the SWTR. In most cases, the t_{10} must be determined through tracer tests.

The primary objective of this study is to determine the hydraulic characteristics of various treatment components of the E. L. Smith Water Treatment Plant in Edmonton, Alberta. Since the use of disinfection materials is associated with the SWTR / CT concept, the emphasis is given to the effective contact time (t_{10}) determination.

Ten tracer tests were conducted using NaCl solution (131,000 mg/L) in a step input at different flow rates (141 to 230 ML/d) and different sampling periods (3 to 52 hours). There were about 2,700 samples taken with the tracer recoveries of 84 to 107 %. Sodium ions in the samples were measured using a flame emission photometer.

The F curves were then generated, in which the t_{10}, t_{90}, Morril's index, and Baffle parameter values were directly obtained. Based on the baffle parameter, the filters are classed as "superior", clarifier no.2 is "poor", and the three reservoirs are "poor" and "unbaffled". Modification is necessary for reservoirs nos. 2 and 3 by constructing baffles or diffusers. Reservoir no. 1 and clarifier no. 2 may need some modification. The filters do not require modification.

The tracer concentration curves were analyzed using the common models found in the literature including the Wolf - Resnick, CMRs - in - series, and Rebhun - Argaman models that based on empirical approaches. For the reservoir without baffle, it was found that early portions of the tracer appeared earlier than predicted. Since the t_{10} is located in that part of the curve, its prediction using the models may not be reliable and will over predict the actual t_{10}. The cause of the extremely low t_{10} values for reservoirs nos. 2 and 3 were thought to be the result of the momentum from the inlet to the outlet. Subsequently, early portions of the residence time distributions were modelled as if they were caused by a jet.

The jet model was found to be adequate in predicting the t_{10} for this situation. The model seemed to indicate that the aberration was caused by the momentum dominant effect in the reservoir. This finding highlights the need to minimize the momentum from the inlet in order to obtain acceptable t_{10} values. Although these two reservoirs are relatively new and would be considered well designed according to traditional design guidelines, the lack of consideration of minimizing the momentum from the inlet has resulted in these two reservoirs to be classed as "poor" for effective contact time.

ACKNOWLEDGEMENT

I would thank Prof. D. W. Smith for his guidance and support throughout this research project. I would also appreciate Prof. S. J. Stanley who provided a great deal of help for completion this work.

I also wish to thank Mr. N. Chernuka, Mr. D. S. Prince, and Mr. B. Yaremko of the Environmental Engineering group for their invaluable help during the field samplings and laboratory analyses. The assistance of Mr T. Lee of the Water Plants Engineering, Water Branch, Public Works, City of Edmonton and the E. L. Smith Water Treatment Plant operators during the testing periods is very appreciated as well.

I also extend a great thank you to the Water Plants Engineering, Water Branch, Public Works, City of Edmonton for the research funding provided throughout this research project. Lastly, I would appreciate friends and others who provided help and support to make this research work a success.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

A = area (m^2)

a = degree of CMR (%)

α = exponential coefficient, or regression parameter

α_1 = shear layer inner angle (°)

α_2 = shear layer outer angle (°)

α_c = entrainment velocity coefficient

AFR = arbitrary flow reactor

A_o = nozzle area (m^2)

A_s = surface control area (m^2)

$\underline{b}$ = r value when u = 0 (m)

b = r value when $u = 0.5 \times u_m$ (m)

β = time shift coefficient (min.), or $b/\underline{b}$, or regression parameter

b_y = distance when $u_s = 0.5\ u_m$ (m)

b_z = distance when $u = 0.5\ u_s$ (m)

C or c = chemical concentration (mg/L)

C_1 = experimental parameter

C_f = final concentration at steady state including background (mg/L)

c_m = maximum chemical concentration (mg)

CMR = complete mixed reactor

C_o = initial chemical concentration (mg/L)

c_p = peak chemical concentration (kg/m^3)

c_s = chemical concentration at X-Z plane (mg/L)

CT = disinfectant concentration times effective contact time (mg/L.min.)

C_t = tracer concentration (mg/L)

d = fraction of dead space (%), or day

DBP = disinfection byproduct

d_o = nozzle diameter (m)

D_x = axial dispersion coefficient (m/min.^{2})

d_x = axial dispersion index

ε = eddy diffusivity

F = constant

f = degree of short circuiting (%)

f, g, h = function of

η = r/b

HPC = heterothropic plate count

H_2SiF_6 = hydrofluosilicic acid

i = suffix

ICP = inductively coupled plasma

k = experimental coefficient

kg = kilogram

L = lag (min.), or liter

l = length of travel (m)

M = total tracer mass (kg)

m = lag factor, or meter

mg = milligram

min = minute

ML = megaliter

N = number of CMRs in series, or number of microorganisms

ν = fluid kinematic viscosity (m^2/min.)

n = suffix, or coefficient of dilution

NaCl = sodium chloride

nm = nanometer

N_o = number of initial microorganisms

NTU = nephelometric turbidity unit

p = degree of PFR (%)

PFR = plug flow reactor

ppb = part per billion

Q = water flow (ML/d)

θ = non dimensional time

Q_d = desired flow (ML/d)

Q_t = tracer study flow (ML/d)

q_t = tracer flow (L/s)

qy, qz = exponential parameters

r = detention time correction factor, or radial distance from jet axis (m)

ρ = fluid density (kg/m^3)

r_1 = inner shear layer radius (m)

r_2 = outer shear layer radius (m)

r_A = chemical reaction rate (mg/L s)

R_e = Reynold number

R_i = Richardson number

r_o = nozzle radius (m)

σ = E curve standard deviation

σ_θ = non dimensional E curve standard deviation

SWTR = the Surface Water Treatment Rule

t = time (min.)

τ = turbulent shear stress (kg/m min.^{2})

$t_{10,50,90}$ = time when certain percentages of flow have passed (min.)

t_{10d} = desired t_{10} (min.)

t_{10t} = tracer study t_{10} (min.)

t_a = actual residence time = time to reach curve centroid (min.)

t_b = time or width of E curve at 10% C_0 (min.)

t_c = time or width of E curve at 50% C_0 (min.)

TCU = true color unit

T_d = theoretical residence time (min.)

T_{dTot} = total theoretical residence time for CMRs in series (min.)

THM = trihalomethane ($CH\text{-}X_3$)

t_p = time to reach peak concentration (min.)

t_z = time when first tracer is monitored (min.)

u = mean axial velocity (m/min.)

u_m = maximum axial velocity (m/min.)

U_o = initial axial velocity (m/min.)

u_s = maximum axial velocity at X-Z plane (m/min.)

USEPA = the United States Environmental Protection Agency

V = volume (m^3)

v = mean radial velocity, or mean vertical velocity (m/min.)

v_e = entrainment velocity (m/min.)

v_{ey} = vertical entrainment velocity (m/min.)

v_{ez} = perpendicular entrainment velocity (m/min.)

ω = experimental parameter

w = mean perpendicular velocity (m/min.)

x = axial distance along jet axis (m)

ψ = experimental parameter

y = vertical distance from jet axis (m)

z = perpendicular distance from jet axis (m)

1.0 INTRODUCTION

1.1 Background

Health risks due to microorganism contamination in drinking water have become critical issues in North America with the emergence of newly - recognized waterborne disease - causing organisms in the last two decades. It was not until 1976 that people started to pay attention to protozoan types of microorganisms (e.g., Giardia lamblia and Cryptosporidium parvum), bacterial type of microorganism (e.g., Legionella pneumophila), and enteric viruses as the causes of many outbreaks of waterborne diseases in the United States (Marroco, 1987, Reasoner, 1991, and Herwaldt et al, 1992). Even helminths were also suspected of causing outbreaks (Philpot, 1989).

The conventional disinfection practice that was able to handle common bacterial outbreaks in the past, such as typhoid and cholera by employing chlorine (in the form of chloride of lime, sodium hypochlorite, Cl_2, and chloramines) needs to be improved since these new types of microorganisms seem to be more formidable to inactivate (White, 1992).

Indicators of microbial quality, such as turbidity, coliform bacteria, and heterothropic plate count bacteria (HPC) that used to be the most common parameters to identify the possible presence of pathogenic organisms should be used cautiously as well. Several studies have proven that these indicators do not correlate well with the occurrence of these more newly recognized organisms (Le Chevallier and Norton, 1992).

Increasing or modifying the conventional disinfection practice is necessary to reduce health risks. Still, it is not only expensive but it also has a potential to produce other health risks such as carcinogenecity of disinfection byproducts (DBPs) (Sobsey et al, 1993). During studies conducted in 1974, chloroform, one type of trihalomethane (THM), was identified in a chlorinated drinking water as a DBP produced from reactions between chlorine and organic materials (Bellar et al, 1974). By 1991, there have been more than 700 types of DBPs identified by the United States Environmental Protection Agency (USEPA) (Moser, 1991).

Reducing the health risk associated with waterborne disease outbreaks needs broader knowledge to be able to determine the method that yields the best risk reduction. Developing and applying an overall health risk assessment for microbial and also chemical contamination are necessary in order to define a health risk management plan (Sobsey, 1993).

In order to handle these problems, a strategy has been proposed using different types of disinfectant that have higher inactivation potency but do not produce THMs directly. Inactivation steps have been improved as well by applying multi - barrier processes in the treatment plant. The first, known as primary disinfection, aims at the total inactivation of pathogenic organisms in the system. For many reasons, chlorine dioxide and ozone are gaining popularity as primary disinfectants. Secondly, baseline treatments, such as filtration and sedimentation, have been integrated into the disinfectant protocols (Bryant et al, 1992). Direct filtration, slow sand filtration, and diatomaceous earth filtration are considered as very good barriers for many kinds of organisms (Guidance Manual, 1989). A case study reported by Glicker and Edwards (1991) shows that unfiltered systems did have serious problems with Giardia . Bank filtration wells constructed near a river were proposed by Hilterbrand et al (1991) as another similar concept of filtration. The last step is secondary disinfection. It protects system from newly introduced or regrowth of pathogenic organisms. Chloramines, due to their stabilities in water, have become a very common type of secondary disinfectant in North America.

The Surface Water Treatment Rule (SWTR) introduced by the USEPA in 1989 sets new treatment requirements to protect all public water supplies using surface water sources and ground water sources under direct influence of surface water. For some microbial contaminations, the SWTR proposes treatment methods as a condition for compliance rather than establishing maximum contaminant levels (MCLs). The SWTR introduces the concentration multiplied by time (CT) concept as a new treatment method to reduce the health risk due to microorganism contaminations in drinking water. The emphasis is given to the inactivation of Giardia lamblia and enteric viruses. Basically, the concept considers disinfectant concentration C and hydraulic effective contact time T as an inseparable unit to ensure the inactivation process. Determining the contact time using tracer studies is the most common method to follow. A tracer chemical can be injected into a system in a continuous or instantaneous input. Statistical curves, the E and F curves, can be developed to represent the residence time distribution of the chemical in the system. The CT concept also gives some credits to physical processes, filtration and sedimentation, that remove unwanted particles and organisms in the water.

It is evident that disinfection is no longer as simple as "chlorination - coliform" any more. It deals not only with the quality of drinking water leaving the plant, but also with the quality of the treatment and distribution systems plus a complex knowledge of health risk concerns. As a consequence, physical processes, fluid mechanics, public health education, risk assessment, and many other areas are gaining significant roles besides other conventional disciplines, such as microbiology and chemistry. This thesis presents a study which assesses the disinfection contact time parameter as applied to the SWTR / CT concept in a large water treatment plant.

1.2 Scope of Study

The primary objective of this study was to the determination of the hydraulic characteristics of various treatment processes of the E. L. Smith Water Treatment Plant in Edmonton, Alberta. The main emphasis is given to determine the t_{10} values of various systems. However, the study does not include overall calculation of the actual CT values of the treatment plant since a preliminary study was already completed by the Process Development Team in 1989 - 1990 (Process Development Team, 1991). The data obtained from this study give additional information to the previous study. It is also important to develop relations between flow rates and residence time distributions to predict the hydraulic characteristics at different flow rates rather than those tested. Confidence in this relationship is required as the City of Edmonton is planning to expand the treatment plant to a greater flow capacity.

In order to meet the objective of the study, tracer tests were conducted for one clarifier, a set of filters and clearwell, and three on - site reservoirs. Most of the tests were completed at two different flow rates. The results were analyzed using traditional residence time distributions, the E and F curves. A number of common models suggested by Marske and Boyle (1973), the Guidance Manual (1989), Thirumurthi (1969), Levenspiel and Bischoff (1963), Wolf and Resnick (1963), and Rebhun and Argaman (1965) were discussed in this study, including the direct interpretation of time values, baffle parameters, dispersion models, degree of PFR and dead space model, and CMRs - in - series model. However, most of those models are based on empirical and statistical approaches. In many cases, they do not fit well with the real data obtained from a particular test. It was therefore necessary to develop a more physically - based model that not only fits the obtained data better, but also gave more confidence in its application at different flow rates.

In the case of three reservoirs tested, it was found that the common models listed above failed to provide satisfactory results. A further investigation found that initial portions of the residence time distribution curves were mostly governed by the initial momentum - dominated jet at the inlet point. The jet model was found to be the appropriate model to use to fit the real data.

Based on tracer tests and analyses of the results, it is possible to present a discussion about residence time distributions of various systems in the treatment plant. The discussion includes an overview of the analysis method using the common models and jet model, and also several comments to the SWTR / CT concept.

2.0 LITERATURE REVIEW

2.1 SWTR and CT Concept

With the promulgation of the new regulation, disinfection practice has reached its new and modern stage. For some microbial contaminants, the SWTR gives an emphasis to the treatment methods as a condition for compliance rather than establishing maximum contaminant levels (MCLs). The CT concept is proposed as the new treatment assessment technique to reduce health risks due to microorganism contamination.

The main idea of the CT concept is based on the Watson model that includes C (disinfectant concentration), T (hydraulic effective contact time), and n (parameter or coefficient of dilution). The relationship among those parameters can be described as follows (Canadian Water and Wastewater Association, 1993):

$$C^nT = \text{constant} \qquad (2.1).$$

Plotting C and T for inactivation of a certain type of microorganism in a particular time T on a log - log scale will give a straight line with a slope equal to n. Inactivation level of 99% is chosen in most cases. For the CT model, it is assumed that n equals to unity. It means that both C and T have the same importance in determining the CT product. Note: C is the important factor for $n>1$, while T becomes the significant factor for $n<1$.

Correlation between the survival of microorganisms N/N_0 and the contact time T can be expressed using the Chick model (Canadian Water and Wastewater Association, 1993):

$$\log \frac{N}{N_0} = -kT \tag{2.2}$$

where k is a constant. Ideally, a plot of log N/N_0 vs. T should yield a straight line, expressing the first order kinetics condition. However, deviations often occur in real situations such as shoulder, initial rapid, and tailing curves (Hoff, 1987).

The Guidance Manual (1989) employs the CT concept to achieve at least 3 log (99.9%) and 4 log (99.99%) inactivation levels of Giardia cysts and viruses, respectively (Guidance Manual, 1989). Higher inactivation levels may be necessary considering the cyst concentration, see Table 2.1 (AWWARF, 1993). The numbers are based on the annual risk of 10^{-4} per person. The infected dose for Giardia can be as low as 1 cyst only. It is assumed that a person drinks 2 L of water a day. In the case of 1 cyst / 100 L for example, it is logical to apply 3 log reduction level in order to have a risk less than 10^{-4}. In the case of viruses, it is assumed that viruses occur at higher concentration in source waters, have more health risks, and are more infectious than Giardia. Therefore, it was decided to have higher inactivation levels than those for Giardia (Guidance Manual, 1989). The Guidance Manual (1989) also assumes that using those two microorganisms as the parameters will also provide protection to heterothropic plate count (HPC) bacteria and Legionella.

The Guidance Manual (1989) assumes that degree of microorganism inactivation is proportional to the product of C (disinfectant concentration used, in mg/L) and T (hydraulic effective contact time, in minutes). As will be discussed later, t_{10} or time for 10% of the flow passes through the process, is assumed to be the hydraulic effective contact time. Standard CT values have been specified for different types of disinfectant: free chlorine, chloramines, chlorine dioxide, ozone, and ultraviolet light, for different pH values (6 to 9), and for different temperatures (0.5° to 25° C). For example,

Table 2.1: Inactivation Levels (adapted from AWWARF, 1993)

Giardia	Geometric Mean of Allowable Daily Average Cyst Concentration (Cysts/100L) <1	1 to 10	10 to 100
Giardia cyst removal - inactivation	3 log	4 log	5 log
Virus removal - inactivation	4 log	5 log	6 log

standard CT values for inactivation of viruses using chlorine dioxide can be seen in Table 2.2. Other standard CT values for different conditions can be found in the Guidance Manual (1989). Filtration gives some credits for the CT values in the range of 1 log (90%) to 2.5 log (99.3%) reductions, depending on the types of filtration used and microorganisms involved. In the case of coagulation / flocculation and filtration, a credit of 2.5 log reduction is given for Giardia cysts and a similar credit of 2.0 log reduction for viruses, with the remaining reduction obtained by the disinfection process (Bryant et al, 1992).

To meet the Guidance Manual (1989) criteria, CT values for a water treatment plant should be investigated. It is assumed that the plant satisfies the requirement if the value meets or exceeds the standard value. Still, standard CT values in the table were generated in perfect laboratory processes without the presence of other chemical compounds. Disinfectant dissipation, especially in the case of chlorine as it reacts with other chemical compounds in real water, should be taken into account (Teefy and Singer, 1990). The change in pH, temperature, and even sunlight penetration for open systems should be considered as well (Auckly and Borgerding, 1991). Another weakness of the CT concept is that one tends to extrapolate the standard value for a particular condition since the experimental data are relatively limited. The extrapolation is valid only if the relation between the surviving microorganisms and contact time in the Chick model (Equation 2.2) is ideal (a straight line for log N/N_0 vs. T). Another difficulty arises in the assumption that n in the Watson model (Equation 2.1) is equal to 1. For disinfectant such as ozone, studies have shown that n may be as high as 3 (Zhou and Smith, 1994). It has generally been reported for chlorine that n is close to 1. Still, even for chlorine the value of n is not always unity (Hoff, 1987).

However, in a general case, the SWTR / CT concept is still an improvement over the use of MCLs as it considers the kinetics aspect of the process leading to

Table 2.2 CT Values for Inactivation of Viruses by Chlorine Dioxide for pH 6 to 9 (adapted from the Guidance Manual, 1989)

Removal	Temperature (°C)					
	≤ 1	5	10	15	20	25
2 log	8.4	5.6	4.2	2.8	2.1	1.4
3 log	25.6	17.1	12.8	8.6	6.4	4.3
4 log	50.1	33.4	25.1	16.7	12.5	8.4

disinfection. As has been mentioned by Regli (1989), the CT concept allows water processors to evaluate accurately their disinfection processes and to optimize the chemical usage in achieving the desired level of performance. The Guidelines for Canadian Drinking Water Quality (1993) is considered to be somewhat behind the SWTR / CT concept as it still uses the maximum acceptable concentration (MAC) to analyze the microbiological parameters without having specific criteria for enteric viruses and protozoa. Therefore, it is a very reasonable idea to apply the CT concept as a general measure of disinfection performance for water treatment plants in Canada although the USEPA itself does not have any legal status in Canada. In recognition of this, a preliminary investigation was completed as early as 1989 - 1990 by the City of Edmonton at the E. L. Smith and Rossdale Water Treatment Plants in Edmonton, Alberta (Process Development Team, 1991).

2.2 Residence Time Distributions

In very general terms, the residence time can be defined as the time needed for fluid particles to pass through in a process. A specific time parameter, in this case the hydraulic effective contact time, can be found by determining the residence time distribution. The use of the E and F curves obtained from tracer studies is the most preferable method to use. A tracer consisting of a non - reactive and non - toxic chemical compound can be added to a system in several ways including random input, cyclic input, slug / pulse input, and step / continuous input. On the whole, slug and step inputs are the most suitable as relatively simple mathematical or statistical modeling can be derived from the results.

2.2.1 Reactor Types

It is assumed that plug flow reactors (PFRs) and complete mixed reactors

(CMRs) are the ideal reactors that describe the two limits of residence time distributions found in actual reactors. In a PFR, the fluid travels smoothly as a "piston flow" from the inlet to the outlet with complete mixing in the axial direction without any longitudinal dispersion. The particles remain in the system for a time equal to the theoretical residence time (T_d):

$$T_d = \frac{V}{Q} \tag{2.3}$$

where:

V = system volume (m^3)

Q = incoming flow (m^3/min.).

Flow through a long system with a high length to width ratio like a pipe and flow through granular media filters are generally assumed to have a close resemblance to this type of flow. In the case of CMRs, complete mixing is expected to occur immediately when the fluid enters the system. The particles disperse throughout the system and leave in proportion to their statistical distribution. It can be achieved only if there is perfect mixing.

Even though the two types of ideal flow reactors have found great use in defining the outer bounds of reactors, arbitrary flow reactors (AFRs) are the most common reactor types found in real situations. They represent some deviations from PFRs and CMRs in that they do not follow either the ideal flow condition. To account for this, the CT concept suggests the use of t_{10} for the contact time, i.e. time when 10% of the flow passes through the system, instead of using the theoretical residence time (T_d) (Guidance Manual, 1989). By using this, it is assumed that at least 90% of fluid in the system has been exposed to the disinfectant for a period greater than t_{10}. Still, as the standard CT values were generated from batch reactor experiments, more studies about the fluid behavior in different types of reactors must be conducted. Lev and Regli (1992) generated data based on dispersion and CMRs - in - series models. The result showed that the t_{10} was reliable only for high t_{10}/T_d values or in the case of low microorganism inactivation levels (up to 2 log reduction, but not for 4 log reduction).

2.2.2 E and F Curves Development

The E and F curves have long been used to assess the residence time distribution in real reactors. In the case of a slug input, a discrete amount of tracer is fed into the system at an instance, normally for a period less than 1/50 times T_d (Thirumurthi, 1969). The slug test residence time distribution function is given by the E curve. It can be explained in that the fraction of material at the outlet point that has been in the system for a time between t and t + dt is equal to E dt. The E(t) vs. t curve can be developed both for discrete and continuous variables as the function of C_i or C(t) (tracer concentration at a particular time in mg/L) and t (time in minutes) (Levenspiel and Bischoff, 1963):

$$E_i \cong \frac{C_i}{\Sigma C_i \Delta t} \qquad \text{,or}$$

$$E(t) = \frac{C(t)}{\int_0^{+\infty} C(t)\, dt} \qquad (2.4).$$

The area under the E curve represents the complete tracer recovery and should be equal to 1:

$$\Sigma E_i\Delta t_i \cong 1 \qquad ,\text{or}$$

$$\int_0^{+\infty} E(t)\, dt = 1 \qquad (2.5).$$

Since the E curve still has dimensions (1/[time] for the vertical axis and [time] for the horizontal axis), it is also possible to use a dimensionless curve, i.e. the $E(\theta)$ vs. θ curve. It can be developed using relations among the previous parameters to define the t_a (actual residence time):

$$t_a \cong \frac{\Sigma\, t_i C_i \Delta t_i}{\Sigma\, C_i \Delta t_i} \qquad ,\text{or}$$

$$= \frac{\int_0^{+\infty} t\, C(t)\, dt}{\int_0^{+\infty} C(t)\, dt} \qquad (2.6)$$

$$\theta = \frac{t}{t_a} \qquad (2.7)$$

$$\theta\, E(\theta) = t\, E(t) \qquad ,\text{then}$$

$$E(\theta) = t_a\, E(t) \qquad (2.8).$$

For a step input, the tracer is added to the system continuously in a uniform concentration for a period of 2 to 3 times T_d or until it reaches the steady state condition (Hudson, 1975). The F(t) vs. t curve, represents the fraction of material at the outlet point that has been in the system for a time less than t. For discrete and continuous variables, the equations are:

$$F_i = \frac{C_i}{C_o} \qquad \text{,or}$$

$$F(t) = \frac{C(t)}{C_o} \qquad (2.9)$$

where C_o is the initial tracer concentration of the step input in mg/L. To represent a complete tracer recovery, the value of F_i or F(t) should equal to 1 at the steady state condition. The non - dimensional curve F(θ) vs. θ, can be generated easily from the F curve as it is already dimensionless in the vertical axis. The horizontal axis can be developed by dividing t with t_a. The relation between the two vertical axes is:

$$F(\theta) = F(t) \qquad (2.10).$$

After either the E or F curve has been identified, the other curve can be formed using the following equations:

$$E(t) = \frac{dF(t)}{dt} \qquad \text{, or}$$

$$F(t) = \int_0^t E(t)\,dt \qquad (2.11)$$

$$E(\theta) = \frac{dF(\theta)}{d\theta} \qquad \text{,or}$$

$$F(\theta) = \int_0^{\theta} E(\theta)\, d\theta \quad (2.12).$$

General equations for PFRs and CMRs have well been developed. In the case of PFRs, the E and F curves are identified as follow (Metcalf and Eddy, 1991):

$$F(t) = \frac{C(t)}{C_o} = 1 \quad ,t \geq Td \quad (2.13)$$

$$E(t) = \frac{C(t)}{C_o} = +\infty \quad ,t = Td \quad (2.14)$$

with the total area for Equation 2.14 equals to 1. For the CMR, it is necessary to develop the mass balance equation. It is expressed as follows (Metcalf and Eddy, 1991):

[Accumulation] = [Inflow] - [Outflow] + [Generation] , or

$$\frac{dC}{dt} V = Q\, C_o - Q\, C(t) + r_A V \quad (2.15)$$

where r_A is the rate of chemical reaction (mg/L.min.). Assuming that the tracer compound is conservative ($r_A = 0$), a new equation for the step input can be derived by integrating Equation 2.15 from C = 0 to C:

$$F(t) = \frac{C(t)}{C_o} = 1 - \exp\left(-\frac{t}{T_d}\right) \quad (2.16).$$

In the case of a slug input, the value of $Q.C_o$ in Equation 2.15 is equal to 0, as no tracer is continuously added after the first addition. The integral is taken from $C = C_o$ to C:

$$E(t) \quad = \frac{C(t)}{C_o} = \exp\left(-\frac{t}{T_d}\right) \qquad (2.17).$$

General equations for the AFR should be identified using tracer studies. Characteristics of the PFR, CMR, and AFR in the form of the E and F curves can be seen in Figure 2.1. Interpretation of the E and F curves is done by assessing the four characteristics listed below:

dead space:	no fluid motion in some parts of the system and there is perfect mixing in other regions,
short circuiting:	nearly instantaneously moving of the flow from the input to the output,
dispersion:	mass transport due to the velocity gradient, usually only axial or longitudinal direction to be considered. It characterizes the degree of back mixing during the flow,
errors factors:	some correction factors due to imperfectness of the system or assumptions made.

2.2.3 Single Stage with Closed - Closed System

The single stage system is formed by only one system. It is characterized by a straight line of the F curve when a log scale is used for the horizontal axis (Wolf and Resnick, 1963). Closed - closed system means that before and after the fluid enters the system, it acts as a PFR. Since the case study is related to reservoir systems with two pipes in the inlets and outlets, only the closed - closed system is going to be discussed.

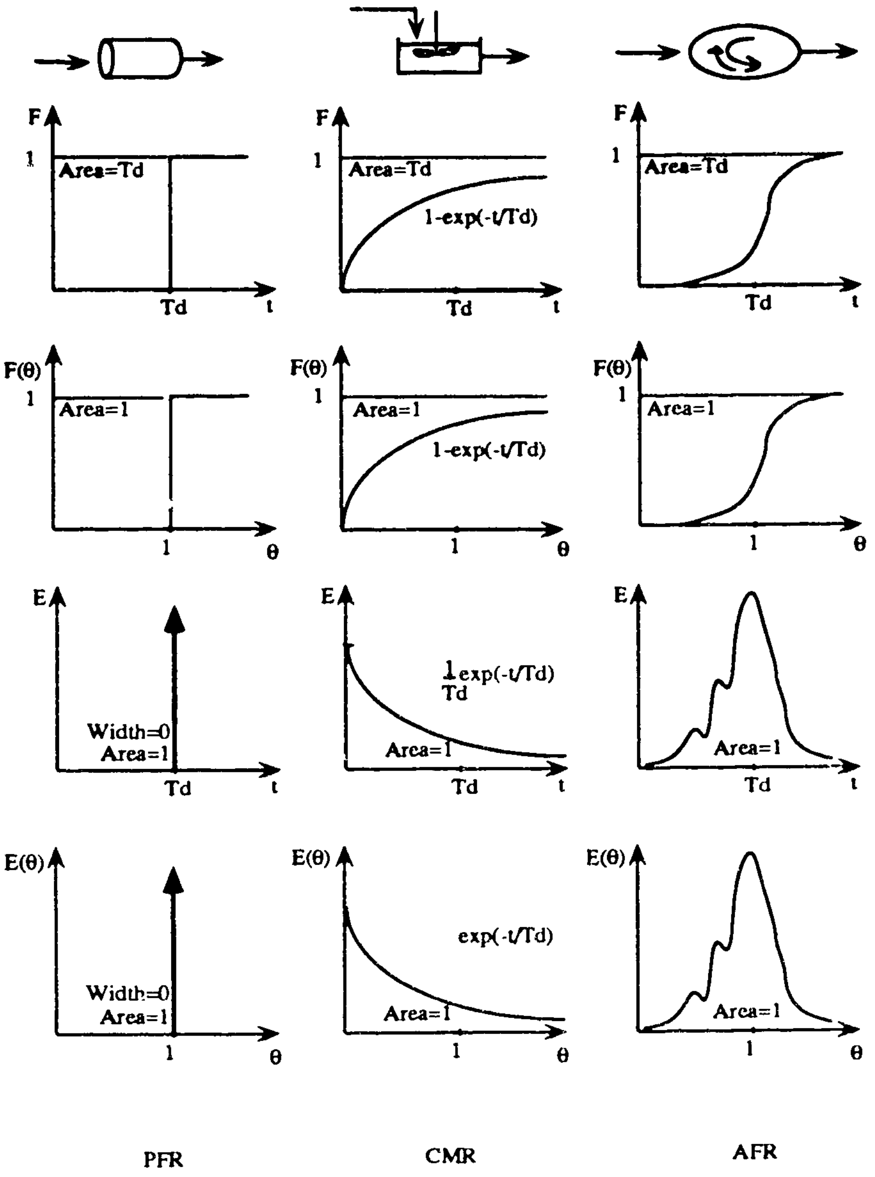


Figure 2.1: E and F Curves (adapted from Levenspiel, 1963)

2.2.3.1 E(t) vs. t Curve Interpretation

Models developed from this curve are quite simple. The idea is based on comparisons of the time parameters obtained from the curve (see Figure 2.2). These are the most common dimensionless parameters to use (Marske and Boyle, 1973):

index of mean residence time = $\frac{t_a}{T_d}$

index of average residence time = $\frac{t_{50}}{T_d}$

index of short circuiting = $\frac{t_Z}{T_d}$

Morril's dispersion index = $\frac{t_{90}}{t_{10}}$

index of modal residence time = $\frac{t_p}{T_d}$

where:

t_{10} = time for 10% of tracer to pass the system (min.)
t_{50} = time for 50% of tracer to pass the system (min.)
t_{90} = time for 90% of tracer to pass the system (min.)
t_a = time to reach the curve centroid (min.)
t_p = time to reach the peak concentration or modal value (min.)
t_Z = time when the first tracer is monitored in the effluent (min.).

In the case of PFRs, all of those parameters should equal to 1. While Brumo (1972) mentions three more dimensionless parameters, although traditionally they have not frequently been used:

index of eddy diffusivity causea by turbulence = $\frac{t_c}{T_d}$

index of turbulence and recirculation eddies = $\frac{t_b}{T_d}$

index of curve eccentricity = $\frac{(t_c-t_p)-(t_p-t_z)}{T_d}$

where:

t_c = time or width of the curve at 50% of C_o (min.)
t_b = time or width of the curve at 10% of C_o (min.).

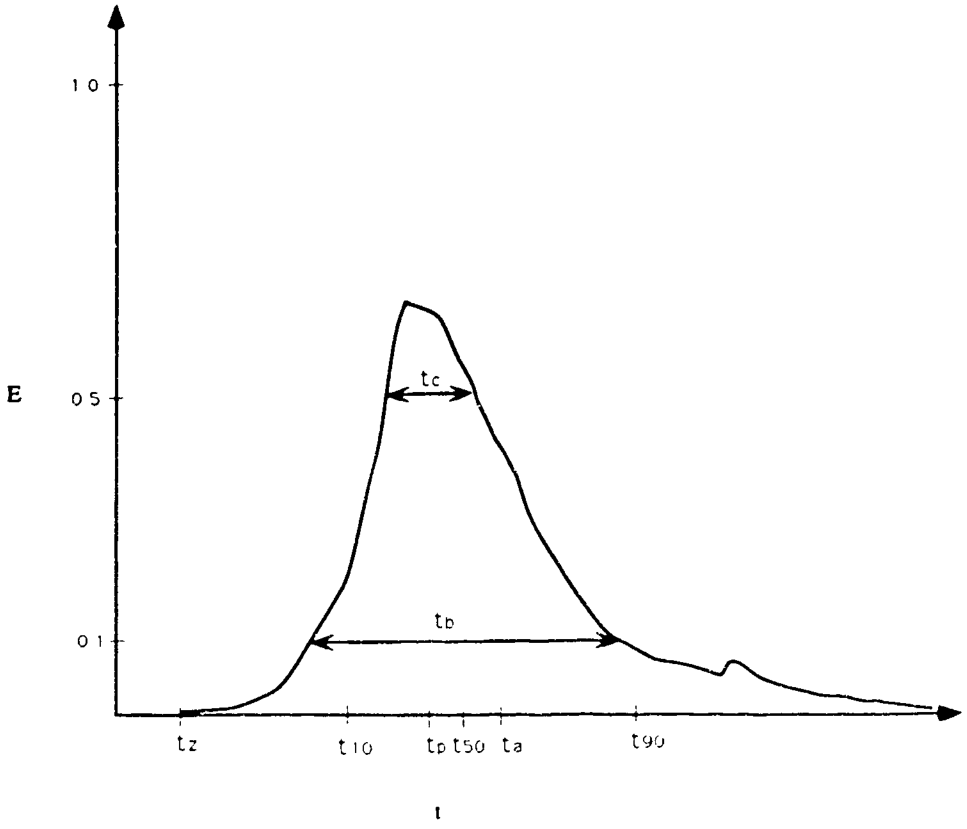


Figure 2.2: Time Parameters in the E Curve (adapted from Levenspiel and Bischoff 1963)

The first and second parameters should equal the tracer addition time in the case of PFRs, and should be 0.7 and 2.3 respectively for CMRs. The last parameter should be 0 for PFRs and 2.3 for CMRs (determined experimentally). However, the Morril's index is assumed as the best approximation to assess the axial dispersion (Gregory and Zabel, 1990).

Another approach is given by Scheible as cited by Thampi (1989). The idea is to consider the tracer concentration as a function of the axial dispersion coefficient (D_x):

$$c_p = \frac{M}{A\sqrt{4\pi D_x t_p}} \exp\left[\frac{-(l-ut_p)^2}{4D_x t_p}\right] \qquad (2.18)$$

where:

c_p = peak tracer concentration (kg/m^3)
M = total mass of tracer (kg)
l = length of travel (m)
A = cross sectional area of the flow (m^2)
u = axial velocity (m/min.)
t_p = time to reach the peak concentration (min.)
D_x = axial dispersion coefficient (m^2/min.).

Unfortunately, this approach is valid only for long cylinder systems. A more general formula that is applicable for any type of reactor can be found as a function of the standard deviation of the non - dimensional E curve (see the next section).

The Guidance Manual (1989) suggests the use of the baffle parameter (t_{10}/Td) to investigate the system performance. Several criteria have been identified, see Table 2.3 Basically, comparisons among the time parameters do give some qualitative

Table 2.3: Baffle Parameters (adapted from the Guidance Manual, 1989).

t_{10}/T_d	BAFFLE PARAMETERS	DESCRIPTIONS
<0.1	mixed flow / unbaffled	agitated basin, very low length to width ratio, high flow velocity
0.3	poor	single or multiple unbaffled inlets and outlets, no intra - basin baffles
0.5	average	baffled inlet or outlet with some intra basin baffles
0.7	superior	perforated inlet baffle, serpentine outlet weir or perforated launders
1.0	perfect (plug flow)	very high length to width ratio (pipe line flow), perforated inlet, outlet, and intra - basin baffles

assessments, but not quantitative determinations, as numerical relations among them are not known.

2.2.3.2 E(θ) vs. θ Curve Interpretation

A better method has been developed by considering the dispersion in the system that can be applied in all conditions. Usually only the axial dispersion is taken into account. The axial dispersion index (d_x) should be 0 in the case of PFRs and +∞ for CMRs. It can be measured as a function of the standard deviation of the non - dimensional curve E(θ) vs. θ. It is considered to be a better model as it considers the entire curve, rather than only several discrete values like in the previous model. Several relations can be generated using these equations (Levenspiel and Bischoff 1963):

$$d_x = \frac{D_x}{u\ l} \qquad (2.19)$$

$$\sigma^2 = \left(\frac{\Sigma t_i^2 C_i}{\Sigma C_i}\right) - t_a^2 \qquad (2.20)$$

$$\sigma_\theta^2 = \frac{\sigma^2}{t_a^2} \qquad (2.21)$$

$$\sigma_\theta^2 = 2d_x - 2d_x^2\,[1 - \exp(-d_x)] \qquad (2.22)$$

$$E(\theta) = \frac{1}{(\pi\theta d_x)^{0.5}} \exp\left[-\frac{(1-\theta)^2}{4\theta d_x}\right] \qquad (2.23)$$

where:

u = axial velocity (m/min.)

l = length of travel (m)

D_x = axial dispersion coefficient (m^2/min.)

d_x = axial dispersion index (no unit)

σ = standard deviation

σ_θ = standard deviation for non - dimensional condition.

Correlation between the E curve and the population of microorganisms over the time is presented by Trussell and Chao (1977) as follows:

$$\frac{N}{N_o} = \frac{1}{T_d}\left[\int_0^{\psi/T_d} E(\theta)\, d\theta + \int_{\psi/T_d}^{+\infty} \left(\frac{\psi}{C_o\, t}\right)^{\omega} E(\theta)\, d\theta\right] \qquad (2.24)$$

where:

N = number of microorganisms at time t

N_o = number of initial microorganisms

ψ = experimental parameter, for example: ψ equals to 2.8 for fecal coliform, etc.

ω = experimental parameter, equals to 3 for the original value, less than 3 as suggested by Hart and Vogiatzis (1982).

2.2.3.3 F(θ) vs. θ Curve Interpretation

Since the actual residence time (t_a) cannot be generated directly from the F curve, it is preferable to use the theoretical residence time (T_d). All of the error factors and other parameters are included in the following models (Wolf and Resnick, 1963):

$$F(\theta) \quad = 1\text{-}\exp\{-\frac{(1\text{-}f)}{ar(1\text{-}d)T_d}[t\text{-}L\text{-}\frac{p(1\text{-}d)rT_d}{(1\text{-}f)} + mar(1\text{-}d)T_d]\} \qquad ,F(\theta) \geq 0 \qquad (2.25).$$

It is obvious that Equation 2.25 is quite complicated. Parameters p and a represent the fraction of the system that acts as a PFR and a CMR respectively, in which $p + a = 1$. Intercept of the curve with vertical axis represents the degree of short circuiting effect (f). Dead space fraction is measured by parameter d, while error factor for residence time can be measured using parameter r. Lag (L) and lag factor (m) represent the lag in response of the system. The model can be simplified in a different form by combining the parameters as can be seen in Equation 2.26:

$$F(\theta) \quad = 1\text{-}\exp[-\alpha \frac{(t\text{-}\beta)}{T_d}] \qquad ,F(\theta) \geq 0 \qquad (2.26).$$

Parameter β represents the system phase shift or the intercept of the curve with horizontal axis, while α is the coefficient of exponent or the skewness of the entire curve. Rebhun and Argaman (1965) made a simplification by regarding only parameters p and d. Basically, this linearizes the Wolf and Resnick model:

$$F(\theta) \quad = 1\text{-}\exp\{-\frac{1}{(1\text{-}p)(1\text{-}d)}[\frac{t}{T_d} - p(1\text{-}d)]\}\text{ , or}$$

$$\ln[1\text{-}F(\theta)] \quad = -\frac{1}{(1\text{-}p)(1\text{-}d)}\frac{t}{T_d} + \frac{p}{(1\text{-}p)} \qquad (2.27).$$

As has been mentioned above, linearization of the original equation should result in a straight line for a single system. Using slope $\frac{1}{(1\text{-}p)(1\text{-}d)}$ and intercept of the line with vertical axis $\frac{p}{(1-p)}$ obtained from the graph, p and d can be determined easily. The Guidance Manual (1989) also suggests the use of this method to assess the t_{10}. Yu et al (1991) conducted a study using basically the same method but a different sign (positive / negative) convention. Note: linearization using a log scale in place of ln scale can be used as well, adding the parameter log e to the equation.

2.2.4 Multi Stage with Closed - Closed System

This system is formed by N numbers of CMRs of the same volume in series. Unlike the single stage system, the F curve will produce a curve in place of a straight line if a log scale is used for the horizontal axis (Wolf and Resnick, 1963). The curves for a multi stage system can be seen in Figure 2.3. The equations for the E and F curves have been developed as written below (Levenspiel and Bischoff, 1963):

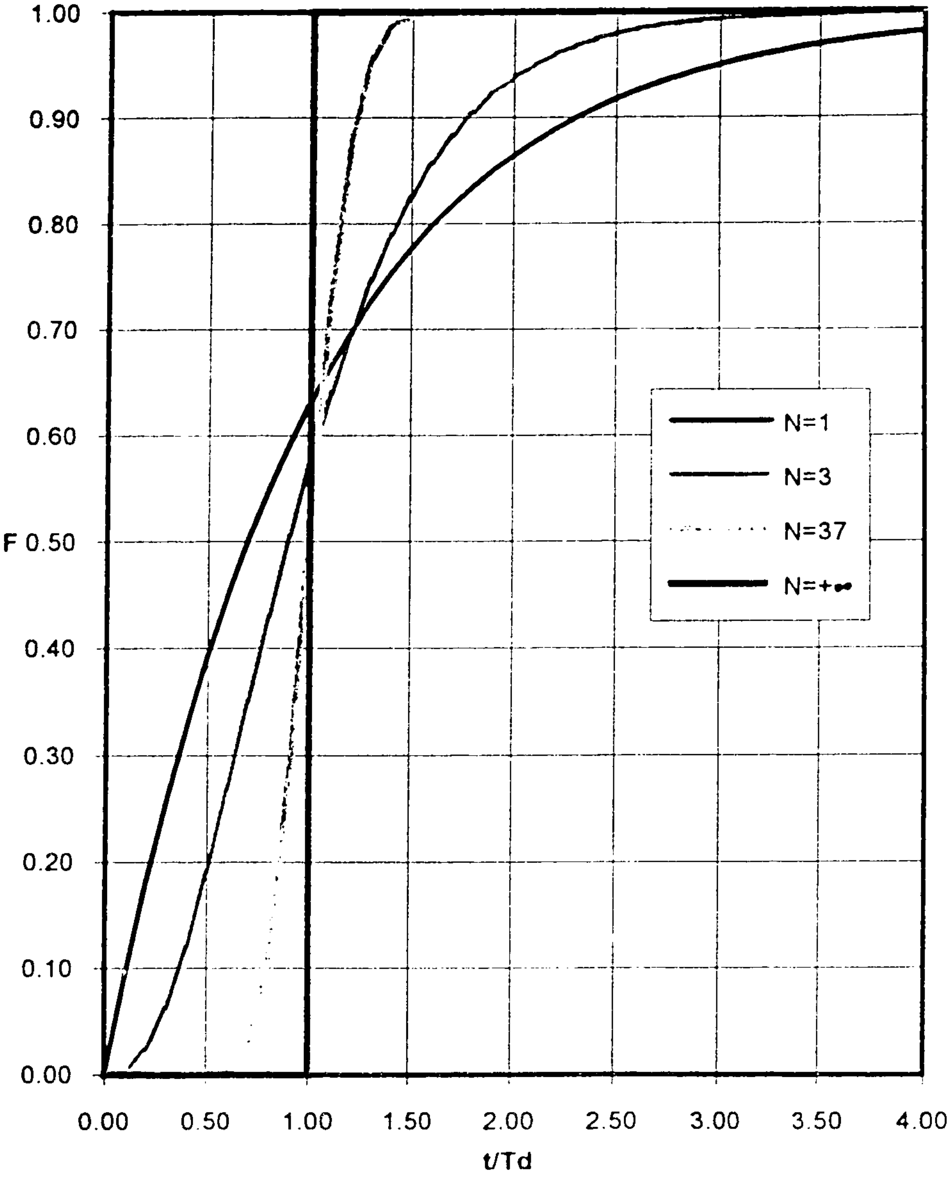
$$E(\theta) = (\frac{t}{Td})^{(N-1)} x \frac{1}{(N-1)!} \exp (\frac{-t}{T_d}) \tag{2.28}$$

$$F(\theta) = 1 - \exp(\frac{-Nt}{T_{dTot}})x[1 + \Sigma_{i=N-1}^{i=1} (\frac{Nt}{T_{dTot}})^{i} \frac{1}{i!}] \tag{2.29}$$

$$T_{dTot} = N\ T_d \tag{2.30}$$

$$N = \frac{t_a^2}{\sigma^2} \tag{2.31}$$

where T_{dTot} is the total theoretical residence time of the whole systems, while t_a and σ can be obtained from the E curve. It is possible to find out parameter N (the number of tanks in series) for a multi stage system that fits to the tracer study data (Teefy and Singer, 1990). Yet, there is not any general formula can be applied as everything depends on the system characteristics. Another different idea is given by Hazen as cited


1.00
0.90
0.80
0.70
0.60
F 0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
t/Td
N=1
N=3
N=37
N=+∞

by Gregory and Zabel (1990):

$$N \quad = \frac{t_{50} - t_p}{t_p} \tag{2.32}$$

where t_p is time to reach the peak concentration.

2.3 Jet Model

Jet theory has commonly been used for years. However, it is employed basically in the area of pure fluid mechanics. The main objective of this study is to introduce the jet model as an applicable tool to predict the hydraulic effective contact time parameter (t_{10}) associated with the SWTR / CT concept. Since the modeling is correlated to reservoir systems with inlet and outlet pipes, only circular types of jets are going to be discussed in this study.

2.3.1 Basic Assumptions

First of all, it is necessary to draw a distinction between jets and plumes. A jet is defined as a source of momentum and energy produced from a discharge of fluid into a large mass of the same or similar fluid. While, a plume is formed by the difference in potential energy or the density difference between the discharged and the surrounding fluid, that creates buoyancy relative to its surroundings. There are five general assumptions made to analyze the jet theory (Rajaratnam, 1976 and Blevins, 1986):

1) homogeneous and Newtonian fluid (shear stress is a linear function of velocity gradient), although it is possible that the fluid carries chemical compounds,
2) non - compressible fluid, or Mach number $(= \frac{\text{flow velocity}}{\text{speed of sound}}) \leq 1$,
3) "slender flow" condition, or thickness of the jet is assumed to be small compared

to the distance of the section from the nozzle,

4) infinite system, fresh water always entrains into the jet, and
5) uniform static pressure, except for the jet action itself.

Due to the limited scope of this study, it is reasonable to apply six more assumptions to simplify the problem:

6) only circular submerged and surface jets are considered,
7) turbulent flow, or Reynold number ($R_e = \frac{\text{inertia force}}{\text{viscous force}}$) ≥ 3000 (Blevins, 1986),
8) no significant density difference between the jet and surrounding fluid, i.e., no buoyancy and plume effects,
9) total flux propagation has the same value no matter the shape of the jet,
10) the jet occurs relatively far from surfaces, walls, or other objects, and
11) constant flow through circular nozzle.

A jet with a nozzle diameter of d_o, or radius of r_o, will produce a flow development region. Basically, the jet development is characterized by the width of turbulent mixing and the decay rates of center line properties. When a jet is moving downstream, it mixes the surrounding fluid forming a shear layer. Turbulence created in the shear layer penetrates outwards and inwards into the jet, reducing continuously the thickness of the "potential core". The core will vanish after the jet has moved at about 9 r_o (see the next explanation). This region is called the flow development region. Usually, it is assumed that the axial velocity (u) and chemical concentration (c) at any point in the flow development region are equal to the initial axial velocity (U_o) and initial chemical concentration (C_o), respectively. Generally, most analyses are conducted in the fully developed region, the region downstream where the potential core has vanished (see Figure 2.4).

There should be three conservation conditions that exist in the fully developed region. The conservation of mass deals with u, U_o, initial nozzle area (A_o), entrainment

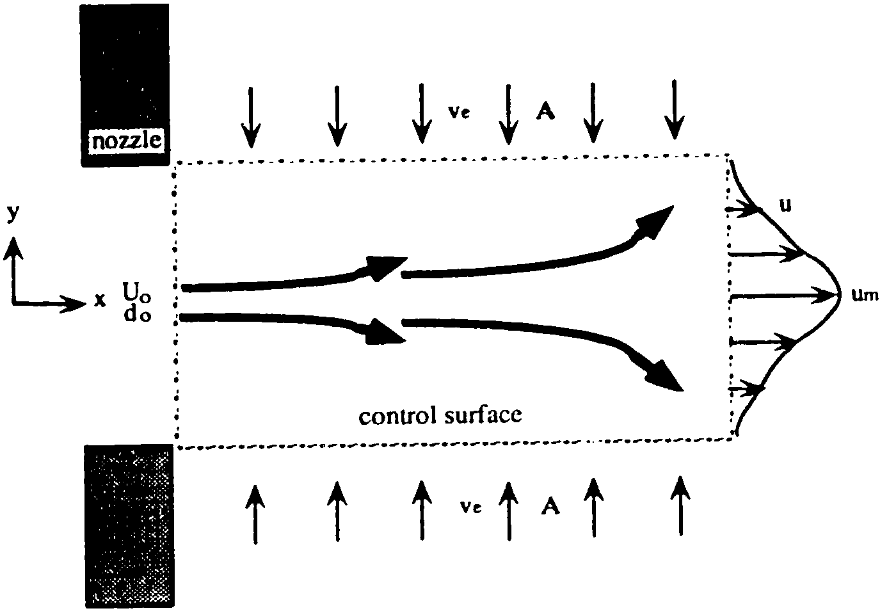


Figure 2.4: Jet Control Area (adapted from Blevins, 1984)

velocity (v_e), and area of the control surface (A_s):

$$U_oA_o + v_eA_s = \int_A u \, dA \qquad (2.33).$$

Chemical concentration C and C_o, are included in the species conservation:

$$C_oU_oA_o = \int_A cu \, dA \qquad (2.34).$$

It is obvious that entrainment must exist in order to achieve the validity between those two equations. Conservation of momentum in the jet is the last condition that must be fulfilled:

$$U_o^2A_o = \int_A u^2 \, dA \qquad (2.35).$$

As the jet moves along its path, it brings or entrains the surrounding water into the jet. The flow increases due to the transfer of the momentum outwards the jet, while the velocity and the concentration decrease as there is more dilution in the jet. More specific forms of the equations are presented in the following sections.

2.3.2 Circular Submerged Turbulent Jet

The flow development region of a circular submerged turbulent jet can be described using a coordinate system of r (radial distance from center line) and x (axial distance from nozzle). Theoretically, a jet always starts to propagate from a certain location behind the nozzle. Yet, for convenience, it can be assumed to occur right at the nozzle itself (Rajaratnam 1983 and 1986). See Figure 2.5 for a complete description.

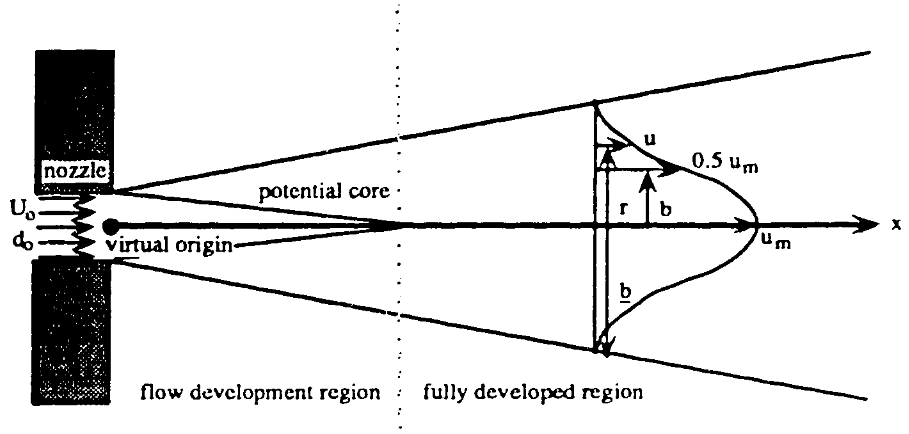


Figure 2.5: Circular Submerged Turbulent Jet (adapted from Rajaratnam, 1983)

The velocity distribution profile in the fully developed region can be determined as follows. The maximum axial velocity (u_m), which occurs at the center line, decreases continuously with the increase of x. Axial velocity (u) at any point at a radial distance r from the center line can be generated using these following equations. It is acceptable to simplify the relevant Reynold equations using axisymmetry and the slender flow condition (Rajaratnam, 1976):

$$u\frac{\delta u}{\delta x} + v\frac{\delta u}{\delta r} = \frac{1}{\rho r}\frac{\delta r\tau}{\delta r} \quad \text{,and} \qquad (2.36)$$

$$\frac{\delta ru}{\delta x} + \frac{\delta rv}{\delta r} = 0 \qquad (2.37)$$

where τ is the total shear at any point in the axial direction, and v is the radial velocity. In the case of turbulent jets, τ will be the same as the turbulent shear. Equation 2.37 represents continuity of the system.

Conservation of the axial momentum flux from Equation 2.35 can be developed in a more specific form by multiplying Equation 2.36 with ρr and then integrating it with respect to r from r = 0 to $+\infty$:

$$\frac{d}{dx}\int_0^{+\infty} 2\pi\rho r u^2 \, dr = 0 \qquad (2.38)$$

where ρ is the fluid density. Initial axial momentum flux at the nozzle (M_o) is given by:

$$M_o = \int_0^{+\infty} 2\pi\rho r u^2 \, dr = \frac{\pi d_o^2}{4}\rho U_o^2 \qquad (2.39).$$

Using the entrainment hypothesis, it is obvious that the flow (Q) always increases along the jet path as it entrains the surrounding fluid. This can be expressed as (Rajaratnam 1983 and 1986):

$$Q \quad = \int_0^{\underline{b}} 2\pi\rho r u \, dr \qquad (2.40)$$

$$v_e \quad = \alpha_e u_m \qquad ,\text{and} \qquad (2.41)$$

$$\frac{d}{dx}\int_0^{\underline{b}} ur \, dr = \alpha_e \underline{b} u_m \qquad (2.42)$$

where v_e is the entrainment velocity, $\underline{b}$ is the the value of r when $u \cong 0$, and α_e is the entrainment coefficient. Equation 2.42 is basically the continuity equation in view of the entrainment hypothesis.

According to the reference, u/u_m is correlated well with $\eta = r/b$, where b is the value of r when $u = 0.5\ u_m$. The axial velocity distribution profile has been proven experimentally to follow a Gaussian normal distribution curve. Several assumptions should be made:

$$\frac{u}{u_m} \quad = f_1(\eta) = \exp\left[-0.693\left(\frac{r}{b}\right)^2\right] \qquad (2.43)$$

$$u_m \quad = k_1 x^p \qquad (2.44)$$

$$b \quad = k_2 x^q \qquad (2.45)$$

$$\frac{d}{dx}(F_1 k_1 k_2^2 x) = \beta\, \alpha_e\, k_1\, k_2 \qquad (2.46)$$

$$k_1 k_2 = \sqrt{\frac{M_o}{2\pi\rho F_1}} \qquad (2.47)$$

where $\beta = \underline{b}/b$, parameters k_1 and k_2 are the x independent coefficients, p and q are the unknown exponents, and F_1 is an integral constant. Equation 2.46 is a development of Equation 2.42 considering those velocity parameters. Equation 2.47 correlates the initial momentum with those velocity parameters. Using the integral momentum and continuity equation, it is possible to calculate the exponents, $q = 1$ and $p = -1$. It is obvious that $u_m = f(1/x)$ and $b = f(x)$, see Rajaratnam (1983 and 1986).

The chemical concentration distribution profile in the fully developed region also has a Gaussian normal distribution type of curve. The maximum chemical concentration (c_m), which occurs in the center line, decreases continuously with the increase of x. Chemical conservation equations can be developed as follow (Rajaratnam,1976):

$$u\frac{\delta c}{\delta x} + v\frac{\delta c}{\delta r} = \frac{1}{r}\frac{\delta}{\delta r}\left(r\,\varepsilon_r\frac{\delta c}{\delta r}\right) \qquad (2.48)$$

$$\frac{d}{dx}\int_0^{+\infty} ucr\, dr = 0 \qquad (2.49)$$

where c is the chemical concentration at any point, and ε_r is the eddy diffusivity for chemical transport. Chemical flux at the nozzle (P_o) can be developed using a similar approach as that used in developing the initial momentum:

$$P_o = \int_0^{+\infty} 2\pi r dr\ u\ c = \frac{\pi d^2}{4} U_o C_o \qquad (2.50).$$

Experimental observations show that c/c_m is correlated well with $\eta = r/b$ even though it has different coefficients than that of u/u_m:

$$\frac{c}{c_m} = f_2(\eta) = \exp[-0.693 (\frac{r}{kb})^2] \qquad (2.51)$$

$$c_m = k_3 x^s \qquad (2.52)$$

$$k_3 = \frac{P_o}{2\pi} \frac{1}{F_2 k_1 k_2^2} \qquad (2.53)$$

where k, k_3, s, F_2 are constants. Equation 2.53 correlates the initial chemical flux with those chemical concentration parameters. Using the same method to solve the exponential parameters, it can be shown that s = -1, so that $c_m = f(1/x)$, see Rajaratnam (1983 and 1986).

The unknown parameters β, k, k_1, k_2, F_1, and F_2 need to be determined. Rajaratnam (1983 and 1986) suggest values of k = 1.17, $k_2 = 0.097$, $\beta = 2.5$, and $\alpha_c = 0.028$ which yield constant $F_1 = 0.361$, $F_2 = 0.417$, and $k_1 = dU_o/0.164$. The new equations are:

$$\frac{u}{u_m} = \exp[-74 (\frac{r}{x})^2] \qquad (2.54)$$

$$\frac{u_m}{U_o} = \frac{6.1\ d_o}{x} \qquad (2.55)$$

$$\frac{c}{c_m} = \exp[-54\,(\frac{r}{x})^2\,] \tag{2.56}$$

$$\frac{c_m}{C_o} = \frac{5.3\ d_o}{x} \tag{2.57}$$

Slightly different results are suggested by Chen and Rodi (1980), $k_2 = 0.086$ (confirmed by Blevins, 1984 and Ramaprian and Chandrasekhara, 1985). Those equations change slightly in the exponential constants, -94 for the velocity profile and -57 for the chemical concentration profile (Equations 2.54 and 2.56). Parameters for maximum values are slightly different as well, 6.0 for the maximum velocity and 5.0 for the maximum chemical concentration (Equations 2.55 and 2.57). Many equations can be derived based on the empirical parameters, still the velocity and chemical concentration profiles will not change as they are obtained from mathematical solutions.

Angles that form the shear layer of a jet development region can be seen in Figure 2.6. Rajaratnam (1976) derived several equations to describe the boundary of the shear layer as follow:

$$\frac{u}{U_o} = f_3\,(\eta) = f_3\,(\frac{r-r_1}{b}) \tag{2.58}$$

where r_1 is the inner radius of the shear layer. Combining those equations with Equation 2.36 gives:

$$(\frac{r_1}{r_o})^2 + (2F_3\frac{b}{r_o})\,\frac{r_1}{r_o} + [2F_4(\frac{b}{r_o})^2 - 1] = 0 \tag{2.59}$$

where F_3 and F_4 are constants which approximately equal 0.31 and 0.07, respectively.

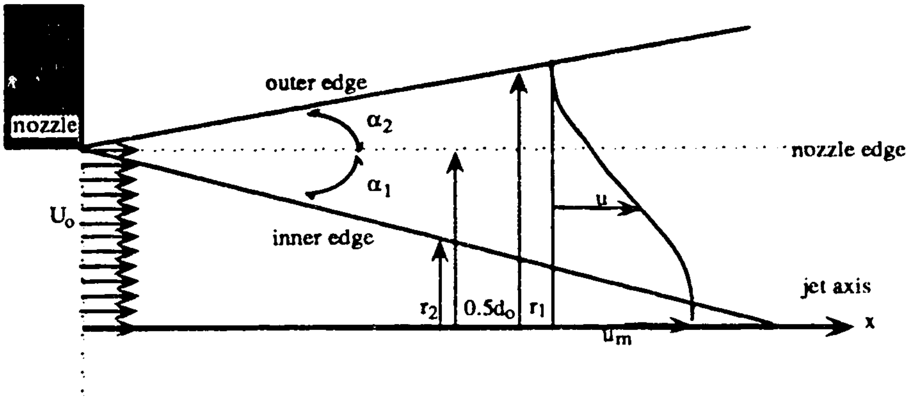


Figure 2.6: Shear Layer (adapted from Rajaratnam, 1976)

Using experimental observations (Rajaratnam, 1976), several new equations can be generated as written below:

$$\frac{r_1}{r_o} = 0.95 - 0.097\,\frac{x}{r_o} \tag{2.60}$$

$$\frac{b}{r_o} = 0.10 + 0.111\,\frac{x}{r_o} \tag{2.61}$$

$$\frac{r_2}{r_o} = 1.07 + 0.158\,\frac{x}{r_o} \tag{2.62}$$

where r_2 is the outer radius of the shear layer. Length of the potential core is about 9 r_o (see Equation 2.62). According to the experiments, α_1 (inner angle of the shear layer) is about 5.7°, while α_2 (the outer angle) is about 9° (Rajaratnam, 1976).

Another approach is given by Mih (1983):

$$\eta = \frac{r}{k_4 x} \tag{2.63}$$

$$\frac{u}{u_m} = \exp(-\eta^2) \tag{2.64}$$

$$\frac{1}{r}\,\frac{d}{dr}(r\,v) + \frac{du}{dx} = 0 \tag{2.65}$$

$$\frac{v}{u_m} = \frac{k_4}{\eta}\,\{\exp(-\eta^2)\,[0.5+\eta^2]-0.5\} \tag{2.66}$$

where Equation 2.64 is another approach to the Gaussian curve. Equation 2.65 is basically the continuity equation by taking account of the mean radial velocity (v). Assuming that $v \cong 0$ at the edge of the outer layer and k_4 (an experimental parameter) =

0.103, it is found that $\frac{r}{x} = 0.115$, or $\alpha_1 = 6.6°$.

2.3.4 Circular Surface Turbulent Jet

A circular surface jet occurs when the nozzle is located at the surface of the fluid, therefore the jet propagates along the fluid surface. It is important to figure out the behavior of this type of jet as the field testing in this study was related to reservoirs with inlet pipes at the water surface. The flow development region can be developed using a three ordinate system, x (axial distance from the nozzle), y (vertical distance from the center line), and z (transverse horizontal distance from the center line), see Figure 2.7. The continuity and Reynold equations are similar to those presented earlier (Rajaratnam 1988):

$$\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z} = 0 \tag{2.67}$$

$$u\frac{\delta u}{\delta x} + v\frac{\delta u}{\delta y} + w\frac{\delta u}{\delta z} = -\left(\frac{\delta}{\delta y}\,\overline{u'v'} + \frac{\delta}{\delta z}\,\overline{u'w'}\right) \tag{2.68}$$

where u, v, and w are the velocities at the axial (x), vertical (y), and perpendicular (z) directions. Under the overbar signs are the time dependent variables of the velocity. By integrating Equation 2.68 from y and z = 0 to +∞, two new equations can be generated:

$$\frac{d}{dx}\int_0^{+\infty}\int_0^{+\infty} ru^2 dydz = 0 \qquad \text{,and} \tag{2.69}$$

$$\int_0^{+\infty}\int_0^{+\infty} ru^2 dydz = M_o = \frac{\pi}{4}\,\frac{U_o^2\,x}{d} \tag{2.70}$$

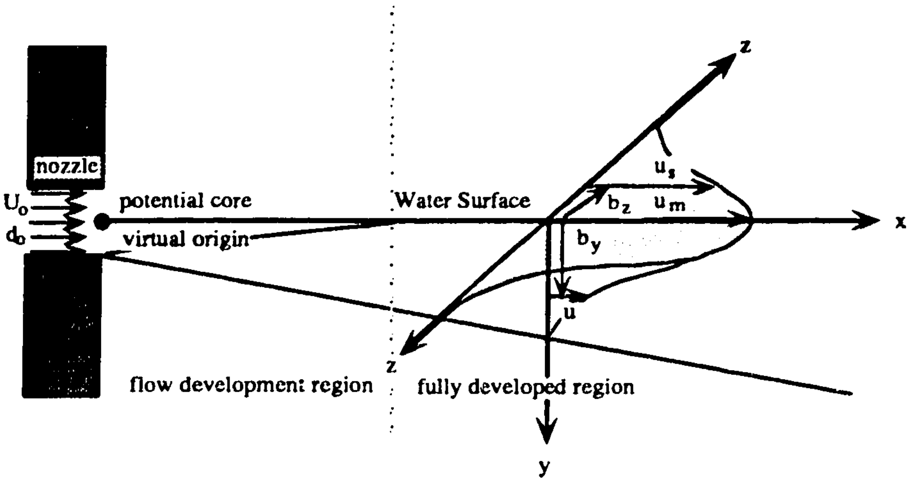


Figure 2.7: Circular Surface Turbulent Jet

where M_o is the initial momentum flux at the nozzle. As shown by Rajaratnam and Pani (1974), analyses for velocity profiles give:

$$\frac{u}{u_s} = f_4\left(\frac{y}{b_y}\right) \tag{2.71}$$

$$\frac{u_s}{u_m} = f_5\left(\frac{z}{b_z}\right) \tag{2.72}$$

$$u = u_m f_4 f_5 \tag{2.73}$$

$$u_m = k_5 x^p \tag{2.74}$$

$$b_y = k_6 x^{qy} \tag{2.75}$$

$$b_z = k_7 x^{qz} \tag{2.76}$$

where u_s is the surface velocity at X-Z plane, while b_y and b_z are the values of y and z when $u = 0.5\ u_s$ and when $u_z = 0.5\ u_m$, respectively. Parameters p, qy, and qz are exponents, while k_5, k_6, and k_7 are the experimental parameters. The entrainment concept is described as:

$$v_{ey} = -\alpha_{ey}\, u_m\, f_4(\eta_y) \tag{2.77}$$

$$v_{ez} = -\alpha_{ez}\, u_m\, f_5(\eta_z) \tag{2.78}$$

$$\frac{d}{dx}\int_0^{+\infty}\int_0^{+\infty} u \, dy \, dz = \int_0^{+\infty} -v_{ey} \, dy + \int_0^{+\infty} -v_{ez} \, dz \qquad (2.79)$$

where v_{ey}, v_{ez}, α_{ey}, and α_{ez} are the entrainment and coefficient velocities for the y and z directions, respectively. Using the same method for a circular submerged turbulent jet, the exponential parameters can be found to be $q_y = q_z = 1$, and $p = -1$. Rajaratnam (1985) mentions that in the case of circular surface turbulent jets, velocity profiles in the X-Y plane and in the X-Z plane follow Gaussian normal curves similar to the circular submerged turbulent jet:

$$\frac{u}{u_s} = f_4(\eta_y) = \exp\left[-0.693\left(\frac{y}{b_y}\right)^2\right] \qquad (2.80)$$

$$\frac{u_s}{u_m} = f_5(\eta_z) = \exp\left[-0.693\left(\frac{z}{b_z}\right)^2\right] \qquad (2.81).$$

Rajaratnam and Humphries (1984) found for the circular surface turbulent jet, that $b_y = 0.044x$ and $b_z = 0.09x$. So that the new equations are:

$$\frac{u}{u_s} = \exp\left[-358\left(\frac{y}{x}\right)^2\right] \qquad (2.82)$$

$$\frac{u_s}{u_m} = \exp\left[-86\left(\frac{z}{x}\right)^2\right] \qquad (2.83)$$

where u_s is the axial velocity in the X-Z plane. Rajaratnam (1985 and 1988) show the correlation between u_m and U_o as follows:

$$\frac{u_m}{U_o} = \frac{9\,d_o}{x} \qquad (2.84).$$

It was also showed that u_s sometimes occurred at some distance under the surface. Yet, it is acceptable to assume that u_s occurs exactly at the surface, so that the Gaussian curve types (Equations 2.80 and 2.81) are still valid (Rajaratnam and Humphries, 1984 and Rajaratnam, 1985).

Basically, similar equations can be developed for the chemical concentration distribution:

$$u\frac{\delta c}{\delta x} + v\frac{\delta c}{\delta y} + w\frac{\delta c}{\delta z} = \frac{1}{y}\frac{\delta}{\delta y}\left(y\,\varepsilon_y\frac{\delta c}{\delta y}\right) + \frac{1}{z}\frac{\delta}{\delta z}\left(z\,\varepsilon_z\frac{\delta c}{\delta z}\right) \tag{2.85}$$

$$\frac{d}{dx}\int_0^{+\infty}\int_0^{+\infty} cu\;dy\;dz = 0 \tag{2.86}$$

$$\int_0^{+\infty}\int_0^{+\infty} cu\;dy\;dz = P_o = \frac{\pi d^2}{4}\,U_o\,C_o \tag{2.87}.$$

Rajaratnam (1985) also shows that concentration profiles both for X-Y and X-Z planes follow the Gaussian normal distribution curves as have been mentioned above (Equations 2.78 and 2.79), but the values for b_y and b_z are different. Several experiments have been conducted considering the Richardson number (R_i) $\left(= \frac{\text{consumption of energy by buoyant convection}}{\text{consumption of energy by turbulent shear flow}}\right)$. However, as the density difference is neglected, the Richardson number becomes very small or $\cong 0$. Rajaratnam (1985) mentions that $b_y = 0.044$, while $b_z = 0.57\ R_i^{\ 1/8}$ for $R_i = 0.00003$ to 0.0031. For the smallest value (0.00003), b_z equals 0.16. So that, the new equations are:

$$\frac{c}{c_s} = \exp\left[-358\left(\frac{y}{x}\right)^2\right] \tag{2.88}$$

$$\frac{c_s}{c_m} = \exp\left[-27 \left(\frac{z}{x}\right)^2\right] \qquad (2.89)$$

where c_s is the chemical concentration at X-Z plane. While the maximum concentration that occurs at the surface can be found using Jen et al data (1966):

$$\frac{c_m}{C_o} = \frac{7\, d_o}{x} \qquad (2.90).$$

During the same experiment, the shear layer for z (X-Z plane) and y (X-Y plane) directions were obtained by them as well: about 13° and 20°, respectively. Tamai et al (1969) confirm those data.

2.3.5 Application to CT Concept

The use of jet hydraulics to analyze tracer test results is balanced by the desire to incorporate a more physically based model which fits the observed results better than existing empirical models. As will be discussed later, it was not until the tests were completed that it was found that for the two reservoirs, the tracer appeared at the outlet almost immediately after its addition. This indicated that momentum from the jet at the inlet might cause this phenomena. However, unlike most hydraulic studies of jets, no velocity nor concentration profiles in the jet were taken due to the closed nature of the reservoirs. As a result, the obtained data are somewhat a "black box" in nature with only the inlet and outlet measurements. The primary goal of this analysis was to determine if the inlet jet could be responsible for the very fast transport of the tracer through the reservoir. If this was found to be the case, results could be used to determine the t_{10} values at other flow rates and plant modifications to improve the residence time distribution. The complexity of the jet analysis was therefore tempered by the lack of measurements to define the jet. Therefore, the overall purpose of this study is to determine the residence time distribution using the jet model, not to do the detailed jet hydraulic analysis.

Theoretically, the circular surface turbulent jet is the most appropriate model to use. Unfortunately, there are several difficulties in analyzing the total flux using this model. Parameters b_y and b_z for the axial velocity are obtained for X-Y and X-Z planes, therefore the use of Equation 2.73 to work out the axial velocity at any point may be a mistake. Even after each velocity and chemical concentration has been found out, the total flux will be very difficult to analyze since the axial velocity and chemical concentration profiles will not be symmetrical. It causes disparate velocity and chemical concentration at any point in the jet. A much more complex model would be required which is beyond the scope of study.

The F (C/C_0 vs. t) curve can be developed using the chemical species (total flux) conservation as shown in Equation 2.34. Basically, the flow development area formed by the jet can be divided into many small elements. Each element has a concentration and a velocity. At a certain distance (outlet point), it is assumed that there is an imaginary plane. Every element that hits the plane is assumed to be removed to the outlet point directly. Total flux (total velocity times area times chemical concentration) should be the same as that at the initial point as the chemical is conservative. As a relative concentration is used where at the steady state condition $C/C_0 = 1$, total flux at the outlet point should be the same as the initial flow (velocity times area). The C/C_0 vs. time curve can be developed by dividing each total flux at any time by the initial flow.

For this study, reservoirs no.2 and 3 were analyzed using the jet model (see Chapter 6.0), and it was found that the existing jet models discussed earlier seemed to fit the observed data adequately. Reservoir no.1 was not analyzed using this model as there is a baffle in front of the inlet point. During the tests, water surface for reservoirs no.2 and 3 covered some parts of the pipe inlets. An imaginary diameter can be used by assuming the equivalent diameter for the same cross section area of water in the pipe. Rajaratnam and Pani (1974) conducted experiments using several types of nozzles (square, triangle, circular, and elliptic) to analyze the three dimensional turbulent wall jet, and stated that the surface turbulent jet should behave similarly. By maintaining the initial velocity (U_o) constant, it was found that velocity profiles along the jets were roughly the same. Knowing that U_o is basically based on the area of the nozzle (assuming that the flow is constant), it is acceptable to assume that for the same nozzle area, the shape will not affect the initial velocity behavior. The imaginary diameter was calculated for each test since the water level changed for each test.

In order to do the analysis, it is assumed that the maximum velocity and concentration profiles follow the circular surface turbulent jet (Equations 2.84 and 2.90), but the velocity and chemical concentration profiles under the water surface follow the circular submerged condition (Equations 2.54 and 2.56). As the amount of flux should be constant, it is acceptable to "flip" the top part of the jet to below the water surface forming a half - circular shape (Metcalf and Eddy, 1991). Note: in the real mathematical hydraulic problem, even the momentum flux is not constant since the ambient pressure is not constant either (Kotsovinos and Angelidis, 1991). The half - circular shape can be used to calculate the total flux. Angles of 0° to 10° from the center line of the jet with 1° increment were used. It was found that up to 10°, the total flux already reached a value of almost 100%. The velocity and chemical concentration profiles have symmetrical shapes. The average is made for the velocity and chemical concentration with the adjacent layers (say between 2° layer and 1° layer). The area of the half - circular layer can be obtained easily = $0.5\ \pi\ (r_2 - r_1)^2$, where r_2 and r_1 are the radius of the adjacent layers (see Figure 2.8).

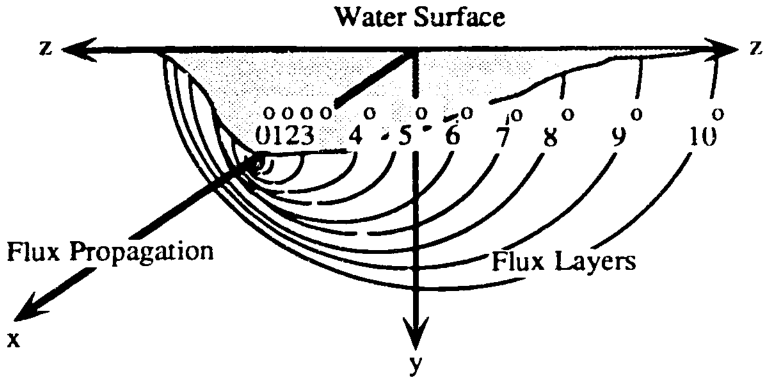


Figure 2.8: Total Flux

This simplification cannot be applied to figure out a particular velocity or chemical concentration at any point in the jet. Although the analysis is not ideal, it still should be valid for the total flux since basically the same total flux will travel, no matter what the velocity or chemical concentration profile 's. The analysis is supposed to be able to indicate whether the momentum effect from the inlet was responsible for the rapid travel of the tracer through the reservoir.

More studies about jet theories in shallow or confined water surfaces have been done by Johnston and Halliwell (1986), Sobey et al (1989), Johnston (1990), and Johnston and Volker (1993). Basically, they classify two types of jets travelling in shallow waters: bed and surface jets. The difference between the two is that the jet mainstream flows in the bottom part and in the top part of the water, respectively. The center line velocity decrease for the bed jet seems to be large compared to the free jet, while the surface jet's decrease is less. However, the investigations are only in preliminary stages. Exact parameters have not been identified yet, especially for the chemical concentration.

2.3.6 Simplified Jet Model

Further simplification of the jet model provides another useful tool for analysis. This assumes that the maximum axial velocity contributes the most effect to predict the t_{10}. There is a constant (C_1) that is applicable for a particular distance (l). The change in the axial velocity is given by:

$$du = \frac{dx}{dt} = \frac{U_0\, C_1\, d_0}{x} \qquad (2.91)$$

set: $x = l$ (length of the system) and $t = t_{10}$, the integration yields:

$$t_{10} = \frac{l^2}{d_o\, U_o\, C_l} \qquad (2.92).$$

As will be shown later in Chapter 6.0, C_l was found to be relatively constant. This simplified form is very useful to make a rough guess of the t_{10} even before the test has been undertaken. Time intervals of the sampling can be arranged to be very small near the important point (the predicted t_{10}) but rather long for other points. This relation can also be used to predict the t_{10} at different flow rates.

2.4 t_{10} Values for Different Flow Rates

After a particular t_{10} value has been found using either the residence time distribution methods (the E and F curves) or the jet method, the next problem is to interpret different t_{10} values from different flow rates without conducting further tracer tests. The Guidance Manual (1989) suggests conducting at least four tracer tests for each system using four flow conditions, one near, two greater, and one below the average flow. The highest one should be at least 91% of the peak flow. Correlation between the t_{10} values and the flow rates should form a curve. Still, only one test at the flow at least 91% of the peak flow is accepted due to practical limitations (Guidance Manual, 1989). Other t_{10} values for different flow rates can be predicted using this ratio:

$$\frac{t_{10t}}{t_{10d}} = \frac{Q_d}{Q_t} \qquad (2.93)$$

where:

t_{10t} = t_{10} obtained from tracer study (min.)

t_{10d} = t_{10} at desired flow (min.)

Q_t = flow at tracer study (ML/min.)

Q_d = desired flow (ML/min.).

As has been mentioned above, correlation between the t_{10} and Q values is not linear. Yu et al (1990) show that the correlation can be exponential as follows:

$$t_{10} = \alpha Q^{\beta} \tag{2.94}$$

where α and β are regression coefficients. It can be concluded that Equation 2.93 will give very conservative results. This seems to agree with another statement mentioned in the Guidance Manual (1989) that the extrapolations are allowed in lower parts of the four points given (see Figure 2.9). A slightly different approach is given by Hart and Gupta (1978) as they tried to correlate the t_{50}/T_d and t_a/T_d with the Q (flow) as a linear function with α and β as linear regression coefficients:

$$\frac{t_{50}}{T_d} \text{ or } \frac{t_a}{T_d} = \alpha Q + \beta \qquad (2.95).$$

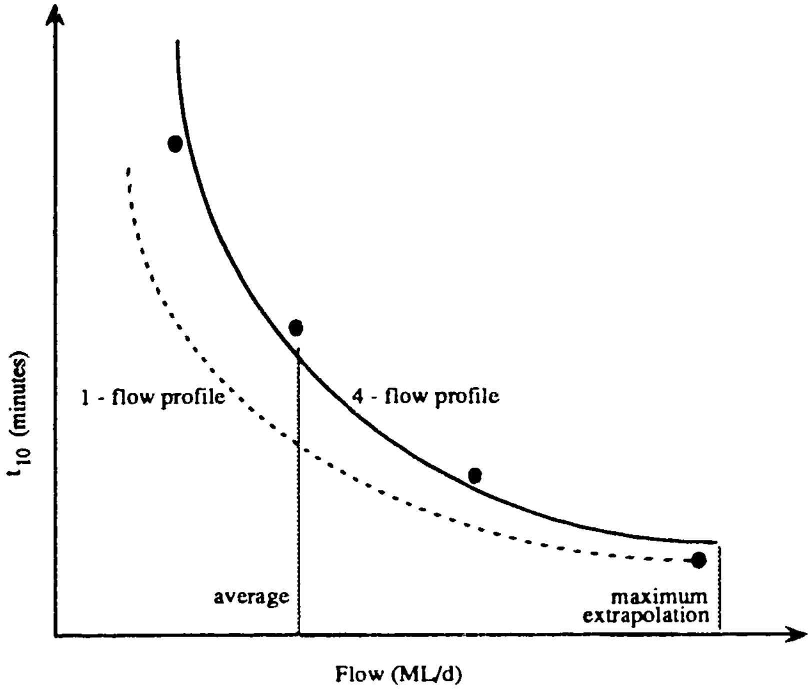


Figure 2.9: t_{10} Values vs. Flow Rates (adapted from the Guidance Manual, 1989)

3.0 CASE STUDY

3.1 Treatment Plant Operation

The E. L. Smith Water Treatment Plant is located on the upstream edge of the City of Edmonton, Alberta. It was built in 1976 with a capacity of 180 - 220 ML/d. Expansion of the plant is currently planned to achieve a capacity of 360 ML/d. The plant, shown in Figure 3.1, uses the following processes: alum coagulation, clarification, chlorine dioxide disinfection, fluoridation, partial softening with lime and recarbonation, rapid sand filtration, and chloramine disinfection to provide a residual.

Under normal operating conditions, the plant is operated in a split flow configuration. Raw water enters the plant from the North Saskatchewan River through low lift pumps. Flow rate is measured using a venturi device meter. The water is dosed with alum and ammonia and then split between the first two clarifiers (C1 and C2) where flocculation and clarification occurs. The effluent from both clarifiers is contacted with the primary disinfectant, chlorine dioxide, prior to its entering the third clarifier (C3) where lime softening takes place. Effluent from C3 is dosed with chlorine which reacts with previously added ammonia to form chloramines. The water is then sent to the recarbonation chamber for pH adjustment and then distributed to the filters. The filtered water is distributed to three on - site reservoirs. High lift pumps send the final water to the distribution system.

The treatment plant operates under a licence from the province of Alberta. This license requires the plant to stay within the Guidelines for Canadian Drinking Water Quality and sets out some additional water quality requirements that should be fulfilled. The treated water quality values including the plant operating ranges can be seen in Table 3.1 (Simpson, 1989).

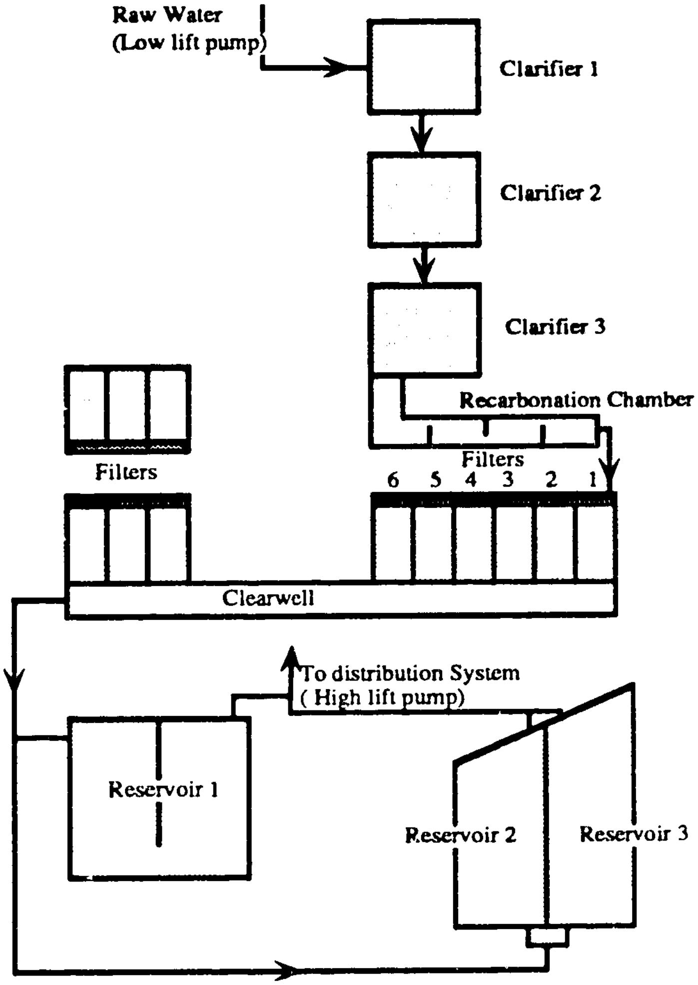


Figure 3.1: E. L. Smith Water Treatment Plant Layout (adapted from Stanley et al, 1993)

Table 3.1: Treated Water Quality Values (adapted from Simpson, 1989)

Parameter	Operating Range	Objective Range	Licence Requirement
Turbidity	≤ 0.5 NTU	≤ 1.0 NTU	≤ 1.0 NTU
Color	≤ 2 TCU	≤ 5 TCU	≤ 15 TCU
pH	8.0 to 8.4	6.5 to 8.5	6.5 to 8.5
Combined Cl Residual [1]	1.8 to 2.2 mg/L	1.8 to 2.4 mg/L	≥ 1.8 mg/L
Fluoride	0.9 to 1.1 mg/L	0.8 to 1.2 mg/L	0.8 to 1.2 mg/L
Total ClO_2 Oxidants [2]	0.2 to 0.4 mg/L	0.2 to 0.5 mg/L	≤ 0.5 mg/L
THMs	≤ 0.005 mg/L	≤ 0.01 mg/L	≤ 0.35 mg/L
Total Coliform	≤ 1/100 mL	≤ 1/100 mL	≤ 10/100 mL
Fecal Coliform	0	0	0
Aggressiveness Index	≥ 11.5	≥ 11.5	------
Total Hardness [3]	110 to120	105 to 125	------
Volatile Organics	0 to 0.005 mg/L	0 to 0.01 mg/L	------
UV Absorbances [4]	0 to 5 mg/L	0 to 10 mg/L	------

1) mostly monochloramine
2) mostly chlorite
3) in mg $CaCO_3$ /L
4) as humic acid equivalents

3.2 Previous Study

The Process Development Team undertook tracer studies for the E. L. Smith and Rossdale Water Treatment Plants in 1989 - 1990. The objective of the study was to investigate the compliance of the systems to the SWTR / CT concept. These studies showed that both treatment plants were likely to meet the overall inactivation of Giardia cysts and viruses in summer conditions but not in winter conditions.

In the case of the E. L. Smith Water Treatment Plant, sodium chloride and fluoride were used as the tracers. However, the tests were relatively limited since not all of the E or F curves reached the steady or balance conditions (shorter sampling times) and less sampling points were taken. Only the effluent points were monitored. Therefore, in the case of reservoir test, only the combined result was obtained, not for the single process. Chlorine dioxide was collected from clarifier no. 3 effluent to get the CT value for the clarifier, while chloramine was monitored in the combined reservoir effluent to obtain the CT value for the reservoirs (Process Development Team, 1991).

3.3 Research Objectives

Based on the Process Development Team results, it was recommended that additional tests be conducted to improve the accuracy of the results. Since their tests assessed the overall performance of the plant, but not individual components, it was almost impossible to determine what components should be modified to most efficiently improve the overall contact time of the plant. Finally, the City of Edmonton also wanted to assess the effect of plant expansion on disinfection contact time.

With the above points in mind, research objectives of this study are as listed below:

1) develop accurate residence time distributions for components of the E. L. Smith Water Treatment Plant,

2) determine the residence time distribution for each component to prioritize possible modifications, and
3) develop models that are capable of predicting the residence time distribution in view of plant expansion.

4.0 METHODS AND MATERIAL

4.1 Tracer Input

Step and slug inputs are the most common methods of injecting the tracer to the system. They have been used as early as the 19th century. The step input, known as the "Lawrence continuous method", was introduced for the first time in 1890, while Clifford suggested the addition of a momentary high dose of tracer in 1905 (Taras, 1956). Theoretically, both of them give the same results with the same accuracy. Still, in a practical situation, a decision should be made to choose the most appropriate method.

The slug input has two advantages, relatively shorter time is spent and relatively small amount of tracer is used in the test. It can lower the cost and health concerns. Unfortunately, the slug input has a number of disadvantages both during the test and the data analysis. The tracer should be added as fast as possible. As has been mentioned in the previous chapter, it should be added in a period less than $T_d/50$ (Thirumurthi, 1969). While Joost et al (1991) suggest to add the tracer in less than one minute. In the case of sodium chloride, when a very high salt concentration is needed, a very intensive mixing is required. Otherwise the high density salt solution will diffuse slowly in the water, or will settle to the bottom of the system (Taras, 1956). Hudson (1975) found that during his tests, the slug input never gave good tracer recoveries. There are many problems found in the data analyses as well. More mathematical manipulations are needed, including normalization of the E curve using Equation 2.4 and a material balance check using Equation 2.5.

The step input has a primary benefit that there is no mathematical manipulation required. As t_a cannot be obtained directly from the F curve (it should be transposed back to the E curve using Equation 2.12), usually T_d is used to avoid the manipulation.

One disadvantage of the step input is that the tracer should be added over a relatively long period of time. As has been mentioned in the previous chapter, at least 2 or 3 times T_d (Hudson, 1975). As a consequence, it needs feed equipment that is capable of distributing the tracer continuously in a constant flow for hours or even days. Concerns like cost and health are not significant as many inexpensive and safe chemical compounds are available. Overall, the step input is considered to be better than the slug input, and it is therefore recommended by the Guidance Manual (1989).

4.2 Tracer Compound

Many chemical compounds have been tried as tracers. However, fluoride, Rhodamine WT®, and sodium chloride seem to be the most popular ones. The Guidance Manual (1989) and Joost et al (1991) give some explanations about selecting chemical compounds. Basically it has to follow certain criteria, including:

1) readily available and inexpensive,
2) conservative or stable, not removed nor consumed in the water process,
3) easily analyzed, and
4) acceptable to use in potable water supplies. Dyes or radio active compounds that may be harmful for health are not recommended, for example: Rhodamine B.

Fluoride is a very popular choice. However, it is a relatively hazardous material in its most commonly used form, H_2SiF_6 (hydrofluosilicic acid). Gloves and face shields are required to handle it. The use of fluoride can be very convenient if the treatment plant has already added it for health reasons. A relatively easy analysis can be done using a specific ion probe for fluoride. As the maximum contaminant level (MCL) for this chemical compound is only 4 mg/L, some water with relatively high fluoride concentration will prevent the use it. One disadvantage of using fluoride is its difficulty to monitor at concentrations less than 0.05 mg/L (Dunn et al, 1991). However, VandeVenter et al (1991) who used an Orion model 1809 on - line fluoride analyzer were able to measure the fluoride concentration in the range of 0.01 to 100 mg/L directly on site. However, the reaction of fluoride with alum is a concern which limits the use of this chemical compound (Hudson, 1975 and Teefy and Singer, 1990).

Rhodamine WT® is one type of fluorescent dye which is commonly used as a tracer. The MCL in drinking water is 0.1 μg/L. Only a small concentration is needed as there is not any fluorescence background in most source water. A fluorometer can be used to measure the concentration accurately and rapidly. Hart (1975) considers it as a good tracer, since it is detectable at low concentration (0.01 ppb) using a Turner Model III Fluorometer, turbidity has very little effect on the fluorosence response, and it is very stable especially in the pH range of 5 to 10. However, Rhodamine WT® reacts with free chlorine which may prevent the use of this type of tracer.

Sodium chloride is probably the best type of tracer to use. As a common salt (NaCl), it is available in very high concentrations at a relatively low cost. It is very conservative, easy to use (it freezes below -20° C) and measure, and not generally considered toxic (the Merck Index, 1989). Probably the only problem is that sodium chloride is a very common chemical compound found in natural water. A very high background concentration may prevent the use of it. The MCL in receiving water is 250 mg/L, however Alberta Environmental Protection stipulates a maximum concentration of only 20 mg/L.

Another type of chloride salt like lithium chloride is mentioned by Joost et al (1991) as an expensive chemical compound which is slightly difficult to analyze, while Leland et al (1990) tried to use calcium chloride in their experiments. Kennedy et al (1993) do not recommend the use of chlorine as it reacts with other chemical compounds in water. Qualls and Johnson (1983) explain the formulae for chlorine decay due to fulvic acids. Similar to fluoride, chlorine can be somewhat convenient to use if it is already added to the system as disinfectant. However, unlike fluoride, direct measurement of chlorine is necessary to avoid its decay rate (Kennedy et al, 1990).

Other types of tracer have been used as well, however they do not seem suitable to apply in drinking water studies due to health concerns. Biological tracer like coliform bacteria is one idea. A study conducted by Polpraset and Bhattarai (1985) shows that coliform decay in the system can be well correlated with the dispersion index. Agunwamba (1992) used coliform bacteria to measure the dispersion number in a waste stabilization pond. Bromide has been tried as well by Hagerman et al (1989), while Sawyer and King (1969) and Mitha and Mohsen (1990) used methylene blue dye to analyze the hydraulic performance of small - scale pilot tanks.

4.3 Measurement Method

Standard Methods (1992) gives three methods to measure sodium ions in samples. The atomic absorption spectrometric method basically measures the amount of light absorbed. The light is directed to the flame, into a monochromator, and then measured by a detector. The flame emission photometer method uses a similar concept, but the sample is aspirated and atomized, and then the amount of light emitted is measured directly. The trace of sodium can be determined at a wave length of 589 nm. The third choice is the ICP emission spectroscopy method. It utilizes of a flowing stream of argon gas that is ionized by an applied radio frequency field. The sample is injected into the ICP and dissociates into atoms due to the high temperature. The light wave length emitted from the ICP is examined by a spectrometer. Complete descriptions for those three methods can be found in the Standard Methods for the Examination of Water and Wastewater (1992).

Among these three methods, the flame emission photometer method seems to be the most suitable one. It is easy, inexpensive, and fast to analyze. It needs less chemical preparation and gives good results. Interference from other ions is probably the main concern. However, in the case of tracer studies for water treatment plants, this concern is not significant as the water analyzed is generally in an excellent quality.

4.4 Tracer Recovery

In the case of conservative tracer compounds, 100% tracer recovery should be obtained for every single test. However, problems are encountered in real situations that may affect the recovery, such as losing some amount of tracer in the system or imperfection of the modeling. The Guidance Manual (1989) suggests that at least 90% tracer recovery should be obtained in each test. Basically, the recovery can be found using this equation:

$$\%\ \text{Recovery} = \frac{C_f\, Q}{C_b\, Q + C_t\, q_t} \qquad (4.1)$$

where:

C_f = final concentration at steady state, including background (mg/L)
C_t = tracer concentration (mg/L)
C_b = background concentration (mg/L)
q_t = tracer flow (L/min.)
Q = water flow (L/min.).

5.0 TEST PROCEDURES AND RESULTS

5.1 Test Procedures

The samples were taken at the treatment plant for filters nos. 1 to 6, clarifier no. 2, and all of the three reservoirs. In total, there were ten tests conducted from February 16, 1993 until June 30, 1993 for different periods of time (3 to 52 hours) and in different types of flow (141 to 230 ML/d or 64% to 105% of the peak flow). The tracer recoveries ranged from 84% to 107% (see Tables 5.1 and 5.2).

Food grade sodium chloride (NaCl) in a saturated solution (131,000 mg/L) was added to the system in a step input. Since the background concentration was about 4 mg/L, the tracer feed was set to add about 15 mg/L of brine in order not to violate the 20 mg/L maximum concentration of salt in the receiving water. A constant head tank was used to maintain the continuity and stability of the tracer flow during the tests. The brine was pumped from a 60,000 L outdoor storage tank to a 2,500 L indoor storage tank. The brine then was circulated to the constant head tank using another pump before being added to the inductor. Since the brine flow was only in the range of about 0.2 to 0.3 L/s, potable water was needed to flush it into the system (see Figure 5.1).

More than 2,700 samples were taken in several locations. In the case of filter test no. 1, six inlet sampling points were chosen right in the beginning of the filters nos. 1 to 6, six outlet sampling points were located at the end of the six filters before the clearwell, and one sampling was taken in the end of the clearwell. The same sampling points were taken during test no. 2, but the inlet points were not taken as the previous test indicated that the flow was evenly distributed to each filter. Test no. 3 was conducted in clarifier no. 2. Two sampling points were located at the top and bottom of the draft tube, four sampling points at the top parts of the clarifier, one point in the

Table 5.1: Samples Taken

TEST #	1
Location	Filters+Clearwell
Date	16-Feb-93
Sampling Time	03:05:00
Flow (ML/d)	180
SAMPLE	NUMBER
Filter 1 Inlet	26
Filter 2 Inlet	26
Filter 3 Inlet	23
Filter 4 Inlet	24
Filter 5 Inlet	23
Filter 6 Inlet	22
Filter 1 Outlet	31
Filter 2 Outlet	29
Filter 3 Outlet	29
Filter 4 Outlet	29
Filter 5 Outlet	33
Filter 6 Outlet	33
End of Clearwells	55
Tracer	1
Total	384

TEST #	2
Location	Filters+Clearwell
Date	24-Feb-93
Sampling Time	03:06:30
Flow (ML/d)	140
SAMPLE	NUMBER
Filter 1 Outlet	34
Filter 2 Outlet	35
Filter 3 Outlet	31
Filter 4 Outlet	31
Filter 5 Outlet	35
Filter 6 Outlet	36
End of Clearwells	54
Tracer	1
Total	257

TEST #	3
Location	Clarifier 2
Date	05-Mar-93
Sampling Time	03:04:00
Flow (ML/d)	180
SAMPLE	NUMBER
Effluent	44
Bottom Clarifier 1	43
Bottom Clarifier 2	43
Manhole	46
Point 1	45
Point 2	45
Point 3	45
Point 4	45
Tracer	1
Total	357

TEST #	4
Location	Reservoir 1
Date	24-Mar-93
Sampling Time	12:35:00
Flow (ML/d)	160
SAMPLE	NUMBER
Inlet	49
Outlet	78
Backround	6
Tracer	4
Total	137

(cont'd)

TEST #	5
Location	Reservoir 2
Date	06-Apr-93
Sampling Time	15:00:00
Flow (ML/d)	167
SAMPLE	**NUMBER**
Inlet	55
Outlet	90
Backround	13
Tracer	7
Total	165

TEST #	6
Location	Reservoir 2
Date	20-Apr-93
Sampling Time	14:16:00
Flow (ML/d)	141
SAMPLE	**NUMBER**
Inlet	45
Outlet	85
Backround	14
Tracer	7
Total	151

TEST #	7
Location	Reservoir 3
Date	28-Apr-93
Sampling Time	14:00:00
Flow (ML/d)	179
SAMPLE	**NUMBER**
Inlet	52
Outlet	84
Backround	14
Tracer	7
Total	157

TEST #	8
Location	Reservoir 1
Date	18-Jun-93
Sampling Time	09:00:00
Flow (ML/d)	230
SAMPLE	**NUMBER**
Inlet	45
Outlet	53
Backround	10
Tracer	6
Total	114

TEST #	9
Location	Reservoir 3
Date	25-Jun-93
Sampling Time	09:30:00
Flow (ML/d)	198
SAMPLE	**NUMBER**
Inlet	46
Outlet	63
Backround	11
Tracer	6
Total	126

TEST #	10
Location	Reservoir 1,2,3
Date	30-Jun-93 until 02-Jul-93
Sampling Time	52:25:00
Flow (ML/d)	170
SAMPLE	**NUMBER**
Inlet 1	83
Inlet 2	33
Outlet 1	138
Outlet 2	126
Outlet 3	131
Convergence	309
Background	50
Tracer	27
Total	897

GRAND TOTAL= 2745

Table 5.2: Test Data

Location	Water Flow (ML/d)	Water Level (m)	Water Volume (m^3)	Na Backgr (mg/L)	Na Final (mg/L)	Tracer[1] Flow (L/s)	Tracer[2] Recovery (%)	T_d (min.)
Filters+Clearwell	180	-	3642	3.72	14.58	0.27	88	29
Filters+Clearwell	140	-	3642	2.62	12.48	0.19	84	37
Clarifier No. 2	180	-	10700	3.59	09.61	0.14	107	86
Reservoir No.1	180	4.1	37140	4.04	12.68	0.22	94	297
Reservoir No.1	230	3.9	35120	3.08	13.57	0.32	86	220
Reservoir No.2	141	3.6	28570	3.92	14.08	0.19	94	292
Reservoir No.2	167	4.0	32050	4.87	12.48	0.18	102	276
Reservoir No.3	179	3.6	35178	4.39	12.07	0.19	100	283
Reservoir No.3	198	4.4	43762	3.47	13.31	0.28	86	318
Reservoirs Nos.1,2,3	170	-	106640	4.52	13.88	0.26	84	926[3]
Reservoir No.1=20%	34	3.9	35120	-	-	-	-	-
Reservoir No.2=38%	65	4.0	32050	-	-	-	-	-
Reservoir No.3=42%	71	4.0	39470	-	-	-	-	-

1) Sodium chloride (NaCl) in a step input was used for all tests.

2) Brine concentration = 131,000 mg/L Na.

3) Including 760 m pipe system with diameter = 2.1 m, assuming PFR.

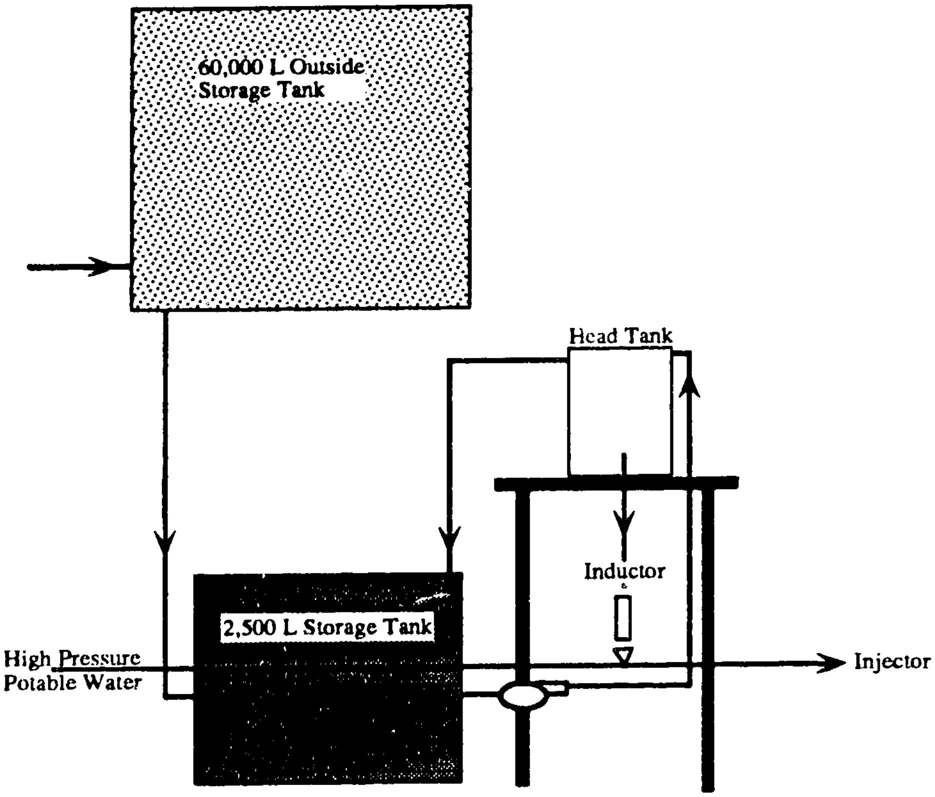


Figure 5.1: Brine Input System (adapted from Stanley et al, 1993)

manhole, and one point at the effluent. For single reservoir tests, (tests nos. 4 to 9), only the inlet and outlet of each reservoir were taken. The last test (test no.10) was conducted for all of those three reservoirs operating in parallel. Two inlet points at reservoirs nos.1 and 2, three outlet points at all of the reservoirs, and one point at the convergence point were chosen as the sampling points. Initial samples were taken for all of the tests, while background samples were taken for tests nos. 4 to 10. Figures 5.2 to 5.4 show the sampling locations for all the tests.

It is important to consider the injection location of the tracer. For all of the ten tests, the points were located at good locations where immediate mixing would occur to avoid the slow diffusing of brine in water. In the case of filters and clearwell tests, the brine was injected at the OG weir at the end of the recarbonation chamber. For the clarifier test, the injection point was located at the rapid mixing point of the raw water in the influent line of the clarifier. In the case of reservoir tests, the brine was flushed right into the clearwell where there is complete mixing (see Figures 5.2 to 5.4). It is possible to calculate the amount of brine needed for all tests after knowing the duration and the tracer velocity for each test (Tables 5.1 and 5.2). There was about 150,500 L of brine required for all of the tests.

Although 2 to 5 minute sampling intervals (from when the first tracer is monitored until the steady condition) are recommended by the Guidance Manual (1989), it was found that the most efficient use of samples were to concentrate them near the expected t_{10}. As a result, early in the test, a sample interval of 1 to 5 minutes was used. After the curve was almost or had already reached the steady state condition (based on estimation), 10 to 20, or even 60 minute sample intervals were used. The samples were taken both manually and automatically using three auto - samplers. Large plastic bottles (250 mL) were used to collect samples in the first test. As the analyses required only a small amount of water, 20 mL small teflon bottles were used for the other tests.

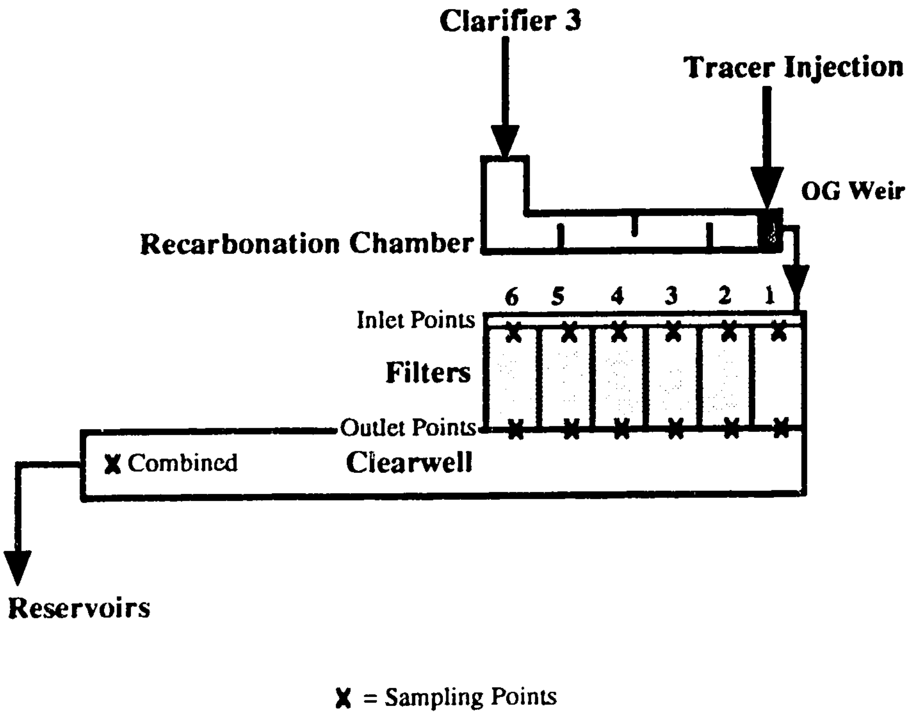
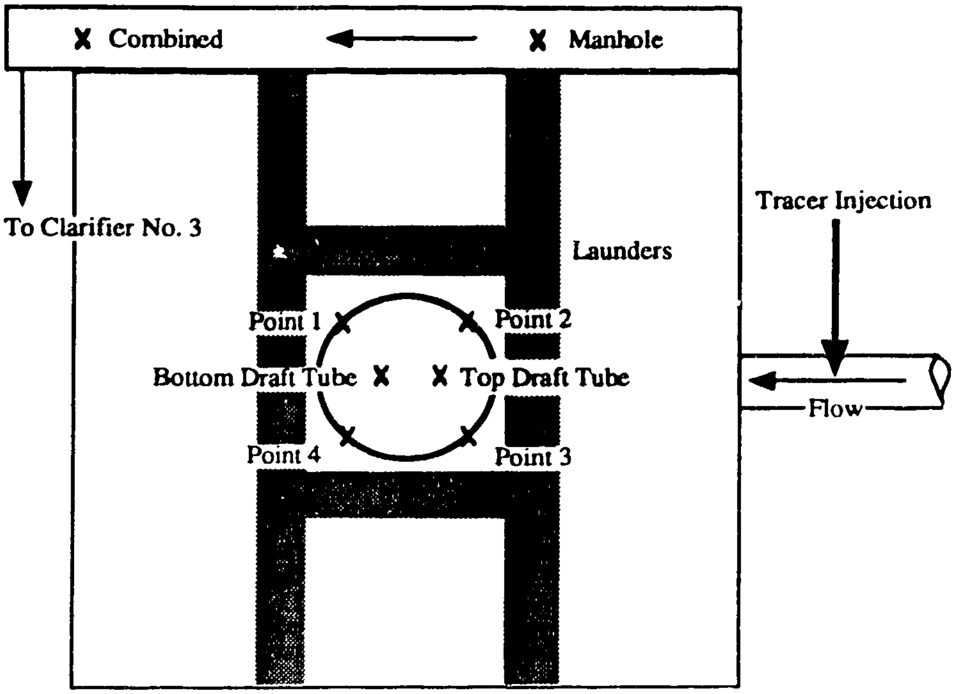


Figure 5.2: Sampling Locations for Filters and Clearwell (Tests Nos. 1 and 2)



X = Sampling Locations

Figure 5.3: Sampling Locations for Clarifier No. 2 (Test No. 3)

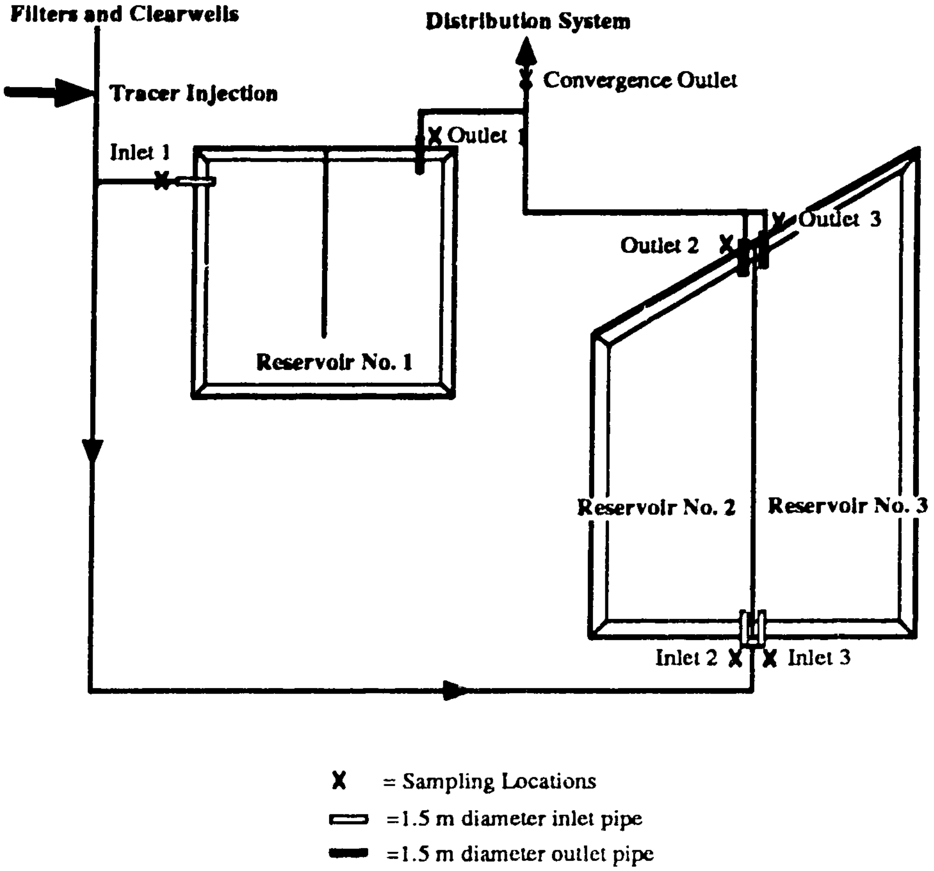


Figure 5.4: Sampling Locations for Reservoir (Tests Nos. 4 to 10)

Analyses were done at the Environmental Engineering and Science Laboratory located at the University of Alberta using a flame emission photometer according to the Standard Method 3500-Na D (Standard Methods, 1992).

Several standard solutions of sodium in the range of 0 mg/L to 20 mg/L were made. The instrument readings were calibrated from the scale of 0 to 100. It is assumed that the correlation between the readings and the standard concentrations is linear. The linear regression method was used to determine the linear equation.

5.2 Curve Development and Error Factors

The final tracer concentration, or equal to the initial amount of tracer added (C_o), was chosen from the steady condition of the inlet / influent concentration. All the inlets / influents reached the steady conditions, but not all the outlets / effluents. Tracer concentration at the clearwell point from tests nos. 1 and 2 did not reach steady conditions. The reason is that there was some water coming into the sampling point in the clearwell from the other filter bank (see Figure 3.1 above). This may explain the noise at the end of clearwell sampling points (see Figures 5.5 and 5.6). Test no. 9 did not last long enough to reach the steady condition for the outlet. Probably two more hours would give a better result. Some judgements should be made when the background increased for test no. 4. The steady condition for the inlet was assumed to happen before the noise.

It was assumed that the end points of the curves became the steady state values, while the initial values were found from the background samples. The F(t) vs. t curves were generated using Equation 2.9 (see Appendix 1). The theoretical residence time (T_d) can be determined based on the incoming flow and the system volume using Equation 2.3. All of the F curves can be seen in Figures 5.5 to 5.14.

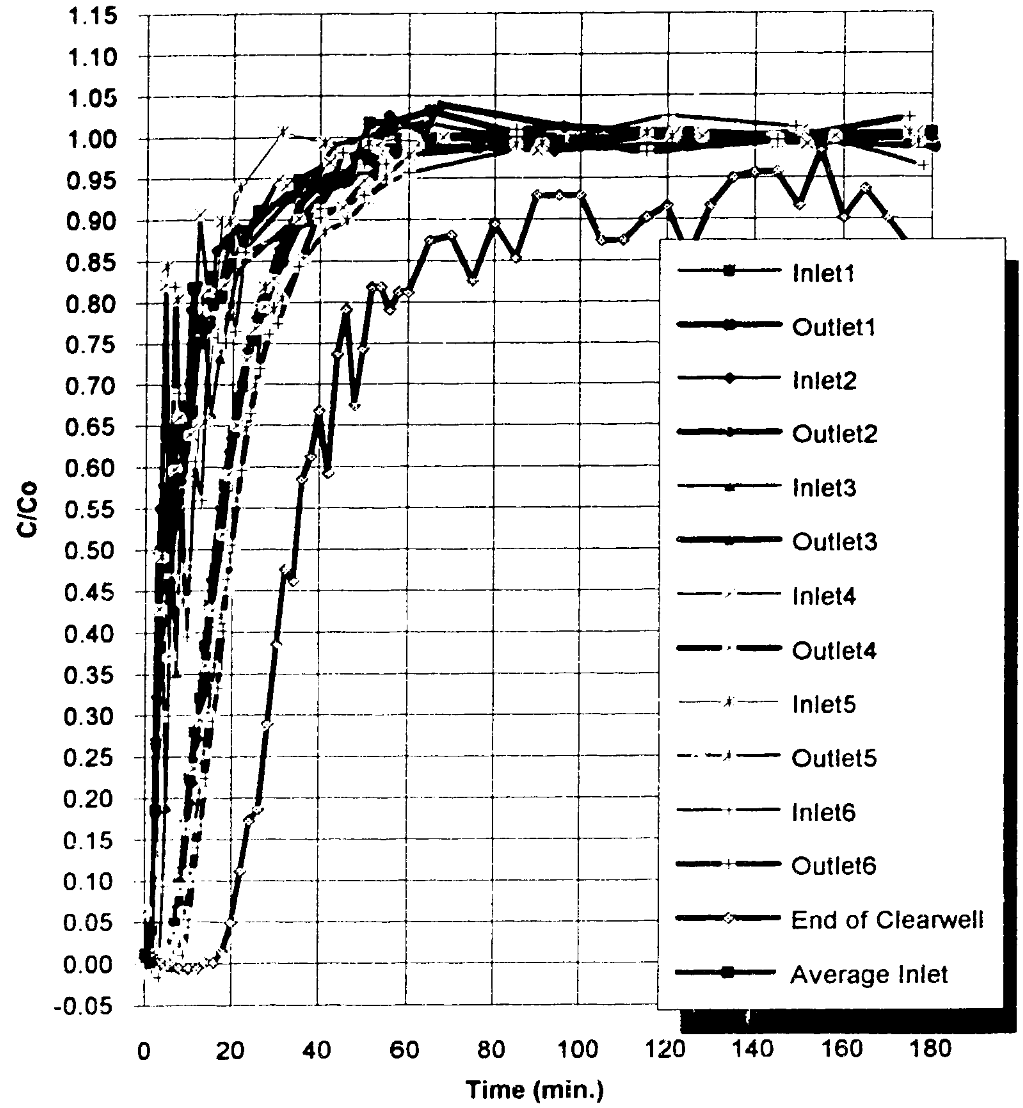


Figure 5.5: Test No.1 - Filters and Clearwell at 180 ML/d

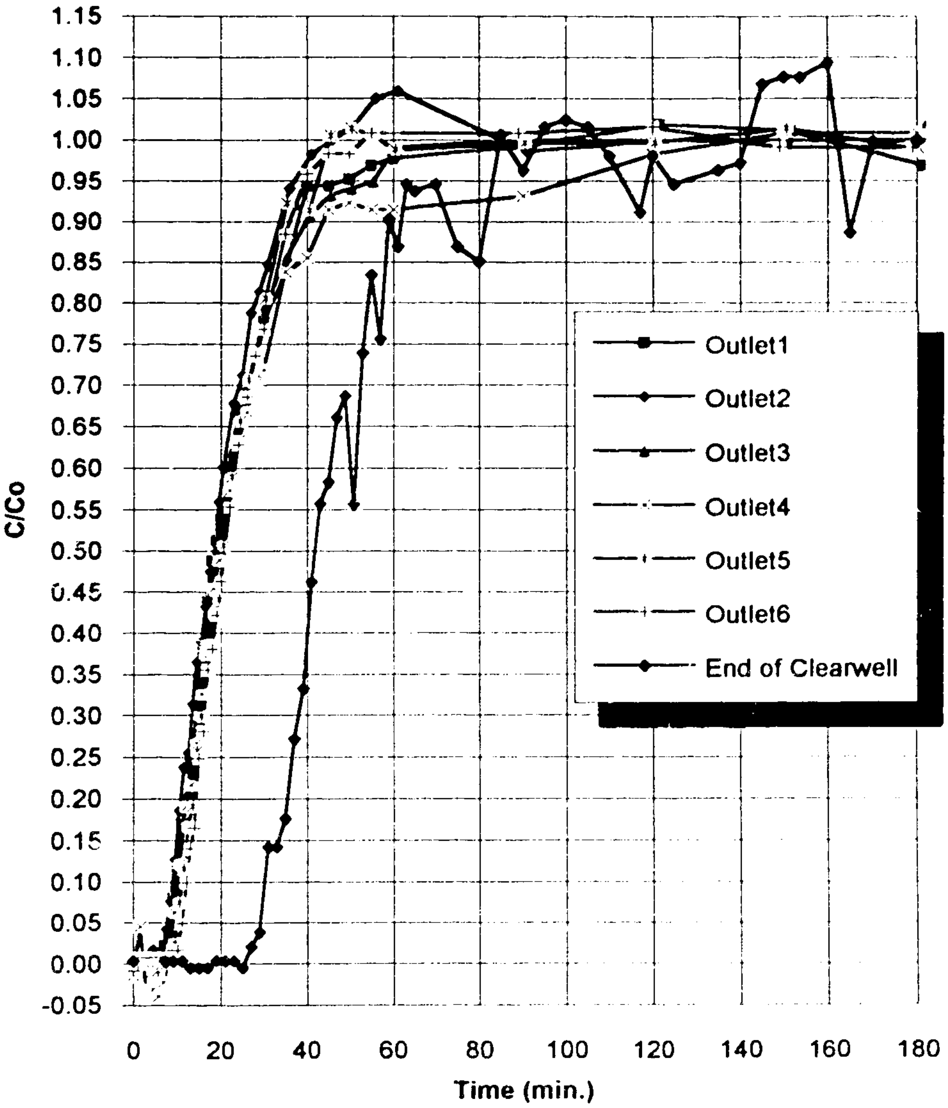


Figure 5.6: Test No.2 - Filters and Clearwell at 140 ML/d

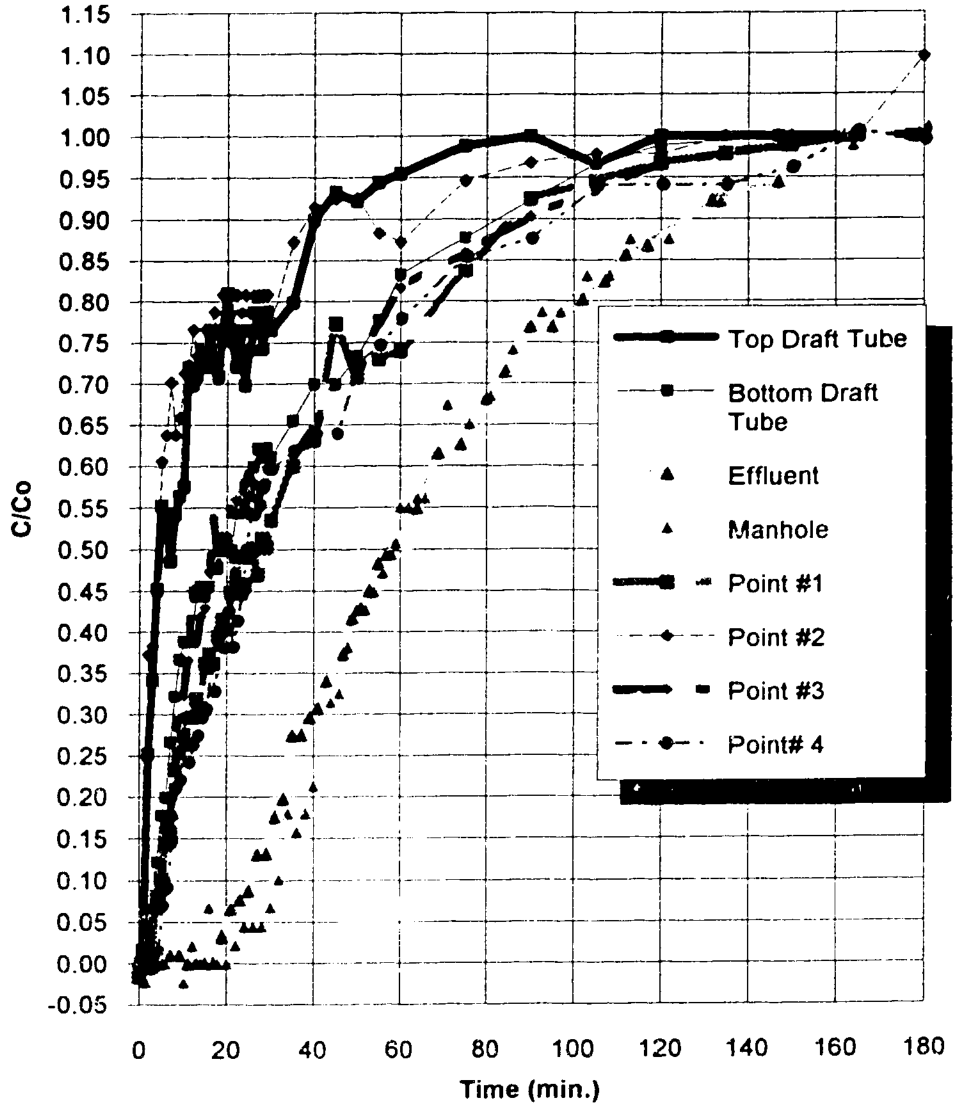


Figure 5.7: Test No.3 - Clarifier No. 2 at 180 ML/d

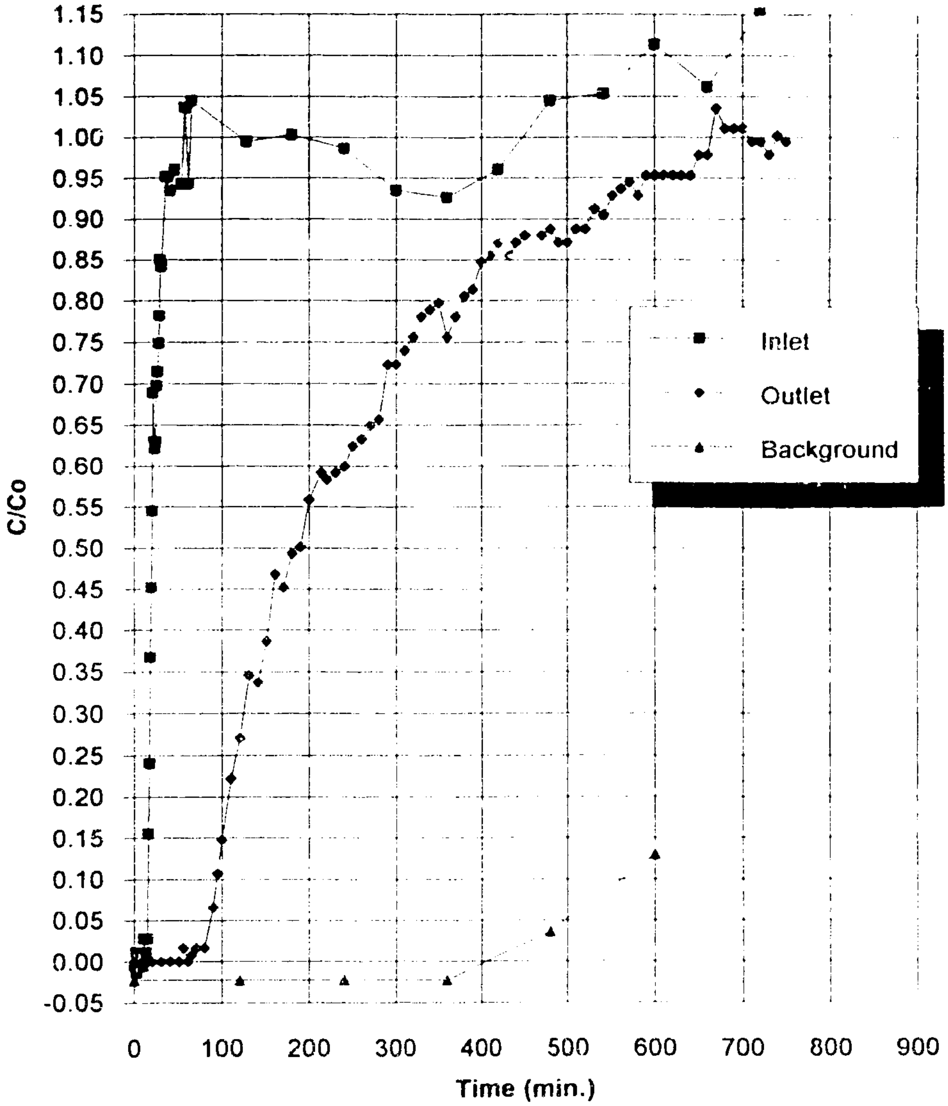


Figure 5.8: Test No.4 - Reservoir No. 1 at 180 ML/d

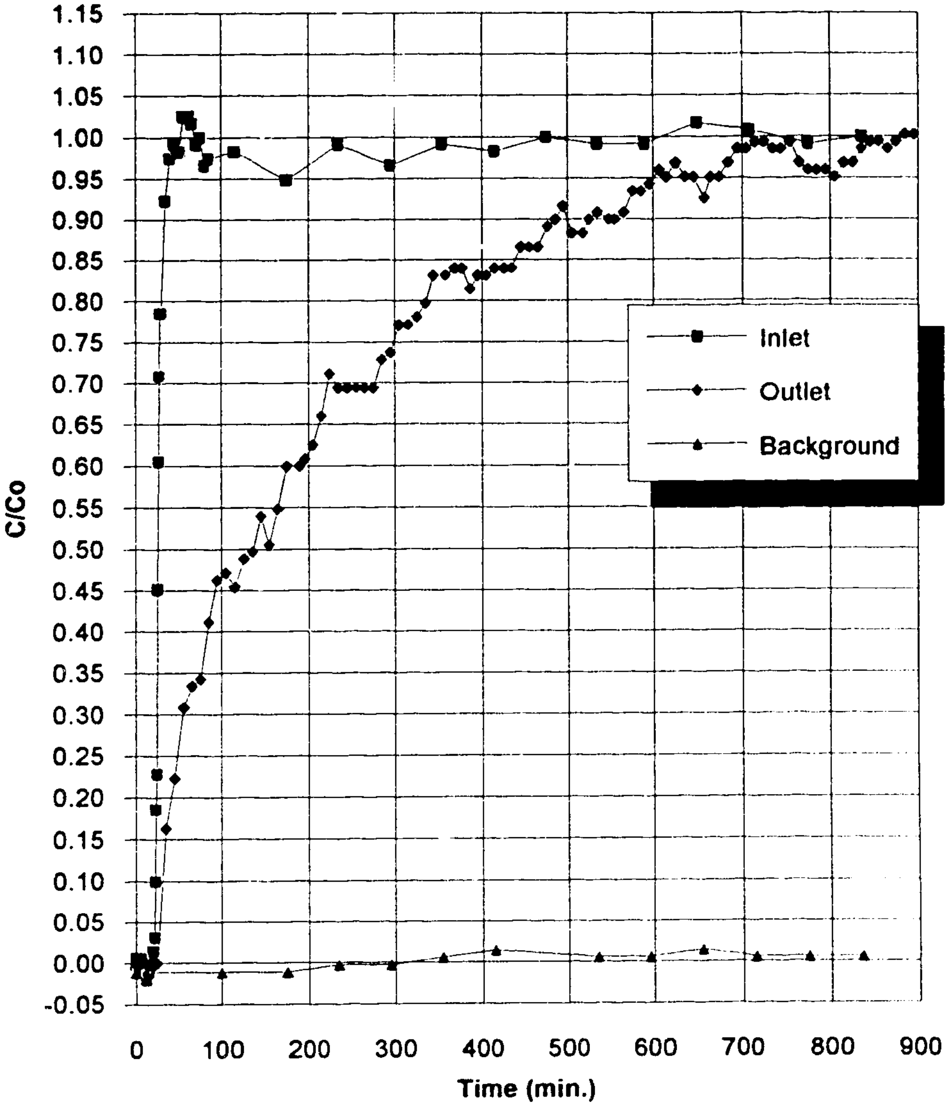


Figure 5.9: Test No.5 - Reservoir No. 2 at 167 ML/d

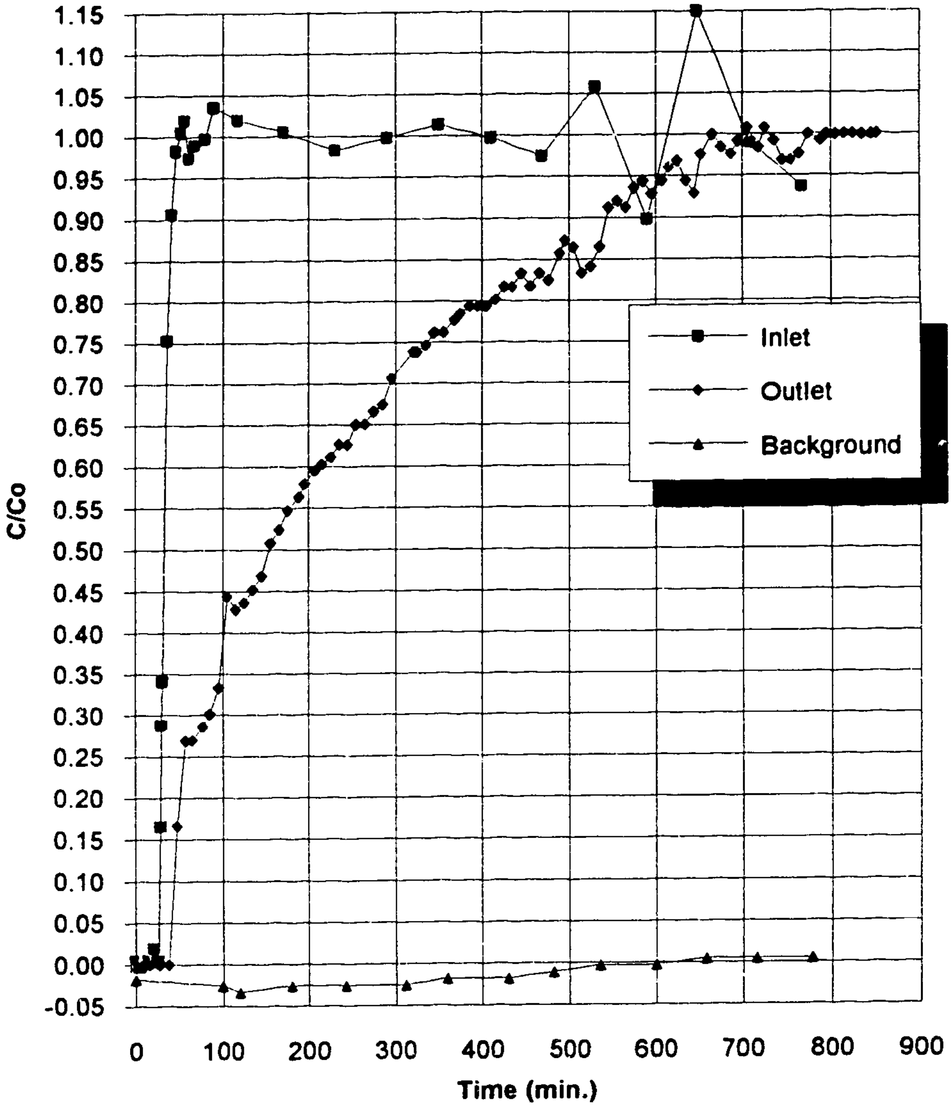


Figure 5.10: Test No.6 - Reservoir No. 2 at 141 ML/d

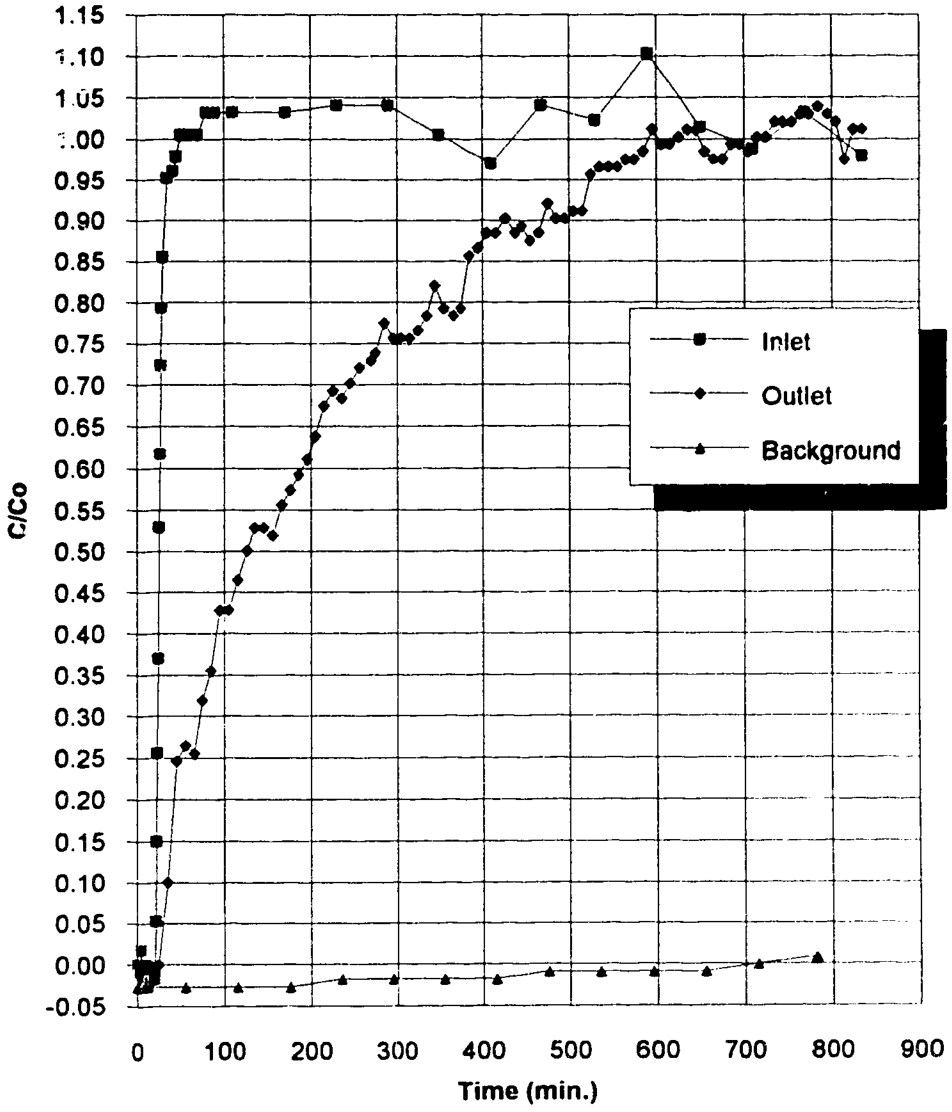


Figure 5.11: Test No.7 - Reservoir No. 3 at 179 ML/d

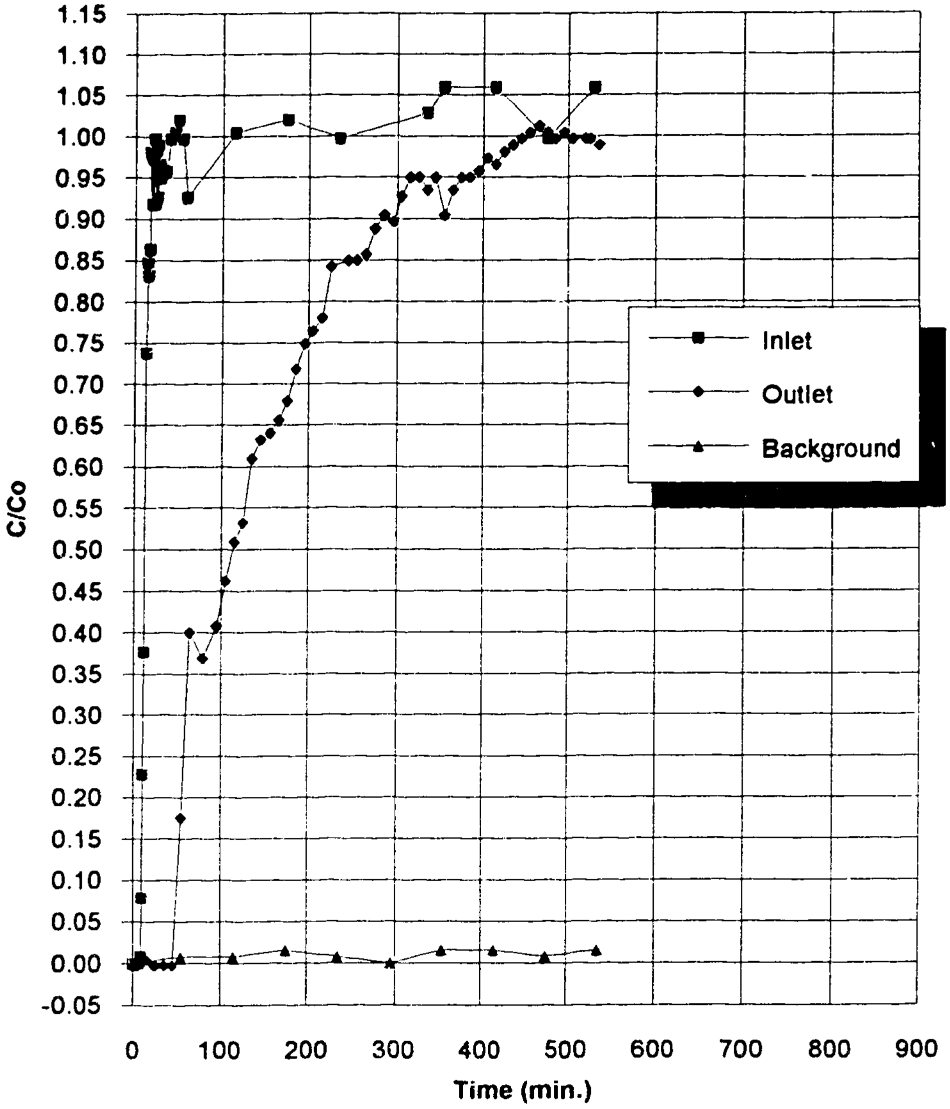


Figure 5.12: Test No.8 - Reservoir No. 1 at 230 ML/d

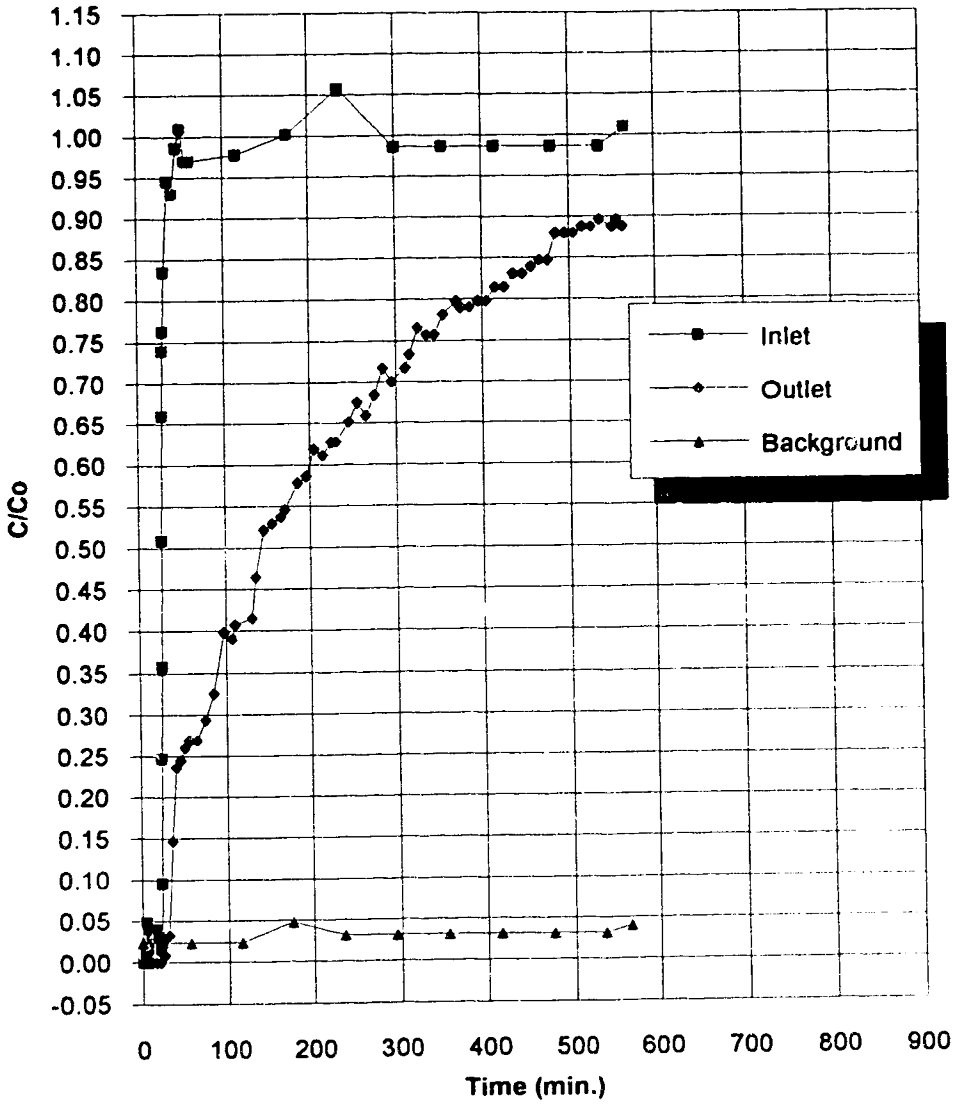


Figure 5.13: Test No.9 - Reservoir No. 3 at 198 ML/d

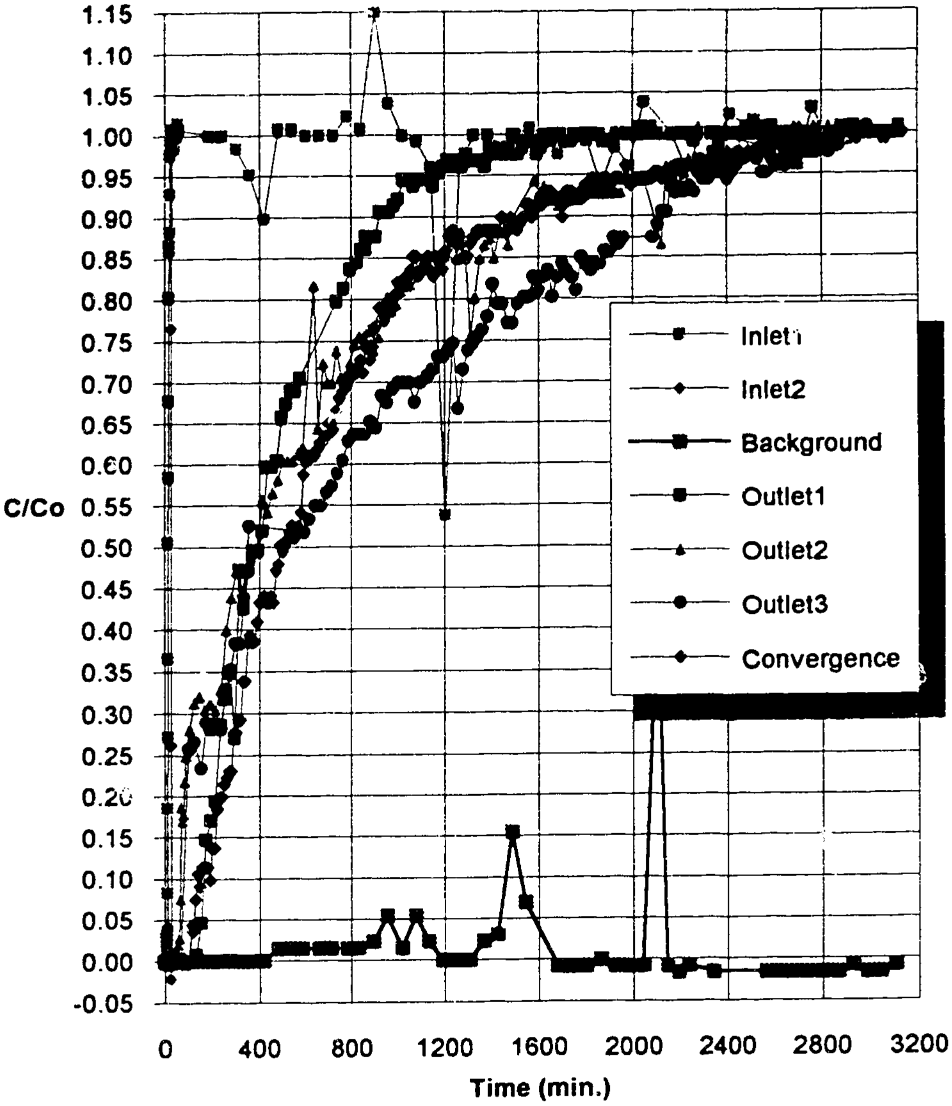


Figure 5.14: Test No.10 - Combined Reservoirs at 170 ML/d

The instrument reading error was found out by testing 30 times for each Na standard solution of 0, 5, 10, 15, and 20 mg/L. The average readings for the samples were 0.0, 33.1, 58.7, 81.0, and 99.0, respectively. While the standard deviations were found to be small: 0.00, 0.36, 0.36, 0.43, and 0.43, respectively. It is evident that the instrument error due to its floating can be neglected (see Appendix 6).

The tracer concentration was found easily by diluting the tracer samples for 1:10,000 in order to set the readings in the range of 0 to 100. The brine was found to be saturated and constant throughout the tests with the Na concentration equal to 131,000 mg/L.

Tracer recoveries are presented in Table 5.2. As indicated by the table, recoveries varied from 84% to 107%. The Guidance Manual (1989) recommends a recovery of at least 90%. Possible sources of errors in the recovery include: sodium analysis errors, loss of tracer to dead zones, inaccuracy in the plant flow rate and system volume, and errors in dose of tracer.

6.0 DISCUSSION

6.1 t_{10} and System Performance

Table 6.1 presents the tracer test results. Included in the table are the t_{10}, t_{90}, T_d, t_{10}/T_d, and t_{90}/t_{10}. From the table, it can be seen that the values of t_{10}/T_d vary from component to component. Time parameters t_{10} and t_{90} can be compared directly with the T_d. In most cases, this following condition must be fulfilled: $t_{10} \leq T_d \leq t_{90}$. The table shows that comparison among those three parameters is satisfied for all tests.

6.1.1 Filters and Clearwell Tests

As more than one inlet points were taken during filters and clearwell tests (tests nos. 1 and 2), the values of t_{10} and t_{90} were determined directly from the outlet points. As a result, the t_{10} and t_{90} values for those systems also include pipes and channels. Reasonable results were obtained from the tests, the decreased the flow the increased the values of t_{10} and t_{90}. The Guidance Manual (1989) considers filters as systems with a high percentage of uniform flow. It is possible to figure out the T_d based on the incoming flow and the effective water volume. In this case, there are two layers of filter media, 0.45 m of anthracite and 0.30 m of sand with porosity numbers of 0.58 and 0.44 respectively, yielding a total effective water volume for the six filters and the clearwell of 3642 m^3 (E. L. Smith Water Treatment Plant, 1993). Ratios of the t_{10} and T_d can be calculated (0.75 for 180 ML/d and 0.81 for 140 ML/d), that are categorized as "superior". Those values are very close to the value of 0.70 mentioned by the Guidance Manual (1989) for filter performance.

Table 6.1: Time Parameter Values

System	Flow (ML/d)	Water Volume (m^3)	t_{90} (min.)	t_{10} (min.)	T_d (min.)	$\frac{t_{10}}{T_d}$	$\frac{t_{90}}{t_{10}}$	Baffle Parameter
Filters + Clearwell	180	3642	91	22	29	0.76	4.1	superior
Filters + Clearwell	140	3642	100	30	37	0.81	3.3	superior
Clarifier No. 2	180	10700	125	25	86	0.29	5.0	poor
Reservoir No. 1	180	37140	494	79	297	0.27	6.3	poor
Reservoir No. 1	230	35120	265	41	220	0.19	6.5	poor
Reservoir No. 2	141	28570	503	16	292	0.05	31.4	nobaffle
Reservoir No. 2	167	32050	447	08	276	0.03	55.9	nobaffle
Reservoir No. 3	179	35178	394	12	283	0.04	32.8	nobaffle
Reservoir No. 3	198	43762	452	10	318	0.03	45.2	nobaffle
Reservoir No. 1,2,3	170	106640	1260	137	926[1]	0.15	9.2	poor
Reservoir Split: 20% Reservoir No.1	34	35120	-	-	-	-	-	-
38% Reservoir No.2	65	32050	-	-	-	-	-	-
42% Reservoir No.3	71	39470	-	-	-	-	-	-

1) Including 760 m pipe system with diameter = 2.1 m, assuming PFR.

6.1.2 Clarifier No. 2 Test

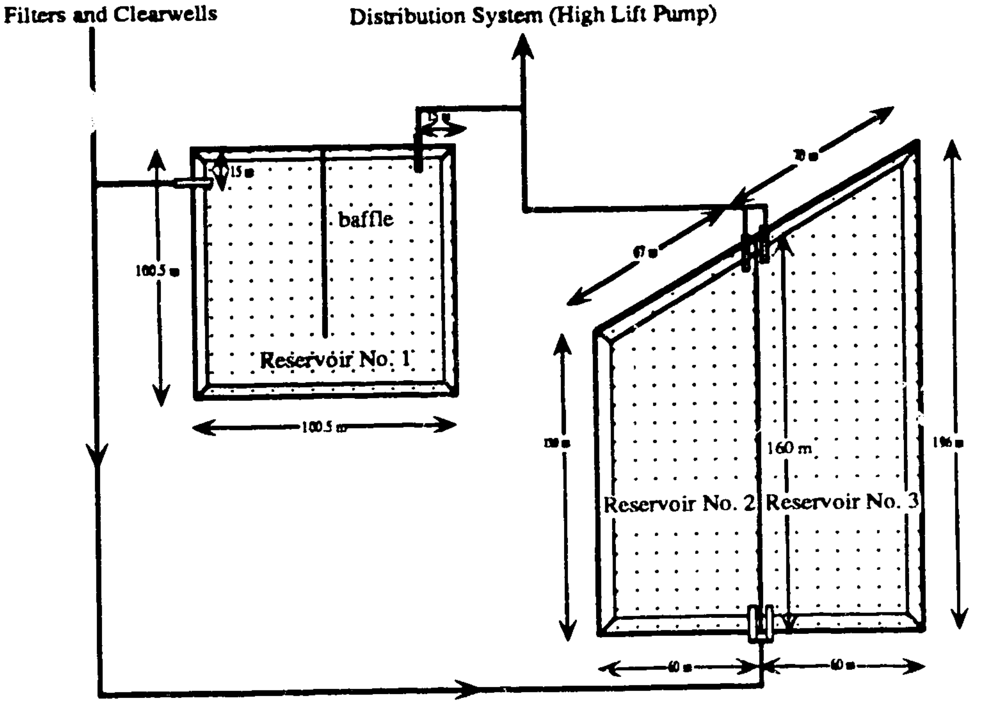
For clarifier no. 2 test (test no. 2), the outlet t_{10} and t_{90} are applied as the time parameters that include pipes and channels. Since there was only one test conducted for clarifier test, it is not possible to make any comparison for the t_{10} or t_{90}. The baffle parameter was found to be about 0.3 or classified as "poor".

6.1.3 Individual Reservoir Tests

In the case of individual reservoir tests (tests nos. 4 to 9), the individual value of t_{10} for each system can be calculated by taking the difference between the outlet t_{10} and the inlet t_{10}. Higher flow rates result in decreased values the t_{10} and t_{90} for each system with the exception of reservoir no.3 at 198 ML/d. The greater water level (water volume) in that system might have had a more dominant effect on the time parameters. The baffle parameters were found to be "poor" for reservoir no. 1 (t_{10}/T_d values range from about 0.2 to 0.3) and "no baffle" for the other two reservoirs (t_{10}/T_d values about 0.0). These values seem logical in consideration of the real physical condition of the reservoirs where one simple baffle was installed for reservoir no.1 and no baffle at all was constructed for reservoirs nos. 2 and 3. See Figure 6.1.

An interesting comparison can be made between the length to width (L/W) ratio vs. t_{10}/T_d results provided by the CH2MHILL (1993) (see Figure 6.2). The figure is based on numerous data collected from many systems. In the case of reservoir no. 1 with a L/W ratio of about 4, the t_{10}/T_d values should be in the range of 0.15 to 0.50 which are higher than the test results. For reservoirs no. 2 and 3 with L/W ratio values about 2.5 to 3, the t_{10}/T_d values given by Figure 6.2 should be in the range of 0.10 to 0.45 which are also greater than those of the real data. It is evident that those reservoirs have poor performance in consideration to the L/W ratio.

Several studies have been done to find out the correlation between the shape or



Note:

◺ -slope inside reservoirs = 18°
8.5 m length x 2.75 width

○ -column diameter = 0.45 m
located every 5.4 m

▭ -1.5 m diameter inlet pipe

▬ -1.5 m diameter outlet pipe

-for reservoirs no. 2 and 3 all pipes
are located at 1.5 m from the wall

Figure 6.1: Reservoirs Nos. 1, 2, and 3 Layout

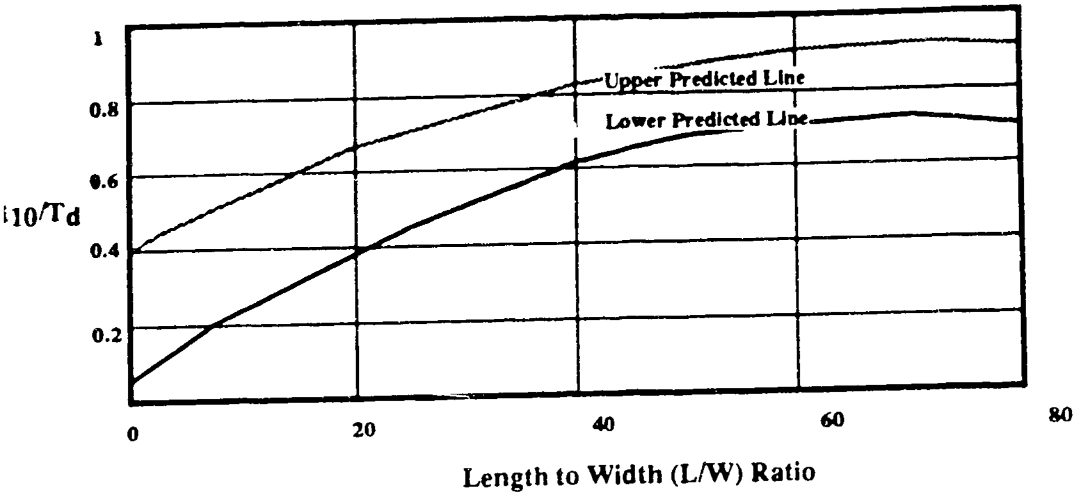


Figure 6.2: L/W Ratio vs. t_{10}/T_d (adapted from CH2MHILL, 1993)

geometric factor of the system and the degree of mixing. They show that an increase of L/W of the system results in a decrease of the mixing degree, but the correlation is poor. Other factors like depth to width ratio, outlet characteristics, turbulence, baffle conditions, and even wind also make differences. In general, a high length to width ratio system, with a depth to width ratio equals to 1 or less, plus one longitudinal baffle will be in a good resemblance with a PFR (Marske and Boyle, 1973). Two studies conducted by Kennedy et al (1991 and 1993) seemed to agree with those results. The first study found that a shallow system with a large surface area gave a nearly complete mixing. While the second study concluded that the system geometry has only little effect on the mixing behavior. The size of the system also makes a difference. The smaller the size, the more sensitive the dispersion number (Mitha and Mohsen, 1990).

Numerous tracer studies have set art to obtain values of t_{10}/T_d, such as Teefy and Singer (1990), Bishop et al (1990 and 1993), Dunn, et al (1991), Kennedy et al (1991), Process Development Team (1991), and Yu et al (1991). The Guidance Manual (1989) has also identified several types of systems to have some correlation with the baffle parameter. Rectangular and circular basins without baffle, with simple baffles, and complex baffles are interpreted as poor, average, and superior baffle conditions, respectively. Bishop et al (1991 and 1993) completed studies to verify those correlations using small pilot - scale circular and rectangular basins. While Hart (1975) used perforated baffles in order to avoid solid buildups in the corner areas. In general, all of those studies seem to agree each other. Still, more intensive hydraulic experiments beyond tracer studies are necessary to acquire such information about flow pattern in the system.

6.1.4 Combined Reservoir Test

The t_{10} and t_{90} obtained from the combined reservoirs in parallel test (test no.

10) were found directly from the outlet F curve, therefore they include all pipes and channels in the whole system. No comparison of the t_{10} and t_{90} values can be made for different flow rates, since there was only one test conducted. The baffle parameter was found to be "poor" with a t_{10}/T_d ratio of about 0.2.

The Process Development Team conducted a similar test for the combined reservoirs in parallel including filters. The total t_{10} was found to be 178 minutes at 160 ML/d, or about 148 minutes excluding the filters. While, the current study found the t_{10} equal to 137 minutes at 170 ML/d. Using Equation 4.1, the t_{10} for 160 ML/d can be predicted to be 146 minutes, with a difference of 6%. A complete investigation of all systems in the treatment plant using the CT concept will not be discussed as it has been done in the previous study (Process Development Team, 1991). After knowing the t_{10} for each system, the required CT value can be obtained from the standard CT tables. A more comprehensive discussion can be found in Andrews et al (1992).

Using the convergence point from test no. 10, it is possible to work out the flow split of the three reservoirs. Reservoirs nos. 1, 2, and 3 receive 20, 38, and 42% of the total flow, respectively (see Appendix 5). It is evident that reservoirs nos. 2 and 3 contribute the most impact on contact time in the disinfection process. Some modification, if any, should be prioritized for those two reservoirs.

6.2 Residence Time Distribution Analyses

The Morril's Index and baffle parameter, CMRs - in - series model, Wolf - Resnick model, Rebhun - Argaman model are the most common models used to analyze the residence time distribution performance. The dispersion model suggested by Thirumurthi and Levenspiel will not be covered as it deals with the E curve (the slug input). The jet model will be used to analyze reservoirs nos. 2 and 3, but not reservoir no. 1 due to its physical condition that makes it difficult to develop the model.

As has been mentioned above, the filters and clearwell, clarifier, and combined reservoirs are assumed as combined systems. The outlet F curves can be interpreted as the system residence time distribution. In the case of single reservoir tests, the residence time distribution curves can be worked out by taking difference of the outlet and inlet points (see Appendix 1). Summary of the results can be seen in Table 6.2.

6.2.1 Wolf - Resnick Model

This model in its simplified form (Equation 2.26) represents the entire residence time distribution. As a result, it gives a good estimation to the nature of the F curve. Parameter β indicates the time shift of the curve, while parameter α gives an estimation to the curve slope / skewness.

Interesting results can be seen in Table 6.2. From a comparison between tests on the two filters and the clearwell, it can be seen that for the low flow test (test no. 2 at 140 ML/d), it seems that the flow behaves more like a PFR than that for the high flow (test no. 1 at 180 ML/d). Note: in the case of PFR, parameter α should equal to 1, while parameter β should be $+\infty$ to form a vertical line right on $t/T_d = 1$. A reasonable explanation can be drawn that there is a smaller momentum effect in the system and the flow is distributed evenly over the filter media. This can be seen from parameters α and β; the lower the flow the bigger the β (intercept with x axis) and the bigger the α (slope) as well. For clarifier and combined reservoir tests, no comparison can be made since only one type of flow test was undertaken for each system.

Some interesting results were obtained from single reservoir tests (tests nos. 4 to 9). Generally, the higher the flow, the lower the β, and the higher the α, with the exception of reservoir no.3. It can be explained by assuming that inside the reservoirs momentum effects are dominant. The higher the flow, the less the β as the water travels faster and appears earlier at the outlet point, hence the lower the time delay. The faster

Table 6.2: Residence Time Distribution Analyses

		FILTERS+C.WELL		CLARIFIER NO.2	RESERVOIR NO. 1		RESERVOIR NO. 2		RESERVOIR NO. 3		COMBINED RESERVOIRS
Data											
Flow	(ML/d)	180	140	180	180	230	141	167	179	198	170
Water Level	(m)	-	-	-	4.1	3.9	3.6	4.0	3.6	4.4	-
Volume	(m^3)	3642	3642	10700	37140	35120	28570	32050	35178	43762	109271
Td	(min.)	29	37	86	297	220	292	276	283	318	926
Direct Measurement											
t10	(min.)	22	30	25	79	41	16	8	12	10	137
t90	(min.)	91	100	125	494	265	503	447	394	452	1260
Morril's Index: t90/t10		4.1	3.3	5.0	6.3	6.5	31.4	55.9	32.8	45.2	9.2
Baffle Parameter: t10/Td		0.76	0.80	0.29	0.27	0.19	0.05	0.03	0.04	0.03	0.15
Baffle Description		superior	superior	poor	poor	poor	no baffle	no baffle	no baffle	no baffle	poor
Wolf - Resnick Model: C/Co = 1-Exp		(-α*(T-β))									
α		1.19	1.81	1.61	1.87	2.22	1.54	1.59	1.68	1.62	1.60
β		0.62	0.73	0.22	0.22	0.16	0.04	0.02	0.01	0.01	0.11
Rebhun - Argaman Model: ln(1-C/Co) = -[1/(1-p)(1-d)] t/Td + p/(1-p)											
p (degree of PFR)	(%)	41.2	58.9	26.5	27.4	25.9	4.5	2.4	2.1	3.7	13.8
d (dead space)	(%)	-50.5	-23.8	18.7	19.3	36.7	21.2	25.6	33.3	29.0	27.7
t10	(min.)	20	28	24	83	46	32	23	20	22	139
CMRs in Series											
N		25	37	3	3	3	1	1	1	1	2
Jet Model											
l (length of travel)	(m)	-	-	-	-	-	145	145	175	175	-
do(imaginary diameter)	(m)	-	-	-	-	-	1.0	1.1	0.7	1.2	-
t10	(min.)	-	-	-	-	-	13	12	10	14	-
Morril's Index		-	-	-	-	-	38.7	37.3	39.4	32.3	-
Baffle Parameter: t10/Td		-	-	-	-	-	0.045	0.043	0.035	0.044	-
Baffle Description		-	-	-	-	-	no baffle	no baffle	no baffle	no baffle	-
Uo	(m/min.)	-	-	-	-	-	124.73	122.10	323.17	122.25	-
C1 (simplified form: t10=l^2/Uo do C1)		-	-	-	-	-	13.0	13.0	13.5	14.9	-

the water travels, the steeper the slope, and the bigger the α. For reservoir no. 3 at 198 ML/d parameter β equals to that at 179 ML/d, but parameter α is smaller. This aberration can be explained by considering the difference of the water levels for these two tests. As reservoir no.3 at 198 ML/d has a higher water level than that at 179 ML/d (4.4 m vs. 3.6 m), it is logical to make a conclusion that the increase in water level (water volume) is more dominant than the increase of flow that gives rise to the decrease of α.

Other interesting points are shown in Figures 6.6 to 6.11 for single reservoir tests. It is clear that the Wolf - Resnick model does not fit the curves obtained from the tracer studies, especially for the early points which are important in determining the value of t_{10} in the CT concept. The most logical explanation is that this model is basically derived from mass balance of the system. It also appears that the model fits reservoir no.1, especially at a low flow rate, better than reservoirs nos. 2 and 3. Reservoir no.1 has only one simple baffle while reservoirs nos. 2 and 3 do not have baffles at all, the momentum / jet effect seems to be more dominant in the latter reservoirs as the water flows almost directly from the inlet to the outlet, so that the early real points from the tests come faster than those from the model.

In the case of filters + clearwell and clarifier tests (Figures 6.3 to 6.5), the model seems to match the whole curve. The same result also occurs for the combined reservoir test (Figure 6.12). This means that basically the momentum effect does not dominate these systems. The fluid does not travel directly from the inlet to the outlet point due to physical conditions in the case of filter and clarifier tests, and due to the low flow (split flow) for the combined reservoir test.

Still, although this model does not fit the real data well, it is still valid to compare the general pattern of one curve with another. For example, if the first curve is steeper (having a bigger α) than the second curve but has the same time shift (the

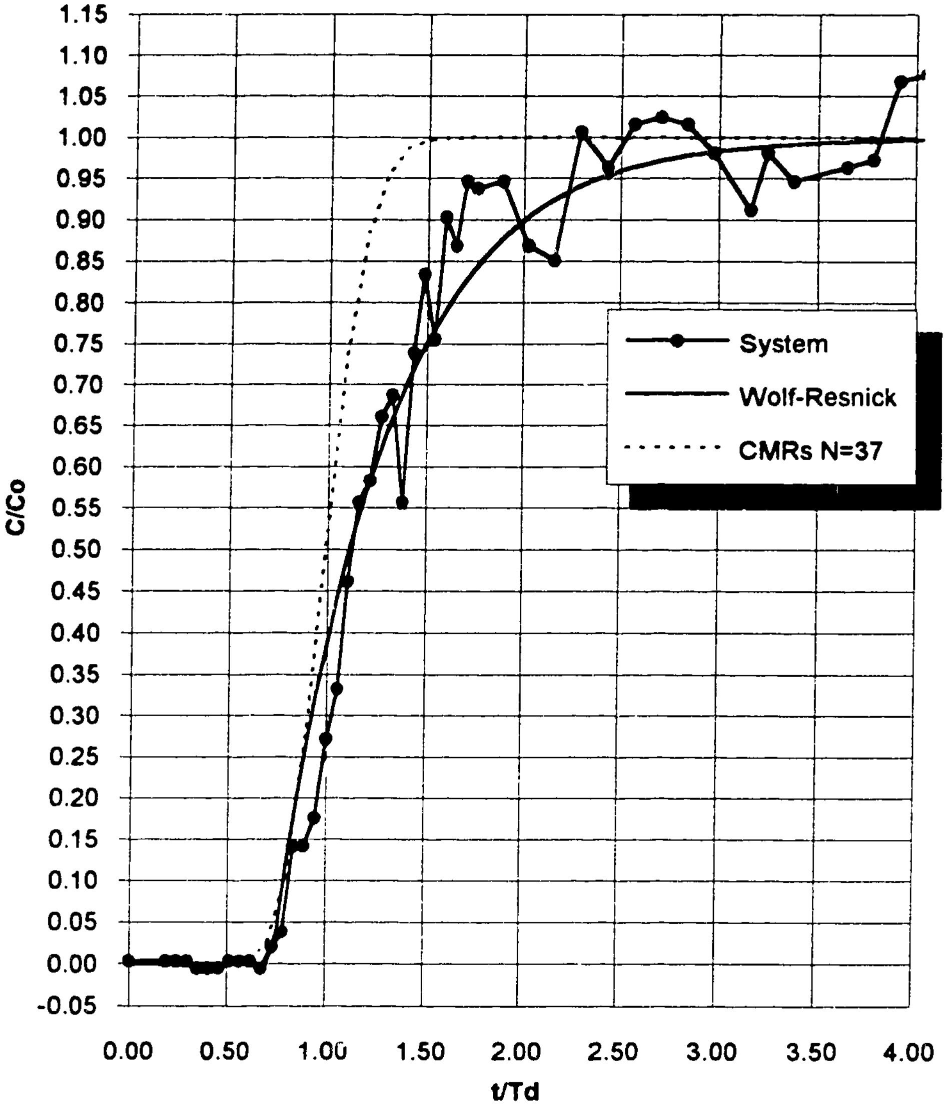


Figure 6.3: Filters + Clearwell at 140 ML/d for Wolf-Resnick and CMRs - in - Series Models

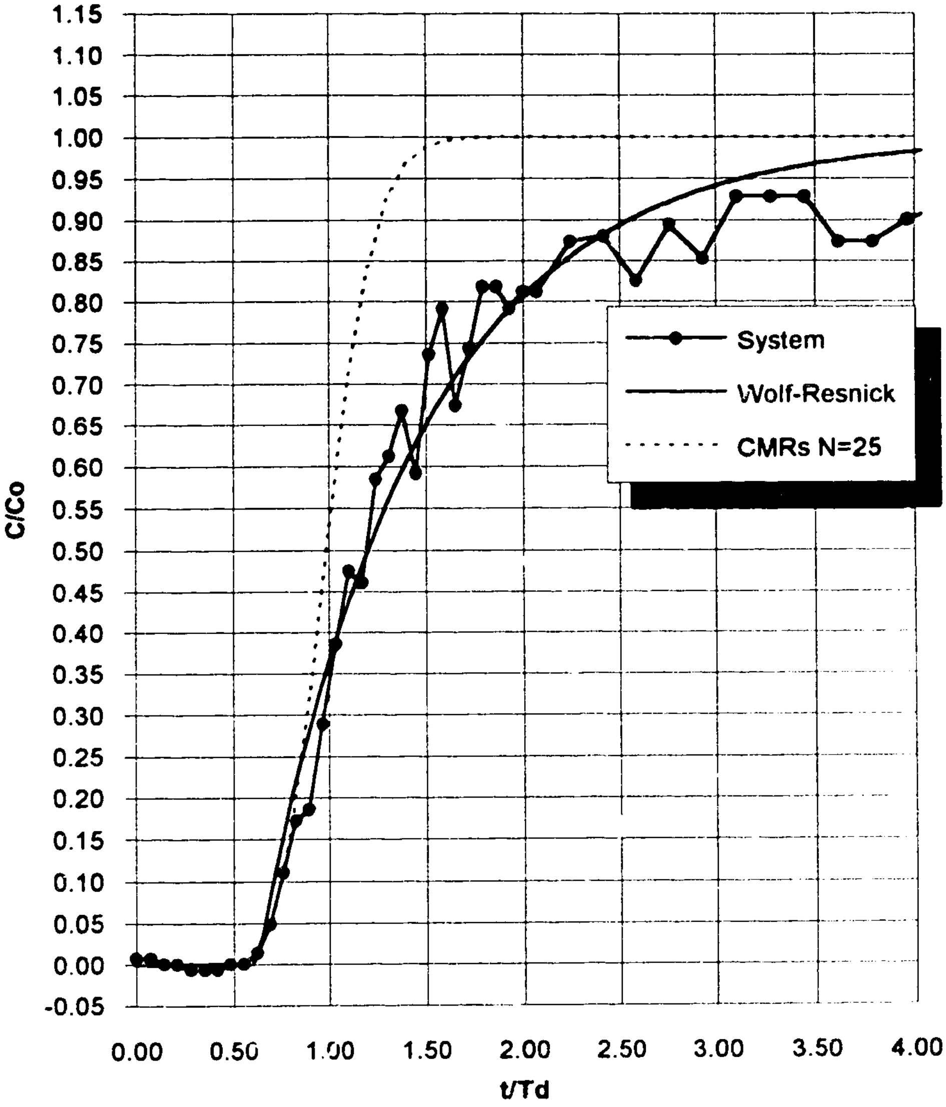


Figure 6.4: Filters + Clearwell at 180 ML/d for Wolf-Resnick and CMRs - in - Series Models

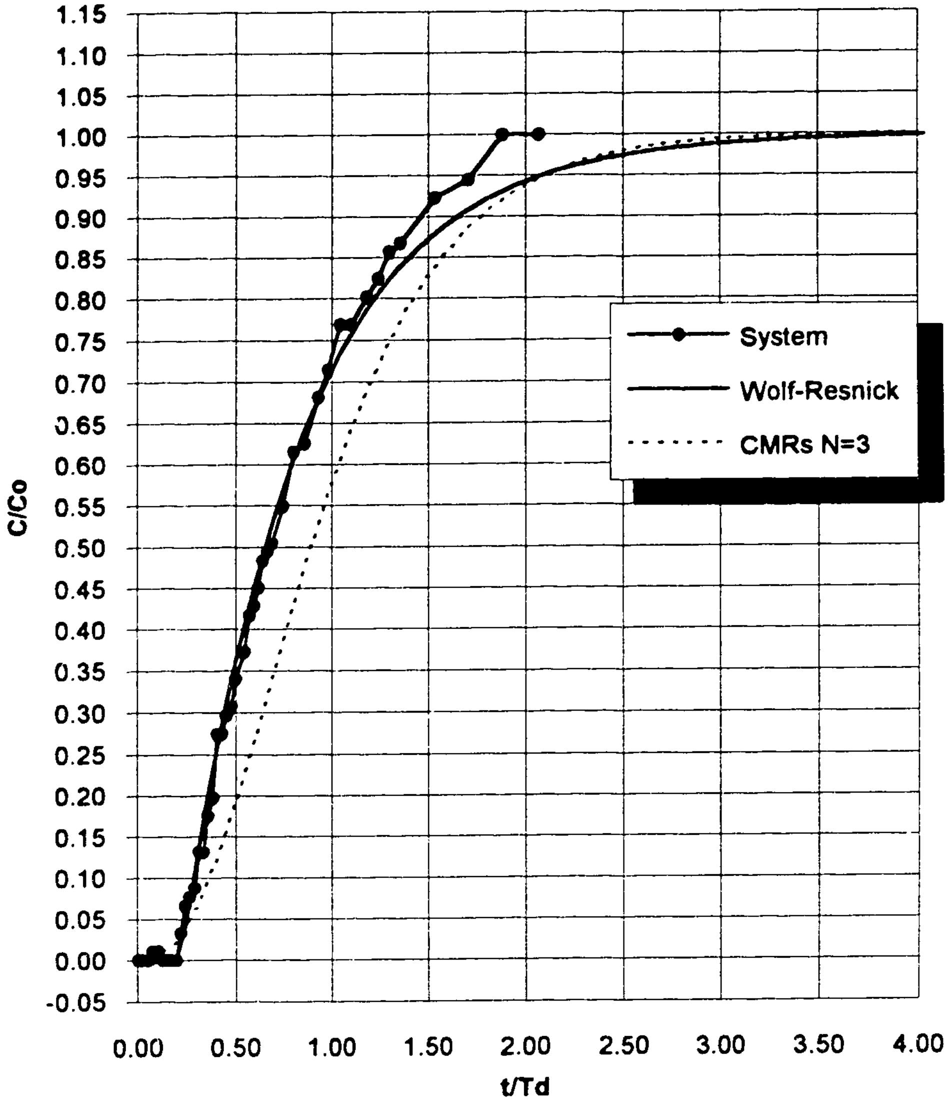


Figure 6.5: Clarifier No.2 at 180 ML/d for Wolf-Resnick and CMRs - in - Series Models

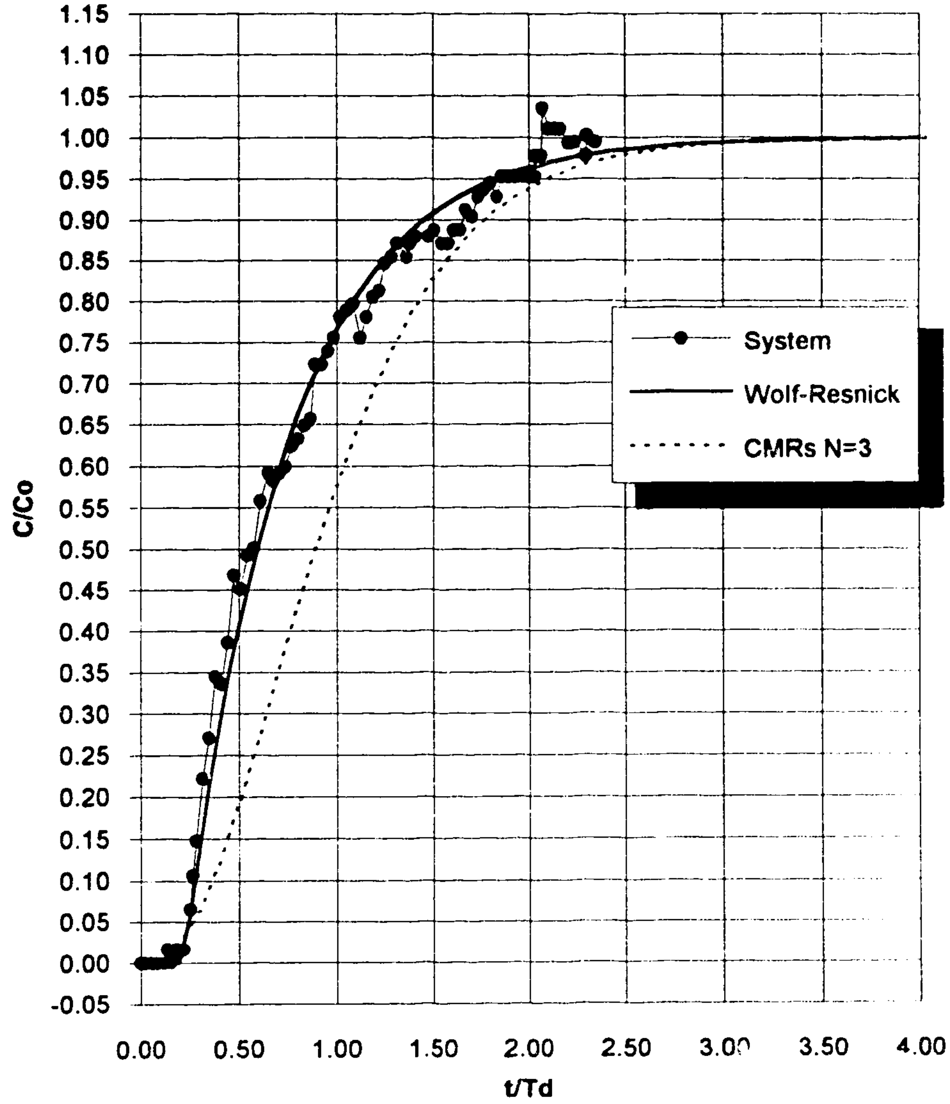


Figure 6.6: Reservoir No.1 at 180 ML/d for Wolf-Resnick and CMRs - in - Series Models

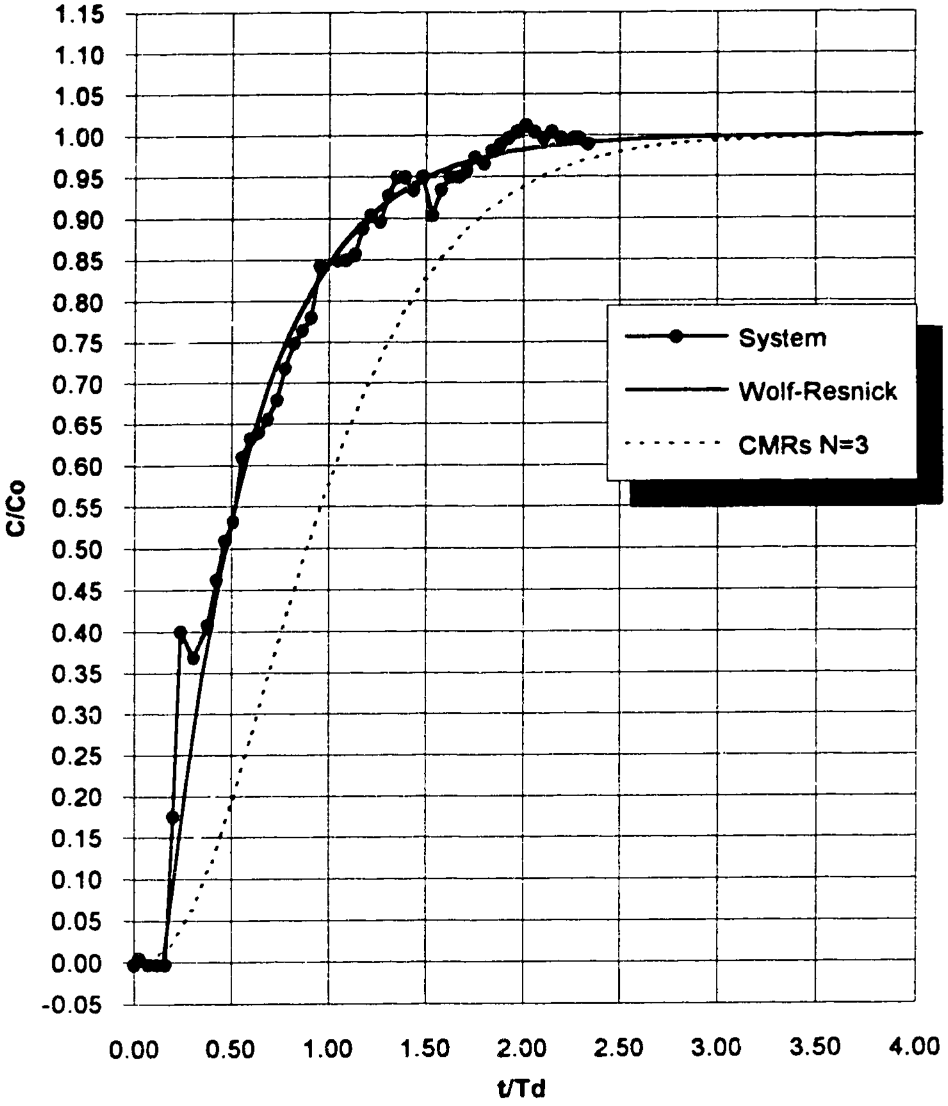


Figure 6.7: Reservoir No.1 at 230 ML/d for Wolf-Resnick and CMRs - in - Series Models

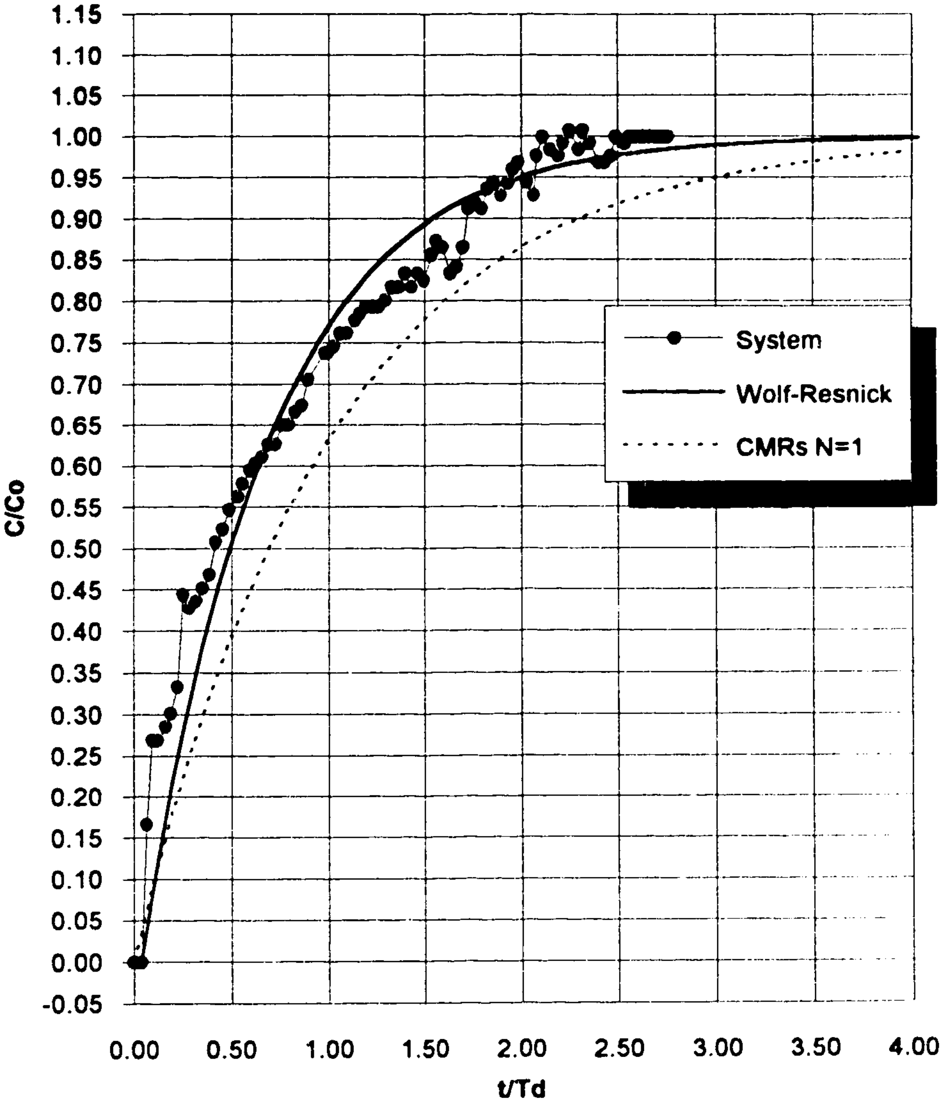


Figure 6.8: Reservoir No.2 at 141 ML/d for Wolf-Resnick and CMRs - in - Series Models

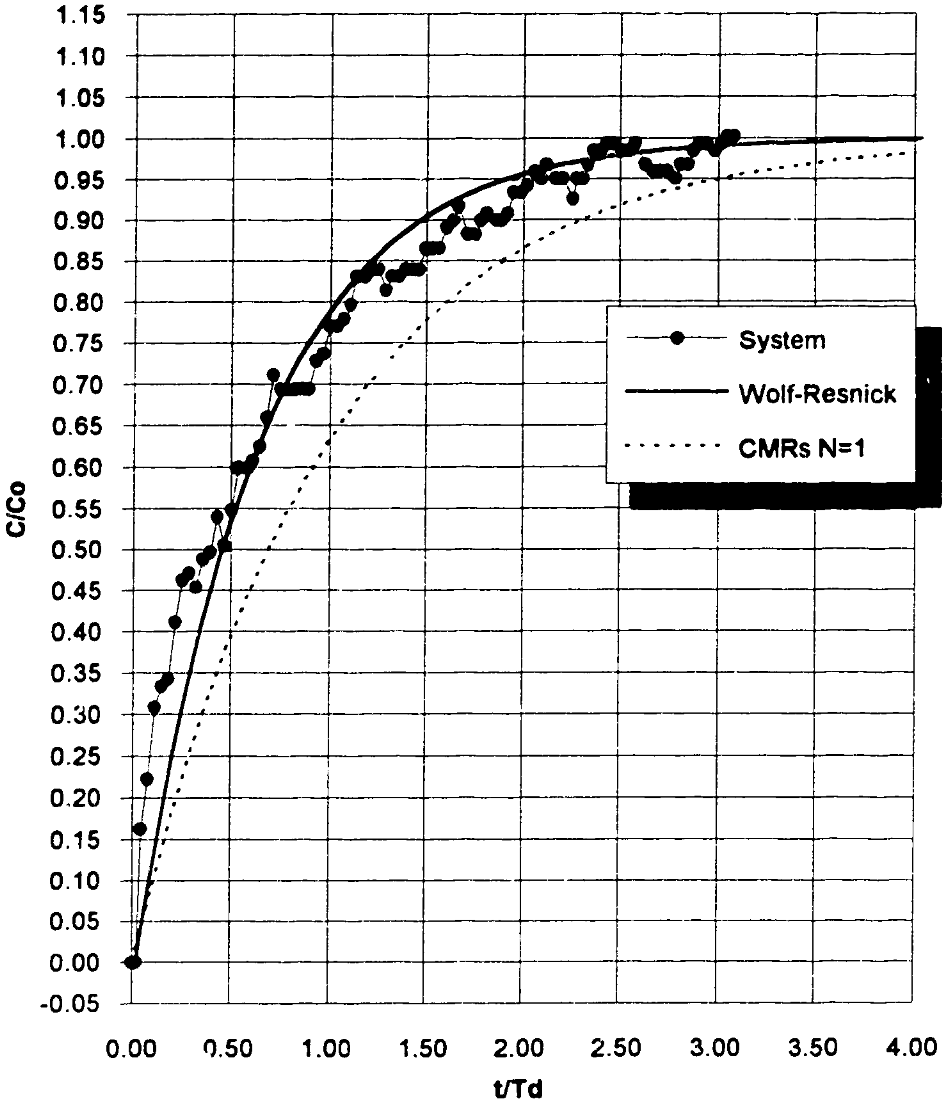


Figure 6.9: Reservoir No.2 at 167 ML/d for Wolf-Resnick and CMRs - in - Series Models

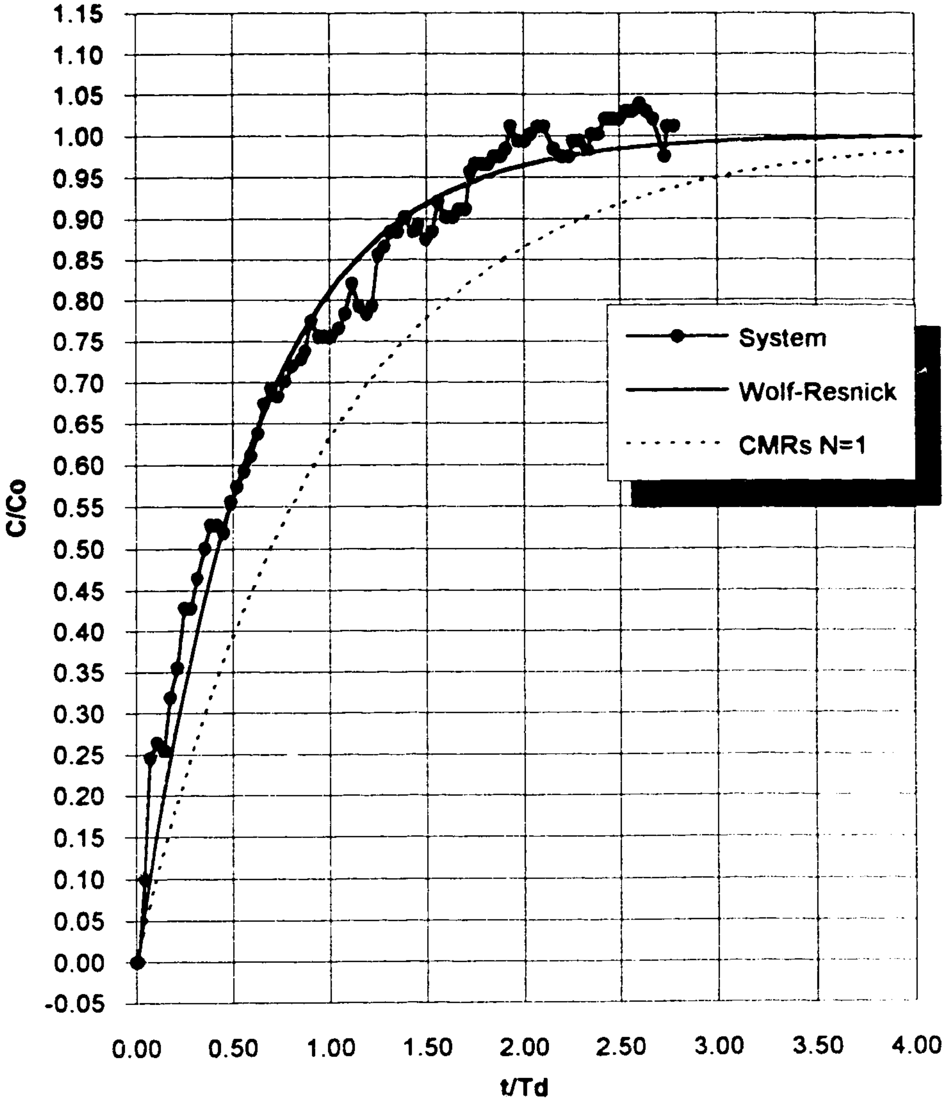


Figure 6.10: Reservoir No.3 at 179 ML/d for Wolf-Resnick and CMRs - in - Series Models

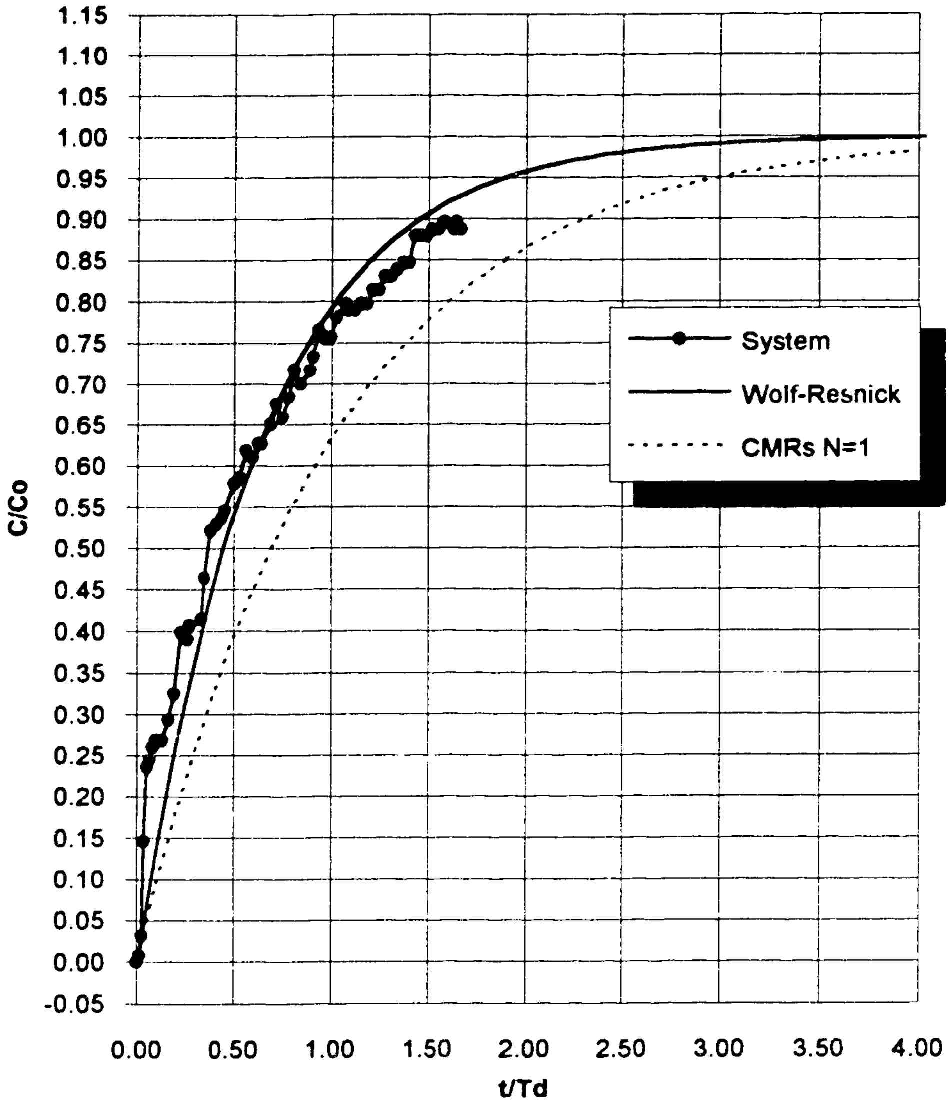


Figure 6.11: Reservoir No.3 at 198 ML/d for Wolf-Resnick and CMRs - in - Series Models

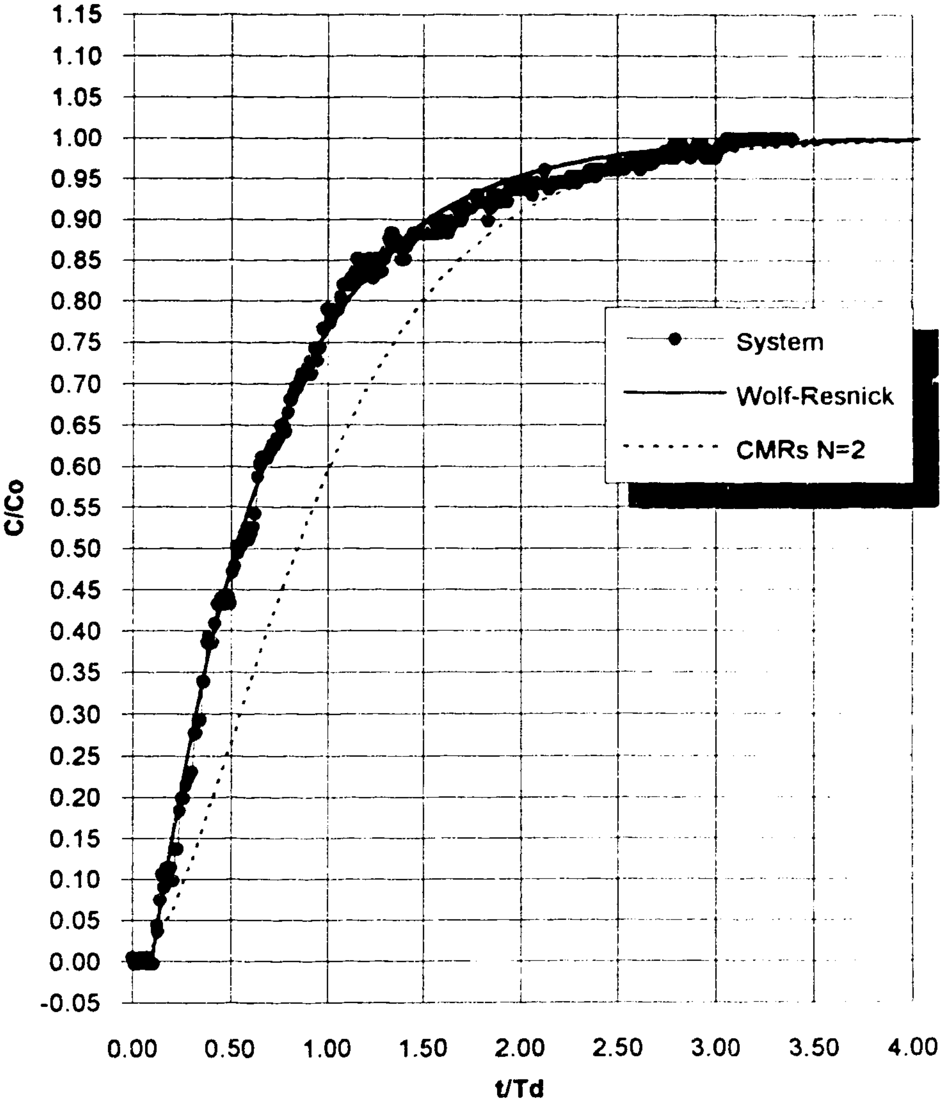


Figure 6.12: Combined Reservoirs at 170 ML/d for Wolf-Resnick and CMRs - in - Series Models

same β), the t_{10} for the first curve must be less than the second one.

6.2.2 CMRs - in - Series Model

This model does not fit the observed data. Again, the greatest difference occurs in the early stage of the curves. The jet effects are dominant in the case of single reservoir tests which are not represented by the model. Figures 6.3 to 6.12 show that after trying several values of N, there is no one that fits the data well.

6.2.3 Rebhun - Argaman Model

This model basically linearizes the Wolf - Resnick equation using a log or ln scale for the horizontal axis. Parameter p indicates the degree of PFR; the higher the p, the bigger the time shift and the steeper the line. Parameter d represents the dead space fraction; the bigger the d, the steeper the line but does not affect the time shift.

Because of a high level of noise in the filters and clearwell data, reliability of the results is questionable (see Figures 6.13 to 6.14). As shown in Table 6.2 above, the dead space fraction should not be less than 0%. In the case of clarifier and combined reservoir tests, the model fits the observed data very well (see Figure 6.15 and 6.22). Once again, no comparison can be made to assess the effect of the flow rate as only one flow rate test conducted for each system.

Interesting results were found in the case of single reservoir tests (tests nos. 4 to 9). Considering data obtained from the tracer studies, it seems that higher flow rates will give rise to a decrease in the p (degree of PFR) and an increase in the d (degree of dead space). But, as can be seen in Table 6.1, the exception occurs again for reservoir no. 3. The same argument can be used: the increase of the reservoir water level (volume) is more dominant than the increase of the flow that affects the t_{10} for reservoir

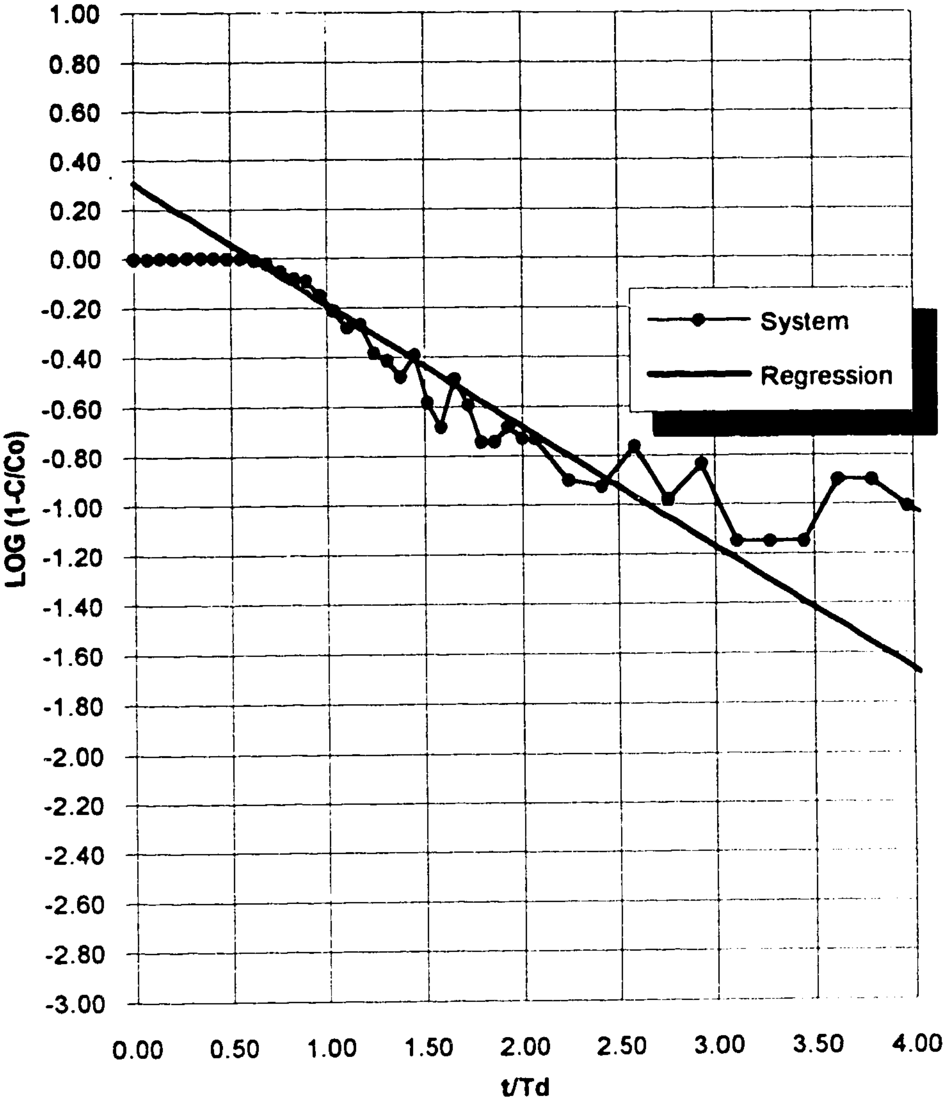


Figure 6.13: Filters + Clearwell at 140 ML/d for Rebhun-Argaman Model

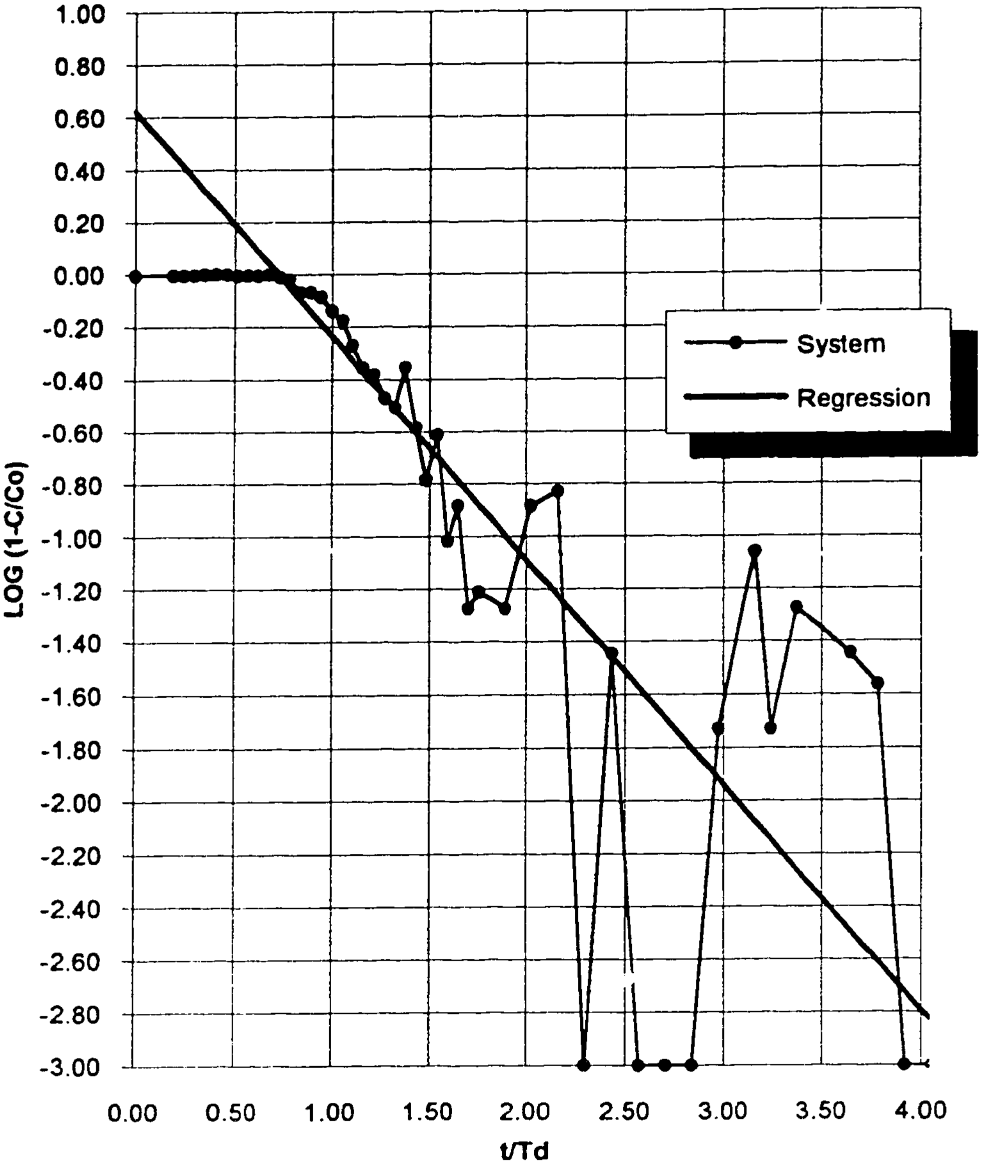


Figure 6.14: Filters + Clearwell at 180 ML/d for Rebhun-Argaman Model

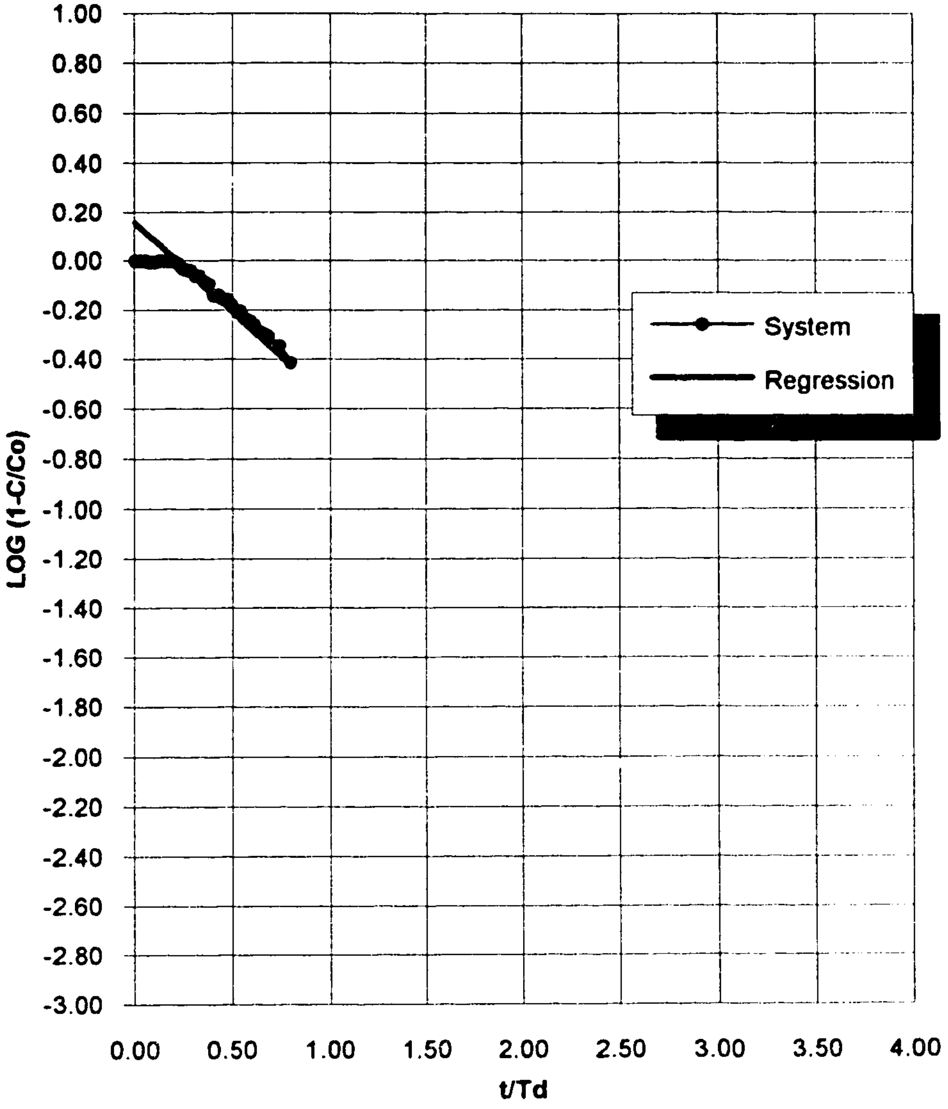


Figure 6.15: Clarifier No.2 at 180 ML/d for Rebhun - Argaman Model

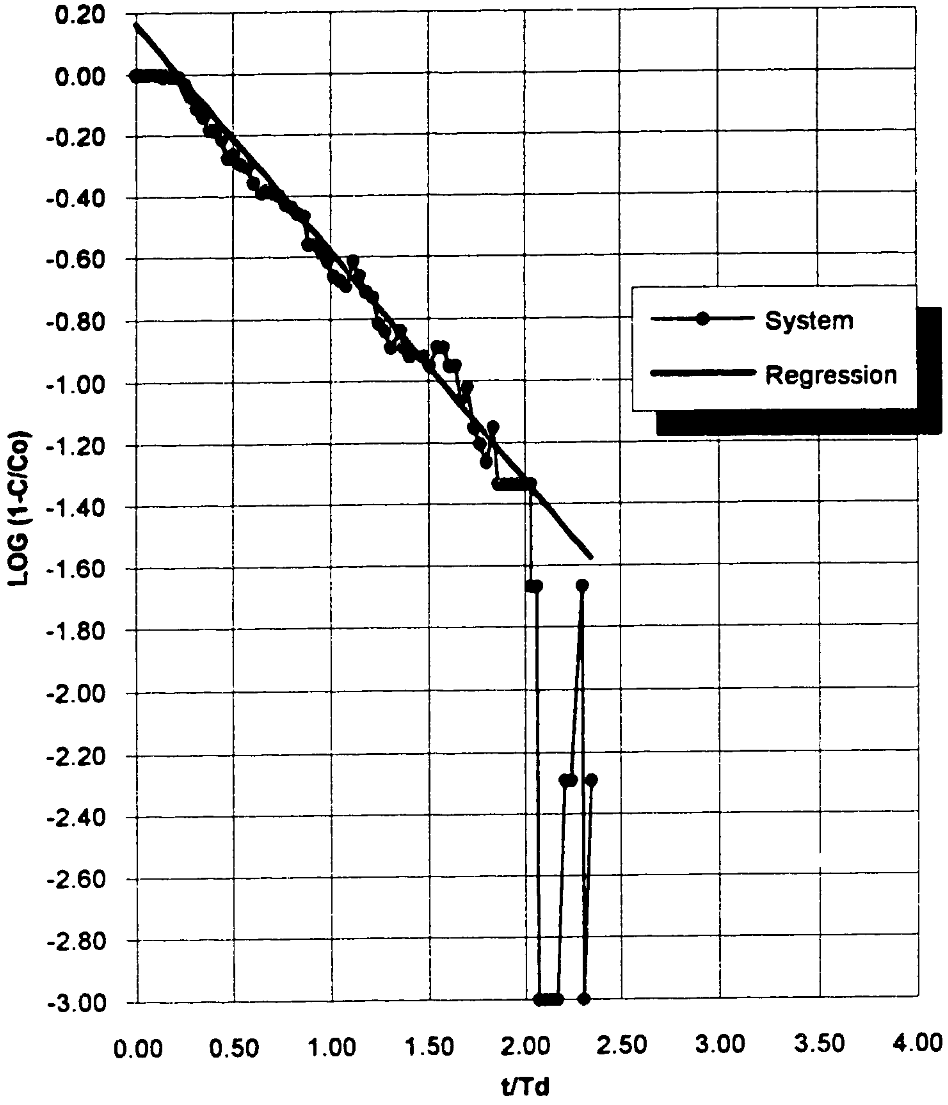


Figure 6.16: Reservoir No.1 at 180 ML/d for Rebhun-Argaman Model

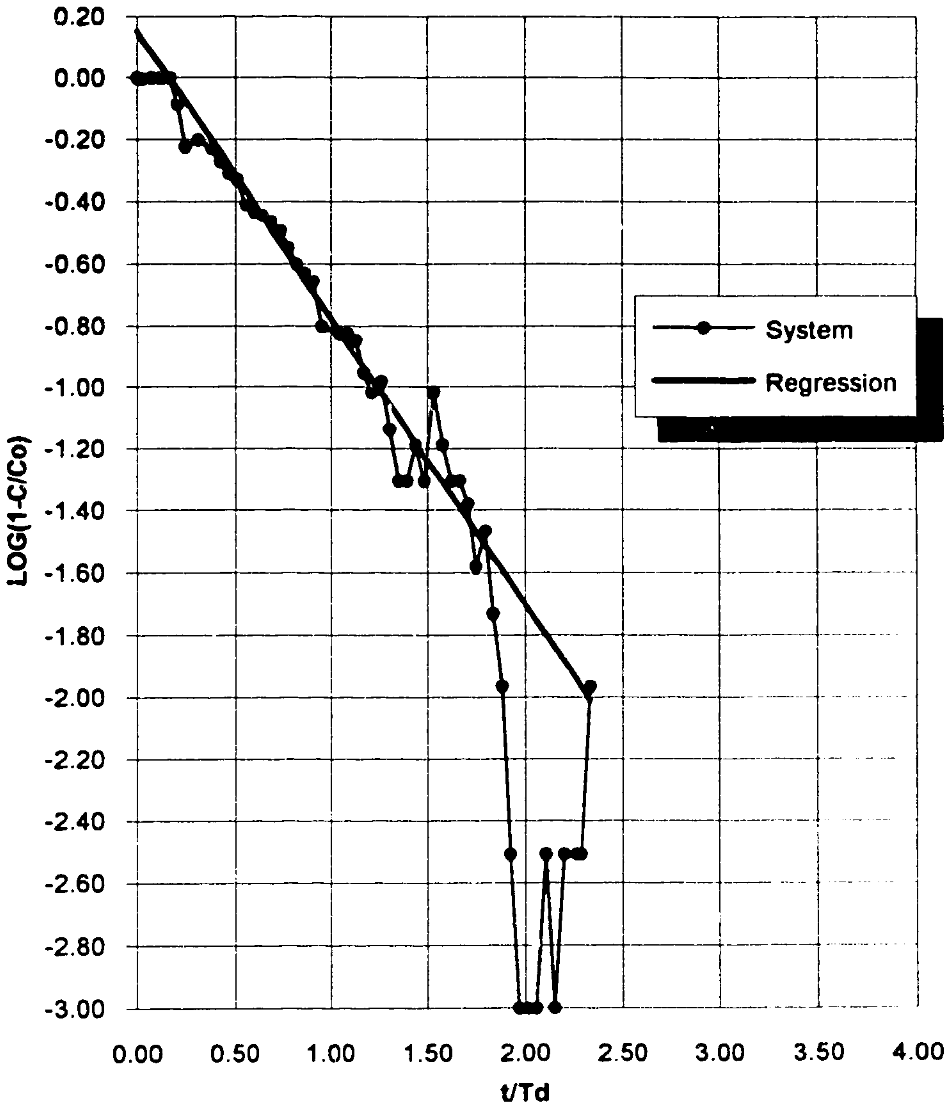


Figure 6.17: Reservoir No.1 at 230 ML/d for Rebhun-Argaman Model

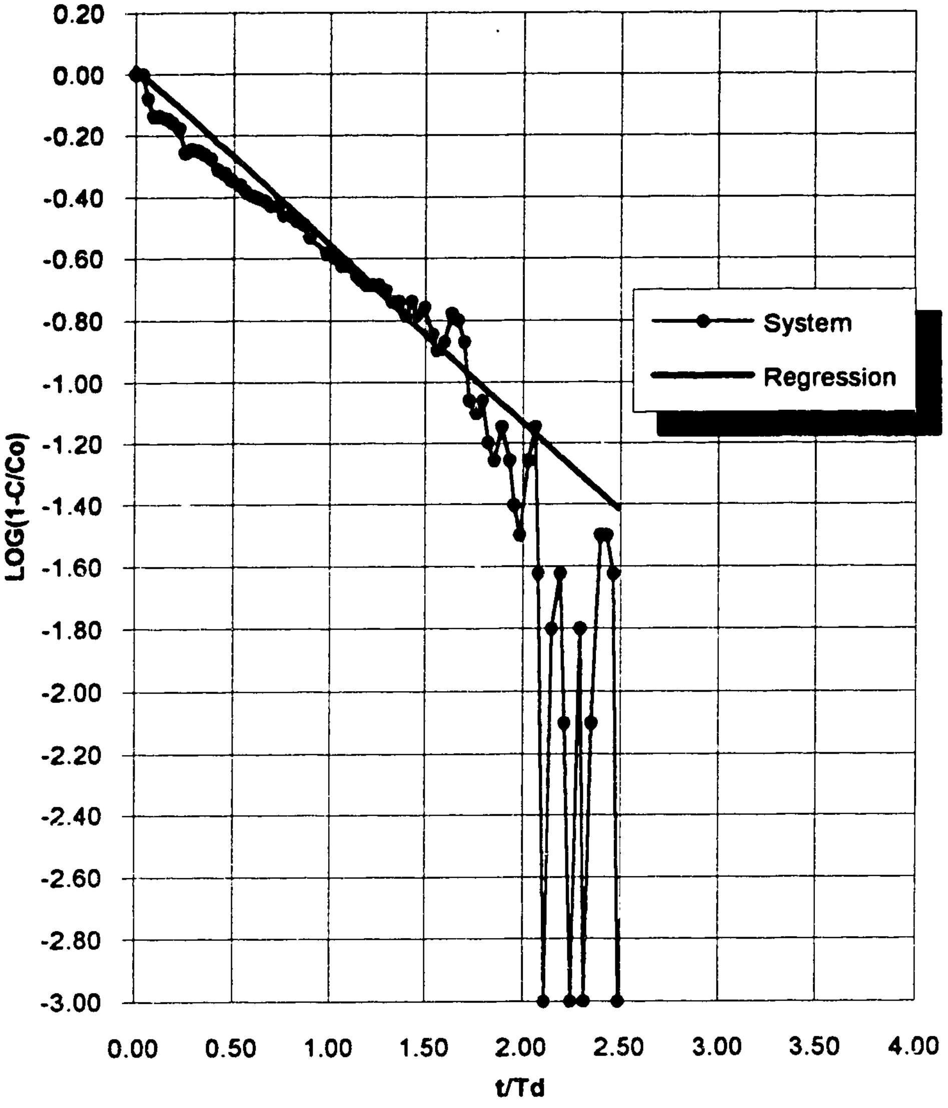


Figure 6.18: Reservoir No.2 at 141 ML/d for Rebhun-Argaman Model

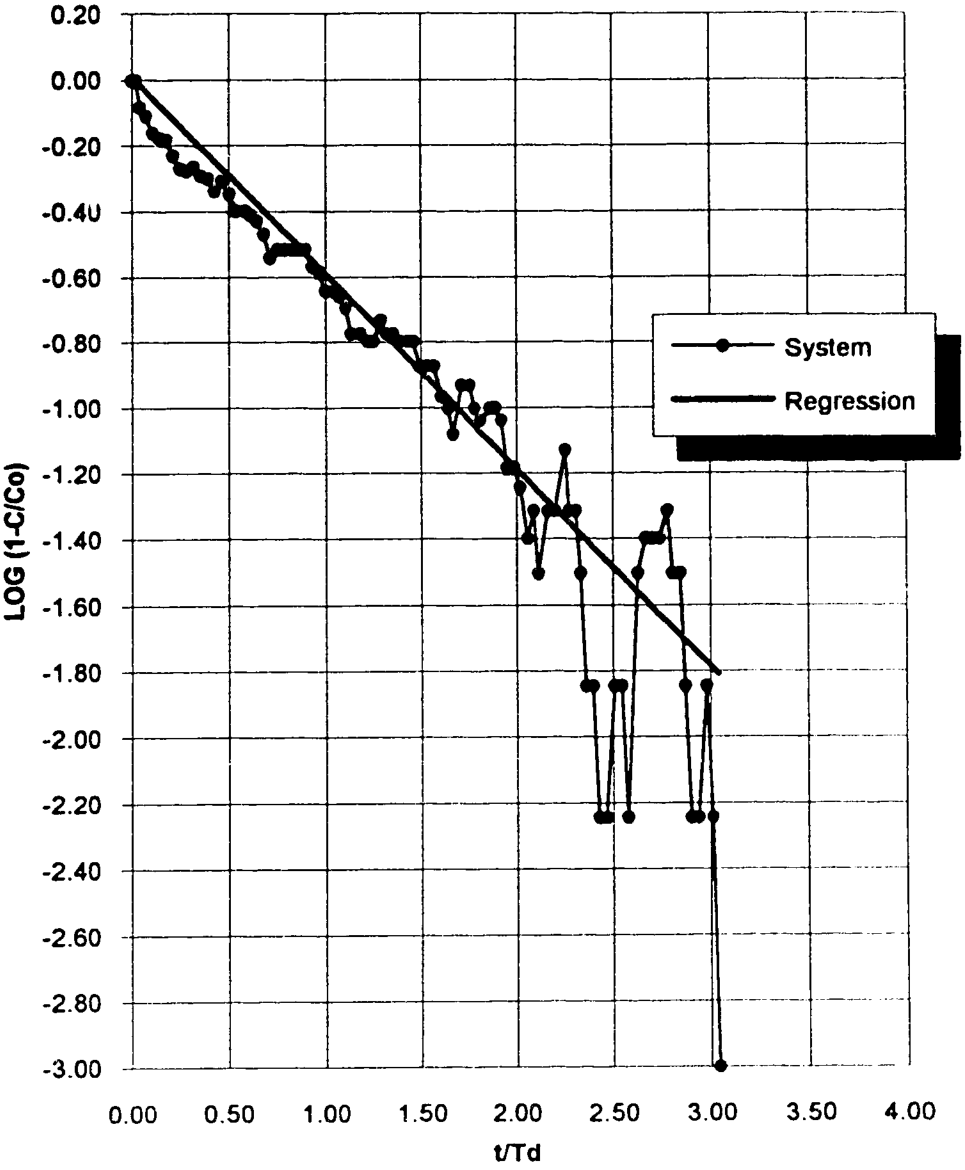


Figure 6.19: Reservoir No.2 at 167 ML/d for Rebhun-Argaman Model

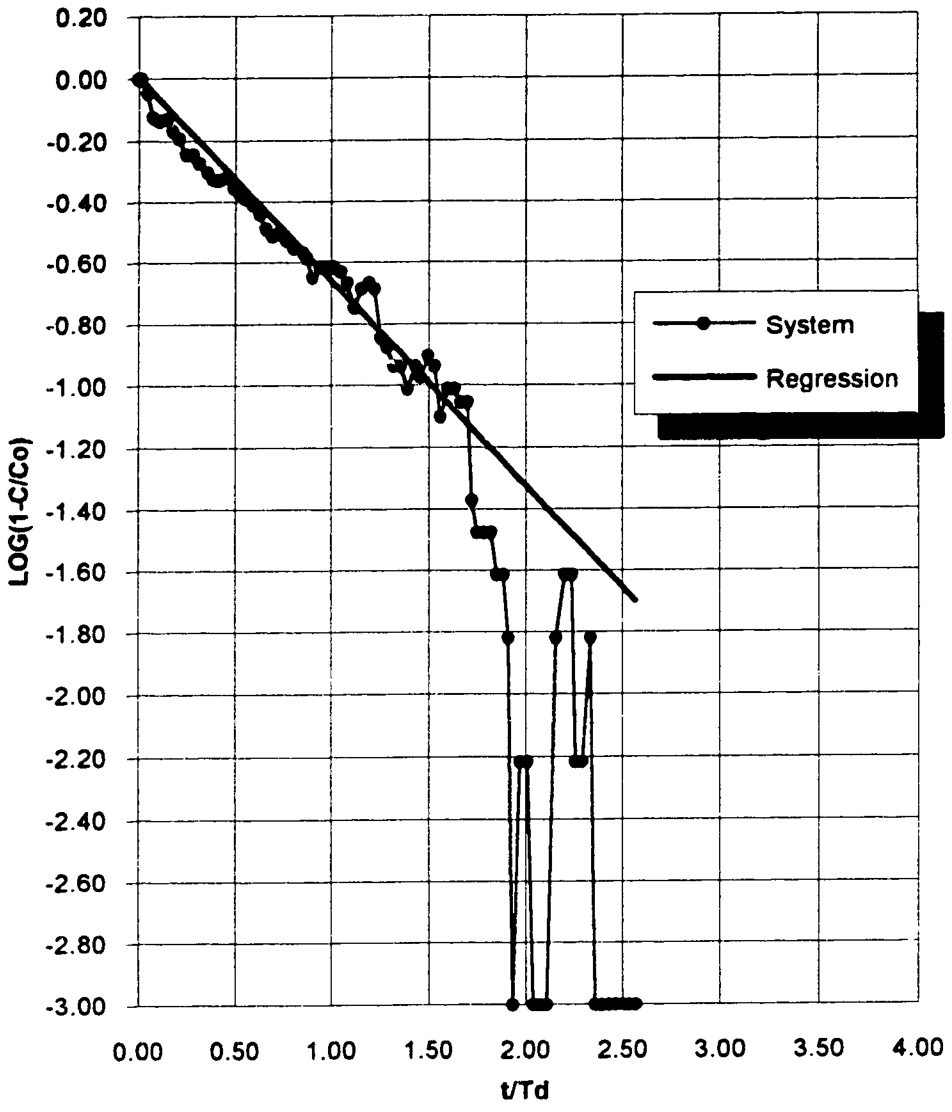


Figure 6.20: Reservoir No.3 at 179 ML/d for Rebhun-Argaman Model

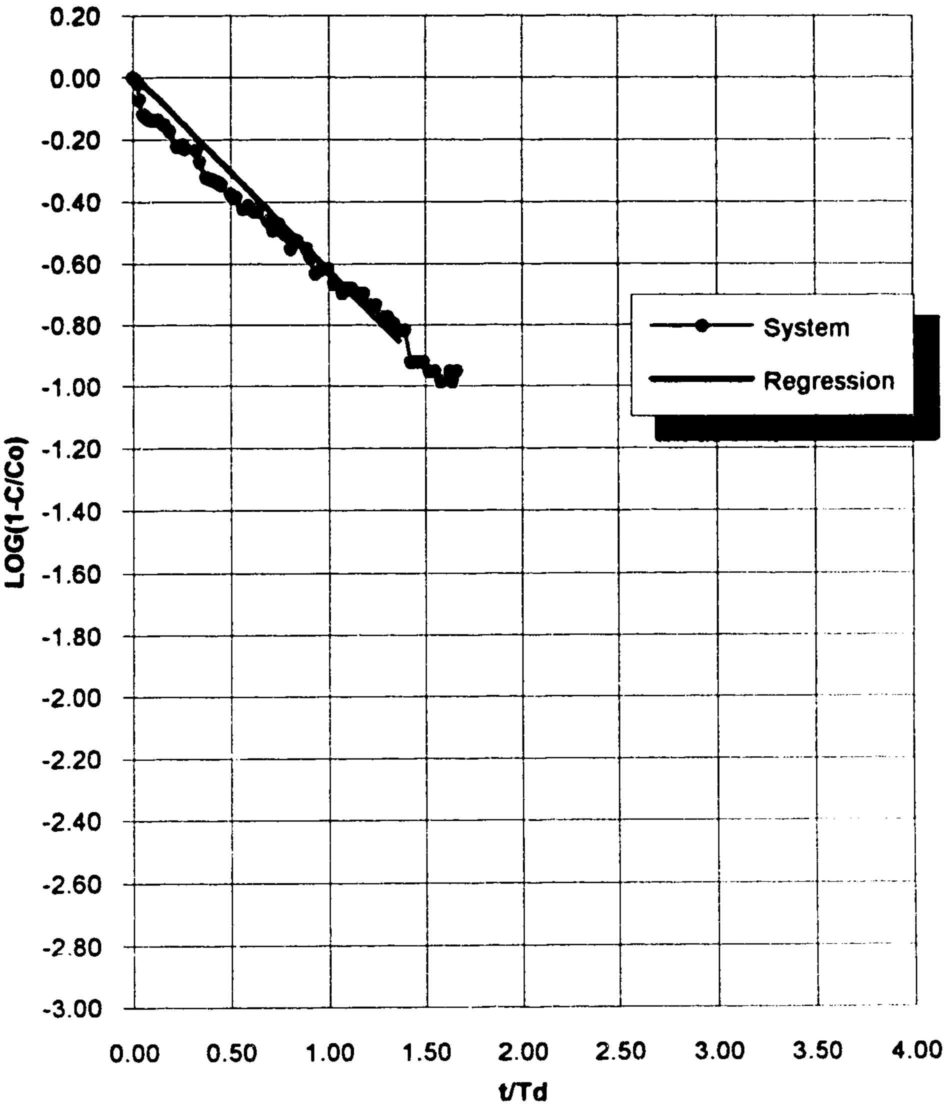


Figure 6.21: Reservoir No.3 at 198 ML/d for Rebhun-Argaman Model

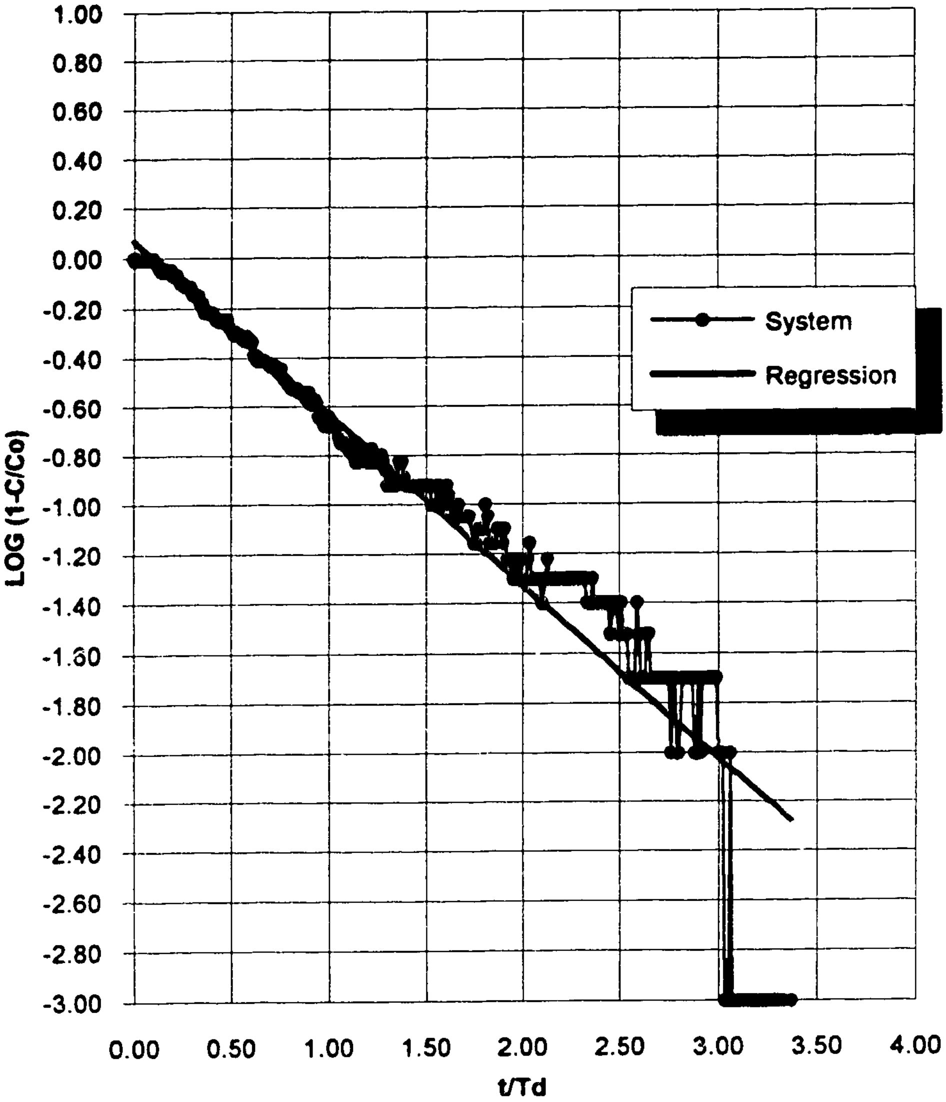


Figure 6.22: Combined Reservoirs at 170 ML/d for Rebhun-Argaman Model

no. 3. See Figures 6.16 to 6.21 above.

The same problem occurs for the early points of the curves for single reservoir tests (tests nos. 4 to 9) but not for the other tests (tests nos. 1, 2, 3, and 10). The same explanation can be given, momentum effects seem dominant for single reservoir tests. Table 6.2 shows that using this model to predict the t_{10} values for reservoirs nos. 2 and 3 can result an over prediction in the order of about 50%. While, in the case of other systems without the momentum effect, prediction using this model seems very good with the maximum difference of about 5% only.

6.2.4 Morril's Index and Baffle Parameter.

The main weakness of the Morril's index (t_{90}/t_{10}) is that it basically depends only on discrete points in the F curve rather than considering the whole residence time distribution. It also does not give a direct qualitative assessment to the SWTR / CT concept. The baffle parameter (t_{10}/T_d) suggested by the Guidance Manual (1989) has the same problem, notwithstanding the fact that it is the only parameter that gives a direct qualitative assessment of a system relative to the SWTR / CT concept. The Morril's index has a slight advantage over the baffle parameter, because the two time parameters (t_{10} and t_{90}) can be found directly from the F curve. In the case of the baffle parameter, T_d needs to be calculated. This means field data such as incoming flow and system volume must be to obtained.

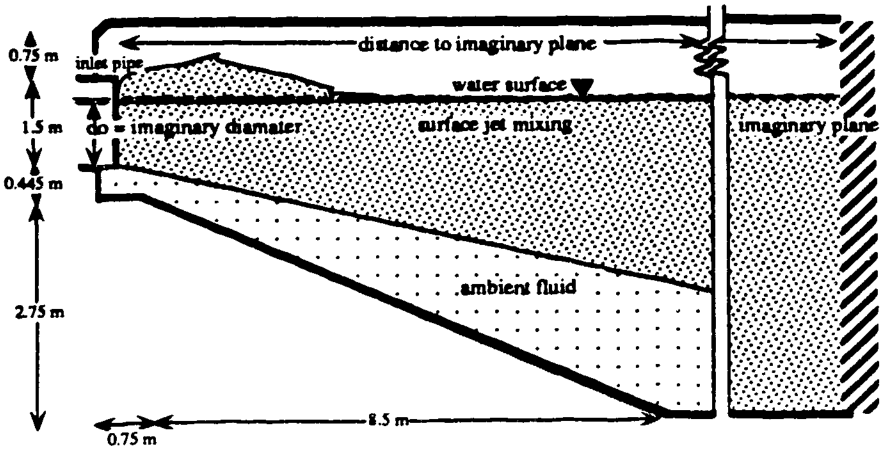
Table 6.2 shows that in the case of filters + clearwell tests and reservoir no. 1 test, both parameters do not seem to be affected by the change of flow rates. In general, the Morril's index tends to increase with the flow, while the baffle parameter does the opposite. The change for the Morril's index due to the flow rate seems to be greater than that for the baffle parameter. From this point of view, the baffle parameter is considered to be better than the Morril's index as it appears to be more constant for different flow rate changes.

6.2.5 Jet Model

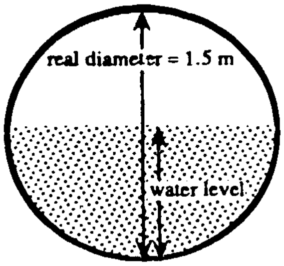
As indicated in the previous section, the empirical models do not tend to fit the observed data well for reservoirs nos. 2 and 3. The poorest fit is in the initial portions of the curve which is important in determining the t_{10}. As these reservoirs have unbaffled inlets and the results indicate that the tracer appeared at the outlet much sooner than expected, it is hypothesized that momentum from the inlet may be responsible for this phenomena.

Flow through the reservoir then was modelled as if there was a jet from the inlet. If velocity and concentration values based on the jet hydraulics tended to match the observed tracer results, it would indicate that the hypothesis could be correct. However, if the jet model indicated that the tracer should arrive much sooner or later than what was observed, doubt would be cast on the hypothesis. Further investigation would be required to determine why the tracer traveled so fast through the reservoir.

The model is based on the standard jet equations that have been explained in chapter 2. A half circular - shape of jet is used which is divided into layers from 0° to 10° from the center line with increments of 1°. Since reservoirs nos. 2 and 3 have the shape of trapezoid, it is assumed that the imaginary planes lie in the middle distances of the diagonal parts, or in the distances of 145 and 175 m, respectively (see Figure 6.23). Each flux that hits the plane is assumed to be removed directly to the outlet point. As the jet model is generated from the inlet profile, it is logical to choose the height of water in each reservoir by taking an average of the water level data for the first hour only, as the inlet profiles reach the steady state before 1 hour (see Figure 6.23). The imaginary diameter can be developed, then the initial velocity of the jet (U_0) can be worked out. The total flux for each layer can be obtained by multiplying the chemical



Note: imaginary plane for Reservoir no. 2 = 145 m
imaginary plane for Reservoir no. 3 = 175 m



Reservoir No.	Flow (ML/d)	Water Level (m)	Length of Travel (m)	Real do (m)	Imaginary do (m)	Uo (m/min)
2	141	3.9	145	1.5	1.0	124.7
2	167	4.0	145	1.5	1.1	122.1
3	179	3.6	175	1.5	0.7	323.2
3	198	4.2	175	1.5	1.2	122.3

Figure 6.23: Surface Turbulent Jet Profile

concentration by the velocity. The C/C_0 values for each system can be found by dividing the total flux by the incoming flow as has been explained in the previous chapter. The detail calculation can be found in Appendix 4.

It was found that all of the C/C_0 values almost reached 1 (about 0.98), representing the total recovery of the tracer. Different calculation was done assuming that only the core of the jet contributed the most flux of the jet. Note: the jet core means the portion of the jet that does not come into contact with the bottom. It has a radius equal to the reservoir depth at the outlet end of the reservoir. It was assumed that the core had an angle of 2° from the center line. Similar calculation was completed considering only up to 2° degree layers that gave a value of C/C_0 of about 0.15 (see Appendix 4).

Figures 6.24 to 6.27 show that the curves obtained from the jet model fit with the real data up to about $C/C_0 = 0.20$ only. This is as expected as the core of the jet has a total tracer (C/C_0) of about 0.15. As the t_{10} lies on the area where the jet model fits to the observed data, it is possible to predict the t_{10} using this model. The estimation is considered to be good (see Table 6.2).

In order to verify the turbulent assumption of the jet, the lowest Reynold number can be obtained for reservoir no. 2 at 141 ML/d. The Reynold number was found to be 1.6×10^6, or much greater than 3,000 for the turbulent flow criterion (Blevins, 1984).

6.2.6 Simplified Jet Model

This model is a development of the previous model. Using Equation 2.92, it is interesting to notice that the constant C_1 seems to be constant in the range of 13.0 and 14. 9 (determined experimentally) or which it should be if the jet effect is dominant (see Table 6.2). This model can be used as a base to determine the t_{10} at other flow rates.

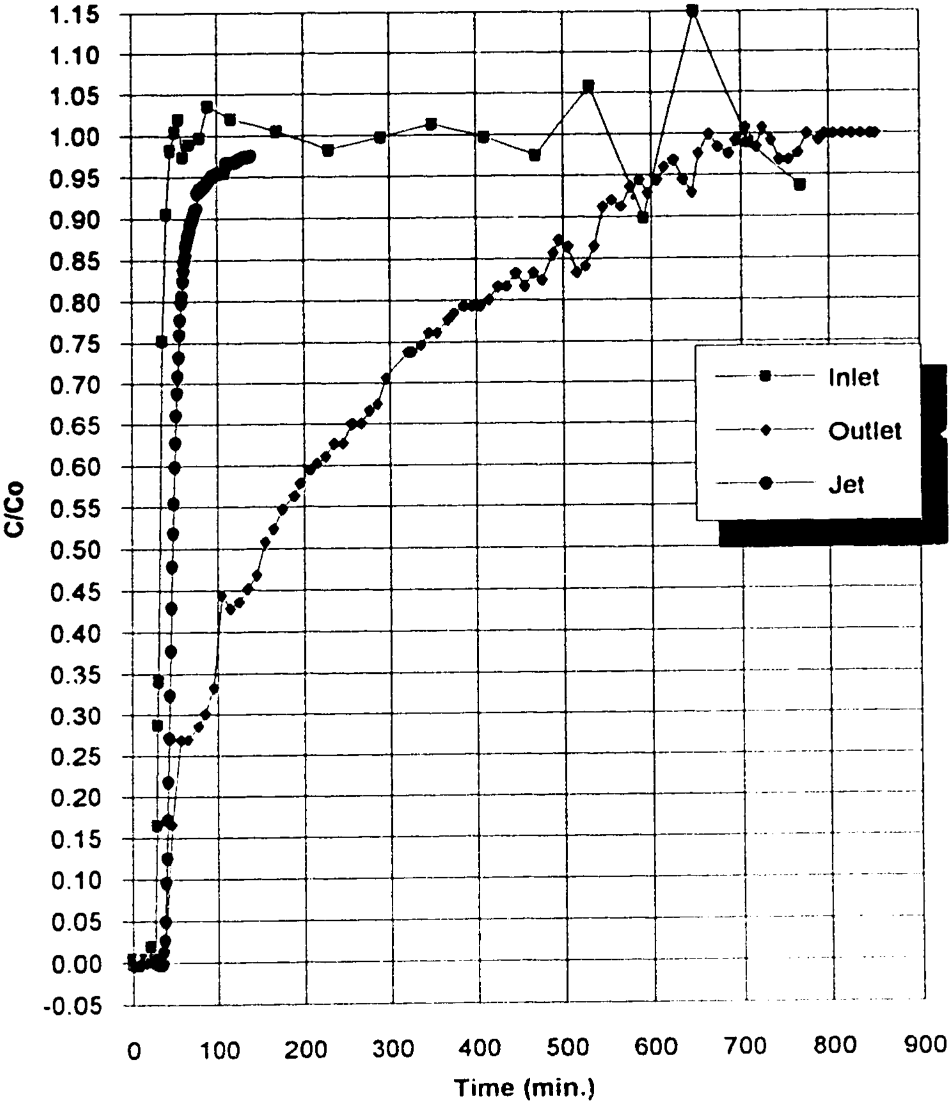


Figure 6.24 Reservoir No. 2 at 141ML/d for Jet Model

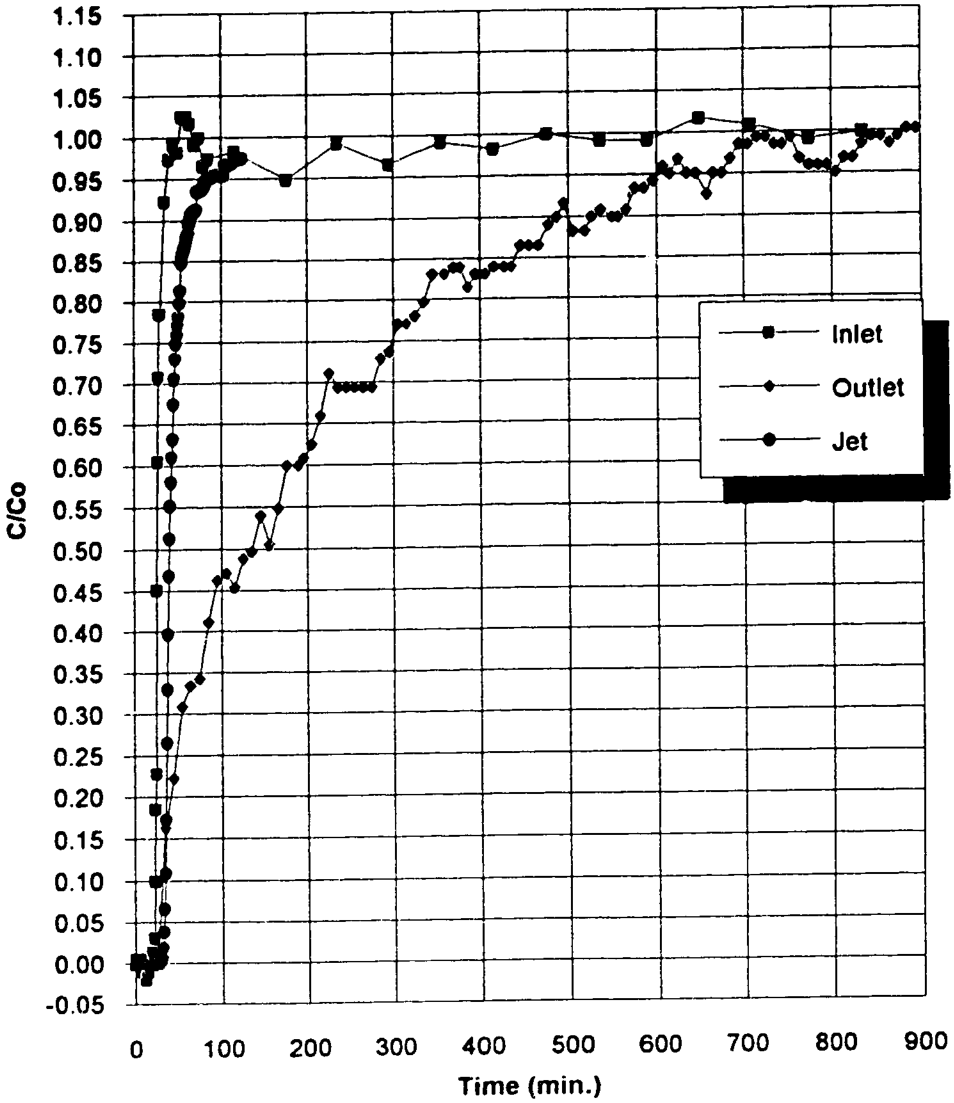


Figure 6.25 Reservoir No. 2 at 167 ML/d for Jet Model

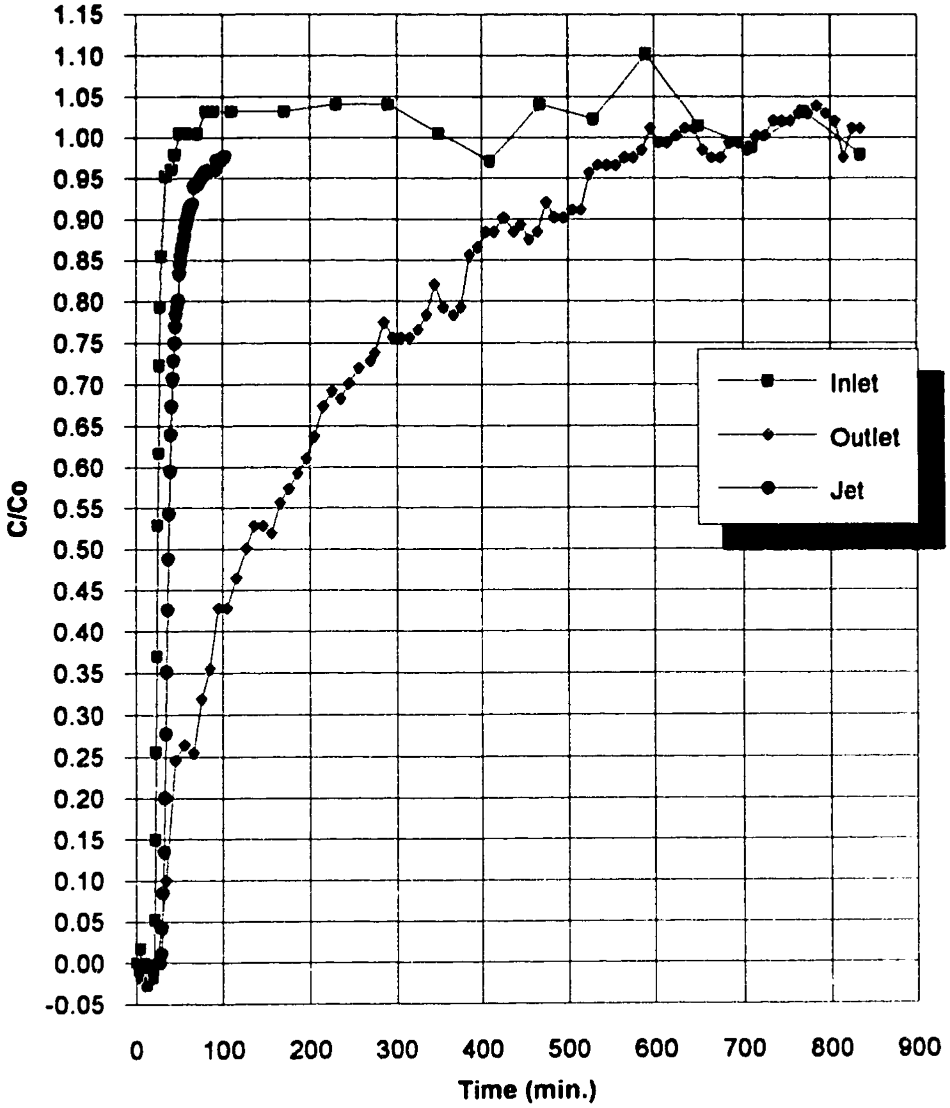


Figure 6.26: Reservoir No. 3 at 179 ML/d for Jet Model

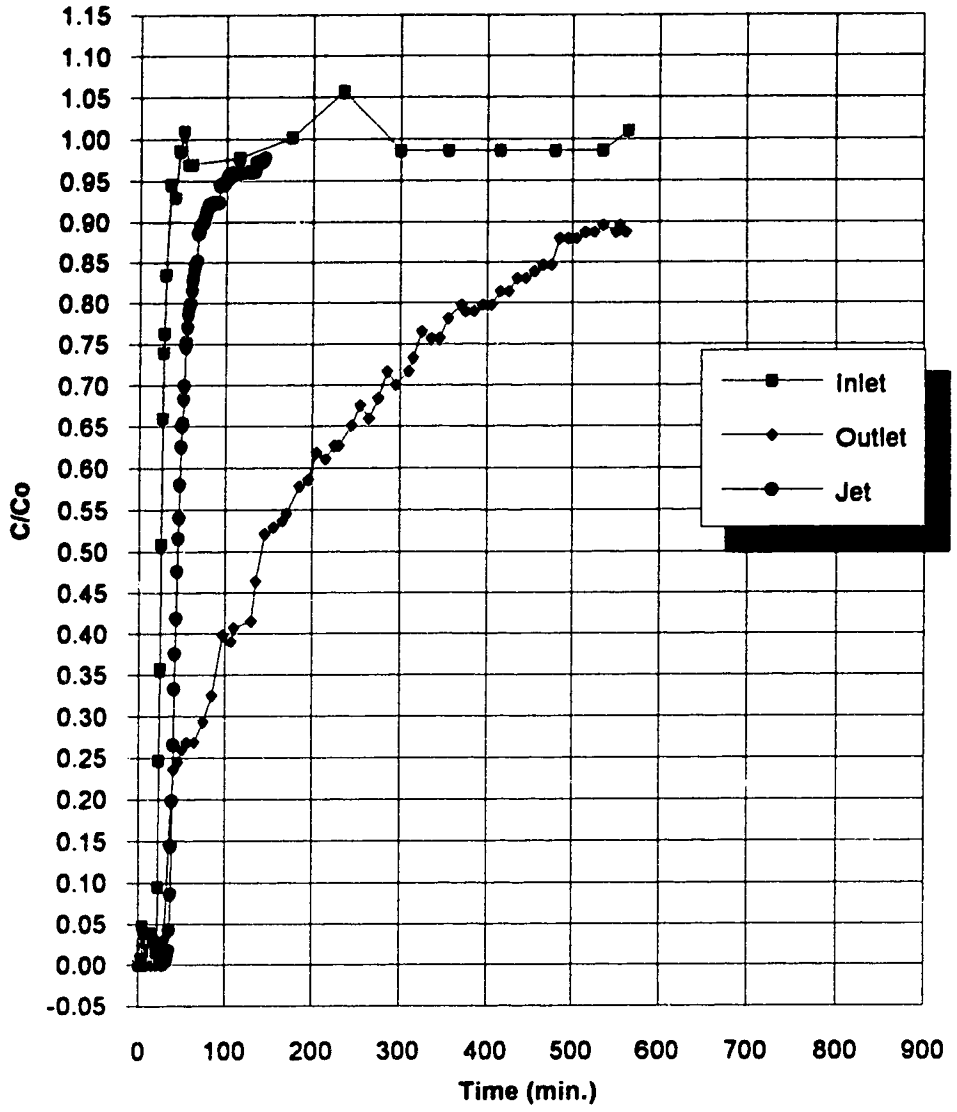


Figure 6.27: Reservoir No. 3 at 198 ML/d for Jet Model

6.3 Suggestions for System Modification

The modeling seems to indicate that jet effect is dominant in the case of reservoirs nos. 2 and 3. t_{10} can be increased by decreasing or eliminating the jet effect. The first alternative is to construct baffles inside the reservoir. Reservoir no. 1 has a baffle that reduces the jet effect. It can be seen from the parameters t_{10}/T_d that are greater compared with those for reservoirs nos. 2 and 3.

Another option is to install diffusers in the inlet. The idea is to spread the momentum across the whole width of the reservoir. In addition, momentum from a jet will dominate the flow for approximately 100 diameters of the jet out from the discharge point. By diffusing the water with many small jets, the momentum dominated distance is greatly reduced. Using a well designed diffuser should result in flow that closely resembles a PFR plus dispersion. Interesting results were recently obtained in another study by the University of Alberta (University of Alberta, 1994). Tracer studies were conducted at the Rossdale Water Treatment Plant in Edmonton, Alberta. Two of the tests were conducted at two identical rectangular stilling basins (6700 L each). The inlet has many weirs to distribute the flow evenly across the inlet of the basin. There was no jet effect found in this case, the t_{10} values are quite large (73 minutes for 55 ML/d and 58 minutes for 75 ML/d), and the output profiles are very close to the PFR with small dispersion.

In the case of filters + clearwell, no modification is required since the system is classified as "superior" already. Clarifier no.2 and reservoir no.1 with the baffle parameters of about 0.3 may also need some modification.

7.0 CONCLUSIONS

The first three conclusions given are related to the general test results for the case study (E. L. Smith Water Treatment Plant performance). While, the second five conclusions relate generally to the residence time distribution in water treatment plants. Three last comments are related to the SWTR / CT concept (1989).

1). The t_{10} values obtained from the tests can be applied to investigate the system compliance to the CT concept. According to the baffle parameter suggested by the Guidance Manual (1989), the mixing quality classification for all reservoirs are "poor" and "no baffle", while clarifier no. 2 is "poor", and the filters + clearwell are "superior". Modification is necessary for reservoirs nos. 2 and 3 by constructing baffle walls or installing diffusers in front of the inlet pipes. Reservoir no. 1 and clarifier no. 2 may need some modification as well. The filters and clearwell combination does not require modification.

2). Overall, the use of sodium chloride, step input, and flame emission photometer gives very good results.

3). A smaller sampling time interval, say 1 minute, is probably necessary as the prediction of the t_{10} is based on discrete points in the F curve.

4). The Morril's index and baffle parameter are based on discrete points in the F curve, therefore they give less accuracy to the estimation. Still, the baffle parameter is the only parameter to give a direct assessment for the CT concept.

5). The Wolf - Resnick, Rebhun - Argaman, and CMRs - in - series models are based on empirical parameters. These models are better than those based on discrete points as they consider the whole curve. However, these models may not always give good estimations of the t_{10}, especially for a system without baffles. In a system without baffles, the momentum may be dominant, and in that case the jet model seems to give better estimations of the t_{10}.

6). The jet model was applied to determine if the momentum from the inlet was the cause of the very small t_{10} values for reservoirs nos. 2 and 3. The jet model appeared to indicate that the inlet jet was responsible to the fast passage of the tracer through the reservoir. Early portions of the residence time distribution were predicted using the jet model without calibration (parameters were taken directly from the references). Application of the jet model may be possible at other sites with similar unbaffled conditions. The model is only applicable, in this case, up to $C/C_0 = 0.2$ which is about the flux associated with the core of the jet. For a well designed reservoir, when the momentum is not dominant, the model is not applicable. The major finding of using the jet model is showing the importance of momentum dissipating of the inlet if long residence times are desired.

7). The simplified jet model is another method to assess the t_{10}. As the constant C_1 was found to be relatively constant, it provides another indication that early portions of the residence time distribution were dominated by the jet / momentum effect for reservoirs nos. 2 and 3.

8). All models described can provide valuable information in assessing the residence time distribution. However, limitation of each must be considered when they are applied.

9). Three comments are addressed to the Guidance Manual (1989) / the SWTR:

a) the assessment of other t_{10} values at different flow rates, which is based only on the flow rates and the t_{10} values, may not be correct as it does not consider the water level (volume) and other factors,

b) suggestion to use the baffle parameter (t_{10}/T_d) to classify the performance of a system might not be correct since it is based on discrete points only. A small error in the critical area may give a significant error in the system performance prediction, and

c) the Rebhun - Argaman model that is suggested to predict the t_{10} should be used cautiously. This model cannot be applied in a system which is dominated by the momentum effect.

8.0 LIST OF REFERENCES

1. ---------------. 1989. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources. AWWA, Denver, Colorado. pp. 26, 108 - 110, and 211 - 256.
2. ---------------. 1989. The Merck Index: an Encyclopedia of Chemicals, Drugs, and Biologicals, 11th edition. S. Budavari, editor. Merck, Rahway, New Jersey. pp. 8545 - 8546.
3. ---------------. 1992. Standard Methods for the Examination of Water and Wastewater, 18th edition. A. E. Greenberg, L. S. Clesceri, and A. D. Eaton, editors. APHA - AWWA - WED, Washington, District of Columbia. pp. 3-93 - 3-95.
4. ---------------. 1993. Flow Measurement, Water Level, and Site Plan Drawing. E. L. Smith Water Treatment Plant, Edmonton, Alberta.
5. ---------------. 1993. Guidelines for Canadian Drinking Water Quality, 5th edition. The Minister of National Health and Welfare, Ottawa. pp. 9 - 13.
6. ---------------. 1993. Recycle Stream Effects on Water Treatment. Report No. 90629. AWWA Research Foundation, Denver, Colorado. pp. 1.
7. ---------------. 1994. Test Results from Tracer Studies at Rossdale Water Treatment Plant. The University of Alberta, Edmonton, Alberta.
8. Agunwamba, J. C. 1992. A New Method for Dispersion Number Determination in Waste Stabilization Pond. Water, Air, and Soil Pollution. **63** : 361 - 369.
9. Andrews, R. C., Ferguson, M., Lee, T., and Reske, J. 1992. Evaluation and Optimization of Conventional Disinfectants using the CT Concept. City of Edmonton, Public Works Department, Edmonton, Alberta. pp. 1 - 26.

10. Auckly, C. and Borgerding, J. 1991. C.T. Disinfection Practice in Open Chlorine Contact Basins. (In) Environmental Engineering: Proceedings of the 1991 Specialty Conference. P. A. Krenkel, editor. ASCE, Reno, Nevada. pp. 661 - 666.

11. Bellar, T. A., Lichtenberg, J. J., and Kroner, R. C. 1974. The Occurrence of Organohalides in Chlorinated Water. Journal AWWA. **66** (12) : 703 - 706.

12. Bishop, M. M., Morgan, J. M., Cornwell, B. L., and Jamison, D. K. 1990. Evaluation of CxT in Water Plants and Methods to Improve Detention Time Characteristics. (In) 1990 Annual Conference Proceedings. AWWA, Cincinnati, Ohio. pp.1559 - 1577.

13. Bishop, M. M., Morgan, J. M., Cornwell, B., and Jamison, D. K. 1993. Improving the Disinfection Detention Time of a Water Plant Clearwell. Journal AWWA. **85** (3) : 68 - 75.

14. Blevins, R. D. 1984. Applied Fluid Dynamics Handbook. Van Nostrand Reinhold, New York, New York. pp. 1 - 4 and 229 - 278.

15. Brumo, G. W. 1972. Interpretation of Tracer Tests on Sedimentation Tanks. Journal TAPPI. **55** (7) : 1097 - 1102.

16. Bryant, E. A., Fulton, G. P., and Budd, G. C. 1992. Disinfection Alternatives for Save Drinking Water. Van Nostrand Reinhold, New York, New York. pp. 1 - 40.

17. Canadian Water and Wastewater Association. 1993. Guidelines for Canadian Drinking Water Quality: Water Treatment Principles and Applications, a Manual for the Production of Drinking Water. Minister of National Health and Welfare, Ottawa. pp. 125 - 127.

18. Chen, J. C. and Rodi, W. 1980. Vertical Turbulent Buoyant Jets: A Review of Experimental Data. Pergamon Press, New York, New York. pp. 31 - 32.

19. CH2MHILL. 1993. Draft Final Report: City of Edmonton Reservoir Circulation Study. CH2MHILL Engineering Ltd. Edmonton, Alberta. pp. 4-5 - 4-7.

20. Dunn, H. J., Pinsky, D. E., and Mahadevan P. 1991. A Hydraulic Investigation of Flow Patterns and Disinfection Requirements for a Circular Clearwell. (In) 1991 Annual Conference Proceedings. AWWA, Philadelphia, Pennsylvania. pp. 323 - 344.

21. Glicker, J. L. and Edwards, R. A. 1991. Giardiasis Risk from an Unfiltered, Protected Surface Water Surface. Journal AWWA. **83** (11) : 46 - 51.

22. Gregory, R. and Zabel, T. F. 1990. Sedimentation and Flotation. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, New York. pp. 367 - 450.

23. Hagerman, J. R., Pickering, N. B., Ritter, W. F., and Steenhuis, T. S. 1989. In Situ Measurement of Preferential Flow. (In) National Water Conference. T. A. Austin, editor. ASCE, Newark, Delaware. pp. 117 - 126.

24. Hart, F. L. 1975. Modifications Improve Chlorine Contact Chamber Performance: Part I. Journal of Water and Sewage Works. **121** (7) : 73 - 75.

25. Hart, F. L. and Gupta, S. K. 1978. Hydraulic Analysis of Model Treatment Units. Journal of the Environmental Engineering Division. **104** (8) : 785 - 798.

26. Hart, F. L. and Vogiatzis, Z. 1982. Performance of Modified Chlorine Contact Chamber. Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers. **108** (6) : 549 - 561.

27. Hart, F. L., Allen, R., DiAlesio, J., and Dzialo, J. 1979. Improving Hydraulic Performance of Chlorine Contact Chamber. Journal WPCF. **51** (12) : 2868 - 2875.

28. Herwaldt, B. L., Craun, G. F., Stokes, S. L., and Juranek, D. D. 1992. Outbreaks of Waterborne Disease in the United States: 1989-90. Journal

AWWA. 84 (4) : 129 - 135.

29. Hilterbrand, D. J., Tiliman, G. M., and Chowdury, Z. K., and Welch, D. K. 1991. Reducing Treatment Requirements with Bank Filtration Wells. (In) 1991 Annual Conference Proceedings. AWWA, Philadelphia, Pennsylvania. pp. 421 - 432.

30. Hoff, J. C. 1987. Strengths and Weaknesses of using C.t Values to Evaluate Disinfection Practice. (In) AWWA Seminar Proceedings. Assurance of Adequate Disinfection, C-T or Not C-T. AWWA, Denver, Colorado. pp. 49 - 66.

31. Hudson, H. E. Jr. 1975. Residence Times in Pretreatment. Journal AWWA. 67 : 45 - 52.

32. Jen, Y., Wiegel, R. L., and Mobarek, I. 1966. Surface Discharge of Horizontal Warm - Water Jet. Journal of the Power Division: Proceedings of the American Society of Civil Engineers. 4 : 1 - 31.

33. Johnston, A. J. 1990. Jet Outfalls Entering Shallow Tailwaters. (In) Encyclopedia of Fluid Mechanics, Vol 10. N. P. Cheremisinoff, editor. Gulf Publishing, Houston, Texas. pp. 267 - 294.

34. Johnston, A. J. and Halliwell, A. R. 1986. Jet Behavior in Shallow Receiving Water. Proceedings of the Institutional of Civil Engineers, Part 2. 81 (12) : 549 - 568.

35. Johnston, A. J. and Volker, R. E. 1993. Round Buoyant Jet Entering Shallow Water. Journal of Hydraulic Research. 31 (1) : 121 - 138.

36. Joost, R., Chowdhury Z. K., and Francis, T. 1990. Plant-Scale Tracer Studies: an Assessment of Actual Detention Times for Primary Disinfection. (In) 1990 Annual Conference Proceedings. AWWA, Cincinnati, Ohio, pp. 1583 - 1600.

37. Kennedy, M. S., Moegling, S., Sarikelle, S., and Suravallop, K. 1993.

Assessing the Effects of Storage Tank Design on Water Quality. Journal AWWA. **85** (7) : 78 - 88.

38. Kennedy, M. S., Sarikelle, S., and Suravallop, K. 1990. Calibration of Water Quality Models for Potable Distribution Systems (In) 1990 Annual Conference Proceedings. AWWA, Cincinnati, Ohio, pp. 93 - 108.

39. Kennedy, M. S., Sarikelle, S., Moegling, S., and Suravallop, K. 1991. Mixing Characteristics in Distribution System Storage Reservoirs. (In) 1991 Annual Conference Proceedings. AWWA, Philadelphia, Pennsylvania. pp. 139 - 155.

40. Kotsovinos, N. E. and Angelidis, P. B. 1991. The Momentum Flux in Turbulent Submerged Jets. Journal of Fluid Mechanics. **229** : 453 - 470.

41. LeChevallier, M. W. and Norton, W. D. 1992. Examining Relationships between Particle Counts and Giardia, Cryptosporidium, and Turbidity. Journal AWWA. **84** (12) : 54 - 60.

42. Leland, D. E. and Damewood, M. III. 1990. Slow Sand Filtration in Small Systems in Oregon. Journal AWWA. **82** (6) : 50 - 59.

43. Lev, O. and Regli, S. 1992. Evaluation of Ozone Disinfection Systems: Characteristic Time T. Journal of Environmental Engineering. **118** : 268 - 285.

44. Levenspiel, O. and Bischoff, K. B. 1963. Patterns of Flow in Channel Process Vessels. (In) Advances in Chemical Engineering. T. B. Drew, J. W. Hoopes, Jr., and T. Vermeulen, editors. Academic Press, New York, New York. pp. 95 - 192.

45. Marroco, F. A. 1987. Application of CT Factors in Pennsylvania Surface Water Supplies. (In) AWWA Seminar Proceedings. Assurance of Adequate Disinfection, C-T or Not C-T. AWWA, Denver, Colorado. pp. 11 - 20.

46. Marske, D. M. and Boyle, J. D. 1973. Chlorine Contact Chamber Design. Journal of Water and Sewage Works. **120** (1) : 70 -77.

47. Metcalf & Eddy, Inc. 1991. Wastewater Engineering: Treatment, Disposal, and Reuse. McGraw - Hill, New York, New York. pp.1221 - 1222 and 1265 - 1273.

48. Mih, W. C. 1989. Equations for Axisymmetric and Two Dimensional Turbulent Jets. Journal of Hydraulics Engineering. 115 (12) : 1715 - 1719.

49. Mitha, S. A. and Mohsen, M. F. N. 1990. Scale Effect on Dispersion in Chlorine Contact Chambers. Canadian Journal of Civil Engineering. 17 : 156 - 165.

50. Moser, R. H. 1991. Overview of the Disinfection By - Product Problem. (In) 1991 Annual Conference Proceedings. AWWA, Philadelphia, Pennsylvania. pp. 1 - 4.

51. Philpot, L. 1989. Nematodes Discovered in Private Distribution System: Are Biological Standards Appropriate? (In) 1989 Water Quality Technology Conference. AWWA, Philadelphia, Pennsylvania. pp. 1127 - 1140.

52. Pinsky, D. E., Dunn, H. J., and Hess, A. F. 1991. CT Compliance Strategies: Three Case Studies. (In) 1991 Annual Conference Proceedings. AWWA, Philadelphia, Pennsylvania. pp. 303 - 344.

53. Polpraset, C. and Bhattarai, K. K. 1985. Dispersion Model for Waste Stabilization Ponds. Journal of Environmental Engineering. 1 (45) : 45 - 59.

54. Process Development Team. 1991. Evaluation of CT Values for Disinfection at Edmonton's Water Treatment Plants. The City of Edmonton, Edmonton, Alberta. pp. 1 - 30.

55. Qualls, R. C. and Johnson, J. D. 1983. Kinetics of the Short Term Consumption of Chlorine by Fulvic Acid. Environmental Science and Technology. 17 (11) : 692 - 698.

56. Rajaratnam, N. 1976. Turbulent Jet. Elsevier, New York, New York. pp.27 -

49, 115 - 129, and 267 - 294.

57. Rajaratnam, N. 1983. Theory of Turbulent Jets. (In) Handbook of Fluids in Motion. N. P. Cheremisinoff and R. Gupta, editors. Ann - Arbor Science, Ann - Arbor, Michigan. pp. 251 - 278.

58. Rajaratnam, N. 1985. An Experimental Study of Bluff Surface Discharges with Small Richardson Number. Journal of Hydraulic Research. **23** (1) : 47 - 54.

59. Rajaratnam, N. 1986. Turbulent Mixing and Diffusion of Jets. (In) Dynamics of Single - Fluid Flows and Mixing: Encyclopedia of Fluid Mechanics, Vol. 2. N. P. Cheremisinoff, editor. Gulf Publishing, Houston, Texas. pp. 391 - 405.

60. Rajaratnam, N. 1988. Turbulent Surface Jets in Stagnant and Moving Ambients. (In) Civil Engineering Practice: 2 / Hydraulics / Mechanics. P. N. Cheremisinoff, N. P. Cheremisinoff, and S. L. Cheng, editors. Technomic Publishing, Lancaster, Pennsylvania. pp. 629 - 658.

61. Rajaratnam, N. and Humphries, J. A. 1984. Turbulent of Non - Buoyant Surface Jets. Journal of Hydraulic Research. **22** (2) : 103 - 115.

62. Rajaratnam, N. and Pani, B. S. 1974. Three - Dimensional Turbulent Wall Jets. Journal of Hydraulic Division. **100** (1) : 69 -83.

63. Ramaprian, B. R. and Chandrasekhara, M. S. 1985. LDA Measurements in Plane Turbulent Jets. Journal of Fluids Engineering Transactions: ASME. **107** : 264 - 271.

64. Reasoner, D. J. 1991. Pathogens in Drinking Water - Are There any New Ones? (In) 1991 Water Technology Conference. AWWA, Orlando, Florida. pp. 509 - 530.

65. Rebhun, M.and Argaman, Y. 1965. Evaluation of Hydraulic Efficiency of Sedimentation Basins. Journal of the Sanitary Engineering Division. **91** (5) : 37 - 45.

66. Regli, S. 1987. USEPA Disinfection Regulations. (In) AWWA Seminar Proceedings. Assurance of Adequate Disinfection, C-T or Not C-T. AWWA, Denver, Colorado. pp. 1 - 10.

67. Regli, S. 1989. Hows and Whys of CTs. (In) 1989 Annual Conference Proceedings. AWWA, Los Angeles, California. pp. 945 - 966.

68. Sawyer, C. M. and King, P. H. 1969. The Hydraulic Performance of Chlorine Contact Tanks. (In) Proceedings of the 24th Industrial Waste Conference. Purdue University, Lafayette, Indiana. pp. 1151 - 1167.

69. Simpson, K. A. 1989. Quality Assurance for Operations: A Case Study. (In) Water Quality Technology Conference. AWWA, Philadelphia, Pennsylvania. pp. 349 - 363.

70. Sobey, R. J., Johnston, A. J. and Keane, R. D. 1988. Horizontal Round Buoyant Jet in Shallow Water. Journal of Hydraulic Engineering. **114** (8) : 910 - 926.

71. Sobsey, M. D., Dufour, A. P., Alfred, P., Gerba, C. P., LeChevallier, M. W., and Payment, P. 1993. Using a Conceptual Framework for Assessing Risks to Health form Microbes in Drinking Water. Journal AWWA. **85** (3): 44 - 48.

72. Stanley, S. J., Smith, D. W., and Prince, D. 1993. Determination of CT Values to Measure the adequacy of Water Treatment Disinfection. (In) Canadian Society of Civil Engineering Annual Conference. CSCE, Fredericton, New Brunswick. pp. 403 - 412.

73. Tamai, N., Wiegel, R. L., and Tornberg, G. F. 1969. Horizontal Surface Discharge of Warm Water Jets. Journal of the Power Division: ASCE. **10** : 253 - 275.

74. Taras, M. 1956. Estimation of Flow - Through Time by Continuous Dose

Method. Joumal AWWA. **48** (6) : 700 - 712.

75. Teefy, S. M. and Singer, P. C. 1990. Performance and Analysis of Tracer Tests to Determine Compliance of a Disinfection Scheme with the SWTR. Joumal AWWA. **82** (12) : 88 - 98.

76. Thampi, M. V. 1990. Basic Guidelines for Specifying the Design of Ultraviolet Disinfection Systems. Joumal of Water Pollution Engineering. **22** (5) : 65 -69.

77. Thirumurthi, D. 1969. A Break Through in the Tracer Studies of Sedimentation Tanks. Joumal WPCF. **6** (11) : R405 - R418.

78. Trussel, R. R. and Chao, J. L. 1977. Rational Design of Chlorine Contact Facilities. Joumal WPCF. **49** (4) : 659 - 667.

79. VandeVenter, L. W., Marston, T. R., and Murphy, L. A. 1991. T_{10} Determination in a Variety of Clearwells and Standpipes Using Fluoride as a Tracer. (In) 1991 Annual Conference Proceedings. AWWA, Philadelphia, Pennsylvania. pp. 345 - 369.

80. White, G. C. 1992. The Handbook of Chlorination, 3rd edition. Van Nostrand Reinhold, New York, New York. pp. 291 - 323 and 479 - 481.

81. Wolf, D. and Resnick, W. 1963. Residence Time Distribution in Real System. Joumal Industrial and Engineering Chemical Fundamentals. **2** (4) : 287 - 293.

82. Yu, C. H., Hattig, B. J., and O'Connel, M. J. 1991. Tracer Study for C*T Compliance Evaluation. (In) Environmental Engineering: Proceedings of the 1991 Specialty Conference. P. A. Krenkel, editor. ASCE, Reno, Nevada. pp. 649 - 654.

83. Zhou, H. and Smith, D. W. 1994. Kinetics of Ozone Disinfection in a Completely Mixed System. Joumal of Environmental Engineering. **120** (4).

9.0 APPENDICES

APPENDIX 1: F CURVE DEVELOPMENT

SAMPLING NO:	1
LOCATION	**Filters & Clearwell**
FLOW (ML/d)	180
SAMPLING DATE	16-Feb-93
TESTING DATE	20-Feb-93
STANDARD MADE	10-Feb-93

STANDARDIZATION

mg/L Na	Initial Reading	Final Reading	Average
0.0	0.0	0.0	0.0
5.0	32.5	32.5	32.5
10.0	58.5	59.0	58.8
15.0	81.0	82.0	81.5
20.0	100.0	100.5	100.3

Regression Statistics	
Multiple R	0.994
R Square	0.989
Adjusted R Square	0.985
Standard Error	0.958
Observations	5

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	247.248	247.248	269.482	0.000
Residual	3	2.752	0.917		
Total	4	250.000			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.821	0.786	-1.045	0.355	-3.323	1.681
x1	0.198	0.012	16.416	0.000	0.160	0.237

General Equation y=0.198x-0.821

TEST NO. 1
FILTERS & CLEARWELL (180 ML/d)

NaBack(mg/L)= 3.72
NaFinal(mg/L)= 18.31
NaTracer(mg/L)= 14.58

				m=	0.2			m=	0.2		m= 0.2
				b=	-1.3			b=	-1.0		b= -1.3

Filter #1 Inlet				Filter #1 Outlet				Filter #2 Inlet			
Time	Reading	Conc. Na	C/Co	Time	Reading	Conc. Na	C/Co	Time	Reading	Conc. Na	C/Co
min		mg/L		min		mg/L		min		mg/L	
0.6	25.0	3.7	0.00	0.0	23.0	3.7	0.00	0.0	24.5	3.8	0.00
1.8	28.0	4.3	0.04	1.3	23.0	3.7	0.00	1.3	24.0	3.7	0.00
2.8	44.5	7.6	0.27	2.4	23.0	3.7	0.00	2.8	47.0	8.4	0.32
3.7	56.5	10.0	0.43	3.5	23.0	3.7	0.00	3.2	63.0	11.7	0.55
4.7	67.0	12.1	0.57	4.7	23.0	3.7	0.00	4.2	65.0	12.2	0.58
5.7	67.0	12.1	0.57	5.8	23.5	3.8	0.01	5.2	58.0	10.7	0.48
6.7	69.5	12.6	0.61	7.0	26.5	4.4	0.05	6.2	69.0	13.0	0.64
7.7	67.0	12.1	0.57	8.3	30.0	5.1	0.10	7.3	63.5	11.9	0.56
8.8	74.0	13.5	0.67	9.3	35.0	6.2	0.17	8.3	65.0	12.2	0.58
9.6	74.0	13.5	0.67	10.3	39.0	7.0	0.22	9.2	72.0	13.6	0.68
10.7	85.0	15.7	0.82	11.5	43.0	7.8	0.28	10.2	80.0	15.3	0.79
11.7	81.5	15.0	0.77	12.6	46.0	8.4	0.32	11.2	82.0	15.7	0.82
13.0	82.0	15.1	0.78	13.7	50.5	9.3	0.38	12.2	82.0	15.7	0.82
15.0	86.0	15.9	0.83	14.8	54.0	10.0	0.43	14.5	78.0	14.9	0.76
17.0	85.5	15.8	0.83	16.5	58.0	10.8	0.49	16.0	85.0	16.3	0.86
19.0	89.0	16.5	0.87	18.3	64.5	12.2	0.58	18.5	86.0	16.5	0.88
21.0	87.0	16.1	0.85	20.3	69.0	13.1	0.64	20.5	87.0	16.7	0.89
23.0	90.0	16.6	0.89	22.3	73.0	13.9	0.70	22.0	85.0	16.3	0.86
35.0	94.5	17.5	0.95	24.3	77.0	14.7	0.75	34.0	90.0	17.3	0.93
45.0	95.0	17.6	0.95	26.3	79.5	15.2	0.79	44.0	93.0	18.0	0.98
55.0	99.0	18.4	1.01	31.3	84.0	16.1	0.85	54.0	93.0	18.0	0.98
65.0	97.5	18.1	0.99	36.3	88.0	16.9	0.91	64.0	94.0	18.2	0.99
95.0	98.0	18.2	1.00	41.3	90.0	17.4	0.93	94.0	93.5	18.1	0.98
124.6	98.5	18.3	1.00	46.3	91.0	17.6	0.95	123.5	94.0	18.2	0.99
150.0	98.5	18.3	1.00	51.3	96.0	18.6	1.02	151.0	95.0	18.4	1.00
175.0	98.0	18.2	1.00	56.3	96.0	18.6	1.02	176.0	95.0	18.4	1.00
				65.0	97.0	18.8	1.03				
				95.0	94.0	18.2	0.99				
				125.0	95.0	18.4	1.00				
				155.0	94.0	18.2	0.99				
				180.0	95.0	18.4	1.00				

Gnrl Eqn	y=0.199x-0.821 (INLET)	
Na start:	3.72	
Na finish:	18.31	
Initial	22.83	(avearge of 3 first samples)
Steady	96.15	(average of 8 last samples from OUTLET)
		(assumed Steady for Inlet = Outlet)

m= 0.2
b= -0.7

Filter #2 Outlet			
Time	Reading	Conc. Na	C/Co
min		mg/L	
0.7	22.0	3.6	-0.01
1.9	22.5	3.7	0.00
2.9	23.0	3.8	0.01
4.0	22.5	3.7	0.00
5.3	22.5	3.7	0.00
6.5	24.5	4.1	0.03
7.6	27.5	4.7	0.07
8.8	31.0	5.4	0.12
9.8	34.5	6.1	0.16
10.9	38.5	6.9	0.22
12.0	42.5	7.7	0.27
13.2	46.5	8.5	0.33
14.3	47.0	8.6	0.33
15.2	56.5	10.5	0.46
17.3	63.0	11.8	0.55
19.3	68.0	12.8	0.62
21.3	73.0	13.7	0.69
23.3	77.0	14.5	0.74
25.3	80.0	15.1	0.78
30.3	86.0	16.3	0.86
35.3	90.0	17.1	0.92
40.3	92.0	17.5	0.95
45.3	92.0	17.5	0.95
50.3	94.5	18.0	0.98
55.7	98.0	18.7	1.03
66.0	96.0	18.3	1.00
96.0	97.0	18.5	1.01
126.0	96.0	18.3	1.00
181.0	95.0	18.1	0.99

m= 0.2
b= -1.2

Filter #3 Inlet			
Time	Reading	Conc. Na	C/Co
min		mg/L	
0.5	25.0	3.7	0.00
1.7	25.0	3.7	0.00
2.8	62.0	11.0	0.50
4.0	56.0	9.9	0.42
5.0	39.0	6.5	0.19
6.1	66.0	11.8	0.56
7.2	51.0	8.9	0.35
8.3	69.0	12.4	0.60
9.5	77.0	14.0	0.71
10.6	81.0	14.8	0.76
13.0	83.0	15.2	0.79
15.0	74.0	13.4	0.67
17.0	79.0	14.4	0.73
19.0	83.0	15.2	0.79
21.0	87.0	16.0	0.84
33.0	91.0	16.8	0.90
43.0	98.0	18.2	0.99
53.0	99.0	18.4	1.00
63.0	100.0	18.6	1.02
93.0	98.0	18.2	0.99
122.6	98.0	18.2	0.99
152.0	99.0	18.4	1.00
174.8	99.0	18.4	1.00

m= 0.2
b= -1.5

Filter #3 Outlet			
Time	Reading	Conc. Na	C/Co
min		mg/L	
0.8	25.0	3.7	0.00
3.0	25.0	3.7	0.00
4.7	25.5	3.8	0.00
6.1	25.0	3.7	0.00
7.6	27.5	4.2	0.03
8.9	33.0	5.4	0.11
10.4	39.0	6.6	0.20
11.8	43.0	7.4	0.25
13.3	49.5	8.8	0.35
14.7	54.0	9.7	0.41
17.0	62.0	11.4	0.53
18.5	65.5	12.1	0.58
19.7	70.0	13.1	0.64
22.0	74.0	13.9	0.70
24.0	78.0	14.7	0.75
26.0	81.5	15.5	0.80
28.0	83.0	15.8	0.83
30.0	85.5	16.3	0.86
38.0	91.5	17.5	0.95
43.0	92.0	17.6	0.95
48.0	92.0	17.6	0.95
53.0	92.0	17.6	0.95
58.0	95.0	18.3	1.00
63.0	95.0	18.3	1.00
67.0	98.0	18.9	1.04
97.0	96.0	18.5	1.01
127.0	95.5	18.4	1.00
157.0	95.0	18.3	1.00
182.0	95.0	18.3	1.00

m= 0.2
b= -1.1

Filter #4 Inlet			
Time	Reading	Conc. Na	C/Co
min		mg/L	
0.2	28.0	4.6	0.06
1.2	23.0	3.6	-0.01
2.2	24.0	3.8	0.01
3.3	54.0	10.0	0.43
4.5	82.0	15.7	0.82
5.6	50.0	9.2	0.37
6.7	66.0	12.4	0.60
7.7	70.5	13.4	0.66
9.0	65.0	12.2	0.58
10.1	69.0	13.0	0.64
12.0	88.0	16.9	0.91
14.0	81.5	15.6	0.81
16.0	81.0	15.5	0.81
18.0	82.0	15.7	0.82
20.0	84.0	16.1	0.85
30.0	91.[illegible]	17.6	0.95
32.0	90.5	17.5	0.94
42.0	92.5	17.9	0.97
53.0	94.0	18.2	0.99
62.0	94.0	18.2	0.99
90.0	93.5	18.1	0.98
121.6	95.0	18.4	1.00
151.7	94.0	18.2	0.99
176.7	95.0	18.4	1.00

m= 0.2 m= 0.2 m= 0.2 m= 0.2
b= -0.5 b= -0.6 b= -0.6 b= -0.9

Filter #4 Outlet				Filter #5 Inlet				Filter #5 Outlet				Filter #6 Inlet			
Time	Reading	Conc. Na	C/Co	Time	Reading	Conc. Na	C/Co	Time	Reading	Conc. Na	C/Co	Time	Reading	Conc. Na	C/Co
min		mg/L		min		mg/L		min		mg/L		min		mg/L	
0.0	22.0	3.7	0.00	0.7	22.0	3.8	0.00	0.0	22.5	3.8	0.00	0.0	23.0	3.7	0.00
2.0	22.0	3.7	0.00	1.8	21.0	3.6	-0.01	2.0	22.0	3.7	0.00	1.2	22.5	3.6	-0.01
3.7	22.5	3.8	0.00	2.9	22.0	3.8	0.00	3.2	22.5	3.8	0.00	2.4	24.0	3.9	0.01
5.3	22.5	3.8	0.00	3.9	58.0	10.9	0.49	4.4	22.5	3.8	0.00	3.4	22.0	3.5	-0.02
6.9	25.0	4.3	0.04	4.7	84.0	16.0	0.84	5.5	23.0	3.9	0.01	4.3	30.0	5.1	0.09
8.3	29.0	5.0	0.09	6.0	56.0	10.5	0.47	6.9	23.5	3.9	0.02	5.5	45.0	8.1	0.30
9.7	34.5	6.1	0.16	7.0	81.0	15.4	0.80	8.0	24.0	4.0	0.02	6.5	83.0	15.7	0.82
11.2	40.0	7.2	0.24	8.7	54.0	10.1	0.44	9.3	27.0	4.6	0.06	7.5	73.5	13.8	0.69
12.5	44.5	8.0	0.29	10.2	57.0	10.7	0.48	10.5	30.5	5.3	0.11	9.6	52.0	9.5	0.39
13.8	49.5	9.0	0.36	12.0	70.0	13.3	0.65	11.5	35.0	6.2	0.17	11.3	67.5	12.6	0.61
15.3	54.5	9.9	0.43	13.5	70.0	13.3	0.65	12.5	38.0	6.8	0.21	12.8	64.0	11.9	0.56
17.8	61.5	11.3	0.52	15.3	78.0	14.8	0.76	13.5	41.5	7.4	0.25	14.5	81.0	15.3	0.79
19.0	67.0	12.3	0.59	17.3	88.0	16.8	0.90	14.5	45.0	8.1	0.30	16.4	78.5	14.8	0.76
21.0	71.5	13.2	0.65	19.2	88.0	16.8	0.90	16.0	49.5	9.0	0.36	18.2	78.0	14.7	0.75
23.0	77.5	14.4	0.73	21.3	91.0	17.4	0.94	17.5	54.0	9.9	0.42	20.4	79.0	14.9	0.76
25.0	80.5	14.9	0.77	31.0	96.0	18.4	1.01	18.5	56.5	10.3	0.45	22.5	86.0	16.3	0.86
27.0	82.5	15.3	0.80	41.0	95.0	18.2	0.99	19.5	59.0	10.8	0.49	40.0	89.0	16.9	0.90
29.0	85.0	15.8	0.83	51.0	95.0	18.2	0.99	21.0	64.5	11.9	0.56	50.0	91.0	17.3	0.93
35.0	90.5	16.9	0.90	61.0	95.5	18.3	1.00	23.0	71.0	13.1	0.65	60.0	93.0	17.7	0.96
40.0	91.0	17.0	0.91	91.0	95.0	18.2	0.99	25.0	75.0	13.9	0.70	120.0	98.0	18.7	1.03
45.0	91.5	17.1	0.91	120.9	95.5	18.3	1.00	27.0	84.0	15.7	0.82	149.1	97.0	18.5	1.01
50.0	94.0	17.5	0.95	150.5	96.0	18.4	1.01	29.0	82.0	15.3	0.79	178.1	93.5	17.8	0.96
55.0	96.0	17.9	0.97	177.0	95.0	18.2	0.99	31.0	83.0	15.5	0.81				
60.0	97.0	18.1	0.99					36.0	86.5	16.1	0.85				
68.0	98.0	18.3	1.00					41.0	89.0	16.6	0.88				
98.0	98.0	18.3	1.00					46.0	90.0	16.8	0.90				
128.0	98.0	18.3	1.00					51.0	92.0	17.2	0.92				
158.0	98.0	18.3	1.00					55.0	94.0	17.6	0.95				
183.0	98.0	18.3	1.00					60.0	96.0	18.0	0.98				
								85.0	97.0	18.2	0.99				
								115.0	98.0	18.4	1.00				
								145.0	97.0	18.2	0.99				
								175.0	98.0	18.4	1.00				

m= 0.2
b= -0.7

m= 0.2
b= -1.0

Filter #6 Outlet				End of Clearwell				
Time	Reading	Conc. Na	C/Co	Time	T/Td	Reading	Conc. Na	C/Co
min		mg/L		min	Td=29		mg/L	
0.0	22.0	3.8	0.00	0.0	0.00	24.0	3.8	0.01
1.8	21.5	3.7	0.00	2.0	0.07	24.0	3.8	0.01
2.7	22.0	3.8	0.00	4.0	0.14	23.5	3.7	0.00
3.7	22.0	3.8	0.00	6.0	0.21	23.5	3.7	0.00
5.0	22.0	3.8	0.00	8.0	0.28	23.0	3.6	-0.01
6.2	22.0	3.8	0.00	10.0	0.34	23.0	3.6	-0.01
7.5	22.0	3.8	0.00	12.0	0.41	23.0	3.6	-0.01
8.8	22.5	3.9	0.01	14.0	0.48	23.5	3.7	0.00
10.0	25.0	4.4	0.04	16.0	0.55	23.5	3.7	0.00
11.0	29.0	5.2	0.10	18.0	0.62	24.5	3.9	0.01
12.0	32.0	5.8	0.14	20.0	0.69	27.0	4.4	0.05
13.0	34.0	6.2	0.17	22.0	0.76	31.5	5.3	0.11
14.0	38.0	7.0	0.22	24.0	0.83	36.0	6.2	0.17
15.5	43.0	8.0	0.29	26.0	0.90	37.0	6.4	0.19
16.8	46.0	8.6	0.33	28.0	0.97	44.5	7.9	0.29
18.0	51.0	9.6	0.40	30.0	1.03	51.5	9.4	0.39
19.0	55.5	10.5	0.46	32.0	1.10	58.0	10.7	0.48
20.0	58.5	11.1	0.51	34.0	1.17	57.0	10.5	0.46
22.0	65.0	12.4	0.60	36.0	1.24	66.0	12.3	0.59
24.0	70.0	13.4	0.66	38.0	1.31	68.0	12.7	0.61
26.0	74.0	14.2	0.72	40.0	1.38	72.0	13.5	0.67
28.0	77.0	14.8	0.76	42.0	1.45	66.5	12.4	0.59
30.0	78.0	15.0	0.77	44.0	1.52	77.0	14.5	0.74
35.0	83.0	16.0	0.84	46.0	1.59	81.0	15.3	0.79
40.0	88.0	17.0	0.91	48.0	1.66	72.5	13.6	0.67
45.0	93.0	18.0	0.98	50.0	1.72	77.5	14.6	0.74
50.0	92.0	17.8	0.97	52.0	1.79	83.0	15.7	0.82
55.0	92.0	17.8	0.97	54.0	1.86	83.0	15.7	0.82
60.0	94.0	18.2	1.00	56.0	1.93	81.0	15.3	0.79
85.0	95.0	18.4	1.01	58.0	2.00	82.5	15.6	0.81
115.0	93.0	18.0	0.98	60.0	2.07	82.5	15.6	0.81
145.0	94.0	18.2	1.00	65.0	2.24	87.0	16.5	0.87
175.0	96.0	18.6	1.02	70.0	2.41	07.5	16.6	0.88
				75.0	2.59	83.5	15.8	0.83
				105.0	3.62	87.0	16.5	0.87
				110.0	3.79	87.0	16.5	0.87
				115.0	3.97	89.0	16.9	0.90
				120.0	4.14	90.0	17.1	0.92
				125.0	4.31	85.5	16.2	0.85
				130.0	4.48	90.0	17.1	0.92
				135.0	4.66	92.5	17.6	0.95
				140.0	4.83	93.0	17.7	0.96
				145.0	5.00	93.0	17.7	0.96
				150.0	5.17	90.0	17.1	0.92
				155.0	5.34	95.0	18.1	0.98
				160.0	5.52	89.0	16.9	0.90
				165.0	5.69	91.5	17.4	0.94
				170.0	5.86	89.0	16.9	0.90
				175.0	6.03	86.5	16.4	0.87
				180.0	6.21	85.0	16.1	0.85

SAMPLING NO:	**2**
LOCATION:	**Filters & Clearwell**
FLOW (ML/d):	140
SAMPLING DATE:	24-Feb-93
TESTING DATE:	25-Feb-93
STANDARD MADE:	22-Feb-93

STANDARDIZATION

mg/L Na	Initial Reading	Final Reading	Average
2.0	13.5	13.0	13.3
5.0	32.5	32.0	32.3
7.0	44.5	43.0	43.8
10.0	59.5	58.0	58.8
12.0	68.0	67.0	67.5
15.0	80.5	80.0	80.3
17.0	88.0	88.0	88.0
20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.996
R Square	0.992
Adjusted R Square	0.990
Standard Error	0.616
Observations	8

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	265.725	265.725	700.872	0.000
Residual	6	2.275	0.379		
Total	7	268.000			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.652	0.525	-3.146	0.016	-2.937	-0.367
x1	0.209	0.008	26.474	0.000	0.190	0.229

General Equation y=0.209x-1.652

TEST NO. 2
FILTERS & CLEARWELL (140 ML/d)

NaBack(mg/L)=	2.62	m=	0.2		m=	0.2
NaFinal(mg/L)=	15.10	b=	-1.7		b=	-1.5
NaTracer(mg/L)=	12.48					

Filter #1 Outlet					Filter #2 Outlet				
Time		Reading	Conc. Na	C/Co	Time		Reading	Conc. Na	C/Co
min	min		mg/L		min	min		mg/L	
00:05:00	0.0	20.5	2.6	0.00	00:05:35	0.6	19.0	2.5	-0.01
00:08:00	3.0	20.5	2.6	0.00	00:07:15	2.3	19.5	2.6	0.00
00:09:00	4.0	21.0	2.7	0.01	00:08:30	3.5	20.0	2.7	0.01
00:10:00	5.0	21.0	2.7	0.01	00:09:30	4.5	20.5	2.8	0.02
00:11:00	6.0	21.0	2.7	0.01	00:10:30	5.5	20.0	2.7	0.01
00:12:00	7.0	22.0	2.9	0.02	00:11:30	6.5	20.0	2.7	0.01
00:13:00	8.0	22.5	3.0	0.03	00:12:30	7.5	22.0	3.1	0.04
00:14:00	9.0	25.5	3.6	0.08	00:13:25	8.4	24.0	3.6	0.08
00:15:00	10.0	27.5	4.0	0.11	00:14:30	9.5	27.0	4.2	0.13
00:16:00	11.0	31.0	4.8	0.17	00:15:30	10.5	30.5	4.9	0.19
00:17:00	12.0	32.5	5.1	0.20	00:16:30	11.5	33.5	5.6	0.24
00:18:00	13.0	35.5	5.7	0.25	00:17:30	12.5	34.5	5.8	0.25
00:19:00	14.0	37.5	6.1	0.28	00:18:30	13.5	38.0	6.5	0.31
00:20:00	15.0	41.5	6.9	0.35	00:19:30	14.5	41.0	7.2	0.36
00:21:00	16.0	43.5	7.4	0.38	00:20:30	15.5	42.5	7.5	0.39
00:22:00	17.0	47.0	8.1	0.44	00:21:30	16.5	45.0	8.0	0.43
00:23:00	18.0	50.0	8.7	0.49	00:22:30	17.5	47.5	8.5	0.47
00:24:00	19.0	51.5	9.0	0.51	00:23:30	18.5	48.5	8.8	0.49
00:25:00	20.0	53.0	9.3	0.54	00:24:30	19.5	52.5	9.6	0.56
00:27:00	22.0	57.0	10.2	0.60	00:25:30	20.5	55.0	10.1	0.60
00:29:00	24.0	61.0	11.0	0.67	00:28:00	23.0	59.5	11.1	0.68
00:31:00	26.0	62.5	11.3	0.70	00:30:00	25.0	61.5	11.5	0.71
00:33:09	28.2	65.0	11.8	0.74	00:32:00	27.0	66.0	12.5	0.79
00:35:00	30.0	67.5	12.3	0.78	00:34:00	29.0	67.5	12.8	0.81
00:40:00	35.0	71.0	13.1	0.84	00:36:00	31.0	69.5	13.2	0.85
00:45:00	40.0	77.5	14.4	0.94	00:41:00	36.0	75.0	14.4	0.94
00:50:06	45.1	77.5	14.4	0.94	00:46:00	41.0	77.5	14.9	0.98
00:55:00	50.0	78.0	14.5	0.95	00:51:00	46.0	78.5	15.1	1.00
01:00:00	55.0	79.0	14.7	0.97	00:56:00	51.0	79.5	15.3	1.02
01:05:00	60.0	79.5	14.8	0.98	01:01:00	56.0	81.5	15.7	1.05
01:36:30	91.5	80.5	15.0	0.99	01:06:00	61.0	82.0	15.8	1.06
02:06:30	121.5	82.0	15.3	1.02	01:36:00	91.0	77.7	14.9	0.99
02:36:30	151.5	81.5	15.2	1.01	02:06:00	121.0	78.5	15.1	1.00
03:06:30	181.5	79.0	14.7	0.97	02:36:00	151.0	78.5	15.1	1.00
					03:06:00	181.0	78.5	15.1	1.00

General Eqn	y=0.209x-1.652	
Na start	2.62	
Na finish	15.10	
Initial	20.4	(avearge of 3 first samples from each location except End of Clearwell)
Steady	80.1	(avearge of 3 last samples from each location except End of Clearwell)

m= 0.2
b= -1.4

Filter #3 Outlet				
Time		Reading	Conc Na	C/Co
min	min		mg/L	
00:05:45	0.8	19.0	2.6	0.00
00:07:16	2.3	19.0	2.6	0.00
00:08:33	3.6	19.0	2.6	0.00
00:09:53	4.9	19.0	2.6	0.00
00:11:27	6.5	18.5	2.5	-0.01
00:12:25	7.4	19.5	2.7	0.01
00:13:39	8.7	21.0	3.0	0.03
00:14:56	9.9	24.5	3.8	0.09
00:16:10	11.2	29.0	4.7	0.17
00:17:29	12.5	31.5	5.2	0.21
00:18:43	13.7	34.5	5.9	0.26
00:19:58	15.0	38.0	6.6	0.32
00:21:15	16.3	41.5	7.3	0.38
00:22:32	17.5	44.5	8.0	0.43
00:23:55	18.9	48.0	8.7	0.49
00:25:01	20.0	50.5	9.2	0.53
00:27:30	22.5	56.0	10.4	0.62
00:29:30	24.5	58.5	10.9	0.66
00:31:30	26.5	61.0	11.4	0.71
00:33:30	28.5	63.5	12.0	0.75
00:35:30	30.5	66.5	12.6	0.80
00:40:30	35.5	70.0	13.3	0.86
00:45:30	40.5	73.0	14.0	0.91
00:50:30	45.5	74.5	14.3	0.93
00:55:30	50.5	75.0	14.4	0.94
01:00:30	55.5	75.5	14.5	0.95
01:05:30	60.5	78.0	15.0	0.99
01:35:30	90.5	78.5	15.1	1.00
02:05:30	120.5	78.5	15.1	1.00
02:35:30	150.5	78.5	15.1	1.00
03:05:30	180.5	78.5	15.1	1.00

m= 0.2
b= -1.7

Filter #4 Outlet				
Time		Reading	Conc Na	C/Co
min	min		mg/L	
00:05:00	0.0	19.5	2.4	-0.01
00:06:33	1.6	23.0	3.2	0.05
00:07:53	2.9	18.5	2.2	-0.03
00:09:15	4.3	18.5	2.2	-0.03
00:10:33	5.6	18.0	2.1	-0.04
00:11:43	6.7	19.0	2.3	-0.02
00:13:02	8.0	20.5	2.7	0.00
00:14:19	9.3	24.0	3.4	0.06
00:15:34	10.6	27.5	4.1	0.12
00:16:52	11.9	31.5	5.0	0.19
00:18:06	13.1	33.0	5.3	0.22
00:19:19	14.3	36.0	6.0	0.27
00:20:36	15.6	39.5	6.7	0.33
00:21:55	16.9	43.0	7.4	0.39
00:23:17	18.3	47.0	8.3	0.45
00:24:30	19.5	49.0	8.7	0.49
00:27:00	22.0	54.0	9.8	0.57
00:29:00	24.0	57.5	10.5	0.63
00:31:00	26.0	59.5	11.0	0.67
00:33:00	28.0	61.5	11.4	0.70
00:35:00	30.0	62.5	11.6	0.72
00:40:00	35.0	69.5	13.1	0.84
00:45:00	40.0	70.5	13.3	0.86
00:50:00	45.0	74.0	14.0	0.91
00:55:00	50.0	74.5	14.1	0.92
01:00:00	55.0	74.0	14.0	0.91
01:05:00	60.0	74.0	14.0	0.91
01:35:00	90.0	75.0	14.3	0.93
02:05:00	120.0	78.0	14.9	0.98
02:35:00	150.0	79.5	15.2	1.01
03:05:00	180.0	79.5	15.2	1.01

m= 0.2
b= -1.6

Filter #5 Outlet				
Time		Reading	Conc Na	C/Co
min	min		mg/L	
00:05:30	0.5	20.0	2.5	-0.01
00:06:30	1.5	21.0	2.7	0.01
00:07:30	2.5	20.5	2.6	0.00
00:08:30	3.5	20.5	2.6	0.00
00:09:30	4.5	20.0	2.5	-0.01
00:10:30	5.5	20.0	2.5	-0.01
00:11:30	6.5	20.5	2.6	0.00
00:12:30	7.5	20.5	2.6	0.00
00:13:30	8.5	21.0	2.7	0.01
00:14:30	9.5	22.0	2.9	0.02
00:15:30	10.5	25.0	3.6	0.07
00:16:30	11.5	27.5	4.1	0.12
00:17:30	12.5	30.5	4.7	0.17
00:18:30	13.5	32.0	5.0	0.19
00:19:30	14.5	36.0	5.8	0.26
00:20:30	15.5	38.5	6.4	0.30
00:21:30	16.5	43.0	7.3	0.37
00:23:30	18.5	46.0	7.9	0.42
00:24:30	19.5	47.0	8.1	0.44
00:25:30	20.5	51.0	8.9	0.51
00:27:30	22.5	56.0	10.6	0.59
00:29:30	24.5	60.0	10.8	0.66
00:31:30	26.5	63.0	11.4	0.71
00:33:30	28.5	65.0	11.9	0.74
00:35:30	30.5	69.0	12.7	0.81
00:40:30	35.5	76.0	14.1	0.92
00:45:30	40.5	75.5	14.0	0.91
00:50:30	45.5	81.0	15.2	1.01
00:55:30	50.5	81.5	15.3	1.01
01:00:30	55.5	81.0	15.2	1.01
01:05:30	60.5	80.0	15.0	0.99
01:35:30	90.5	80.5	15.1	1.00
02:05:30	120.5	80.5	15.1	1.00
02:35:30	150.5	81.5	15.3	1.01
03:05:30	180.5	80.0	15.0	0.99

m= 0.2
b= -2.0

m= 0.2
b= -2.3

Filter #6 Outlet				
Time		Reading	Conc Na	C/Co
min	min		mg/L	
00:05:00	0.0	22.0	2.5	-0.01
00:06:00	1.0	22.5	2.6	0.00
00:07:00	2.0	23.0	2.7	0.01
00:08:00	3.0	23.0	2.7	0.01
00:09:00	4.0	23.0	2.7	0.01
00:10:00	5.0	23.0	2.7	0.01
00:11:00	6.0	23.0	2.7	0.01
00:12:00	7.0	23.0	2.7	0.01
00:13:00	8.0	23.0	2.7	0.01
00:14:00	9.0	23.5	2.8	0.02
00:15:00	10.0	23.5	2.8	0.02
00:16:00	11.0	25.5	3.2	0.05
00:17:00	12.0	28.5	3.9	0.10
00:18:00	13.0	31.0	4.4	0.14
00:19:00	14.0	32.5	4.7	0.17
00:20:00	15.0	37.5	5.7	0.25
00:21:00	16.0	39.5	6.1	0.28
00:22:00	17.0	44.0	7.1	0.36
00:23:00	18.0	45.5	7.4	0.38
00:24:00	19.0	48.0	7.9	0.42
00:25:00	20.0	50.5	8.4	0.46
00:27:00	22.0	56.0	9.5	0.55
00:29:00	24.0	60.5	10.5	0.63
00:31:00	26.0	64.0	11.2	0.69
00:33:00	28.0	67.0	11.8	0.74
00:35:00	30.0	69.0	12.2	0.77
00:40:00	35.0	76.0	13.7	0.88
00:45:00	40.0	80.5	14.6	0.96
00:50:00	45.0	82.0	14.9	0.98
00:55:00	50.0	82.0	14.9	0.98
01:00:00	55.0	83.5	15.2	1.01
01:05:00	60.0	83.5	15.2	1.01
01:34:00	89.0	83.5	15.2	1.01
02:05:00	120.0	84.0	15.3	1.02
02:34:00	149.0	82.5	15.0	0.99
03:04:00	179.0	82.5	15.0	0.99

End of Clearwell					
Time		T/Td	Reading	Conc Na	C/Co
min	min	Td=37		mg/L	
00:05:00	0.0	0.00	23.0	2.7	0.00
00:07:00	7.0	0.19	23.0	2.7	0.00
00:09:00	9.0	0.24	23.0	2.7	0.00
00:11:00	11.0	0.30	23.0	2.7	0.00
00:13:00	13.0	0.35	22.5	2.6	0.00
00:15:00	15.0	0.41	22.5	2.6	0.00
00:17:00	17.0	0.46	22.5	2.6	0.00
00:19:00	19.0	0.51	23.0	2.7	0.00
00:21:00	21.0	0.57	23.0	2.7	0.00
00:23:00	23.0	0.62	23.0	2.7	0.00
00:25:00	25.0	0.68	22.5	2.6	0.00
00:27:00	27.0	0.73	24.0	2.9	0.02
00:29:00	29.0	0.78	25.0	3.1	0.04
00:31:00	31.0	0.84	31.0	4.4	0.14
00:33:00	33.0	0.89	31.0	4.4	0.14
00:35:00	35.0	0.95	33.0	4.8	0.18
00:37:00	37.0	1.00	38.5	6.0	0.27
00:39:00	39.0	1.05	42.0	6.8	0.33
00:41:00	41.0	1.11	49.5	8.4	0.46
00:43:00	43.0	1.16	55.0	9.6	0.56
00:45:00	45.0	1.22	56.5	9.9	0.58
00:47:00	47.0	1.27	61.0	10.9	0.66
00:49:00	49.0	1.32	62.5	11.2	0.69
00:51:00	51.0	1.38	55.0	9.6	0.56
00:53:00	53.0	1.43	65.5	11.8	0.74
00:55:00	55.0	1.49	71.0	13.0	0.83
00:57:00	57.0	1.54	66.5	12.1	0.76
00:59:00	59.0	1.59	75.0	13.9	0.90
01:01:00	61.0	1.65	73.0	13.5	0.87
01:03:00	63.0	1.70	77.5	14.4	0.95
01:05:00	65.0	1.76	77.0	14.3	0.94
01:10:00	70.0	1.89	77.5	14.4	0.95
01:15:00	75.0	2.03	73.0	13.5	0.87
01:20:00	80.0	2.16	72.0	13.3	0.85
01:25:00	85.0	2.30	81.0	15.2	1.01
01:30:00	90.0	2.43	78.5	14.7	0.96
01:45:00	105.0	2.84	81.5	15.3	1.02
01:50:00	110.0	2.97	79.5	14.9	0.98
01:57:00	117.0	3.16	75.5	14.0	0.91
02:00:00	120.0	3.24	79.5	14.9	0.98
02:05:00	125.0	3.38	77.5	14.4	0.95
02:15:00	135.0	3.65	78.5	14.7	0.96
02:20:00	140.0	3.78	79.0	14.8	0.97
02:25:00	145.0	3.92	84.5	16.0	1.07
02:30:00	150.0	4.05	85.0	16.1	1.08
02:33:30	153.5	4.15	85.0	16.1	1.08
02:40:00	160.0	4.32	86.0	16.3	1.09
02:45:00	165.0	4.46	74.0	13.7	0.89
02:50:00	170.0	4.59	80.5	15.1	1.00
03:00:00	180.0	4.86	80.5	15.1	1.00
03:04:00	184.0	4.97	83.0	15.6	1.04

SAMPLING NO	**3**	
LOCATION	**Clarifier 2**	
FLOW (ML/d)	**180**	
SAMPLING DATE	**05-Mar-93**	
TESTING DATE	**08-Mar-93**	**(use these data)**
	09-Mar-93	**(check the data)**
	19-Mar-93	**(check the sludge effect)**
	21-Mar-93	**(check the sludge effect)**
STANDARD MADE	**22-Feb-93**	

STANDARDIZATION

mg/L Na	Initial Reading	Initial Reading	Average
2.0	14.0	14.0	14.0
5.0	32.5	32.5	32.5
7.0	43.0	42.5	42.8
10.0	58.5	59.0	58.8
12.0	67.0	68.0	67.5
17.0	88.5	89.0	88.8
20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.996
R Square	0.993
Adjusted R Square	0.991
Standard Error	0.599
Observations	7

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	247.918	247.918	690.140	0.000
Residual	5	1.796	0.359		
Total	6	249.714			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.702	0.514	-3.309	0.016	-3.024	-0.380
x1	0.210	0.008	26.271	0.000	0.190	0.231

General Equation y=0.210x-1.702

TEST NO. 3
CLARIFIER NO. 2 (180 ML/d)

Na back.(mg/L)=	3.59	m=	0.2	0.2
Na Final (mg/L)=	13.20	b=	-1.7	-1.9
Na Tracer (mg/L)	9.61			

Effluent						Bottom Draft Tube				
Time		T/Td	Reading	Conc. Na	C/Co	Time		Reading	Conc. Na	C/Co
min	min	Td=86		mg/L		min	min		mg/L	
00:03:30	0.5	0.01	25.0	3.6	0.00	00:03:00	0.0	25.0	3.5	-0.01
00:05:50	2.8	0.03	25.0	3.6	0.00	00:04:00	1.0	26.0	3.7	0.01
00:08:20	5.3	0.06	25.0	3.6	0.00	00:05:00	2.0	27.5	4.0	0.04
00:10:00	7.0	0.08	25.5	3.7	0.01	00:06:00	3.0	28.5	4.2	0.07
00:12:00	9.0	0.10	25.5	3.7	0.01	00:07:00	4.0	31.0	4.8	0.12
00:14:00	11.0	0.13	25.0	3.6	0.00	00:08:00	5.0	33.5	5.3	0.18
00:16:00	13.0	0.15	25.0	3.6	0.00	00:09:00	6.0	34.5	5.5	0.20
00:18:00	15.0	0.17	25.0	3.6	0.00	00:10:00	7.0	37.5	6.2	0.27
00:20:00	17.0	0.20	25.0	3.6	0.00	00:11:00	8.0	40.0	6.7	0.32
00:22:00	19.0	0.22	26.0	3.8	0.02	00:12:00	9.0	42.0	7.1	0.37
00:24:00	21.0	0.24	28.0	4.2	0.07	00:13:00	10.0	43.0	7.3	0.39
00:26:00	23.0	0.27	28.5	4.3	0.08	00:14:00	11.0	43.0	7.3	0.39
00:28:00	25.0	0.29	29.0	4.4	0.09	00:15:00	12.0	43.5	7.4	0.40
00:30:00	27.0	0.31	31.0	4.9	0.13	00:16:00	13.0	45.5	7.9	0.44
00:32:00	29.0	0.34	31.0	4.9	0.13	00:17:00	14.0	46.0	8.0	0.46
00:34:00	31.0	0.36	33.0	5.3	0.18	00:18:00	15.0	45.5	7.9	0.44
00:36:00	33.0	0.38	34.0	5.5	0.20	00:19:00	16.0	46.0	8.0	0.46
00:38:00	35.0	0.41	37.5	6.2	0.27	00:20:00	17.0	47.0	8.2	0.48
00:40:00	37.0	0.43	37.5	6.2	0.27	00:21:00	18.0	47.0	8.2	0.48
00:42:00	39.0	0.45	38.5	6.4	0.30	00:22:00	19.0	48.0	8.4	0.50
00:44:00	41.0	0.48	39.0	6.6	0.31	00:23:00	20.0	48.5	8.5	0.51
00:46:00	43.0	0.50	40.5	6.9	0.34	00:24:00	21.0	48.0	8.4	0.50
00:50:00	47.0	0.55	42.0	7.2	0.37	00:25:00	22.0	50.0	8.8	0.54
00:52:00	49.0	0.57	44.0	7.6	0.42	00:26:00	23.0	50.0	8.8	0.54
00:54:00	51.0	0.59	44.5	7.7	0.43	00:27:00	24.0	50.5	8.9	0.56
00:56:00	53.0	0.62	45.5	7.9	0.45	00:28:00	25.0	51.0	9.0	0.57
00:58:00	55.0	0.64	47.0	8.2	0.48	00:29:00	26.0	52.5	9.4	0.60
01:00:00	57.0	0.66	47.5	8.3	0.49	00:30:00	27.0	53.5	9.6	0.62
01:02:00	59.0	0.69	48.0	8.5	0.51	00:31:00	28.0	53.0	9.5	0.61
01:07:00	64.0	0.74	50.0	8.9	0.55	00:32:00	29.0	53.5	9.6	0.62
01:12:00	69.0	0.80	53.0	9.5	0.62	00:33:00	30.0	53.0	9.5	0.61
01:17:00	74.0	0.86	53.5	9.6	0.63	00:38:00	35.0	55.0	9.9	0.66
01:23:00	80.0	0.93	56.0	10.1	0.68	00:43:00	40.0	57.0	10.3	0.70
01:27:30	84.5	0.98	57.5	10.5	0.71	00:48:00	45.0	57.0	10.3	0.70
01:33:00	90.0	1.05	60.0	11.0	0.77	00:53:00	50.0	58.5	10.6	0.73
01:38:00	95.0	1.10	60.0	11.0	0.77	00:58:00	55.0	60.5	11.1	0.78
01:45:00	102.0	1.19	61.5	11.3	0.80	01:03:00	60.0	63.0	11.6	0.83
01:50:00	107.0	1.24	62.5	11.5	0.82	01:18:00	75.0	65.0	12.0	0.88
01:55:00	112.0	1.30	64.0	11.8	0.86	01:33:00	90.0	67.0	12.5	0.92
02:00:00	117.0	1.36	64.5	11.9	0.87	01:48:00	105.0	69.0	12.9	0.97
02:15:00	132.0	1.53	67.0	12.5	0.92	02:03:00	120.0	70.0	13.1	0.99
02:30:00	147.0	1.71	68.0	12.7	0.95	02:30:00	147.0	70.5	13.2	1.00
02:45:00	162.0	1.86	70.5	13.2	1.00	03:00:00	177.0	70.5	13.2	1.00
03:01:00	178.0	2.07	70.5	13.2	1.00					

General Eqn	y=0.210x-1.702	
Na start	3.6	
Na finish	13.2	
Initial	25.2	(evearge of 2 first samples from each location)
Steady	71.0	(average of 2 last samples from each location)

Note: Bottom Draft Tube is assumed as the Inlet

0.2
-1.9

Top Draft Tube				
Time		Reading	Conc. Na	C/Co
min	min		mg/L	
00:03:00	0.0	25.5	3.5	-0.01
00:04:00	1.0	26.0	3.6	0.01
00:05:00	2.0	37.0	6.0	0.25
00:06:00	3.0	41.0	6.9	0.34
00:07:00	4.0	46.0	7.9	0.45
00:08:00	5.0	50.5	8.9	0.55
00:09:00	6.0	50.0	8.8	0.54
00:10:00	7.0	47.5	8.3	0.49
00:11:00	8.0	50.0	8.8	0.54
00:12:00	9.0	51.0	9.0	0.56
00:13:00	10.0	51.5	9.1	0.58
00:14:00	11.0	58.0	10.5	0.72
00:15:00	12.0	57.0	10.3	0.70
00:16:00	13.0	57.5	10.4	0.71
00:17:00	14.0	59.0	10.7	0.74
00:18:00	15.0	58.0	10.5	0.72
00:19:00	16.0	60.0	10.9	0.77
00:20:00	17.0	58.5	10.6	0.73
00:21:00	18.0	57.5	10.4	0.71
00:22:00	19.0	60.0	10.9	0.77
00:23:00	20.0	62.0	11.4	0.81
00:24:00	21.0	59.5	10.8	0.75
00:25:00	22.0	58.0	10.5	0.72
00:26:00	23.0	60.0	10.9	0.77
00:27:00	24.0	57.0	10.3	0.70
00:28:00	25.0	59.0	10.7	0.74
00:29:00	26.0	60.0	10.9	0.77
00:30:00	27.0	61.0	11.2	0.79
00:31:00	28.0	59.0	10.7	0.74
00:32:00	29.0	61.0	11.2	0.79
00:33:00	30.0	60.0	10.9	0.77
00:38:00	35.0	61.5	11.3	0.80
00:43:00	40.0	66.0	12.2	0.90
00:48:00	45.0	67.5	12.6	0.93
00:53:00	50.0	67.0	12.5	0.92
00:58:00	55.0	68.0	12.7	0.94
01:03:00	60.0	68.5	12.8	0.96
01:18:00	75.0	70.0	13.1	0.99
01:33:00	90.0	70.5	13.2	1.00
01:48:00	105.0	69.0	12.9	0.97
02:03:00	120.0	70.5	13.2	1.00
02:30:00	147.0	70.5	13.2	1.00
03:00:00	177.0	70.5	13.2	1.00

0.2
-2.0

Manhole				
Time		Reading	Conc. Na	C/Co
min	min		mg/L	
00:04:30	1.5	25.0	3.4	-0.02
00:06:55	3.9	26.0	3.6	0.00
00:08:55	5.9	26.0	3.6	0.00
00:10:55	7.9	34.0	5.3	0.18
00:13:00	10.0	25.0	3.4	-0.02
00:15:00	12.0	27.0	3.8	0.02
00:17:00	14.0	26.0	3.6	0.00
00:19:00	16.0	29.0	4.2	0.07
00:21:00	18.0	26.0	3.6	0.00
00:23:00	20.0	26.0	3.6	0.00
00:25:00	22.0	27.0	3.8	0.02
00:27:00	24.0	28.0	4.0	0.04
00:29:00	26.0	28.0	4.0	0.04
00:31:00	28.0	28.0	4.0	0.04
00:33:00	30.0	29.0	4.2	0.07
00:35:00	32.0	30.5	4.6	0.10
00:37:00	34.0	34.0	5.3	0.18
00:39:00	36.0	33.0	5.1	0.16
00:41:00	38.0	34.0	5.3	0.18
00:43:00	40.0	35.5	5.6	0.21
00:47:00	44.0	40.0	6.6	0.31
00:49:00	46.0	40.5	6.7	0.33
00:51:00	48.0	43.0	7.3	0.38
00:53:00	50.0	45.0	7.7	0.43
00:55:00	52.0	45.0	7.7	0.43
00:57:00	54.0	46.0	7.9	0.45
00:59:00	56.0	47.0	8.1	0.47
01:01:00	58.0	48.0	8.3	0.49
01:03:00	60.0	50.5	8.9	0.55
01:05:00	62.0	50.5	8.9	0.55
01:07:00	64.0	51.0	9.0	0.56
01:09:00	66.0	51.0	9.0	0.56
01:14:00	71.0	56.0	10.1	0.67
01:19:00	76.0	55.0	9.9	0.65
01:24:00	81.0	56.5	10.2	0.69
01:29:00	86.0	59.0	10.7	0.74
01:35:41	92.7	61.0	11.2	0.79
01:40:00	97.0	61.0	11.2	0.79
01:46:00	103.0	63.0	11.6	0.83
01:51:00	108.0	63.0	11.6	0.83
01:56:00	113.0	65.0	12.0	0.88
02:04:35	121.6	65.0	12.0	0.88
02:17:00	134.0	67.0	12.4	0.92
02:32:00	149.0	70.0	13.1	0.99
02:47:00	164.0	70.0	13.1	0.99
03:04:00	181.0	71.0	13.3	1.01

0.2
-1.7

Point #1				
Time		Reading	Conc. Na	C/Co
min	min		mg/L	
00:03:00	0.0	24.5	3.4	-0.02
00:04:00	1.0	26.0	3.7	0.02
00:05:00	2.0	25.0	3.5	-0.01
00:06:00	3.0	25.5	3.6	0.01
00:07:00	4.0	29.0	4.4	0.08
00:08:00	5.0	30.0	4.6	0.10
00:09:00	6.0	32.0	5.0	0.15
00:10:00	7.0	32.5	5.1	0.16
00:11:00	8.0	36.0	5.8	0.23
00:12:00	9.0	37.0	6.0	0.25
00:13:00	10.0	38.0	6.2	0.28
00:14:00	11.0	37.5	6.1	0.26
00:15:00	12.0	39.0	6.5	0.30
00:16:00	13.0	40.0	6.7	0.32
00:17:00	14.0	39.5	6.6	0.31
00:18:00	15.0	42.0	7.1	0.36
00:19:00	16.0	42.5	7.2	0.37
00:20:00	17.0	42.0	7.1	0.36
00:21:00	18.0	43.5	7.4	0.39
00:22:00	19.0	44.5	7.6	0.42
00:23:00	20.0	44.0	7.5	0.41
00:24:00	21.0	46.0	7.9	0.45
00:25:00	22.0	48.0	8.3	0.49
00:26:00	23.0	46.0	7.9	0.45
00:27:00	24.0	46.5	8.0	0.46
00:28:00	25.0	48.0	8.3	0.49
00:29:00	26.0	48.5	8.4	0.50
00:30:00	27.0	47.0	8.1	0.4[illegible]
00:31:00	28.0	49.0	8.5	0.51
00:32:00	29.0	48.5	8.4	0.50
00:33:00	30.0	50.0	8.7	0.54
00:38:00	35.0	53.0	9.4	0.60
00:43:00	40.0	54.5	9.7	0.63
00:48:00	45.0	61.0	11.0	0.77
00:53:00	50.0	58.0	10.4	0.71
00:58:00	55.0	59.0	10.6	0.73
01:03:00	60.0	59.5	10.7	0.74
01:18:00	75.0	64.0	11.6	0.84
01:33:00	90.0	68.0	12.5	0.92
01:48:00	105.0	69.0	12.7	0.95
02:03:00	120.0	70.0	12.9	0.97
02:18:00	135.0	70.5	13.0	0.98
02:33:00	150.0	71.0	13.1	0.99
02:48:00	165.0	71.5	13.2	1.00
03:03:00	180.0	71.5	13.2	1.00

0.2 0.2 0.2
-1.5 -1.6 -1.4

Point #2					Point #3							Point #4		
Time		Reading	Conc. Ns	C/Co	Time		Reading	Conc. Ns	C/Co	Time		Reading	Conc. Ns	C/Co
min	min		mg/L		min	min		mg/L		min	min		mg/L	
00:03:00	0.0	25.0	3.6	0.00	00:03:00	0.0	25.0	3.6	0.00	00:03:30	0.5	24.5	3.6	0.01
00:04:00	1.0	25.0	3.6	0.00	00:04:00	1.0	25.0	3.6	0.00	00:04:30	1.5	24.0	3.5	-0.01
00:05:00	2.0	42.5	7.2	0.37	00:05:00	2.0	25.0	3.6	0.00	00:05:30	2.5	24.5	3.6	0.01
00:06:00	3.0	43.0	7.3	0.38	00:06:00	3.0	27.5	4.1	0.05	00:06:30	3.5	24.0	3.5	-0.01
00:07:00	4.0	46.5	8.0	0.46	00:07:00	4.0	28.0	4.2	0.06	00:07:30	4.5	25.0	3.7	0.02
00:08:00	5.0	53.5	9.4	0.61	00:08:00	5.0	29.0	4.4	0.09	00:08:30	5.5	27.5	4.3	0.07
00:09:00	6.0	55.0	9.7	0.64	00:09:00	6.0	33.0	5.2	0.17	00:09:30	6.5	28.5	4.5	0.09
00:10:00	7.0	58.0	10.3	0.70	00:10:00	7.0	33.0	5.2	0.17	00:10:30	7.5	31.0	5.0	0.15
00:11:00	8.0	55.0	9.7	0.64	00:11:00	8.0	36.0	5.9	0.24	00:11:30	8.5	34.0	5.6	0.21
00:12:00	9.0	56.0	9.9	0.66	00:12:00	9.0	40.0	6.7	0.32	00:12:30	9.5	34.5	5.7	0.22
00:13:00	10.0	58.5	10.4	0.71	00:13:00	10.0	40.0	6.7	0.32	00:13:30	10.5	38.0	6.4	0.30
00:14:00	11.0	59.0	10.5	0.72	00:14:00	11.0	42.0	7.1	0.37	00:14:30	11.5	35.5	5.9	0.24
00:15:00	12.0	61.0	11.0	0.77	00:15:00	12.0	46.0	7.9	0.45	00:15:30	12.5	36.5	6.1	0.26
00:16:00	13.0	59.5	10.6	0.73	00:16:00	13.0	43.0	7.3	0.39	00:16:30	13.5	37.0	6.2	0.27
00:17:00	14.0	59.0	10.5	0.72	00:17:00	14.0	44.5	7.6	0.42	00:17:30	14.5	38.0	6.4	0.30
00:18:00	15.0	61.0	11.0	0.77	00:18:00	15.0	45.0	7.7	0.43	00:18:30	15.5	38.5	6.5	0.31
00:19:00	16.0	61.0	11.0	0.77	00:19:00	16.0	47.0	8.1	0.47	00:19:30	16.5	41.0	7.1	0.36
00:20:00	17.0	62.0	11.2	0.79	00:20:00	17.0	50.0	8.8	0.54	00:20:30	17.5	39.5	6.7	0.33
00:21:00	18.0	59.0	10.5	0.72	00:21:00	18.0	47.5	8.2	0.48	00:21:30	18.5	43.0	7.5	0.40
00:22:00	19.0	63.0	11.4	0.81	00:22:00	19.0	49.0	8.6	0.52	00:22:30	19.5	42.0	7.3	0.38
00:23:00	20.0	62.0	11.2	0.79	00:23:00	20.0	49.0	8.6	0.52	00:23:30	20.5	44.0	7.7	0.42
00:24:00	21.0	61.0	11.0	0.77	00:24:00	21.0	50.5	8.9	0.55	00:24:30	21.5	42.0	7.3	0.38
00:25:00	22.0	63.0	11.4	0.81	00:25:00	22.0	51.0	9.0	0.56	00:25:30	22.5	43.5	7.6	0.41
00:26:00	23.0	62.0	11.2	0.79	00:26:00	23.0	51.0	9.0	0.56	00:26:30	23.5	45.0	7.9	0.45
00:27:00	24.0	63.0	11.4	0.81	00:27:00	24.0	52.0	9.2	0.58	00:27:30	24.5	47.5	8.4	0.50
00:28:00	25.0	62.0	11.2	0.79	00:28:00	25.0	52.5	9.3	0.59	00:28:30	25.5	49.5	8.8	0.54
00:29:00	26.0	63.0	11.4	0.81	00:29:00	26.0	52.0	9.2	0.58	00:29:30	26.5	49.5	8.8	0.54
00:30:00	27.0	63.0	11.4	0.81	00:30:00	27.0	51.0	9.0	0.56	00:30:30	27.5	50.0	8.9	0.55
00:31:00	28.0	63.0	11.4	0.81	00:31:00	28.0	52.0	9.2	0.58	00:31:30	28.5	51.0	9.1	0.58
00:32:00	29.0	63.0	11.4	0.81	00:32:00	29.0	52.0	9.2	0.58	00:32:30	29.5	52.0	9.3	0.60
00:33:00	30.0	61.5	11.1	0.78	00:33:00	30.0	53.0	9.4	0.60	00:33:30	30.5	52.0	9.3	0.60
00:38:00	35.0	66.0	12.0	0.87	00:38:00	35.0	53.5	9.5	0.61	00:38:30	35.5	53.0	9.5	0.62
00:43:00	40.0	68.0	12.4	0.91	00:43:00	40.0	55.0	9.8	0.65	00:43:30	40.5	54.0	9.7	0.64
00:48:00	45.0	68.5	12.5	0.93	00:48:00	45.0	57.5	10.3	0.70	00:48:30	45.5	54.0	9.7	0.64
00:53:00	50.0	68.5	12.5	0.93	00:53:00	50.0	58.0	10.4	0.71	00:53:30	50.5	58.0	10.6	0.73
00:58:00	55.0	66.5	12.1	0.88	00:58:00	55.0	61.0	11.0	0.77	00:58:30	55.5	59.0	10.8	0.75
01:03:00	60.0	66.0	12.0	0.87	01:03:00	60.0	63.0	11.4	0.82	01:03:30	60.5	60.5	11.1	0.78
01:18:00	75.0	69.5	12.7	0.95	01:18:00	75.0	65.0	11.9	0.86	01:18:30	75.5	64.0	11.8	0.85
01:33:00	90.0	70.5	12.9	0.97	01:33:00	90.0	67.0	12.3	0.90	01:33:30	90.5	65.0	12.0	0.88
01:48:00	105.0	71.0	13.0	0.98	01:48:00	105.0	68.5	12.6	0.94	01:48:30	105.5	68.0	12.6	0.94
02:03:00	120.0	71.0	13.0	0.98	02:03:00	120.0	70.0	12.9	0.97	02:03:30	120.5	68.0	12.6	0.94
02:18:00	135.0	72.0	13.2	1.00	02:18:00	135.0	70.5	13.0	0.98	02:18:30	135.5	68.0	12.6	0.94
02:33:00	150.0	72.0	13.2	1.00	02:33:00	150.0	71.0	13.1	0.99	02:33:30	150.5	69.0	12.8	0.96
02:48:00	165.0	72.0	13.2	1.00	02:48:00	165.0	71.5	13.2	1.00	02:48:30	165.5	71.0	13.3	1.01
03:03:00	180.0	76.5	14.1	1.10	03:03:00	180.0	71.5	13.2	1.00	03:03:30	180.5	70.5	13.1	0.99

SAMPLING NO:	**4**	
LOCATION	**Reservoir 1**	
FLOW (ML/d)	**180**	
SAMPLING DATE	**24-Mar-93**	
TESTING DATE	**30-Mar-93**	**(omit these data)**
	09-Apr-93	**(use these data)**
STANDARD MADE:	**22-Feb-93**	**(old standard)**
	09-Apr-93	**(new standrad)**

STANDARDIZATION

mg/L Na	Initial Reading	Initial Reading	Average
2.5	18.5	17.5	18.0
5.0	35.0	34.5	34.8
10.0	61.5	60.5	61.0
15.0	83.0	81.5	82.3
17.5	91.0	91.0	91.0
20.0	100.0	98.0	99.0

Regression Statistics	
Multiple R	0.995
R Square	0.989
Adjusted R Square	0.986
Standard Error	0.819
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	243.152	243.152	362.681	0.000
Residual	4	2.682	0.670		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.156	0.799	-2.698	0.043	-4.375	0.063
x1	0.215	0.011	19.044	0.000	0.184	0.246

General Equation y=0.215x-2.156

TEST NO. 4
RESERVOIR NO. 1 (180 ML/d)

NaBack(mg/L)=	4.04	m=	0.2			m=	0.2
NaFinal(mg/L)=	16.72	b=	-2.2			b=	-1.6
NaTracer(mg/L)=	12.68						

Inlet						Outlet					
Time		t/Td	Reading	Conc. Na	C/Co	Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=297		mg/L		min	min	Td=297		mg/L	
00:05:00	0.0	0.00	28.5	4.0	-0.01	00:05:00	0.0	0.00	27.0	4.0	0.00
00:06:00	1.0	0.00	28.5	4.0	-0.01	00:15:00	10.0	0.03	27.0	4.0	0.00
00:07:00	2.0	0.01	29.5	4.2	0.01	00:25:00	20.0	0.07	27.0	4.0	0.00
00:08:00	3.0	0.01	28.0	3.9	-0.01	00:35:00	30.0	0.10	27.0	4.0	0.00
00:09:00	4.0	0.01	29.0	4.1	0.00	00:45:00	40.0	0.13	27.0	4.0	0.00
00:10:00	5.0	0.02	28.5	4.0	-0.01	00:55:00	50.0	0.17	27.0	4.0	0.00
00:11:00	6.0	0.02	29.0	4.1	0.00	01:00:00	55.0	0.19	28.0	4.3	0.02
00:12:00	7.0	0.02	29.0	4.1	0.00	01:05:00	60.0	0.20	27.0	4.0	0.00
00:13:00	8.0	0.03	29.0	4.1	0.00	01:10:00	65.0	0.22	27.5	4.1	0.01
00:14:00	9.0	0.03	28.5	4.0	-0.01	01:15:00	70.0	0.24	28.0	4.3	0.02
00:15:00	10.0	0.03	28.5	4.0	-0.01	01:25:00	80.0	0.27	28.0	4.3	0.02
00:16:00	11.0	0.04	30.5	4.4	0.03	01:35:00	90.0	0.30	31.0	4.9	0.07
00:17:00	12.0	0.04	29.5	4.2	0.01	01:40:00	95.0	0.32	33.5	5.4	0.11
00:18:00	13.0	0.04	29.0	4.1	0.00	01:45:00	100.0	0.34	36.0	5.9	0.15
00:19:00	14.0	0.05	29.5	4.2	0.01	01:55:00	110.0	0.37	40.5	6.9	0.22
00:20:00	15.0	0.05	30.5	4.4	0.03	02:05:00	120.0	0.40	43.5	7.5	0.27
00:21:00	16.0	0.05	38.0	6.0	0.16	02:15:00	130.0	0.44	48.0	8.4	0.35
00:22:00	17.0	0.06	43.0	7.1	0.24	02:25:00	140.0	0.47	47.5	8.3	0.34
00:23:00	18.0	0.06	50.5	8.7	0.37	02:35:00	150.0	0.51	50.5	8.9	0.39
00:24:00	19.0	0.06	55.5	9.8	0.45	02:45:00	160.0	0.54	55.5	10.0	0.47
00:25:00	20.0	0.07	61.0	11.0	0.55	02:55:00	170.0	0.57	54.5	9.8	0.45
00:26:00	21.0	0.07	69.5	12.8	0.69	03:05:00	180.0	0.61	57.0	10.3	0.49
00:27:00	22.0	0.07	66.0	12.0	0.63	03:15:00	190.0	0.64	57.5	10.4	0.50
00:28:00	23.0	0.08	65.5	11.9	0.62	03:25:00	200.0	0.67	61.0	11.1	0.56
00:29:00	24.0	0.08	66.0	12.0	0.63	03:38:00	213.0	0.72	63.0	11.5	0.59
00:30:00	25.0	0.08	70.0	12.9	0.70	03:45:00	220.0	0.74	62.5	11.4	0.58
00:31:00	26.0	0.09	71.0	13.1	0.71	03:55:00	230.0	0.77	63.0	11.5	0.59
00:32:00	27.0	0.09	73.0	13.5	0.75	04:05:00	240.0	0.81	63.5	11.7	0.60
00:33:00	28.0	0.09	75.0	14.0	0.78	04:15:00	250.0	0.84	65.0	12.0	0.62
00:34:00	29.0	0.10	79.0	14.8	0.85	04:25:00	260.0	0.88	65.5	12.1	0.63
00:35:00	30.0	0.10	78.5	14.7	0.84	04:35:00	270.0	0.91	66.5	12.3	0.65
00:40:00	35.0	0.12	85.0	16.1	0.95	04:45:00	280.0	0.94	67.0	12.4	0.66
00:45:00	40.0	0.13	84.0	15.9	0.94	04:55:00	290.0	0.98	71.0	13.2	0.72
00:50:00	45.0	0.15	85.5	16.2	0.96	05:05:00	300.0	1.01	71.0	13.2	0.72
00:58:23	53.4	0.18	84.5	16.0	0.94	05:15:00	310.0	1.04	72.0	13.4	0.74
01:01:40	56.7	0.19	90.0	17.2	1.04	05:25:00	320.0	1.08	73.0	13.6	0.76
01:06:00	61.0	0.21	84.5	16.0	0.94	05:35:00	330.0	1.11	74.5	13.9	0.78
01:10:00	65.0	0.22	90.5	17.3	1.05	05:45:00	340.0	1.14	75.0	14.1	0.79
02:12:00	127.0	0.43	87.5	16.7	0.99	05:55:00	350.0	1.18	75.5	14.2	0.80
03:05:00	180.0	0.61	88.0	16.8	1.00	06:05:00	360.0	1.21	73.0	13.6	0.76
04:05:00	240.0	0.81	87.0	16.5	0.99	06:15:00	370.0	1.25	74.5	13.9	0.78
05:05:00	300.0	1.01	84.0	15.9	0.94	06:25:00	380.0	1.28	76.0	14.3	0.81
06:05:00	360.0	1.21	83.5	15.8	0.93	06:35:00	390.0	1.31	76.5	14.4	0.81
07:05:00	420.0	1.41	85.5	16.2	0.96	06:45:00	400.0	1.35	78.5	14.8	0.85
08:05:00	480.0	1.62	90.5	17.3	1.05	06:55:00	410.0	1.38	79.0	14.9	0.86
09:05:00	540.0	1.82	91.0	17.4	1.05	07:05:00	420.0	1.41	80.0	15.1	0.87
10:05:00	600.0	2.02	94.5	18.2	1.11	07:19:00	434.0	1.46	79.0	14.9	0.86
11:05:00	660.0	2.22	91.5	17.5	1.06	07:25:00	440.0	1.48	80.0	15.1	0.87
12:05:00	720.0	2.42	97.0	18.7	1.16	07:35:00	450.0	1.52	80.5	15.2	0.88
						07:55:00	470.0	1.58	80.5	15.2	0.88
						08:05:00	480.0	1.62	81.0	15.3	0.89
						08:15:00	490.0	1.65	80.0	15.1	0.87
						08:25:00	500.0	1.68	80.0	15.1	0.87
						08:35:00	510.0	1.72	81.0	15.3	0.89
						08:45:00	520.0	1.75	81.0	15.3	0.89
						08:55:00	530.0	1.78	82.5	15.6	0.91
						09:05:00	540.0	1.82	82.0	15.5	0.90
						09:15:00	550.0	1.85	83.5	15.8	0.93
						09:25:00	560.0	1.89	84.0	15.9	0.94
						09:35:00	570.0	1.92	84.5	16.0	0.95
						09:45:00	580.0	1.95	83.5	15.8	0.93
						09:55:00	590.0	1.99	85.0	16.1	0.95
						10:05:00	600.0	2.02	85.0	16.1	0.95
						10:15:00	610.0	2.05	85.0	16.1	0.95
						10:25:00	620.0	2.09	85.0	16.1	0.95
						10:35:00	630.0	2.12	85.0	16.1	0.95
						10:45:00	640.0	2.15	85.0	16.1	0.95
						10:55:00	650.0	2.19	86.5	16.5	0.98
						11:05:00	660.0	2.22	86.5	16.5	0.98
						11:15:00	670.0	2.26	90.0	17.2	1.04
						11:25:00	680.0	2.29	88.5	16.9	1.01
						11:35:00	690.0	2.32	88.5	16.9	1.01
						11:45:00	700.0	2.36	88.5	16.9	1.01

11:55:00	710.0	2.39	87.5	16.7	0.99
12:05:00	730.0	2.42	87.5	16.7	0.99
12:15:00	730.0	2.46	86.5	16.5	0.98
12:25:00	740.0	2.49	88.0	16.8	1.00
12:35:00	750.0	2.53	87.5	16.7	0.99

Gnrl Eqn: $y=0.215x-2.156$

	(INLET)	(OUTLET)	
Na start:	4.04	3.65	
Na finish:	16.72	16.72	
Initial:	28.8	27.0	(average of 3 first samples)
Steady:	87.8	87.8	(average of 8 last samples from OUTLET) (assumed Steady for Inlet = Outlet)

m= 0.2
b= -2.2

System				
Time In	TOut-TIn	T/Td	Time Correction	
Eqvl	min	Td=297	C/Co	Time(min)
14.0	0.0	0.00	0.00	14.0
14.0	0.0	0.00	0.05	15.0
14.0	6.0	0.02	0.10	15.5
14.0	16.0	0.05	0.15	16.0
14.0	26.0	0.09	0.20	16.5
14.0	36.0	0.12	0.25	17.0
14.3	40.7	0.14	0.30	17.5
14.0	46.0	0.15	0.35	18.0
14.2	50.8	0.17	0.40	18.5
14.3	55.7	0.19	0.45	19.0
14.3	65.7	0.22	0.50	19.5
15.2	74.8	0.25	0.55	20.0
15.6	79.4	0.27	0.60	20.5
16.0	84.0	0.28	0.65	22.0
16.7	93.3	0.31	0.70	25.0
17.2	102.8	0.35	0.75	27.0
18.0	112.0	0.38	0.80	28.0
17.9	122.1	0.41	0.85	29.0
18.4	131.6	0.44	0.90	33.0
19.2	140.8	0.47	0.95	35.0
19.0	151.0	0.51	1.00	55.0
19.4	160.6	0.54		
19.5	170.5	0.57		
20.1	179.9	0.61		
20.4	192.6	0.65		
20.3	199.7	0.67		
20.4	209.6	0.71		
20.5	219.5	0.74		
21.2	228.8	0.77		
21.5	238.5	0.80		
22.0	248.0	0.84		
22.5	257.5	0.87		
25.9	264.1	0.89		
25.9	274.1	0.92		
26.6	283.4	0.95		
27.1	292.9	0.99		
27.6	302.4	1.02		
27.8	312.2	1.05		
28.0	322.0	1.08		
27.1	332.9	1.12		
27.6	342.4	1.15		
28.1	351.9	1.18		
28.3	361.7	1.22		
28.9	371.1	1.25		
29.4	380.6	1.28		
30.7	389.3	1.31		
29.4	404.6	1.36		
30.7	409.3	1.38		
31.4	418.6	1.41		
31.4	438.6	1.48		
32.0	448.0	1.51		
30.7	459.3	1.55		
30.7	469.3	1.58		
32.0	478.0	1.61		
32.0	488.0	1.64		
33.5	496.5	1.67		
33.2	506.8	1.71		
34.2	515.8	1.74		
34.5	525.5	1.77		
34.8	535.2	1.80		
34.2	545.8	1.84		
36.5	553.5	1.86		
36.5	563.5	1.90		
36.5	573.5	1.93		
36.5	583.5	1.96		
36.5	593.5	2.00		
36.5	603.5	2.03		
46.4	603.6	2.03		
46.4	613.6	2.07		
55.0	615.0	2.07		
55.0	625.0	2.10		
55.0	635.0	2.14		
55.0	645.0	2.17		

Background					
Time		t/Td	Reading	Conc. N	C/Co
min	min	Td=297		mg/L	
00:05:00	0.0	0.00	27.5	3.8	0.0
02:05:00	120.0	0.40	27.5	3.8	0.0
04:05:00	240.0	0.81	27.5	3.8	0.0
06:05:00	360.0	1.21	27.5	3.8	0.0
08:05:00	480.0	1.62	31.0	4.5	0.0
10:05:00	600.0	2.02	36.5	5.7	0.1

52.9	657.1	2.21
52.9	667.1	2.25
46.4	683.6	2.30
55.0	685.0	2.31
52.9	697.1	2.35

SAMPLING NO:	**5**
LOCATION	**Reservoir 2**
FLOW (ML/d)	**167**
SAMPLING DATE:	**06-Apr-93**
TESTING DATE:	**09-Apr-93**
STANDARD MADE:	**09-Apr-93**

STANDARDIZATION

mg/L Na	Initial Reading	Final Reading	Average
2.5	18.5	18.5	18.5
5.0	35.0	35.0	35.0
10.0	61.5	61.5	61.5
15.0	83.0	83.0	83.0
17.5	91.0	91.0	91.0
20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.995
R Square	0.990
Adjusted R Square	0.987
Standard Error	0.800
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	243.270	243.270	379.677	0.000
Residual	4	2.563	0.641		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.224	0.784	-2.836	0.036	-4.402	-0.047
x1	0.214	0.011	19.485	0.000	0.184	0.245

General Equation: y=0.214x-2.224

TEST NO. 5
RESERVOIR NO.2 (167 ML/d)

NaBack(mg/L)= 4.87
NaFinal(mg/L)= 17.36
NaTracer(mg/L)= 12.48

m= 0.2
b= -2.2

m= 0.2
b= -2.1

Inlet						Outlet					
Time		t/Td	Reading	Conc. Na	C/Co	Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=276		mg/L	Data	min	min	Td=276		mg/L	Data
00:05:00	0.0	0.00	33.0	4.8	0.00	-	0.0	0.00	-	-	0.00
00:06:00	1.0	0.00	33.5	4.9	0.01	00:10:00	5.0	0.02	32.5	4.9	0.00
00:07:00	2.0	0.01	33.0	4.8	0.00	00:20:00	15.0	0.05	32.5	4.9	0.00
00:08:00	3.0	0.01	33.0	4.8	0.00	00:30:00	25.0	0.09	32.5	4.9	0.00
00:09:00	4.0	0.01	33.0	4.8	0.00	00:40:00	35.0	0.13	42.0	6.9	0.16
00:10:00	5.0	0.02	33.0	4.8	0.00	00:50:00	45.0	0.16	45.5	7.7	0.22
00:11:00	6.0	0.02	33.0	4.8	0.00	01:00:00	55.0	0.20	50.5	8.7	0.31
00:12:00	7.0	0.03	33.0	4.8	0.00	01:10:00	65.0	0.24	52.0	9.0	0.33
00:13:00	8.0	0.03	33.0	4.8	0.00	01:20:00	75.0	0.27	52.5	9.2	0.34
00:14:00	9.0	0.03	32.5	4.7	-0.01	01:30:00	85.0	0.31	56.5	10.0	0.41
00:15:00	10.0	0.04	33.5	4.9	0.01	01:40:00	95.0	0.34	59.5	10.7	0.46
00:16:00	11.0	0.04	33.0	4.8	0.00	01:50:00	105.0	0.38	60.0	10.8	0.47
00:17:00	12.0	0.04	32.0	4.6	-0.02	02:00:00	115.0	0.42	59.0	10.5	0.45
00:18:00	13.0	0.05	32.5	4.7	-0.01	02:10:00	125.0	0.45	61.0	11.0	0.49
00:19:00	14.0	0.05	32.5	4.7	-0.01	02:20:00	135.0	0.49	61.5	11.1	0.50
00:20:00	15.0	0.05	32.5	4.7	-0.01	02:30:00	145.0	0.53	64.0	11.6	0.54
00:21:00	16.0	0.06	33.0	4.8	0.00	02:40:00	155.0	0.56	62.0	11.2	0.51
00:22:00	17.0	0.06	33.0	4.8	0.00	02:50:00	165.0	0.60	64.5	11.7	0.55
00:23:00	18.0	0.07	33.5	4.9	0.01	03:00:00	175.0	0.63	67.5	12.4	0.60
00:24:00	19.0	0.07	34.0	5.1	0.01	03:13:30	188.5	0.68	67.5	12.4	0.60
00:25:00	20.0	0.07	33.5	4.9	0.01	03:20:00	195.0	0.71	68.0	12.5	0.61
00:26:00	21.0	0.08	34.0	5.1	0.01	03:30:00	205.0	0.74	69.0	12.7	0.63
00:27:00	22.0	0.08	35.0	5.3	0.03	03:40:00	215.0	0.78	71.0	13.1	0.66
00:28:00	23.0	0.08	39.0	6.1	0.10	03:50:00	225.0	0.82	74.0	13.8	0.71
00:29:00	24.0	0.09	44.0	7.2	0.19	04:00:00	235.0	0.85	73.0	13.5	0.69
00:30:00	25.0	0.09	46.5	7.7	0.23	04:10:00	245.0	0.89	73.0	13.5	0.69
00:31:00	26.0	0.09	59.5	10.5	0.45	04:20:00	255.0	0.92	73.0	13.5	0.69
00:32:00	27.0	0.10	68.5	12.4	0.61	04:30:00	265.0	0.96	73.0	13.5	0.69
00:33:00	28.0	0.10	74.5	13.7	0.71	04:40:00	275.0	1.00	73.0	13.5	0.69
00:34:00	29.0	0.11	79.0	14.7	0.79	04:50:00	285.0	1.03	75.0	14.0	0.73
00:35:00	30.0	0.11	79.0	14.7	0.79	05:00:00	295.0	1.07	75.5	14.1	0.74
00:40:00	35.0	0.13	87.0	16.4	0.92	05:10:00	305.0	1.11	77.5	14.5	0.77
00:45:00	40.0	0.14	90.0	17.0	0.97	05:20:00	315.0	1.14	77.5	14.5	0.77
00:50:00	45.0	0.16	91.0	17.3	0.99	05:30:00	325.0	1.18	78.0	14.6	0.78
00:55:45	50.8	0.18	90.5	17.1	0.98	05:40:00	335.0	1.21	79.0	14.8	0.80
01:00:00	55.0	0.20	93.0	17.7	1.03	05:50:00	345.0	1.25	81.0	15.3	0.83
01:06:00	61.0	0.22	93.0	17.7	1.03	06:03:00	358.0	1.30	81.0	15.3	0.83
01:10:00	65.0	0.24	92.5	17.6	1.02	06:14:30	369.5	1.34	81.5	15.4	0.84
01:15:00	70.0	0.25	91.0	17.3	0.99	06:22:00	377.0	1.37	81.5	15.4	0.84
01:20:00	75.0	0.27	91.5	17.4	1.00	06:31:30	386.5	1.40	80.0	15.0	0.81
01:25:00	80.0	0.29	89.5	16.9	0.97	06:40:00	395.0	1.43	81.0	15.3	0.83
01:30:00	85.0	0.31	90.0	17.0	0.97	06:50:00	405.0	1.47	81.0	15.3	0.83
02:00:00	115.0	0.42	90.5	17.1	0.98	07:00:00	415.0	1.50	81.5	15.4	0.84
03:00:00	175.0	0.63	88.5	16.7	0.95	07:11:30	426.5	1.55	81.5	15.4	0.84
04:00:00	235.0	0.85	91.0	17.3	0.99	07:20:00	435.0	1.58	81.5	15.4	0.84
05:00:00	295.0	1.07	89.5	16.9	0.97	07:30:00	445.0	1.61	83.0	15.7	0.87
06:00:00	355.0	1.29	91.0	17.3	0.99	07:40:00	455.0	1.65	83.0	15.7	0.87
07:00:00	415.0	1.50	90.5	17.1	0.98	07:50:00	465.0	1.68	83.0	15.7	0.87
08:00:00	475.0	1.72	91.5	17.4	1.00	08:01:30	476.5	1.73	84.5	16.0	0.89
09:00:00	535.0	1.94	91.0	17.3	0.99	08:11:00	486.0	1.76	85.0	16.1	0.90
09:54:30	589.5	2.14	91.0	17.3	0.99	08:20:00	495.0	1.79	86.0	16.3	0.92
10:54:30	649.5	2.35	92.5	17.6	1.02	08:30:00	505.0	1.83	84.0	15.9	0.88
11:54:00	709.0	2.57	92.0	17.5	1.01	08:42:30	517.5	1.88	84.0	15.9	0.88
13:00:00	775.0	2.81	91.0	17.3	0.99	08:50:00	525.0	1.90	85.0	16.1	0.90
14:00:00	835.0	3.03	91.5	17.4	1.00	09:00:00	535.0	1.94	85.5	16.2	0.91
						09:13:00	548.0	1.99	85.0	16.1	0.90
						09:20:00	555.0	2.01	85.0	16.1	0.90
						09:30:00	565.0	2.05	85.5	16.2	0.91
						09:40:00	575.0	2.08	87.0	16.5	0.93
						09:50:00	585.0	2.12	87.0	16.5	0.93
						10:00:00	595.0	2.16	87.5	16.6	0.94
						10:12:00	607.0	2.20	88.5	16.9	0.96
						10:20:00	615.0	2.23	88.0	16.8	0.95
						10:30:00	625.0	2.26	89.0	17.0	0.97
						10:40:00	635.0	2.30	88.0	16.8	0.95
						10:50:00	645.0	2.34	88.0	16.8	0.95
						11:03:00	658.0	2.38	86.5	16.4	0.93
						11:10:00	665.0	2.41	88.0	16.8	0.95
						11:20:00	675.0	2.45	88.0	16.8	0.95
						11:30:00	685.0	2.48	89.0	17.0	0.97
						11:40:00	695.0	2.52	90.0	17.2	0.99
						11:50:00	705.0	2.55	90.0	17.2	0.99
						12:00:00	715.0	2.59	90.5	17.3	0.99

12:10:00	725.0	2.63	90.5	17.3	0.99
12:20:00	735.0	2.66	90.0	17.2	0.99
12:30:00	745.0	2.70	90.0	17.2	0.99
12:40:00	755.0	2.74	90.5	17.3	0.99
12:50:00	765.0	2.77	89.0	17.0	0.97
13:00:00	775.0	2.81	88.5	16.9	0.96
13:10:00	785.0	2.84	88.5	16.9	0.96
13:20:00	795.0	2.88	88.5	16.9	0.96
13:30:00	805.0	2.92	88.0	16.8	0.95
13:40:00	815.0	2.95	89.0	17.0	0.97
13:50:00	825.0	2.99	89.0	17.0	0.97
14:00:00	835.0	3.03	90.0	17.2	0.99
14:10:00	845.0	3.06	90.5	17.3	0.99
14:20:00	855.0	3.10	90.5	17.3	0.99
14:30:00	865.0	3.13	90.0	17.2	[illegible]
14:40:00	875.0	3.17	90.5	17.3	0.99
14:50:00	885.0	3.21	91.0	17.4	1.00
15:00:00	895.0	3.24	91.0	17.4	1.00

Gnrl Eqn.	y=0.214x-2.224		
	(INLET)	(OUTLET)	
Na start	4.87	4.73	
Na finish	17.36	17.21	
Initial	33.2	32.5	(average of 3 first samples)
Steady	91.5	90.8	(average of 3 last samples)

m= 0.2
b= -2.2

System					Background					
Time In	TOut-TIn	T/Td	Time Correction		Time		t/Td	Reading	Conc Na	C/Co
Eqvl.	min.	Td=276	C/Co	Time(min)	min	min	Td=276		mg/L	
20.0	0.0	0.00	0.00	20.0	00:05:00	0.0	0.00	32.5	4.7	-0.01
20.0	0.0	0.00	0.05	22.0	01:45:00	100.0	0.36	32.5	4.7	-0.01
20.0	0.0	0.00	0.10	23.0	03:00:00	175.0	0.63	32.5	4.7	-0.01
20.0	5.0	0.02	0.15	23.5	04:00:00	235.0	0.85	33.0	4.8	0.00
23.6	11.4	0.04	0.20	24.0	05:00:00	295.0	1.07	33.0	4.8	0.00
24.2	20.8	0.08	0.25	24.5	06:00:00	355.0	1.29	33.5	4.9	0.01
25.1	29.9	0.11	0.30	25.0	07:00:00	415.0	1.50	34.0	5.1	0.01
25.3	39.7	0.14	0.35	25.5	09:00:00	535.0	1.94	33.5	4.9	0.01
25.4	49.6	0.18	0.40	26.0	10:00:00	595.0	2.16	33.5	4.9	0.01
26.0	59.0	0.21	0.45	26.0	11:00:00	655.0	2.37	34.0	5.1	0.01
26.1	68.9	0.25	0.50	26.5	12:00:00	715.0	2.59	33.5	4.9	0.01
26.2	78.8	0.29	0.55	26.5	13:00:00	775.0	2.81	33.5	4.9	0.01
26.0	89.0	0.32	0.60	27.0	14:00:00	835.0	3.03	33.5	4.9	0.01
26.4	98.6	0.36	0.65	27.5						
26.5	108.5	0.39	0.70	28.0						
26.5	118.5	0.43	0.75	28.5						
26.5	128.5	0.47	0.80	30.0						
26.5	138.5	0.50	0.85	32.0						
27.0	148.0	0.54	0.90	34.0						
27.0	161.5	0.59	0.95	37.5						
27.1	167.9	0.61	1.00	45.0						
27.3	177.7	0.64								
27.6	187.4	0.68								
28.1	196.9	0.71								
27.9	207.1	0.75								
27.9	217.1	0.79								
27.9	227.1	0.82								
27.9	237.1	0.86								
27.9	247.1	0.90								
28.3	256.7	0.93								
28.4	266.6	0.97								
29.1	275.9	1.00								
29.1	285.9	1.04								
29.4	295.6	1.07								
29.9	305.1	1.11								
31.3	313.7	1.14								
31.3	326.7	1.18								
31.6	337.9	1.22								
31.6	345.4	1.25								
30.6	355.9	1.29								
31.3	363.7	1.32								
31.3	373.7	1.35								
31.6	383.4	1.39								
31.6	394.9	1.43								
31.6	403.4	1.46								
32.6	412.4	1.49								
32.6	422.4	1.53								
32.6	432.4	1.57								
33.7	442.8	1.60								
34.0	452.0	1.64								
35.2	459.8	1.67								
33.3	471.7	1.71								
33.3	484.2	1.75								
34.0	491.0	1.78								
34.6	500.4	1.81								
34.0	514.0	1.86								
34.0	521.0	1.89								
34.6	530.4	1.92								
36.4	538.6	1.95								
36.4	548.6	1.99								
37.0	558.0	2.02								
39.0	568.0	2.06								
37.7	577.3	2.09								
40.3	584.7	2.12								
37.7	597.3	2.16								
37.7	607.3	2.20								
35.8	622.2	2.25								
37.7	627.3	2.27								
37.7	637.3	2.31								
40.3	644.7	2.34								
42.9	652.1	2.36								
42.9	662.1	2.40								
44.1	670.9	2.43								

44.1	680.9	2.47
42.9	692.1	2.51
42.9	702.1	2.54
44.1	710.9	2.58
40.3	724.7	2.63
39.0	736.0	2.67
39.0	746.0	2.70
39.0	756.0	2.74
37.7	767.3	2.78
40.3	776.7	2.81
40.3	784.7	2.84
42.9	792.1	2.87
44.1	800.9	2.90
44.1	810.9	2.94
42.9	822.1	2.98
44.1	830.9	3.01
45.0	840.0	3.04
45.0	850.0	3.08

SAMPLING NO:	**6**
LOCATION:	**Reservoir 2**
FLOW (ML/d):	**141**
SAMPLING DATE:	**20-Apr-93**
TESTING DATE:	**22-Apr-93**
STANDARD MADE:	**09-Apr-93**

STANDARDIZATION

mg/L Na	Initial Reading	Final Reading	Average
2.5	17.5	17.5	17.5
5.0	32.5	32.5	32.5
10.0	58.5	58.0	58.3
15.0	80.5	80.0	80.3
17.5	89.5	89.0	89.3
20.0	100.0	98.0	99.0

Regression Statistics	
Multiple R	0.997
R Square	0.995
Adjusted R Square	0.993
Standard Error	0.575
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	244.509	244.509	738.681	0.000
Residual	4	1.324	0.331		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.813	0.549	-3.304	0.021	-3.337	-0.290
x1	0.215	0.008	27.178	0.000	0.193	0.237

General Equation: y=0.215x-1.813

TEST NO. 6
RESERVOIR NO.2 (141 ML/d)

NaBack(mg/L)=	3.92	m=	0.2	m=	0.2
NaFinal(mg/L)=	18.00	b=	-1.8	b=	-2.0
NaTracer(mg/L)=	14.08				

Inlet						Outlet					
Time		t/Td	Reading	Conc. Na	C/Co	Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=292		mg/L	Data	min	min	Td=292		mg/L	Data
00:05:00	0.0	0.00	27.0	4.0	0.01	-	0.0	0.00	-	-	0.00
00:06:00	1.0	0.00	26.5	3.9	0.00	00:13:30	8.5	0.03	26.5	3.9	0.00
00:07:00	2.0	0.01	26.5	3.9	0.00	00:20:20	15.3	0.05	26.5	3.9	0.00
00:08:00	3.0	0.01	26.5	3.9	0.00	00:31:15	26.3	0.09	26.5	3.9	0.00
00:09:00	4.0	0.01	26.5	3.9	0.00	00:41:30	36.5	0.13	26.5	3.9	0.00
00:10:00	5.0	0.02	26.5	3.9	0.00	00:52:00	47.0	0.16	37.0	6.3	0.17
00:11:00	6.0	0.02	26.5	3.9	0.00	01:01:50	56.8	0.19	43.5	7.7	0.27
00:15:00	10.0	0.03	27.0	4.0	0.01	01:10:00	65.0	0.22	43.5	7.7	0.27
00:16:00	11.0	0.04	27.0	4.0	0.01	01:22:00	77.0	0.26	44.5	7.9	0.29
00:17:00	12.0	0.04	27.0	4.0	0.01	01:30:00	85.0	0.29	45.5	8.2	0.30
00:18:00	13.0	0.04	27.0	4.0	0.01	01:40:00	95.0	0.33	47.5	8.6	0.33
00:19:00	14.0	0.05	27.0	4.0	0.01	01:50:00	105.0	0.36	54.5	10.2	0.44
00:20:00	15.0	0.05	27.0	4.0	0.01	02:00:00	115.0	0.39	53.5	10.0	0.43
00:23:00	18.0	0.06	27.0	4.0	0.91	02:10:00	125.0	0.43	54.0	10.1	0.44
00:24:00	19.0	0.07	27.0	4.0	0.01	02:20:00	135.0	0.46	55.0	10.3	0.45
00:25:00	20.0	0.07	28.0	4.2	0.02	02:30:00	145.0	0.50	56.0	10.5	0.47
00:26:00	21.0	0.07	27.0	4.0	0.01	02:40:00	155.0	0.53	58.5	11.1	0.51
00:27:00	22.0	0.08	27.0	4.0	0.01	02:50:00	165.0	0.57	59.5	11.3	0.52
00:28:00	23.0	0.08	27.0	4.0	0.01	03:00:00	175.0	0.60	61.0	11.6	0.55
00:29:00	24.0	0.08	27.0	4.0	0.01	03:13:30	188.5	0.65	62.0	11.9	0.56
00:30:00	25.0	0.09	27.0	4.0	0.01	03:20:00	195.0	0.67	63.0	12.1	0.58
00:33:00	28.0	0.10	37.5	6.2	0.17	03:31:30	206.5	0.71	64.0	12.3	0.60
00:34:00	29.0	0.10	45.5	8.0	0.29	03:40:00	215.0	0.74	64.5	12.4	0.60
00:35:00	30.0	0.10	49.0	8.7	0.34	03:50:00	225.0	0.77	65.0	12.5	0.61
00:40:00	35.0	0.12	76.0	14.5	0.75	04:00:00	235.0	0.80	66.0	12.7	0.63
00:45:00	40.0	0.14	86.0	16.7	0.91	04:10:00	245.0	0.84	66.0	12.7	0.63
00:50:00	45.0	0.15	91.0	17.8	0.98	04:20:00	255.0	0.87	67.5	13.1	0.65
00:55:45	50.8	0.17	92.5	18.1	1.01	04:30:00	265.0	0.91	67.5	13.1	0.65
01:00:00	55.0	0.19	93.5	18.3	1.02	04:40:00	275.0	0.94	68.5	13.3	0.67
01:05:00	60.0	0.21	90.5	17.6	0.97	04:50:00	285.0	0.98	69.0	13.4	0.67
01:12:30	67.5	0.23	91.5	17.9	0.99	05:00:00	295.0	1.01	71.0	13.9	0.71
01:25:00	80.0	0.27	92.0	18.0	1.00	05:26:00	321.0	1.10	73.0	14.3	0.74
01:34:00	89.0	0.30	94.5	18.5	1.04	05:30:00	325.0	1.11	73.0	14.3	0.74
02:02:20	117.3	0.40	93.5	18.3	1.02	05:40:00	335.0	1.15	73.5	14.4	0.75
02:55:00	170.0	0.58	92.5	18.1	1.01	05:50:00	345.0	1.18	74.5	14.6	0.76
03:55:00	230.0	0.79	91.0	17.8	0.98	06:00:00	355.0	1.22	74.5	14.6	0.76
04:55:00	290.0	0.99	92.0	18.0	1.00	06:13:00	368.0	1.26	75.5	14.9	0.78
05:55:00	350.0	1.20	93.0	18.2	1.01	06:20:00	375.0	1.28	76.0	15.0	0.79
06:55:00	410.0	1.40	92.0	18.0	1.00	06:30:30	385.5	1.37	76.5	15.1	0.79
07:53:00	468.0	1.60	90.5	17.6	0.97	06:40:00	395.0	1.35	76.5	15.1	0.79
08:55:00	530.0	1.82	96.0	18.8	1.06	06:50:00	405.0	1.39	76.5	15.1	0.79
09:55:00	590.0	2.02	85.5	16.6	0.90	07:00:00	415.0	1.42	77.0	15.2	0.80
10:53:00	648.0	2.22	102.0	20.1	1.15	07:10:00	425.0	1.46	78.0	15.4	0.82
11:54:00	709.0	2.43	91.5	17.9	0.99	07:20:00	435.0	1.49	78.0	15.4	0.82
12:53:00	768.0	2.63	88.0	17.1	0.94	07:30:00	445.0	1.52	79.0	15.7	0.83
						07:40:00	453.0	1.56	78.0	15.4	0.82
						07:50:00	465.0	1.39	79.0	15.7	0.83
						08:00:00	475.0	1.63	78.5	15.5	0.83
						08:13:00	488.0	1.67	80.5	16.0	0.86
						08:20:00	495.0	1.70	81.5	16.2	0.87
						08:30:00	505.0	1.73	81.0	16.1	0.87
						08:40:00	515.0	1.76	79.0	15.7	0.83
						08:50:00	525.0	1.80	79.5	15.8	0.84
						09:00:00	535.0	1.83	81.0	16.1	0.87
						09:10:00	545.0	1.87	84.0	16.8	0.91
						09:20:00	555.0	1.90	84.5	16.9	0.92
						09:30:00	565.0	1.93	84.0	16.8	0.91
						09:40:00	575.0	1.97	85.5	17.1	0.94
						09:50:00	585.0	2.00	86.0	17.2	0.94
						10:00:00	595.0	2.04	85.0	17.0	0.93
						10:12:00	607.0	2.08	86.0	17.2	0.94
						10:20:00	615.0	2.11	87.0	17.4	0.96
						10:30:00	625.0	2.14	87.5	17.6	0.97
						10:40:00	635.0	2.17	86.0	17.2	0.94
						10:50:00	645.0	2.21	85.0	17.0	0.93
						10:58:00	653.0	2.24	88.0	17.7	0.98
						11:10:00	665.0	2.28	89.5	18.0	1.00
						11:20:00	675.0	2.31	88.5	17.8	0.98
						11:32:00	687.0	2.35	88.0	17.7	0.98
						11:40:00	695.0	2.38	89.0	17.9	0.99
						11:50:00	705.0	2.41	90.0	18.1	1.01
						12:03:00	718.0	2.46	88.5	17.8	0.98
						12:10:00	725.0	2.48	90.0	18.1	1.01

12:20:00	735.0	2.52	89.0	17.9	0.99
12:30:00	745.0	2.55	87.5	17.6	0.97
12:40:00	755.0	2.59	67.5	17.6	0.97
12:50:00	765.0	2.62	88.0	17.7	0.98
13:00:00	775.0	2.65	89.5	18.0	1.00
13:13:00	788.0	2.70	89.0	17.9	0.99
13:20:00	795.0	2.72	89.5	18.0	1.00
13:30:00	805.0	2.76	89.5	18.0	1.00
13:40:00	815.0	2.79	89.5	18.0	1.00
13:50:00	825.0	2.83	89.5	18.0	1.00
14:00:00	835.0	2.86	89.5	18.0	1.00
14:10:00	845.0	2.89	89.5	18.0	1.00
14:16:00	851.0	2.91	89.5	18.0	1.00

Gnrl Eqn: $y=0.215x-1.813$

	(INLET)	(OUTLET)	
Na start:	3.92	3.88	
Na finish:	18.00	17.43	
Initial:	26.7	26.5	(average of 3 first samples)
Steady:	92.1	89.5	(average of 3 last samples)
			(assumed Steady Inlet =before noises started at 08:55))

m= 0.2
b= -1.8

System					Background					
Time In	TOut-Tin	T/Td	Time Correction		Time		t/Td	Reading	Conc. Na	C/Co
Eqvt	min	Td=292	C/Co	Time(min)	min	min	Td=292		mg/L	
25.0	0.0	0.00	0.00	25.0	00:05:00	0.0	0.00	25.5	3.7	0.0
25.0	0.0	0.00	0.05	26.0	01:44:00	99.0	0.34	25.0	3.6	0.0
25.0	0.0	0.00	0.10	27.0	02:05:00	120.0	0.41	24.5	3.5	0.0
25.0	1.3	0.00	0.15	28.0	03:05:00	180.0	0.62	25.0	3.6	0.0
25.0	11.5	0.04	0.20	28.5	04:08:00	243.0	0.83	25.0	3.6	0.0
28.2	18.8	0.06	0.25	29.0	05:17:00	312.0	1.07	25.0	3.6	0.0
29.2	27.6	0.09	0.30	29.5	06:04:00	359.0	1.23	25.5	3.7	0.0
29.2	35.8	0.12	0.35	30.0	07:15:00	430.0	1.47	25.5	3.7	0.0
29.4	47.6	0.16	0.40	31.0	08:06:00	481.0	1.65	26.0	3.8	0.0
29.5	55.5	0.19	0.45	31.5	09:00.00	535.0	1.83	26.5	3.9	0.0
29.8	65.2	0.22	0.50	32.0	10:05:00	600.0	2.05	26.5	3.9	0.0
31.4	73.6	0.25	0.55	32.5	11:02:30	657.5	2.25	27.0	4.0	0.0
31.3	83.7	0.29	0.60	33.0	12:00:00	715.0	2.45	27.0	4.0	0.0
31.4	93.6	0.32	0.65	34.0	13:03:00	778.0	2.66	27.0	4.0	0.0
31.5	103.5	0.35	0.70	34.5						
31.7	113.3	0.39	0.75	35.0						
32.1	122.9	0.42	0.80	37.0						
32.2	132.8	0.45	0.85	38.0						
32.5	142.5	0.49	0.90	40.0						
32.6	155.9	0.53	0.95	43.0						
32.8	162.2	0.56	1.00	48.0						
33.0	173.5	0.59								
33.1	181.9	0.62								
33.2	191.8	0.66								
33.5	201.5	0.69								
33.5	211.5	0.72								
34.0	221.0	0.76								
34.0	231.0	0.79								
34.2	240.8	0.82								
34.2	250.8	0.86								
34.6	260.4	0.89								
34.9	286.1	0.98								
34.9	290.1	0.99								
35.0	300.0	1.03								
35.5	309.5	1.06								
35.5	319.5	1.09								
36.1	331.9	1.14								
36.4	338.6	1.16								
36.7	348.8	1.19								
36.7	358.3	1.23								
36.7	368.3	1.26								
37.0	378.0	1.29								
37.3	387.7	1.33								
37.3	397.7	1.36								
37.7	407.3	1.39								
37.3	417.7	1.43								
37.7	427.3	1.46								
37.5	437.5	1.50								
38.3	449.7	1.54								
38.9	456.1	1.56								
[illegible]	466.4	1.60								
37.7	477.3	1.63								
37.8	487.2	1.67								
38.6	496.4	1.70								
40.8	504.2	1.73								
41.2	513.8	1.76								
40.8	524.2	1.80								
42.2	532.8	1.82								
42.7	542.3	1.86								
41.7	553.3	1.89								
42.7	564.3	1.93								
44.0	571.0	1.96								
44.8	580.2	1.99								
42.7	592.3	2.03								
41.7	603.3	2.07								
45.6	607.4	2.08								
48.0	617.0	2.11								
46.4	628.6	2.15								
45.6	641.4	2.20								
47.2	647.8	2.22								
48.0	657.0	2.25								
46.4	671.6	2.30								
48.0	677.0	2.32								

47.2	687.8	2.36
44.8	700.2	2.40
44.8	710.2	2.43
45.6	719.4	2.46
48.0	727.0	2.49
47.2	740.8	2.54
48.0	747.0	2.56
48.0	757.0	2.59
48.0	767.0	2.63
48.0	777.0	2.66
48.0	787.0	2.70
48.0	797.0	2.73
48.0	803.0	2.75

SAMPLING NO:	**7**
LOCATION	**Reservoir 3**
FLOW (ML/d)	**179**
SAMPLING DATE	**28-Apr-93**
TESTING DATE	**02-May-93**
STANDARD MADE	**09-Apr-93**

STANDARDIZATION

mg/L Na	Initial Reading	Final Reading	Average
2.5	18.5	18.5	18.5
5.0	33.5	34.0	33.8
10.0	59.0	59.5	59.3
15.0	81.0	81.5	81.3
17.5	91.0	91.5	91.3
20.0	100.0	101.0	100.5

Regression Statistics	
Multiple R	0.998
R Square	0.995
Adjusted R Square	0.994
Standard Error	0.543
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	244.652	244.652	828.319	0.000
Residual	4	1.181	0.295		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.999	0.524	-3.814	0.012	-3.454	-0.544
x1	0.213	0.007	28.781	0.000	0.193	0.234

General Equation y=0.213x-1.999

TEST NO. 7
RESERVOIR NO. 3 (179 ML/d)

NaBack(mg/L)= 4.39
NaFinal(mg/L)= 16.46
NaTracer(mg/L)= 12.07

m= 0.2
b= -2.0

m= 0.2
b= -2.1

Inlet					
Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=283		mg/L	Dgts
00:05:00	0.0	0.00	30.0	4.4	0.00
00:06:00	1.0	0.00	30.0	4.4	0.00
00:07:00	2.0	0.01	30.0	4.4	0.00
00:08:00	3.0	0.01	30.0	4.4	0.00
00:09:00	4.0	0.01	29.5	4.3	-0.01
00:10:00	5.0	0.02	31.0	4.6	0.02
00:11:00	6.0	0.02	29.5	4.3	-0.01
00:12:00	7.0	0.02	29.5	4.3	-0.01
00:13:00	8.0	0.03	29.0	4.2	-0.02
00:14:00	9.0	0.03	29.0	4.2	-0.02
00:15:00	10.0	0.04	30.0	4.4	0.00
00:16:00	11.0	0.04	29.0	4.2	-0.02
00:17:00	12.0	0.04	29.0	4.2	-0.02
00:18:00	13.0	0.05	28.5	4.1	-0.03
00:19:00	14.0	0.05	29.0	4.2	-0.02
00:20:00	15.0	0.05	29.0	4.2	-0.02
00:21:00	16.0	0.06	29.0	4.2	-0.02
00:22:00	17.0	0.06	29.5	4.3	-0.01
00:23:00	18.0	0.06	29.0	4.2	-0.02
00:24:00	19.0	0.07	29.0	4.2	-0.02
00:25:00	20.0	0.07	29.0	4.2	-0.02
00:26:00	21.0	0.07	29.5	4.3	-0.01
00:27:00	22.0	0.08	33.0	5.0	0.05
00:28:00	23.0	0.08	38.5	6.2	0.15
00:29:00	24.0	0.08	44.5	7.5	0.26
00:30:00	25.0	0.09	51.0	8.9	0.37
00:31:00	26.0	0.09	60.0	10.8	0.53
00:32:00	27.0	0.10	65.0	11.8	0.62
00:33:00	28.0	0.10	71.0	13.1	0.72
00:34:00	29.0	0.10	75.0	14.0	0.79
00:35:00	30.0	0.11	78.5	14.7	0.86
00:40:00	35.0	0.12	84.0	15.9	0.95
00:46:20	41.3	0.15	84.5	16.0	0.96
00:50:00	45.0	0.16	85.5	16.2	0.98
00:55:00	50.0	0.18	87.0	16.5	1.01
01:03:00	58.0	0.20	87.0	16.5	1.01
01:15:00	70.0	0.25	87.0	16.5	1.01
01:25:00	80.0	0.28	88.5	16.9	1.03
01:35:00	90.0	0.32	88.5	16.9	1.03
01:55:00	110.0	0.39	88.5	16.9	1.03
02:55:00	170.0	0.60	88.5	16.9	1.03
03:55:00	230.0	0.81	89.0	17.0	1.04
04:55:00	290.0	1.02	89.0	17.0	1.04
05:55:00	350.0	1.24	87.0	16.5	1.01
06:55:00	410.0	1.45	85.0	16.1	0.97
07:53:00	468.0	1.65	89.0	17.0	1.04
08:55:00	530.0	1.87	88.0	16.7	1.02
09:55:00	590.0	2.08	92.5	17.7	1.10
10:55:00	650.0	2.30	87.5	16.6	1.01
11:55:00	710.0	2.51	86.0	16.3	0.99
12:55:00	770.0	2.72	88.5	16.9	1.03
14:00:00	835.0	2.95	85.5	16.2	0.98

Outlet					
Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=283		mg/L	Initial
00:10:00	5.0	0.02	29.5	4.4	0.00
00:20:00	15.0	0.05	29.5	4.4	0.00
00:30:00	25.0	0.09	29.5	4.4	0.00
00:40:00	35.0	0.12	35.0	5.6	0.10
00:50:00	45.0	0.16	43.0	7.4	0.25
01:00:00	55.0	0.19	44.0	7.6	0.26
01:10:30	65.5	0.23	43.5	7.5	0.26
01:20:00	75.0	0.27	47.0	8.2	0.32
01:30:00	85.0	0.30	49.0	8.7	0.36
01:40:00	95.0	0.34	53.0	9.6	0.43
01:50:00	105.0	0.37	53.0	9.6	0.43
02:00:00	115.0	0.41	55.0	10.0	0.47
02:11:30	126.5	0.45	57.0	10.4	0.50
02:20:00	135.0	0.48	58.5	10.8	0.53
02:30:00	145.0	0.51	58.5	10.8	0.53
02:40:00	155.0	0.55	58.0	10.7	0.52
02:50:00	165.0	0.58	60.0	11.1	0.56
03:00:00	175.0	0.62	61.0	11.3	0.57
03:10:00	185.0	0.65	62.0	11.5	0.59
03:20:00	195.0	0.69	63.0	11.8	0.61
03:30:00	205.0	0.72	64.5	12.1	0.64
03:40:00	215.0	0.76	66.5	12.5	0.67
03:50:00	225.0	0.80	67.5	12.8	0.69
04:00:00	235.0	0.83	67.0	12.6	0.68
04:10:00	245.0	0.87	68.0	12.9	0.70
04:21:00	256.0	0.90	69.0	13.1	0.72
04:35:00	270.0	0.95	69.3	13.2	0.73
04:40:00	275.0	0.97	70.0	13.3	0.74
04:50:00	285.0	1.01	72.0	13.7	0.78
05:00:00	295.0	1.04	71.0	13.5	0.76
05:10:00	305.0	1.08	71.0	13.5	0.76
05:20:00	315.0	1.11	71.0	13.5	0.76
05:30:00	325.0	1.15	71.5	13.6	0.77
05:40:00	335.0	1.18	72.5	13.9	0.78
05:50:00	345.0	1.22	74.5	14.3	0.82
06:00:00	355.0	1.25	73.0	14.0	0.79
06:11:30	366.5	1.30	72.5	13.9	0.78
06:20:00	375.0	1.33	73.0	14.0	0.79
06:30:00	385.0	1.36	76.5	14.7	0.86
06:40:00	395.0	1.40	77.0	14.8	0.87
06:50:00	405.0	1.43	78.0	15.1	0.88
07:00:00	415.0	1.47	78.0	15.1	0.88
07:11:00	426.0	1.51	79.0	15.3	0.90
07:22:00	437.0	1.54	78.0	15.1	0.88
07:30:00	445.0	1.57	78.5	15.2	0.89
07:40:00	455.0	1.61	77.5	15.0	0.88
07:50:00	465.0	1.64	78.0	15.1	0.88
08:00:00	475.0	1.68	80.0	15.5	0.92
08:10:00	485.0	1.71	79.0	15.3	0.90
08:20:00	495.0	1.75	79.0	15.3	0.90
08:30:00	505.0	1.78	79.5	15.4	0.91
08:40:00	515.0	1.82	79.5	15.4	0.91
08:50:00	525.0	1.86	82.0	15.9	0.96
09:00:00	535.0	1.89	82.5	16.1	0.97
09:10:00	545.0	1.93	82.5	16.1	0.97
09:20:00	555.0	1.96	82.5	16.1	0.97
09:30:00	565.0	2.00	83.0	16.2	0.98
09:40:00	575.0	2.03	83.0	16.2	0.98
09:50:00	585.0	2.07	83.5	16.3	0.98
10:00:00	595.0	2.10	85.0	16.6	1.01
10:10:00	605.0	2.14	84.0	16.4	0.99
10:20:00	615.0	2.17	84.0	16.4	0.99
10:30:00	625.0	2.21	84.5	16.5	1.00
10:40:00	635.0	2.24	85.0	16.6	1.01
10:50:00	645.0	2.28	85.0	16.6	1.01
11:00:00	655.0	2.31	83.5	16.3	0.98
11:10:00	665.0	2.35	83.0	16.2	0.98
11:20:00	675.0	2.39	83.0	16.2	0.98
11:30:00	685.0	2.42	84.0	16.4	0.99
11:40:00	695.0	2.46	84.0	16.4	0.99
11:50:00	705.0	2.49	83.5	16.3	0.98
12:00:00	715.0	2.53	84.5	16.5	1.00
12:10:00	725.0	2.56	84.5	16.5	1.00

12:20:00	735.0	2.60	85.5	16.7	1.02
12:30:00	745.0	2.63	85.5	16.7	1.02
12:40:00	755.0	2.67	85.5	16.7	1.02
12:50:00	765.0	2.70	86.0	16.8	1.03
13:00:00	775.0	2.74	86.0	16.8	1.03
13:10:00	785.0	2.77	86.5	16.9	1.04
13:20:00	795.0	2.81	86.0	16.8	1.03
13:30:00	805.0	2.84	85.5	16.7	1.02
13:40:00	815.0	2.88	83.0	16.2	0.98
13:50:00	825.0	2.92	85.0	16.6	1.01
14:00:00	835.0	2.95	85.0	16.6	1.01

Gnrl Eqn 0.213x-1.999

	(INLET)	(OUTLET)	
Ns start	4.39	4.39	
Ns finish	16.46	16.46	
First condition	30.0	29.5	(average of 3 first samples)
Steady condition	86.7	84.3	(average of 3 last samples)

m= 0.2
b= -2.0

System					Background					
Time In	TOut-TIn	T/Td	Time Correction		Time		t/Td	Reading	Conc Na	C/Co
Eqvl	min	Td=283	C/Co	Time(min)	min	min	Td=283		mg/L	
21.0	0.0	0.00	0.00	21.0	00:05:00	0.0	0.00	28.5	4.1	0.0
21.0	0.0	0.00	0.05	22.0	01:00:00	55.0	0.19	28.5	4.1	0.0
21.0	4.0	0.01	0.10	22.5	02:00:00	115.0	0.41	28.5	4.1	0.0
22.5	12.5	0.04	0.15	23.0	03:00:00	175.0	0.62	28.5	4.1	0.0
24.0	21.0	0.07	0.20	23.5	04:00:00	235.0	0.83	29.0	4.2	0.0
24.1	30.9	0.11	0.25	24.0	05:00:00	295.0	1.04	29.0	4.2	0.0
24.1	41.4	0.15	0.30	24.5	06:00:00	355.0	1.25	29.0	4.2	0.0
24.7	50.3	0.18	0.35	25.0	07:00:00	415.0	1.47	29.0	4.2	0.0
25.0	60.0	0.21	0.40	25.0	08:00:00	475.0	1.68	29.5	4.3	0.0
25.5	69.7	0.25	0.45	25.5	09:00:00	535.0	1.89	29.5	4.3	0.0
25.3	79.7	0.28	0.50	26.0	10:00:00	595.0	2.10	29.5	4.3	0.0
25.7	89.3	0.32	0.55	26.5	11:00:00	655.0	2.31	29.5	4.3	0.0
26.0	100.5	0.36	0.60	27.0	12:00:00	715.0	2.53	30.0	4.4	0.0
26.3	108.7	0.38	0.65	27.5	13:07:00	782.0	2.76	30.5	4.5	0.0
26.3	118.7	0.42	0.70	28.0						
26.2	128.8	0.46	0.75	28.5						
26.6	138.4	0.49	0.80	29.0						
26.7	148.3	0.52	0.85	30.0						
26.9	158.1	0.55	0.90	32.0						
27.1	167.9	0.59	0.95	35.0						
27.4	177.6	0.63	1.00	48.0						
27.7	187.3	0.66								
27.9	197.1	0.70								
27.8	207.2	0.73								
28.0	217.5	0.77								
28.2	227.8	0.80								
28.3	241.7	0.85								
28.4	246.6	0.87								
28.8	256.2	0.91								
28.6	266.4	0.94								
28.6	276.4	0.98								
28.6	286.4	1.01								
28.7	296.3	1.05								
28.8	306.2	1.08								
29.4	315.6	1.12								
28.9	326.[illegible]	1.15								
28.8	337.7	1.19								
28.9	346.1	1.22								
30.3	354.7	1.25								
30.7	364.3	1.29								
31.4	373.6	1.32								
31.4	383.6	1.36								
32.2	393.8	1.39								
31.4	405.6	1.43								
31.7	413.3	1.46								
31.0	424.0	1.50								
31.4	433.6	1.53								
33.3	441.7	1.56								
32.2	452.8	1.60								
32.2	462.8	1.64								
32.7	472.3	1.67								
32.7	482.3	1.70								
36.9	488.1	1.72								
39.3	495.7	1.75								
39.3	505.7	1.79								
39.3	515.7	1.82								
41.7	523.3	1.85								
41.7	533.3	1.88								
44.0	541.0	1.91								
48.0	547.0	1.93								
46.4	558.6	1.97								
46.4	568.6	2.01								
48.0	577.0	2.04								
48.0	587.0	2.07								
48.0	597.0	2.11								
44.0	611.0	2.16								
41.7	623.3	2.20								
41.7	633.3	2.24								
46.4	638.6	2.26								
46.4	648.6	2.29								
44.0	661.0	2.34								
48.0	667.0	2.36								
48.0	677.0	2.39								

48.0	687.0	2.43
48.0	697.0	2.46
48.0	707.0	2.50
48.0	717.0	2.53
48.0	727.0	2.57
48.0	737.0	2.60
48.0	747.0	2.64
48.0	757.0	2.67
41.7	773.3	2.73
48.0	777.0	2.75
48.0	787.0	2.78

SAMPLING NO:	**9**
LOCATION	**Reservoir 1**
FLOW (ML/d)	230
SAMPLING DATE	18-Jun-93
TESTING DATE	19-Jun-93
STANDARD MADE	19-Jun-93

STANDARDIZATION

mg/L Na	Initial Reading	Initial Reading	Average
2.5	18.5	18.0	18.3
[illegible].0	33.0	32.5	32.8
10.0	61.0	58.5	59.8
15.0	82.5	80.5	81.5
17.5	91.5	90.0	90.8
20.0	100.0	99.0	99.5

Regression Statistics	
Multiple R	0.997
R Square	0.993
Adjusted R Square	0.992
Standard Error	0.645
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	244.167	244.167	586.172	0.000
Residual	4	1.666	0.417		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.928	0.620	-3.108	0.027	-3.650	-0.206
x1	0.213	0.009	24.211	0.000	0.189	0.238

General Equation y=0.213x-1.928

TEST NO. 8
RESERVOIR NO. 1 (230 ML/d)

NaBack(mg/L)=	3.08	m=	0.2	m=	0.2
NaFinal(mg/L)=	16.65	b=	-1.9	b=	-1.7
NaTracer(mg/L)=	13.57				

Inlet						Outlet					
Time		t/Td	Reading	Conc. Na	C/Co	Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=220		mg/L	Initial	min	min	Td=220		mg/L	Initial
00:05:00	0.0	0.00	23.5	3.1	0.00	00:05:00	0.0	0.0	22.5	3.0	0.00
00:06:00	1.0	0.00	23.5	3.1	0.00	00:10:00	5.0	0.0	22.5	3.0	0.00
00:07:00	2.0	0.01	23.5	3.1	0.00	00:20:00	15.0	0.1	23.0	3.1	0.01
00:08:00	3.0	0.01	23.5	3.1	0.00	00:30:00	25.0	0.1	22.5	3.0	0.00
00:09:00	4.0	0.02	23.5	3.1	0.00	00:40:00	35.0	0.2	22.5	3.0	0.00
00:10:00	5.0	0.02	23.5	3.1	0.00	00:50:00	45.0	0.2	22.5	3.0	0.00
00:11:00	6.0	0.03	23.5	3.1	0.00	01:00:00	55.0	0.3	34.0	5.5	0.18
00:12:00	7.0	0.03	23.5	3.1	0.00	01:10:00	65.0	0.3	48.5	8.5	0.40
00:13:00	8.0	0.04	23.5	3.1	0.00	01:25:00	80.0	0.4	46.5	8.1	0.37
00:14:00	9.0	0.04	24.0	3.2	0.01	01:40:00	95.0	0.4	49.0	8.6	0.41
00:15:00	10.0	0.05	28.5	4.1	0.08	01:50:00	105.0	0.5	52.5	9.3	0.46
00:16:00	11.0	0.05	38.0	6.2	0.23	02:00:00	115.0	0.5	55.5	10.0	0.51
00:17:00	12.0	0.05	47.5	8.2	0.38	02:10:00	125.0	0.6	57.0	10.3	0.53
00:18:00	13.0	0.06	70.5	13.1	0.74	02:20:00	135.0	0.6	62.0	11.3	0.61
00:19:00	14.0	0.06	70.5	13.1	0.74	02:30:00	145.0	0.7	63.5	11.7	0.63
00:20:00	15.0	0.07	77.5	14.6	0.85	02:40:00	155.0	0.7	64.0	11.8	0.64
00:21:00	16.0	0.07	76.5	14.4	0.83	02:50:00	165.0	0.8	65.0	12.0	0.66
00:22:00	17.0	0.08	78.5	14.8	0.86	03:00:00	175.0	0.8	66.5	12.3	0.68
00:23:00	18.0	0.08	86.0	16.4	0.98	03:10:00	185.0	0.8	69.0	12.8	0.72
00:24:00	19.0	0.09	85.5	16.3	0.97	03:20:00	195.0	0.9	71.0	13.2	0.75
00:25:00	20.0	0.09	82.0	15.5	0.92	03:30:00	205.0	0.9	72.0	13.4	0.76
00:26:00	21.0	0.10	86.0	16.4	0.98	03:40:00	215.0	1.0	73.0	13.7	0.78
00:27:00	22.0	0.10	87.0	16.6	1.00	03:50:00	225.0	1.0	77.0	14.5	0.84
00:28:00	23.0	0.10	82.0	15.5	0.92	04:10:00	245.0	1.1	77.5	14.6	0.85
00:29:00	24.0	0.11	86.0	16.4	0.98	04:20:00	255.0	1.2	77.5	14.6	0.85
00:30:00	25.0	0.11	82.5	15.6	0.93	04:30:00	265.0	1.2	78.0	14.7	0.86
00:31:00	26.0	0.12	86.5	16.5	0.99	04:40:00	275.0	1.3	80.0	15.1	0.89
00:32:00	27.0	0.12	84.0	16.0	0.95	04:50:00	285.0	1.3	81.0	15.3	0.90
00:33:00	28.0	0.13	85.0	16.2	0.97	05:00:00	295.0	1.3	80.5	15.2	0.90
00:34:00	29.0	0.13	84.0	16.0	0.95	05:10:00	305.0	1.4	82.5	15.7	0.93
00:35:00	30.0	0.14	84.5	16.1	0.96	05:20:00	315.0	1.4	84.0	16.0	0.95
00:40:00	35.0	0.16	84.5	16.1	0.96	05:30:00	325.0	1.5	84.0	16.0	0.95
00:45:00	40.0	0.18	87.0	16.6	1.00	05:40:00	335.0	1.5	83.0	15.8	0.93
00:50:00	45.0	0.20	87.5	16.7	1.00	05:50:00	345.0	1.6	84.0	16.0	0.95
00:55:00	50.0	0.23	88.5	16.9	1.02	06:00:00	355.0	1.6	81.0	15.3	0.90
01:00:00	55.0	0.25	87.0	16.6	1.00	06:10:00	365.0	1.7	83.0	15.8	0.93
01:05:00	60.0	0.27	82.5	15.6	0.93	06:20:00	375.0	1.7	84.0	16.0	0.95
02:00:00	115.0	0.52	87.5	16.7	1.00	06:30:00	385.0	1.8	84.0	16.0	0.95
03:00:00	175.0	0.80	88.5	16.9	1.02	06:40:00	395.0	1.8	84.5	16.1	0.96
04:00:00	235.0	1.07	87.0	16.6	1.00	06:50:00	405.0	1.8	85.5	16.3	0.97
05:40:00	335.0	1.52	89.0	17.0	1.03	07:00:00	415.0	1.9	85.0	16.2	0.97
06:00:00	355.0	1.61	91.0	17.5	1.06	07:10:00	425.0	1.9	86.0	16.4	0.98
07:00:00	415.0	1.89	91.0	17.5	1.06	07:20:00	435.0	2.0	86.5	16.5	0.99
08:00:00	475.0	2.16	87.0	16.6	1.00	07:30:00	445.0	2.0	87.0	16.6	1.00
08:55:00	530.0	2.41	91.0	17.5	1.06	07:40:00	455.0	2.1	87.5	16.7	1.00
						07:50:00	465.0	2.1	88.0	16.8	1.01
						08:00:00	475.0	2.2	87.5	16.7	1.00
						08:10:00	485.0	2.2	87.0	16.6	1.00
						08:20:00	495.0	2.3	87.5	16.7	1.00
						08:30:00	505.0	2.3	87.0	16.6	1.00
						08:44:00	519.0	2.4	87.0	16.6	1.00
						08:50:00	525.0	2.4	87.0	16.6	1.00
						09:00:00	535.0	2.4	86.5	16.5	0.99

Gnrl Eqn 0.213x-1.928

	(INLET)	(OUTLET)	
Na start	3.08	2.90	
Na finish	16.65	16.65	
First condition	23.5	22.7	(evearge of 3 first samples)
Steady condition	87.2	87.2	(average of 10 last samples)
			(assumed steady state for Inlet = Outlet)

m= 0.2
b= -1.9

System					Background					
Time In	TOut-TIn	T/Td	Time Correction		Time		t/Td	Reading	Conc Na	C/Co
Eqvl	min	Td=220	C/Co	Time(min)	min	min	Td=220		mg/L	
9.0	0.0	0.00	0.00	9.0	00:05:00	0.0	0.0	23.5	3.1	0.0
9.0	0.0	0.00	0.05	9.5	01:00:00	55.0	0.3	24.0	3.2	0.0
9.1	5.9	0.03	0.10	10.0	02:00:00	115.0	0.5	24.0	3.2	0.0
9.0	16.0	0.07	0.15	10.5	03:00:00	175.0	0.8	24.5	3.3	0.0
9.0	26.0	0.12	0.20	11.0	04:00:00	235.0	1.1	24.0	3.2	0.0
9.0	36.0	0.16	0.25	11.5	05:00:00	295.0	1.3	23.5	3.1	0.0
10.8	44.2	0.20	0.30	11.5	06:00:00	355.0	1.6	24.5	3.3	0.0
12.0	53.0	0.24	0.35	12.0	07:00:00	415.0	1.9	24.5	3.3	0.0
12.0	68.0	0.31	0.40	12.0	08:00:00	475.0	2.2	24.0	3.2	0.0
12.0	83.0	0.38	0.45	12.0	09:00:00	535.0	2.4	24	3.3	0.0
12.1	92.9	0.42	0.50	12.5						
12.5	102.5	0.47	0.55	12.5						
12.5	112.5	0.51	0.60	13.0						
13.0	122.0	0.55	0.65	13.0						
13.0	132.0	0.60	0.70	13.0						
13.0	142.0	0.65	0.75	14.0						
13.0	152.0	0.69	0.80	14.5						
13.0	162.0	0.74	0.85	15.0						
13.4	171.6	0.78	0.90	17.5						
14.0	181.0	0.82	0.95	18.0						
14.1	190.9	0.87	1.00	22.0						
14.3	200.7	0.91								
14.9	210.1	0.95								
15.0	230.0	1.05								
15.0	240.0	1.09								
15.4	249.6	1.13								
16.9	258.1	1.17								
17.5	267.5	1.22								
17.3	277.7	1.26								
17.8	287.2	1.31								
18.0	297.0	1.35								
18.0	307.0	1.40								
17.8	317.2	1.44								
18.0	327.0	1.49								
17.5	337.5	1.53								
17.8	347.2	1.58								
18.0	357.0	1.62								
18.0	367.0	1.67								
18.7	376.3	1.71								
19.9	385.1	1.75								
19.3	395.7	1.80								
20.5	404.5	1.84								
21.1	413.9	1.88								
21.8	423.2	1.92								
22.0	433.0	1.97								
22.0	443.0	2.01								
22.0	453.0	2.06								
21.8	463.2	2.11								
22.0	473.0	2.15								
21.8	483.2	2.20								
21.8	497.2	2.26								
21.8	503.2	2.29								
21.1	513.9	2.34								

SAMPLING NO:	**9**
LOCATION:	**Reservoir 3**
FLOW (ML/d):	**198**
SAMPLING DATE:	**25-Jun-93**
TESTING DATE:	**26-Jun-93**
STANDARD MADE:	**19-Jun-93**

STANDARDIZATION

mg/L Na	Initial Reading	Initial Reading	Average
2.5	19.0	19.0	19.0
5.0	33.0	33.0	33.0
10.0	59.5	59.5	59.5
15.0	80.0	80.5	80.3
17.5	89.5	89.5	89.5
20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.998
R Square	0.995
Adjusted R Square	0.994
Standard Error	0.542
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	244.657	244.657	831.705	0.000
Residual	4	1.177	0.294		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.096	0.526	-3.984	0.010	-3.556	-0.635
x1	0.217	0.008	28.839	0.000	0.196	0.237

General Equation y=0.217x-2.096

TEST NO.
RESERVOIR NO. 3 (198 ML/d)

NaBack(mg/L)=	3.44	m=	0.2	m=	0.2
NaFinal(mg/L)=	17.08	b=	-2.1	b=	-2.6
NaTracer(mg/L)=	13.64				

Inlet						Outlet					
Time		t/Td	Reading	Conc. Na	C/Co	Time		t/Td	Reading	Conc. Na	C/Co
min	min	Td=318		mg/L		min	min	Td=318		mg/L	
00:05:00	0.0	0.00	25.5	3.4	0.00	00:05:00	0.0	0.00	27.0	3.4	0.00
00:06:00	1.0	0.00	25.5	3.4	0.00	00:10:00	5.0	0.02	27.0	3.4	0.00
00:07:00	2.0	0.01	25.5	3.4	0.00	00:15:00	10.0	0.03	27.0	3.4	0.00
00:08:00	3.0	0.01	26.0	3.5	0.01	00:20:00	15.0	0.05	27.0	3.4	0.00
00:09:00	4.0	0.01	26.0	3.5	0.01	00:25:00	20.0	0.06	27.0	3.4	0.00
00:10:00	5.0	0.02	28.5	4.1	0.05	00:30:00	25.0	0.08	27.5	3.5	0.01
00:11:00	6.0	0.02	27.0	3.8	0.02	00:35:00	30.0	0.09	29.0	3.9	0.03
00:12:00	7.0	0.02	28.0	4.0	0.04	00:40:00	35.0	0.11	36.0	5.4	0.15
00:13:00	8.0	0.03	27.0	3.8	0.02	00:45:00	40.0	0.13	41.5	6.7	0.24
00:14:00	9.0	0.03	27.0	3.8	0.02	00:50:00	45.0	0.14	42.0	6.8	0.24
00:15:00	10.0	0.03	27.0	3.8	0.02	00:55:00	50.0	0.16	43.0	7.0	0.26
00:16:00	11.0	0.03	26.5	3.7	0.02	01:00:00	55.0	0.17	43.5	7.1	0.27
00:17:00	12.0	0.04	27.0	3.8	0.02	01:10:00	65.0	0.20	43.5	7.1	0.27
00:18:00	13.0	0.04	26.5	3.7	0.02	01:20:00	75.0	0.24	45.0	7.4	0.29
00:19:00	14.0	0.04	27.0	3.8	0.02	01:30:00	85.0	0.27	47.0	7.9	0.33
00:20:00	15.0	0.05	28.0	4.0	0.04	01:42:00	97.0	0.31	51.5	8.9	0.40
00:21:00	16.0	0.05	27.0	3.8	0.02	01:52:00	107.0	0.34	51.0	8.8	0.39
00:22:00	17.0	0.05	27.5	3.9	0.03	01:55:00	110.0	0.35	52.0	9.0	0.41
00:23:00	18.0	0.06	27.5	3.9	0.03	02:15:00	130.0	0.41	52.5	9.1	0.42
00:24:00	19.0	0.06	26.5	3.7	0.02	02:20:00	135.0	0.42	55.5	9.8	0.46
00:25:00	20.0	0.06	26.5	3.7	0.02	02:30:00	145.0	0.46	59.0	10.6	0.52
00:26:00	21.0	0.07	26.5	3.7	0.02	02:40:00	155.0	0.49	59.5	10.7	0.53
00:27:00	22.0	0.07	27.0	3.8	0.02	02:50:00	165.0	0.52	60.0	10.8	0.54
00:28:00	23.0	0.07	31.5	4.7	0.10	02:55:00	170.0	0.53	60.5	10.9	0.55
00:29:00	24.0	0.08	41.0	6.8	0.25	03:10:00	185.0	0.58	62.5	11.3	0.58
00:30:00	25.0	0.08	48.0	8.3	0.36	03:20:00	195.0	0.61	63.0	11.4	0.59
00:31:00	26.0	0.08	57.5	10.4	0.51	03:30:00	205.0	0.64	65.0	11.9	0.62
00:32:00	27.0	0.08	67.0	12.4	0.66	03:40:00	215.0	0.68	64.5	11.8	0.61
00:33:00	28.0	0.09	72.0	13.5	0.74	03:50:00	225.0	0.71	65.5	12.0	0.63
00:34:00	29.0	0.09	73.5	13.9	0.76	03:55:00	230.0	0.72	65.5	12.0	0.63
00:35:00	30.0	0.09	78.0	14.8	0.83	04:10:00	245.0	0.77	67.0	12.3	0.65
00:40:00	35.0	0.11	85.0	16.3	0.95	04:20:00	255.0	0.80	68.5	12.7	0.68
00:45:00	40.0	0.13	84.0	16.1	0.93	04:30:00	265.0	0.83	67.5	12.4	0.66
00:50:00	45.0	0.14	87.5	16.9	0.99	04:40:00	275.0	0.86	69.0	12.8	0.68
00:55:00	50.0	0.16	89.0	17.2	1.01	04:50:00	285.0	0.90	71.0	13.2	0.72
01:00:00	55.0	0.17	86.5	16.7	0.97	05:00:00	295.0	0.93	70.0	13.0	0.70
01:05:00	60.0	0.19	86.5	16.7	0.97	05:15:00	310.0	0.97	71.0	13.2	0.72
02:00:00	115.0	0.36	87.0	16.8	0.98	05:20:00	315.0	0.99	72.0	13.4	0.73
03:00:00	175.0	0.55	88.5	17.1	1.00	05:30:00	325.0	1.02	74.0	13.9	0.77
04:00:00	235.0	0.74	92.0	17.9	1.06	05:40:00	335.0	1.05	73.5	13.8	0.76
05:05:00	300.0	0.94	87.5	16.9	0.99	05:50:00	345.0	1.08	73.5	13.8	0.76
06:00:00	355.0	1.12	87.5	16.9	0.99	06:00:00	355.0	1.12	75.0	14.1	0.78
07:00:00	415.0	1.31	87.5	16.9	0.99	06:15:00	370.0	1.16	76.0	14.3	0.80
08:05:00	480.0	1.51	87.5	16.9	0.99	06:20:00	375.0	1.18	75.5	14.2	0.79
09:00:00	535.0	1.68	87.5	16.9	0.99	06:30:00	385.0	1.21	75.5	14.2	0.79
09:30:00	565.0	1.78	89.0	17.2	1.01	06:40:00	395.0	1.24	76.0	14.3	0.80
						06:50:00	405.0	1.27	76.0	14.3	0.80
						07:00:00	415.0	1.31	77.0	14.6	0.81
						07:10:00	425.0	1.34	77.0	14.6	0.81
						07:20:00	435.0	1.37	78.0	14.8	0.83
						07:30:00	445.0	1.40	78.0	14.8	0.83
						07:40:00	455.0	1.43	78.5	14.9	0.84
						07:50:00	465.0	1.46	79.0	15.0	0.85
						08:00:00	475.0	1.49	79.0	15.0	0.85
						08:10:00	485.0	1.53	81.0	15.4	0.88
						08:20:00	495.0	1.56	81.0	15.4	0.88
						08:30:00	505.0	1.59	81.0	15.4	0.88
						08:40:00	515.0	1.62	81.5	15.6	0.89
						08:50:00	525.0	1.65	81.5	15.6	0.89
						09:00:00	535.0	1.68	82.0	15.7	0.90
						09:15:00	550.0	1.73	81.5	15.6	0.89
						09:20:00	555.0	1.75	82.0	15.7	0.90
						09:27:00	562.0	1.77	81.5	15.6	0.89

Gnrl Eqn 0.217x-2.096

	(INLET)	(OUTLET)	
Na start	3.44	3.76	
Na finish	17.08	17.08	
First condition	25.5	27.0	(aveerge of 3 first samples)
Steady condition	88.4	88.4	(average of 8 last inlet samples) (assumed steady state for Inlet= Outlet)

m= 0.2
b= -2.1

System					Background					
Time In	TOut-TIn	T/Td	Time Correction		Time		t/Td	Reading	Conc Na	C/Co
[illegible]	min	Td=318	C/Co	Time(min)	min	min	Td=318		mg/L	
20.0	0.0	0.00	0.00	20.0	00:05:00	0.0	0.00	27.0	3.8	0.0
20.0	0.0	0.00	0.05	22.5	01:00:00	55.0	0.17	27.0	3.8	0.0
20.0	0.0	0.00	0.10	23.0	02:00:00	115.0	0.36	27.0	3.8	0.0
20.5	0.0	0.00	0.15	23.5	03:00:00	175.0	0.55	28.5	4.1	0.0
20.2	0.0	0.00	0.20	24.0	04:00:00	235.0	0.74	27.5	3.9	0.0
20.6	4.6	0.01	0.25	24.0	05:00:00	295.0	0.93	27.5	3.9	0.0
21.6	8.4	0.03	0.30	24.5	06:00:00	355.0	1.12	27.5	3.5	0.0
23.5	11.5	0.04	0.35	25.0	07:00:00	415.0	1.31	27.5	3.9	0.0
24.0	16.0	0.05	0.40	25.5	08:00:00	475.0	1.49	27.5	3.9	0.0
24.0	21.0	0.07	0.45	25.5	09:00.00	535.0	1.68	27.5	3.9	0.0
24.1	25.9	0.08	0.50	26.0	09:30:00	565.0	1.78	28.0	4.0	0.0
24.2	30.8	0.10	0.55	26.0						
24.2	40.8	0.13	0.60	26.5						
24.4	50.6	0.16	0.65	27.0						
24.8	60.2	0.19	0.70	27.5						
25.5	71.5	0.22	0.75	28.0						
25.4	81.6	0.26	0.80	29.0						
25.5	84.5	0.27	0.85	30.0						
25.5	104.5	0.33	0.90	32.0						
25.6	109.4	0.34	0.95	34.0						
26.0	119.0	0.37	1.00	44.0						
26.0	129.0	0.41								
26.0	139.0	0.44								
26.0	144.0	0.45								
26.3	158.7	0.50								
26.4	168.6	0.53								
26.7	178.3	0.56								
26.6	188.4	0.59								
26.8	198.2	0.62								
26.8	203.2	0.64								
27.0	218.0	0.69								
27.3	227.7	0.72								
27.1	237.9	0.75								
27.3	247.7	0.78								
27.7	257.3	0.81								
27.5	267.5	0.84								
27.7	282.3	0.89								
27.8	287.2	0.90								
28.3	296.7	0.93								
28.2	306.8	0.96								
28.2	316.8	1.00								
28.6	326.4	1.03								
29.0	341.0	1.07								
28.8	346.2	1.09								
28.8	356.2	1.12								
29.0	366.0	1.15								
29.0	376.0	1.18								
29.3	385.7	1.21								
29.3	395.7	1.24								
29.6	405.4	1.27								
29.6	415.4	1.31								
29.8	425.2	1.34								
29.9	435.1	1.37								
29.9	445.1	1.40								
31.2	453.8	1.43								
31.2	463.8	1.46								
31.2	473.8	1.49								
31.5	483.5	1.52								
31.5	493.5	1.55								
31.8	503.2	1.58								
31.5	518.5	1.63								
31.8	523.2	1.65								
31.5	530.5	1.67								

SAMPLING NO:	10		
LOCATION	**Reservoirs 1-2-3**		
FLOW (ML/d)	170		
SAMPLING DATE	30-Jun-93	until	02-Jul-93
TESTING DATE	03-Jul-93	and	06-Jul-93
STANDARD MADE	19-Jun-93		

STANDARDIZATION (BACKGROUND)

mg/L Na	Initial Reading	Final Reading	Average
2.5	18.5	19.0	18.8
5.0	32.5	33.0	32.8
10.0	59.5	59.0	59.3
15.0	80.0	80.0	80.0
17.5	89.5	89.5	89.5
20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.998
R Square	0.995
Adjusted R Square	0.994
Standard Error	0.526
Observations	6

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1	244.725	244.725	883.159	0.000
Residual	4	1.108	0.277		
Total	5	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.021	0.508	-3.976	0.011	-3.432	-0.610
x1	0.216	0.007	29.718	0.000	0.196	0.236

STANDARDIZATION (INLET CELL#1)

mg/L Na	Initial Reading	Final Reading	Ave Rdg
2.5	19.5	19.5	19.5
5.0	34.0	33.0	33.5
10.0	60.0	59.0	59.5
15.0	81.0	79.5	80.3
17.5	90.0	88.0	89.0
20.0	100.0	98.0	99.0

Regression Statistics	
Multiple R	0.997
R Square	0.995
Adjusted R Square	0.993
Standard Error	0.577
Observations	6.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.000	244.500	244.500	733.384	0.000
Residual	4.000	1.334	0.333		
Total	5.000	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.306	0.567	-4.065	0.010	-3.881	-0.731
x1	0.220	0.008	27.081	0.000	0.198	0.243

STANDARDIZATION (INLET CELL#2)

mg/L Na	Initial Reading	Final Reading	Ave Rdg
2.5	19.0	19.5	19.3
5.0	33.0	34.0	33.5
10.0	59.5	60.5	60.0
15.0	81.5	81.5	81.5
17.5	90.0	91.0	90.5

20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.997
R Square	0.994
Adjusted R Square	0.993
Standard Error	0.595
Observations	6.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.000	244.416	244.416	689.938	0.000
Residual	4.000	1.417	0.354		
Total	5.000	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.165	0.580	-3.733	0.014	-3.775	-0.555
x1	0.216	0.008	26.267	0.000	0.193	0.239

STANDARDIZATION (OUTLET CELL#1)

mg/L Na	Initial Reading	Final Reading	Ave Rdg
2.5	19.0	18.0	18.5
5.0	33.0	31.5	32.3
10.0	59.0	58.0	58.5
15.0	79.5	79.5	79.5
17.5	88.0	87.0	87.5
20.0	98.0	98.5	98.3

Regression Statistics	
Multiple R	0.997
R Square	0.994
Adjusted R Square	0.993
Standard Error	0.587
Observations	6.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.000	244.457	244.457	710.562	0.000
Residual	4.000	1.376	0.344		
Total	5.000	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.054	0.568	-3.618	0.015	-3.630	-0.478
x1	0.220	0.008	26.656	0.000	0.197	0.243

STANDARDIZATION (OUTLET CELL#2)

mg/L Na	Initial Reading	Final Reading	Ave Rdg
2.5	19.5	19.5	19.5
5.0	33.5	34.0	33.8
10.0	60.0	60.5	60.3
15.0	81.0	81.5	81.3
17.5	90.0	90.5	90.3
20.0	100.0	101.0	100.5

Regression Statistics	
Multiple R	0.997
R Square	0.995
Adjusted R Square	0.993
Standard Error	0.573
Observations	6.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.000	244.519	244.519	743.957	0.000
Residual	4.000	1.315	0.329		
Total	5.000	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*

Intercept	-2.229	0.561	-3.975	0.011	-3.785	-0.672
x1	0.216	0.008	27.276	0.000	0.194	0.238

STANDARDIZATION (OUTLET CELL#3)

mg/L Na	Initial Reading	Final Reading	Ave Rdg
2.5	19.0	19.0	19.0
5.0	33.0	33.5	33.3
10.0	59.0	59.5	59.3
15.0	80.5	81.0	80.8
17.5	89.0	89.5	89.3
20.0	100.0	100.0	100.0

Regression Statistics	
Multiple R	0.998
R Square	0.995
Adjusted R Square	0.994
Standard Error	0.548
Observations	6.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.000	244.632	244.632	814.684	0.000
Residual	4.000	1.201	0.300		
Total	5.000	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-2.116	0.532	-3.976	0.011	-3.594	-0.639
x1	0.217	0.008	28.543	0.000	0.196	0.238

STANDARDIZATION (OUTLET CONVERGENCE)

mg/L Na	Initial Reading	Final Reading	Ave Rdg
2.5	18.5	18.5	18.5
5.0	32.0	32.5	32.3
10.0	58.5	59.0	58.8
15.0	79.5	80.0	79.8
17.5	89.0	88.5	88.8
20.0	100.0	99.0	99.5

Regression Statistics	
Multiple R	0.998
R Square	0.995
Adjusted R Square	0.994
Standard Error	0.527
Observations	6.000

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.000	244.721	244.721	879.820	0.000
Residual	4.000	1.113	0.278		
Total	5.000	245.833			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.956	0.507	-3.857	0.012	-3.365	-0.548
x1	0.217	0.007	29.662	0.000	0.196	0.237

General Equation:	Background:	y=0.216x-2.021
	Inlet Cell 1:	y=0.220x-2.306
	Inlet Cell 2:	y=0.216x-2.165
	Outlet Cell 1:	y=0.220x-2.054
	Outlet Cell 2	y=0.216x-2.229
	Outlet Cell 3	y=0.217x-2.116
	Outlet Converg	y=0.217x-1.956

TEST NO. 10
RESERVOIR NOS. 1,2,3 (170 ML/d)

Slope	m=	0.2	m=	0.2
Intercept	b=	-2.1	b=	-2.3
Gnrl.Eqn	y=0.220x-2.306 (INLET1)		y=0.216x-2.165 (INLET2)	
Na back.(mg/L)=	4.44		4.60	
Na Final (mg/L)=	18.48		18.32	
a Tracer (mg/L)=	14.04		13.72	
First condition	30.67		31.3	
Steady condition	94.5		94.8	

Inlet1					Inlet2				
Time		Reading	Conc. Na	C/Co	Time		Reading	Conc. Na	C/Co
min	min		mg/L	Initial	min	min		mg/L	Initial
00:05:00	0.0	30.5	4.5	0.00	00:05:00	0.0	31.0	4.4	-0.01
00:06:00	1.0	31.0	4.6	0.01	00:06:00	1.0	31.5	4.6	0.00
00:07:00	2.0	30.5	4.5	0.00	00:07:00	2.0	31.5	4.6	0.00
00:08:00	3.0	31.0	4.6	0.01	00:08:00	3.0	31.5	4.6	0.00
00:09:00	4.0	31.5	4.7	0.01	00:09:00	4.0	31.5	4.6	0.00
00:10:00	5.0	31.0	4.6	0.01	00:10:00	5.0	32.0	4.7	0.01
00:11:00	6.0	32.5	4.9	0.03	00:11:00	6.0	32.0	4.7	0.01
00:12:00	7.0	31.5	4.7	0.01	00:12:00	7.0	31.5	4.6	0.00
00:13:00	8.0	32.0	4.8	0.02	00:13:00	8.0	31.5	4.6	0.00
00:14:00	9.0	33.0	5.0	0.04	00:14:00	9.0	34.0	5.1	0.04
00:15:00	10.0	36.0	5.7	0.08	00:15:00	10.0	33.0	4.9	0.03
00:16:00	11.0	42.5	7.1	0.19	00:16:00	11.0	32.0	4.7	0.01
00:17:00	12.0	48.0	8.3	0.27	00:17:00	12.0	32.0	4.7	0.01
00:18:00	13.0	54.0	9.6	0.37	00:18:00	13.0	32.0	4.7	0.01
00:19:00	14.0	63.0	11.6	0.51	00:19:00	14.0	32.0	4.7	0.01
00:20:00	15.0	68.0	12.6	0.58	00:20:00	15.0	31.5	4.6	0.00
00:21:00	16.0	74.0	13.9	0.68	00:21:00	16.0	32.0	4.7	0.01
00:22:00	17.0	82.0	15.7	0.80	00:22:00	17.0	31.5	4.6	0.00
00:23:00	18.0	85.5	16.4	0.86	00:23:00	18.0	31.5	4.6	0.00
00:24:00	19.0	86.0	16.6	0.87	00:24:00	19.0	31.5	4.6	0.00
00:25:00	20.0	87.0	16.8	0.88	00:25:00	20.0	31.0	4.4	-0.01
00:26:00	21.0	90.0	17.4	0.93	00:26:00	21.0	31.5	4.6	0.00
00:27:00	22.0	93.0	18.1	0.98	00:27:00	22.0	30.0	4.2	-0.02
00:28:00	23.0	94.0	18.3	0.99	00:28:00	23.0	30.0	4.2	-0.02
00:29:00	24.0	94.0	18.3	0.99	00:29:00	24.0	30.0	4.2	-0.02
00:30:00	25.0	95.0	18.5	1.01	00:30:00	25.0	31.0	4.4	-0.01
00:35:00	30.0	94.0	18.3	0.99	00:31:00	26.0	48.0	8.2	0.26
00:40:00	35.0	94.5	18.4	1.00	00:32:00	27.0	80.0	15.2	0.77
00:45:00	40.0	93.5	18.2	0.98	00:33:00	28.0	94.0	18.2	0.99
00:50:00	45.0	95.0	18.5	1.01	00:34:00	29.0	94.5	18.3	0.99
00:55:00	50.0	94.5	18.4	1.00	00:35:00	30.0	95.0	18.4	1.00
01:00:00	55.0	95.5	18.6	1.02	00:36:00	31.0	94.5	18.3	0.99
01:05:00	60.0	95.0	18.5	1.01	00:37:00	32.0	95.0	18.4	1.00
03:10:00	185.0	94.5	18.4	1.00	04:08:00	3123.0	-	-	1.00
04:05:00	240.0	94.5	18.4	1.00					
05:05:00	300.0	93.5	18.2	0.98					
06:05:00	360.0	91.5	17.7	0.95					
07:05:00	420.0	88.0	17.0	0.90					
08:05:00	480.0	95.0	18.5	1.01					
09:05:00	540.0	95.0	18.5	1.01					
10:05:00	600.0	94.5	18.4	1.00					
11:05:00	660.0	94.5	18.4	1.00					
12:05:00	720.0	94.5	18.4	1.00					
13:05:00	780.0	96.0	18.7	1.02					
14:05:00	840.0	95.0	18.5	1.01					
15:05:00	900.0	104.0	20.5	1.15					
16:05:00	960.0	97.0	18.9	1.04					
17:05:00	1020.0	94.5	18.4	1.00					
18:08:00	1083.0	94.0	18.3	0.99					
19:05:00	1140.0	92.0	17.9	0.96					
20:07:00	1202.0	65.0	12.0	0.54					
21:07:00	1262.0	92.0	17.9	0.96					
22:08:00	1323.0	94.5	18.4	1.00					
23:08:00	1383.0	94.5	18.4	1.00					
00:08:00	1443.0	93.5	18.2	0.98					
01:08:00	1503.0	94.5	18.4	1.00					
02:08:00	1563.0	95.0	18.5	1.01					
03:08:00	1623.0	94.5	18.4	1.00					
04:08:00	1683.0	93.0	18.1	0.98					
05:08:00	1743.0	94.0	18.3	0.99					
06:08:00	1803.0	94.0	18.3	0.99					
07:08:00	1863.0	90.5	17.5	0.94					
08:08:00	1923.0	93.5	18.2	0.98					
09:08:00	1983.0	92.0	17.9	0.96					

10 08 00	2043 0	97 0	18 9	1 04
12 08 00	2163 0	94 5	18.4	1.00
13 05 00	2220 0	92 0	17.9	0.96
14 05 00	2280 0	92 5	18.0	0.97
15 05 00	2340 0	93 0	18 1	0.98
16 18 00	2413 0	96 0	18 7	1 02
17 30 00	2485 0	95 0	18 5	1 01
18 02 00	2517.0	95 5	18.6	1.02
18 30 00	2543.0	95 0	18 5	1.01
19 08 00	2583.0	94 5	18.4	1.00
20 08 00	2643 0	94 0	18.3	0.99
21 08 00	2703 0	92 0	17.9	0.96
22 08.00	2763 0	96.5	18.8	1 03
23 08 00	2823.0	94.0	18.3	0.99
00 08 00	2883 0	95 0	18.5	1.01
01 08.00	2943.0	94 0	18.3	0.99
02 08 00	3003.0	94.5	18 4	1.00
03.08 00	3063.0	94.0	18.3	0.99
04 08 00	3123 0	95 0	18.5	1.01

m= 0.2
b= -2.1

m= 0.2
b= -2.0

y=0.216x-2.021
(BACKGROUND)
4.57
18.46
13.90
30.5
94.8

y=0.220x-2.054
(OUTLET1)
4.66
18.85
14.19
30.5
96.0

Background					Outlet1				
Time		Reading	Conc. Na	C/Co	Time		Reading	Conc. Na	C/Co
min	min		mg/L		min	min		mg/L	
00:05:00	0.0	30.5	4.5	0.00	01:58:00	113.0	30.5	4.5	0.00
01:05:00	60.0	30.5	4.5	0.00	02:18:00	133.0	31.0	4.6	0.01
02:30:00	145.0	30.5	4.5	0.00	02:38:00	153.0	33.5	5.2	0.05
03:05:00	180.0	30.5	4.5	0.00	02:58:00	173.0	40.0	6.6	0.15
04:05:00	240.0	30.5	4.5	0.00	03:18:00	193.0	41.5	6.9	0.17
05:05:00	300.0	30.5	4.5	0.00	03:30:00	213.0	43.0	7.2	0.19
06:05:00	360.0	30.5	4.5	0.00	03:58:00	233.0	49.0	8.5	0.29
07:05:00	420.0	30.5	4.5	0.00	04:18:00	253.0	51.0	8.9	0.32
08:05:00	480.0	31.5	4.7	0.02	04:38:00	273.0	53.0	9.4	0.35
09:05:00	540.0	31.5	4.7	0.02	04:58:00	293.0	48.0	8.3	0.27
09:50:00	585.0	31.5	4.7	0.02	05:18:00	313.0	61.0	11.1	0.47
11:[illegible]0	660.0	31.5	4.7	0.02	05:38:00	333.0	58.0	10.4	0.43
11:57:00	712.0	31.5	4.7	0.02	05:58:00	353.0	61.0	11.1	0.47
13:05:00	780.0	31.5	4.7	0.02	06:18:00	373.0	62.5	11.4	0.50
13:57:00	832.0	31.5	4.7	0.02	06:38:00	393.0	62.5	11.4	0.50
15:00:00	895.0	32.0	4.8	0.02	06:58:00	413.0	64.0	11.7	0.52
16:00:00	955.0	34.0	5.3	0.05	07:18:00	433.0	69.0	12.8	0.60
17:05:00	1020.0	31.5	4.7	0.02	07:38:00	453.0	69.0	12.8	0.60
18:05:00	1080.0	34.0	5.3	0.05	07:58:00	473.0	69.5	12.9	0.60
18:57:00	1132.0	32.0	4.8	0.02	08:18:00	493.0	73.0	13.7	0.66
19:57:00	1192.0	30.5	4.5	0.00	08:38:00	513.0	74.0	13.9	0.67
20:53:00	1248.0	30.5	4.5	0.00	08:58:00	533.0	75.0	14.1	0.69
21:52:00	1307.0	30.5	4.5	0.00	09:18:00	553.0	75.0	14.1	0.69
22:50:00	1365.0	32.0	4.8	0.02	09:38:00	573.0	76.0	14.3	0.71
23:50:00	1425.0	32.5	5.0	0.03	12:20:00	735.0	82.0	15.6	0.80
00:50:00	1485.0	40.5	6.7	0.15	12:50:00	765.0	83.0	15.8	0.81
01:50:00	1545.0	35.0	5.5	0.07	13:19:00	794.0	84.5	16.1	0.84
04:05:00	1680.0	30.0	4.4	-0.01	13:48:00	823.0	85.0	16.2	0.84
05:05:00	1740.0	30.0	4.4	-0.01	14:08:00	843.0	86.0	16.5	0.86
06:05:00	1800.0	30.0	4.4	-0.01	14:27:00	862.0	86.0	16.5	0.86
07:05:00	1860.0	30.5	4.5	0.00	14:28:00	863.0	87.0	16.7	0.88
08:05:00	1920.0	30.0	4.4	-0.01	14:48:00	883.0	87.0	16.7	0.88
09:05:00	1980.0	30.0	4.4	-0.01	15:08:00	903.0	87.0	16.7	0.88
10:05:00	2040.0	30.0	4.4	-0.01	15:28:00	923.0	89.0	17.1	0.91
11:05:00	2100.0	60.0	10.9	0.46	15:48:00	943.0	89.0	17.1	0.91
11:49:00	2144.0	30.0	4.4	-0.01	16:08:00	963.0	89.0	17.1	0.91
12:37:00	2192.0	29.5	4.3	-0.02	16:28:00	983.0	89.5	17.2	0.91
13:21:00	2236.0	30.0	4.4	-0.01	16:48:00	1003.0	90.0	17.3	0.92
15:05:00	2340.0	29.5	4.3	-0.02	17:08:00	1023.0	91.5	17.6	0.95
18:50:00	2565.0	29.5	4.3	-0.02	17:28:00	1043.0	91.5	17.6	0.95
19:52:00	2627.0	29.5	4.3	-0.02	17:55:00	1070.0	91.0	17.5	0.94
20:00:00	2635.0	29.5	4.3	-0.02	18:08:00	1083.0	91.5	17.6	0.95
20:50:00	2685.0	29.5	4.3	-0.02	17:55:00	1070.0	91.0	17.5	0.94
21:50:00	2745.0	29.5	4.3	-0.02	18:35:00	1110.0	91.5	17.6	0.95
22:50:00	2805.0	29.5	4.3	-0.02	19:17:00	1152.0	91.0	17.5	0.94
23:50:00	2865.0	29.5	4.3	-0.02	19:17:00	1152.0	92.0	17.8	0.95
00:51:00	2926.0	30.0	4.4	-0.01	19:37:00	1172.0	92.0	17.8	0.95
01:50:00	2985.0	29.5	4.3	-0.02	19:59:00	1194.0	92.5	17.9	0.96
02:50:00	3045.0	29.5	4.3	-0.02	20:17:00	1212.0	93.0	18.0	0.97
03:50:00	3105.0	30.0	4.4	-0.01	20:37:00	1232.0	92.5	17.9	0.96
					20:57:00	1252.0	93.0	18.0	0.97
					21:17:00	1272.0	92.5	17.9	0.96
					21:37:00	1292.0	93.5	18.1	0.98
					21:57:00	1312.0	93.0	18.0	0.97
					22:17:00	1332.0	93.0	18.0	0.97
					22:37:00	1352.0	93.0	18.0	0.97
					22:57:00	1372.0	92.5	17.9	0.96
					23:17:00	1392.0	94.0	18.2	0.98
					23:37:00	1412.0	93.5	18.1	0.98
					23:57:00	1432.0	93.5	18.1	0.98
					00:17:00	1452.0	93.5	18.1	0.98
					00:37:00	1472.0	94.0	18.2	0.98
					00:57:00	1492.0	93.5	18.1	0.98
					01:17:00	1512.0	93.5	18.1	0.98

01:37:00	1532.0	94.0	18.2	0.98
01:57:00	1552.0	94.5	18.3	0.99
02:17:00	1572.0	94.5	18.3	0.99
02:37:00	1592.0	93.5	18.1	0.98
02:57:00	1612.0	94.0	18.2	0.98
03:17:00	1632.0	94.5	18.3	0.99
03:37:00	1652.0	94.5	18.3	0.99
03:57:00	1672.0	95.0	18.4	1.00
04:17:00	1692.0	95.0	18.4	1.00
04:37:00	1712.0	94.5	18.3	0.99
04:57:00	1732.0	94.5	18.3	0.99
05:17:00	1752.0	95.0	18.4	1.00
05:37:00	1772.0	95.0	18.4	1.00
05:57:00	1792.0	95.0	18.4	1.00
06:17:00	1812.0	95.0	18.4	1.00
06:37:00	1832.0	95.0	18.4	1.00
06:57:00	1852.0	95.0	18.4	1.00
07:17:00	1872.0	94.5	18.3	0.99
07:37:00	1892.0	94.5	18.3	0.99
07:57:00	1912.0	94.5	18.3	0.99
08:17:00	1932.0	95	18.4	1.00
08:37:00	1952.0	95	18.4	1.00
08:57:00	1972.0	95	18.4	1.00
09:17:00	1992.0	95	18.4	1.00
09:37:00	2012.0	95	18.4	1.00
09:57:00	2032.0	95.5	18.5	1.01
10:17:00	2052.0	95	18.4	1.00
10:37:00	2072.0	95.5	18.5	1.01
10:57:00	2092.0	95	18.4	1.00
11:17:00	2112.0	95	18.4	1.00
11:37:00	2132.0	95	18.4	1.00
11:57:00	2152.0	95	18.4	1.00
12:00:00	2155.0	95	18.4	1.00
12:17:00	2172.0	95	18.4	1.00
12:42:00	2197.0	95	18.4	1.00
00:57:00	1492.0	95	18.4	1.00
13:18:00	2233.0	95	18.4	1.00
13:44:00	2259.0	94.5	18.3	0.99
13:59:00	2274.0	95	18.4	1.00
14:59	2334.0	95	18.4	1.00
15:20:00	2355.0	95	18.4	1.00
15:30:00	2365.0	94	18.2	0.98
16:15:00	2410.0	95	18.4	1.00
16:45:00	2440.0	95	18.4	1.00
17:28:00	2483.0	95	18.4	1.00
17:58:00	2513.0	95	18.4	1.00
18:23:00	2538.0	95	18.4	1.00
18:37:00	2552.0	95	18.4	1.00
18:57:00	2572.0	95	18.4	1.00
19:17:00	2592.0	95.5	18.5	1.01
19:37:00	2612.0	95	18.4	1.00
19:57:00	2632.0	95	18.4	1.00
20:17:00	2652.0	95	18.4	1.00
20:37:00	2672.0	95	18.4	1.00
20:57:00	2692.0	95	18.4	1.00
21:17:00	2712.0	94.5	18.3	0.99
21:37:00	2732.0	95	18.4	1.00
21:57:00	2752.0	95	18.4	1.00
22:17:00	2772.0	94.5	18.3	0.99
22:37:00	2792.0	95	18.4	1.00
22:57:00	2812.0	94.5	18.3	0.99
23:17:00	2832.0	95	18.4	1.00
23:37:00	2852.0	95	18.4	1.00
23:57:00	2872.0	95	18.4	1.00
00:17:00	2892.0	95	18.4	1.00
00:37:00	2912.0	95	18.4	1.00
00:57:00	2932.0	95.5	18.5	1.01
01:17:00	2952.0	95	18.4	1.00
01:37:00	2972.0	95	18.4	1.00
01:57:00	2992.0	95	18.4	1.00
02:17:00	3012.0	95	18.4	1.00
02:37:00	3032.0	95	18.4	1.00
02:57:00	3052.0	95	18.4	1.00
03:17:00	3072.0	95	18.4	1.00

m= 0.2
b= -2.2

m= 0.2
b= -2.2

y=0.216x-2.229
(OUTLET2)
4.50
18.18
13.68
31.2
94.5

y=0.217x-2.116
(OUTLET3)
4.54
18.28
13.74
30.7
94.0

Outlet2					Outlet3				
Time		Reading	Conc. Na	C/Co	Time		Reading	Conc. Na	C/Co
min	min		mg/L		min	min		mg/L	
00:05:00	0.0	31.0	4.5	0.00	00:05:00	0.0	30.5	4.5	0.00
00:10:00	5.0	31.5	4.6	0.01	00:10:00	5.0	30.5	4.5	0.00
00:15:00	10.0	31.0	4.5	0.00	00:15:00	10.0	31.0	4.6	0.01
00:20:00	15.0	31.0	4.5	0.00	00:20:00	15.0	30.5	4.5	0.00
00:25:00	20.0	31.5	4.6	0.01	00:25:00	20.0	31.0	4.6	0.01
00:30:00	25.0	31.0	4.5	0.00	00:30:00	25.0	31.0	4.6	0.01
00:35:00	30.0	31.5	4.6	0.01	00:35:00	30.0	31.0	4.6	0.01
00:40:00	35.0	31.5	4.6	0.01	00:40:00	35.0	31.0	4.6	0.01
00:50:00	45.0	32.0	4.7	0.01		67.5			0.00
01:00:00	55.0	32.5	4.8	0.02	01:45:00	100.0	47.0	8.1	0.26
01:05:00	60.0	33.0	4.9	0.03	01:50:00	105.0	47.0	8.1	0.26
01:10:00	65.0	36.0	5.6	0.08	02:10:00	125.0	47.5	8.2	0.27
01:15:00	70.0	43.0	7.1	0.19	02:40:00	155.0	45.5	7.8	0.23
01:20:00	75.0	42.0	6.9	0.17	03:00:00	175.0	49.0	8.5	0.29
01:25:00	80.0	42.5	7.0	0.18	03:15:00	190.0	48.5	8.4	0.28
01:30:00	85.0	45.0	7.6	0.22	03:20:00	195.0	48.5	8.4	0.28
01:35:00	90.0	47.0	8.0	0.25	03:40:00	215.0	49.0	8.5	0.29
01:50:00	105.0	49.0	8.4	0.28	04:00:00	235.0	48.5	8.4	0.28
02:10:00	125.0	51.0	8.9	0.31	04:20:00	255.0	51.5	9.1	0.33
02:32:00	147.0	51.5	9.0	0.32	04:40:00	275.0	53.0	9.4	0.35
02:54:00	169.0	50.5	8.8	0.31	05:00:00	295.0	55.0	9.9	0.38
03:16:00	191.0	51.0	8.9	0.31	05:20:00	315.0	55.0	9.9	0.38
03:38:00	213.0	50.5	8.8	0.31	05:40:00	335.0	58.5	10.6	0.44
04:00:00	235.0	52.0	9.1	0.33	06:00:00	355.0	64.0	11.8	0.53
04:22:00	257.0	56.5	10.1	0.40	09:59:00	594.0	63.5	11.7	0.52
04:44:00	279.0	59.0	10.6	0.44	10:23:00	618.0	64.5	11.9	0.53
05:06:00	301.0	61.0	11.1	0.47	10:47:00	642.0	65.5	12.2	0.55
05:28:00	323.0	59.5	10.7	0.45	11:11:00	666.0	65.5	12.2	0.55
05:50:00	345.0	61.0	11.1	0.47	11:35:00	690.0	66.5	12.4	0.57
06:12:00	367.0	62.0	11.3	0.49	11:59:00	714.0	67.0	12.5	0.57
06:34:00	389.0	62.5	11.4	0.49	12:23:00	738.0	68.0	12.7	0.59
06:56:00	411.0	66.5	12.3	0.56	12:47:00	762.0	69.0	12.9	0.61
07:18:00	433.0	65.5	12.0	0.54	13:11:00	786.0	70.5	13.3	0.63
07:40:00	455.0	67.0	12.4	0.57	13:35:00	810.0	71.0	13.4	0.64
08:02:00	477.0	68.0	12.6	0.58	13:59:00	834.0	71.0	13.4	0.64
08:24:00	499.0	69.5	12.9	0.61	14:23:00	858.0	71.0	13.4	0.64
08:46:00	521.0	69.5	12.9	0.61	14:47:00	882.0	72.0	13.6	0.65
09:08:00	543.0	69.5	12.9	0.61	15:11:00	906.0	71.5	13.5	0.64
09:30:00	565.0	70.0	13.0	0.61	15:35:00	930.0	74.0	14.0	0.68
09:52:00	587.0	70.5	13.1	0.62	15:59:00	954.0	73.5	13.9	0.68
10:39:00	634.0	83.0	15.9	0.82	16:23:00	978.0	74.5	14.1	0.69
10:59:00	654.0	72.0	13.5	0.64	16:47:00	1002.0	75.0	14.2	0.70
11:19:00	674.0	77.0	14.6	0.72	17:11:00	1026.0	75.0	14.2	0.70
11:39:00	694.0	75.5	14.2	0.70	17:35:00	1050.0	75.0	14.2	0.70
11:59:00	714.0	75.5	14.2	0.70	17:59:00	1074.0	73.5	13.9	0.68
12:19:00	734.0	78.0	14.8	0.74	18:23:00	1098.0	75.0	14.2	0.70
12:39:00	754.0	76.0	14.3	0.71	18:56:00	1131.0	75.5	14.3	0.71
12:59:00	774.0	76.0	14.3	0.71	19:17:00	1152.0	76.0	14.5	0.72
13:19:00	794.0	77.0	14.6	0.72	19:38:00	1173.0	77.0	14.7	0.73
13:39:00	814.0	78.5	14.9	0.75	19:59:00	1194.0	77.0	14.7	0.73
13:59:00	834.0	79.0	15.0	0.76	20:20:00	1215.0	77.5	14.8	0.74
14:19:00	854.0	79.0	15.0	0.76	20:41:00	1236.0	78.0	14.9	0.75
14:39:00	874.0	79.5	15.1	0.76	21:02:00	1257.0	73.0	13.8	0.67
14:59:00	894.0	78.0	14.8	0.74	21:23:00	1278.0	76.0	14.5	0.72
15:19:00	914.0	79.0	15.0	0.76	21:44:00	1299.0	77.5	14.8	0.74
15:39:00	934.0	81.0	15.4	0.79	22:05:00	1320.0	78.0	14.9	0.75
15:59:00	954.0	82.0	15.7	0.80	22:26:00	1341.0	78.5	15.0	0.76
16:19:00	974.0	81.0	15.4	0.79	22:47:00	1362.0	79.0	15.1	0.76
16:39:00	994.0	81.5	15.6	0.79	23:08:00	1383.0	80.0	15.3	0.78
16:59:00	1014.0	82.5	15.8	0.81	23:29:00	1404.0	82.5	15.9	0.82
17:19:00	1034.0	83.0	15.9	0.82	23:50:00	1425.0	81.0	15.6	0.79
17:39:00	1054.0	83.0	15.9	0.82	00:11:00	1446.0	81.0	15.6	0.79
19:35:00	1170.0	84.5	16.2	0.84	00:32:00	1467.0	79.5	15.2	0.77
20:55:00	1250.0	85.0	16.3	0.85	00:53:00	1488.0	79.5	15.2	0.77

21:15:00	1270.0	87.0	16.8	0.88
21:35:00	1290.0	85.0	16.3	0.85
21:55:00	1310.0	79.0	15.0	0.76
22:15:00	1330.0	82.0	15.7	0.80
22:35:00	1350.0	85.0	16.3	0.85
22:55:00	1370.0	86.0	16.5	0.87
23:15:00	1390.0	86.5	16.6	0.87
23:35:00	1410.0	85.0	16.3	0.85
23:55:00	1430.0	87.0	16.8	0.88
00:15:00	1450.0	87.0	16.8	0.88
00:35:00	1470.0	86.0	16.5	0.87
00:55:00	1490.0	88.0	17.0	0.90
02:30:00	1585.0	91.0	17.6	0.94
02:50:00	1605.0	90.0	17.4	0.93
03:10:00	1625.0	90.5	17.5	0.94
03:30:00	1645.0	89.5	17.3	0.92
03:50:00	1665.0	89.5	17.3	0.92
04:10:00	1685.0	89	17.2	0.91
04:30:00	1705.0	90	17.4	0.93
05:10:00	1745.0	89.5	17.3	0.92
05:30:00	1765.0	89.5	17.3	0.92
05:50:00	1785.0	90	17.4	0.93
06:10:00	1805.0	90	17.4	0.93
06:30:00	1825.0	90	17.4	0.93
06:50:00	1845.0	90	17.4	0.93
07:10:00	1865.0	90	17.4	0.93
07:30:00	1885.0	90	17.4	0.93
07:50:00	1905.0	91	17.6	0.94
08:10:00	1925.0	90	17.4	0.93
08:30:00	1945.0	90	17.4	0.93
09:30:00	2005.0	91	17.6	0.94
09:50:00	2025.0	91	17.6	0.94
10:10:00	2045.0	91	17.6	0.94
11:24:00	2119.0	86	16.5	0.87
11:44:00	2139.0	92	17.9	0.96
12:04:00	2159.0	92	17.9	0.96
12:24:00	2179.0	91	17.6	0.94
12:44:00	2199.0	92	17.9	0.96
13:04:00	2219.0	91.5	17.7	0.95
13:24:00	2239.0	92.5	18.0	0.97
13:44:00	2259.0	92.5	18.0	0.97
14:04:00	2279.0	95	18.5	1.01
18:26:00	2541.0	93.5	18.2	0.98
18:54:00	2569.0	94	18.3	0.99
19:14:00	2589.0	94.5	18.4	1.00
19:34:00	2609.0	94.5	18.4	1.00
19:54:00	2629.0	94.5	18.4	1.00
20:14:00	2649.0	94	18.3	0.99
20:34:00	2669.0	94.5	18.4	1.00
20:54:00	2689.0	95	18.5	1.01
21:14:00	2709.0	95	18.5	1.01
21:34:00	2729.0	94.5	18.4	1.00
21:54:00	2749.0	94.5	18.4	1.00
22:14:00	2769.0	95	18.5	1.01
22:34:00	2789.0	95	18.5	1.01
22:54:00	2809.0	94.5	18.4	1.00
23:14:00	2829.0	95	18.5	1.01
23:34:00	2849.0	94.5	18.4	1.00
23:54:00	2869.0	94.5	18.4	1.00
00:14:00	2889.0	94.5	18.4	1.00
00:34:00	2909.0	94.5	18.4	1.00
04:00:00	3115.0	94.5	18.4	1.00

01:14:00	1509.0	81.0	15.6	0.79
01:45:00	1540.0	81.5	15.7	0.80
02:05:00	1560.0	81.5	15.7	0.80
02:25:00	1580.0	83.0	16.0	0.83
02:45:00	1600.0	82.0	15.8	0.81
03:05:00	1620.0	83.0	16.0	0.83
03:25:00	1640.0	83.5	16.1	0.83
03:45:00	1660.0	81.5	15.7	0.80
04:05:00	1680.0	83.0	16.0	0.83
04:25:00	1700.0	84.0	16.2	0.84
04:45:00	1720.0	83.5	16.1	0.83
05:05:00	1740.0	83.0	16.0	0.83
05:25:00	1760.0	82.0	15.8	0.81
05:45:00	1780.0	84.5	16.3	0.85
06:05:00	1800.0	84.0	16.2	0.84
06:25:00	1820.0	83.5	16.1	0.83
06:45:00	1840.0	84.0	16.2	0.84
07:05:00	1860.0	84.0	16.2	0.84
07:25:00	1880.0	85.0	16.4	0.86
07:45:00	1900.0	85.0	16.4	0.86
:05:00	1920.0	86.0	16.6	0.87
08:25:00	1940.0	85.5	16.5	0.87
08:45:00	1960.0	86.0	16.6	0.87
10:47:00	2082.0	86.0	16.6	0.87
11:07:00	2102.0	87.0	16.9	0.89
11:27:00	2122.0	88.0	17.1	0.91
11:47:00	2142.0	88.0	17.1	0.91
12:07:00	2162.0	90.0	17.5	0.94
12:27:00	2182.0	89.5	17.4	0.93
12:47:00	2202.0	90.0	17.5	0.94
13:07:00	2222.0	89.5	17.4	0.93
13:27:00	2242.0	90.0	17.5	0.94
13:47:00	2262.0	89.5	17.4	0.93
14:07:00	2282.0	91.0	17.7	0.95
14:27:00	2302.0	90.5	17.6	0.94
14:47:00	2322.0	90.5	17.6	0.94
15:07:00	2342.0	91.0	17.7	0.95
15:27:00	2362.0	91.0	17.7	0.95
15:47:00	2382.0	91.5	17.9	0.96
16:07:00	2402.0	90.5	17.6	0.94
16:27:00	2422.0	91.0	17.7	0.95
16:47:00	2442.0	91.5	17.9	0.96
17:07:00	2462.0	94.0	18.4	1.00
18:17:00	2532.0	92.0	18.0	0.97
18:37:00	2552.0	91.0	17.7	0.95
18:57:00	2572.0	91.0	17.7	0.95
19:17:00	2592.0	92.0	18.0	0.97
19:37:00	2612.0	91.5	17.9	0.96
19:57:00	2632.0	92.0	18.0	0.97
20:17:00	2652.0	91.5	17.9	0.96
20:37:00	2672.0	92.0	18.0	0.97
20:57:00	2692.0	92.0	18.0	0.97
21:17:00	2712.0	92.5	18.1	0.98
21:37:00	2732.0	93.0	18.2	0.98
21:57:00	2752.0	92.5	18.1	0.98
22:17:00	2772.0	92.5	18.1	0.98
22:37:00	2792.0	93.0	18.2	0.98
22:57:00	2812.0	93.0	18.2	0.98
23:17:00	2832.0	92.5	18.1	0.98
23:37:00	2852.0	93.0	18.2	0.98
23:57:00	2872.0	93.0	18.2	0.98
00:17:00	2892.0	93.5	18.3	0.99
00:37:00	2912.0	93.5	18.3	0.99
01:52:00	2987.0	94.5	18.5	1.01
02:12:00	3007.0	94.0	18.4	1.00
02:30:00	3025.0	94.0	18.4	1.00
03:20:00	3075.0	94.0	18.4	1.00

m= 0 2
b= -2 0

y=0 217x-1.956
(CONVERGENCE)
4 59
18 55
13 96
30 2
94 5

(AVERAGE FROM INLET 1& 2)
4 52
18 40
13 88

Convergence					
Time		T/Td	Reading	Conc Na	C/Co
min	min	Td=926		mg/L	
00 05 00	0 0	0 00	30 5	4 6	0 01
00 15 00	10 0	0 01	30 0	4 5	0 00
00 25 00	20 0	0 02	30 0	4 5	0 00
00 35 00	30 0	0 03	30 0	4 5	0 00
00.45 00	40 0	0 04	30 5	4 6	0 01
00.55 00	50 0	0 05	30 5	4 6	0 01
01.05 00	60 0	0 06	30 5	4 6	0 01
01.17 00	72 0	0 08	30 0	4 5	0 00
01 25 00	80 0	0 09	30 5	4 6	0 01
01 35 00	90 0	0 10	30 0	4 5	0 00
01 45 00	100 0	0 11	30 0	4 5	0 00
02 01 00	116 0	0 13	33 0	5 1	0 04
02 05 00	120 0	0 13	32 5	5 0	0 04
02 15 00	130 0	0 14	35 0	5 6	0 08
02 25 00	140 0	0 15	37 0	6 0	0 11
02 35 00	150 0	0 16	36 0	5 8	0 09
02 45 00	160 0	0 17	37 5	6 1	0 11
02:55 00	170 0	0.18	37 5	6 1	0 11
03 05 00	180 0	0 19	37 5	6 1	0 11
03 15 00	190 0	0 21	36 5	5 9	0 10
03 25 00	200 0	0 22	39 0	6 4	0 14
03 35 00	210 0	0 23	39 0	6 4	0 14
03 45 00	220 0	0 24	42 0	7 1	0 18
03 55 00	230 0	0 25	43 0	7 3	0 20
04 05.00	240 0	0 26	43 0	7 3	0 20
04 15 00	250 0	0 27	44 0	7 5	0 22
04 25 00	260 0	0 28	44 5	7 6	0 22
04 35 00	270 0	0 29	45 0	7 7	0 23
04 45 00	280 0	0 30	45 0	7 7	0 23
04 55 00	290 0	0 31	48 0	8 4	0 28
05 05 00	300 0	0 32	48 0	8 4	0 28
05 15 00	310 0	0 33	49 0	8 6	0 29
05 25 00	320 0	0 35	49 0	8 6	0 29
05 35 00	330 0	0 36	52 0	9 2	0 34
05 45 00	340 0	0 37	52 0	9 2	0 34
05 55 00	350 0	0 38	55 0	9 9	0 39
06 05 00	360 0	0 39	55 5	10 0	0 39
06 15 00	370 0	0 40	55 0	9 9	0 39
06 25 00	380 0	0 41	56 0	9 9	0 39
06 35 00	390 0	0 42	56 5	10 2	0 41
06 45 00	400 0	0 43	58 0	10 5	0 43
06 55 00	410 0	0 44	58 0	10 5	0 43
07 05 00	420 0	0 45	58 5	10 6	0 44
07 15 00	430 0	0 46	58 0	10 5	0 43
07 25 00	440 0	0 48	58 0	10 5	0 43
07.35 00	450 0	0 49	58 5	10 6	0 44
07 45 00	460 0	0 50	58 0	10 5	0 43
07 55 00	470 0	0 51	60 5	11 1	0 47
08 05 00	480 0	0 52	61 0	11 2	0 48
08 15 00	490 0	0 53	62 5	11 5	0 50
08 25 00	500 0	0 54	62 0	11 4	0 49
08 35 00	510 0	0 55	62 5	11 5	0 50
08 45 00	520 0	0 56	63 0	11 6	0 51
08 55 00	530 0	0 57	63 5	11 7	0 52
09 05 00	540 0	0 58	64 0	11 8	0 53
09 15 00	550 0	0 59	63 0	11 6	0 51
09 25 00	560 0	0 60	63 5	11 7	0 52
09 35.00	570 0	0 62	64 0	11 8	0 53
09 45 00	580 0	0 63	65 0	12 0	0 54
09 55 00	590 0	0 64	68 0	12 7	0 59
10 05 00	600 0	0 65	69 0	12 9	0 60
10 15 00	610 0	0 66	69 0	13 0	0 61
10 25 00	620 0	0 67	69 0	13 0	0 61
10 35 00	630 0	0 68	69 5	13 0	0 61

10 45 00	640 0	0 69	69 5	13 0	0 61
10 55 00	650 0	0 70	70 0	13 1	0 62
11 06 00	661 0	0 71	70 5	13 2	0 63
11 18 00	673 0	0 73	70 5	13 2	0 63
11 27 00	682 0	0 74	71 0	13 3	0 63
11 35 00	690 0	0 75	71 0	13 3	0 63
11 45 00	700 0	0 76	72 0	13 5	0 65
11 55 00	710 0	0 77	72 0	13 5	0 65
12 06 00	721 0	0 78	71 5	13 4	0 64
12 18 00	733 0	0 79	73 0	13 8	0 67
12 28 00	743 0	0 80	74 0	14 0	0.68
12 35 00	750 0	0.81	74 0	14 0	0.68
12.45 00	760 0	0 82	74 5	14.1	0.69
12.55 00	770 0	0.83	75 0	14 2	0 70
13 05 00	780 0	0 84	75 0	14 2	0 70
13 15.00	790 0	0 85	75 5	14.3	0.70
13 25 00	800 0	0.86	76 0	14 4	0.71
13.35 00	810.0	0 87	76.0	14 4	0 71
13 45 00	820 0	0 89	76.0	14 4	0.71
13 55 00	830 0	0 90	76 5	14 5	0 72
14.05 00	840 0	0 91	77.0	14 6	0.73
14 15 00	850 0	0 92	76 0	14 4	0 71
14 25 00	860 0	0.93	78 0	14 8	0 74
14 35 00	870 0	0.94	78 0	14 8	0 74
14 45 00	880 0	0 95	77 0	14 6	0 73
14 55 00	890 0	0 96	78 0	14 8	0 74
15 05 00	900 0	0 97	79 5	15 2	0 77
15 25 00	920 0	0 99	81 0	15 5	0 79
15 35 00	930 0	1.00	81 0	15 5	0 79
15 45 00	940 0	1 02	80 0	15 3	0 77
15 55 00	950 0	1 03	80 5	15 4	0.78
16 05 00	960 0	1 04	81 0	15 5	0 79
16 15 00	970 0	1 05	81 0	15.5	0 79
16.25 00	980 0	1 06	81.0	15 5	0 79
16 35 00	990 0	1 07	82 0	15 7	0 81
16 45 00	1000 0	1.08	83.0	13 9	0 82
16 55 00	1010 0	1 09	83 0	15.9	0 82
17 05 00	1020 0	1 10	83.0	15 9	0 82
17 15 00	1030 0	1 11	83 0	15 9	0.82
17 25 00	1040 0	1 12	83 5	16 0	0 83
17.35 00	1050 0	1 13	83 0	15 9	0 82
17 45 00	1060 0	1 14	84 0	16 1	0 84
17 55 00	1070 0	1 16	86.0	16 4	0 85
18 05 00	1080 0	1 17	86 0	16 4	0 85
18 15 00	1090 0	1 18	83 5	16 0	0 83
18 25 00	1100.0	1 19	84 0	16 1	0.84
18 35 00	1110 0	1.20	84 0	16 1	0 84
18 45 00	1120 0	1 21	84 5	16 2	0 84
18 55 00	1130 0	1.22	86 0	16 4	0.85
19 05 00	1140 0	1 23	84 0	16 1	0 84
19 15 00	1150 0	1 24	83 5	16 0	0 83
19 25 00	1160 0	1 25	86 0	16 4	0 85
19 35 00	1170 0	1 26	84 0	16 1	0.84
19 45 00	1180 0	1.27	86 0	16 4	0 85
19 55 00	1190 0	1 29	84.0	16 1	0 84
20 05 00	1200 0	1.30	86 0	16 4	0 85
20 15 00	1210 0	1 31	86 5	16 5	0 86
20 25.00	1220 0	1.32	86 5	16 7	0.88
20.35 00	1230 0	1.33	87 0	16 8	0.88
20 45 00	1240 0	1 34	87 0	16 8	0.88
20 55 00	1250 0	1 35	86.0	16 6	0 87
21 05 00	1260 0	1 36	86 5	16 7	0.88
21 15 00	1270 0	1.37	86 0	16 6	0 87
21 25 00	1280 0	1 38	86.0	16 4	0 85
21 35 00	1290 0	1 39	86 0	16 4	0 85
21 45 00	1300 0	1.40	86 0	16 4	0 85
21 55 00	1310 0	1 41	86 0	16 6	0 87
22 05 00	1320 0	1 43	86 5	16 7	0 88
22 15 00	1330 0	1 44	86.5	16 7	0 88
22 25 00	1340 0	1 45	87.0	16 8	0 88
22 35 00	1350 0	1 46	87.0	16.8	0.88
22 45 00	1360 0	1 47	87.0	16 8	0.88
22 55 00	1370 0	1.48	87.0	16 8	0.88
23 05 00	1380 0	1 49	87.0	16 8	0.88
23 15 00	1390 0	1 50	87.0	16 8	0.88
23.25 00	1400 0	1 51	87 0	16 8	0 88
23 35.00	1410 0	1 52	87 0	16.8	0 88
23 45 00	1420 0	1.53	87.0	16 8	0.88
23.55 00	1430 0	1.54	87.0	16 8	0.88
00 05 00	1440 0	1 56	88 0	17 0	0 90
00 15 00	1450 0	1 57	88 0	17.0	0 90
00 25 00	1460.0	1.58	87 0	16 8	0 88
00 35 00	1470 0	1 59	87 0	16 8	0 88
00 45 00	1480 0	1 60	88 0	17 0	0 90

00:55:00	1490.0	1.61	87.5	16.9	0.89
01:05:00	1500.0	1.62	87.5	16.9	0.89
01:15:00	1510.0	1.63	87.0	16.8	0.88
01:25:00	1520.0	1.64	87.5	16.9	0.89
01:35:00	1530.0	1.65	88.0	17.0	0.90
01:45:00	1540.0	1.66	88.0	17.0	0.90
01:55:00	1550.0	1.67	89.0	17.2	0.91
02:05:00	1560.0	1.68	89.0	17.2	0.91
02:15:00	1570.0	1.70	88.0	17.0	0.90
02:25:00	1580.0	1.71	88.5	17.1	0.91
02:35:00	1590.0	1.72	89.0	17.2	0.91
02:45:00	1600.0	1.73	89.0	17.2	0.91
02:55:00	1610.0	1.74	89.0	17.2	0.91
03:05:00	1620.0	1.75	89.0	17.2	0.91
03:25:00	1640.0	1.77	90.0	17.4	0.93
03:35:00	1650.0	1.78	90.0	17.4	0.93
03:45:00	1660.0	1.79	89.5	17.3	0.92
03:55:00	1670.0	1.80	89.5	17.3	0.92
04:05:00	1680.0	1.81	89.5	17.3	0.92
04:15:00	1690.0	1.83	89.5	17.3	0.92
04:25:00	1700.0	1.84	88.0	17.0	0.90
04:35:00	1710.0	1.85	89.0	17.2	0.91
04:45:00	1720.0	1.86	90.0	17.4	0.93
04:55:00	1730.0	1.87	90.0	17.4	0.93
05:05:00	1740.0	1.88	90.0	17.4	0.93
05:15:00	1750.0	1.89	89.5	17.3	0.92
05:25:00	1760.0	1.90	89.5	17.3	0.92
05:35:00	1770.0	1.91	89.5	17.3	0.92
05:45:00	1780.0	1.92	90.0	17.4	0.93
05:55:00	1790.0	1.93	89.5	17.3	0.92
06:05:00	1800.0	1.94	90.5	17.5	0.94
06:10:00	1805.0	1.95	90.5	17.5	0.94
06:25:00	1820.0	1.97	90.5	17.5	0.94
06:35:00	1830.0	1.98	91.0	17.6	0.95
06:45:00	1840.0	1.99	90.5	17.5	0.94
06:55:00	1850.0	2.00	91.0	17.6	0.95
07:05:00	1860.0	2.01	90.5	17.5	0.94
07:15:00	1870.0	2.02	91.0	17.6	0.95
07:25:00	1880.0	2.03	91.0	17.6	0.95
07:35:00	1890.0	2.04	91.0	17.6	0.95
07:45:00	1900.0	2.05	90.5	17.5	0.94
07:55:00	1910.0	2.06	90.0	17.4	0.93
08:05:00	1920.0	2.07	91.0	17.6	0.95
08:15:00	1930.0	2.08	91.0	17.6	0.95
08:25:00	1940.0	2.10	91.0	17.6	0.95
08:35:00	1950.0	2.11	91.0	17.6	0.95
08:45:00	1960.0	2.12	91.0	17.6	0.95
08:55:00	1970.0	2.13	92.0	17.9	0.96
09:05:00	1980.0	2.14	91.0	17.6	0.95
09:15:00	1990.0	2.15	90.5	17.5	0.94
09:25:00	2000.0	2.16	91.0	17.6	0.95
09:35:00	2010.0	2.17	91.0	17.6	0.95
09:45:00	2020.0	2.18	91.0	17.6	0.95
09:55:00	2030.0	2.19	91.0	17.6	0.95
10:05:00	2040.0	2.20	91.0	17.6	0.95
10:15:00	2050.0	2.21	91.0	17.6	0.95
10:25:00	2060.0	2.22	91.0	17.6	0.95
10:35:00	2070.0	2.24	91.0	17.6	0.95
10:45:00	2080.0	2.25	91.0	17.6	0.95
10:55:00	2090.0	2.26	91.5	17.8	0.95
11:05:00	2100.0	2.27	91.5	17.8	0.95
11:15:00	2110.0	2.28	91.5	17.8	0.95
11:25:00	2120.0	2.29	91.0	17.6	0.95
11:35:00	2130.0	2.30	91.5	17.8	0.95
11:45:00	2140.0	2.31	91.5	17.8	0.95
11:55:00	2150.0	2.32	91.5	17.8	0.95
12:05:00	2160.0	2.33	91.5	17.8	0.95
12:15:00	2170.0	2.34	91.5	17.8	0.95
12:25:00	2180.0	2.35	92.0	17.9	0.96
12:35:00	2190.0	2.37	92.0	17.9	0.96
12:45:00	2200.0	2.38	92.0	17.9	0.96
12:55:00	2210.0	2.39	91.5	17.8	0.95
13:05:00	2220.0	2.40	92.0	17.9	0.96
13:15:00	2230.0	2.41	92.0	17.9	0.96
13:25:00	2240.0	2.42	92.0	17.9	0.96
13:36:00	2251.0	2.43	92.0	17.9	0.96
13:45:00	2260.0	2.44	92.0	17.9	0.96
13:55:00	2270.0	2.45	92.0	17.9	0.96
14:05:00	2280.0	2.46	92.0	17.9	0.96
14:15:00	2290.0	2.47	92.5	18.0	0.97
14:32:00	2307.0	2.49	92.0	17.9	0.96
14:39:00	2314.0	2.50	92.0	17.9	0.96
14:46:00	2321.0	2.51	92.0	17.9	0.96
15:00:00	2335.0	2.52	92.5	18.0	0.97

15:10:00	2345.0	2.53	92.0	17.9	0.96
15:25:00	2360.0	2.55	92.5	18.0	0.97
15:35:00	2370.0	2.56	92.5	18.0	0.97
15:47:00	2382.0	2.57	93.0	18.1	0.98
15:58:00	2393.0	2.58	93.0	18.1	0.98
16:12:00	2407.0	2.60	93.0	18.1	0.98
16:25:00	2420.0	2.61	92.0	17.9	0.96
16:35:00	2430.0	2.62	92.5	18.0	0.97
16:45:00	2440.0	2.63	93.0	18.1	0.98
16:55:00	2450.0	2.65	93.0	18.1	0.98
17:05:00	2460.0	2.66	93.0	18.1	0.98
17:15:00	2470.0	2.67	92.5	18.0	0.97
17:25:00	2480.0	2.68	92.5	18.0	0.97
17:35:00	2490.0	2.69	93.0	18.1	0.98
17:45:00	2500.0	2.70	93.0	18.1	0.98
17:55:00	2510.0	2.71	93.0	18.1	0.98
18:05:00	2520.0	2.72	93.0	18.1	0.98
18:15:00	2530.0	2.73	93.0	18.1	0.98
18:25:00	2540.0	2.74	93.5	18.2	0.98
18:35:00	2550.0	2.75	93.5	18.2	0.98
18:45:00	2560.0	2.76	93.5	18.2	0.98
18:55:00	2570.0	2.78	93.0	18.1	0.98
19:05:00	2580.0	2.79	94.0	18.3	0.99
19:15:00	2590.0	2.80	93.0	18.1	0.98
19:25:00	2600.0	2.81	93.5	18.2	0.98
19:35:00	2610.0	2.82	94.0	18.3	0.99
19:45:00	2620.0	2.83	94.0	18.3	0.99
19:55:00	2630.0	2.84	93.5	18.2	0.98
20:05:00	2640.0	2.85	93.5	18.2	0.98
20:15:00	2650.0	2.86	93.5	18.2	0.98
20:25:00	2660.0	2.87	93.0	18.1	0.98
20:35:00	2670.0	2.88	93.5	18.2	0.98
20:45:00	2680.0	2.89	93.5	18.2	0.98
20:55:00	2690.0	2.90	94.0	18.3	0.99
21:05:00	2700.0	2.92	94.0	18.3	0.99
21:15:00	2710.0	2.93	93.5	18.2	0.98
21:25:00	2720.0	2.94	94.0	18.3	0.99
21:35:00	2730.0	2.95	93.0	18.1	0.98
21:45:00	2740.0	2.96	93.5	18.2	0.98
21:55:00	2750.0	2.97	93.0	18.1	0.98
22:05:00	2760.0	2.98	93.5	18.2	0.98
22:15:00	2770.0	2.99	93.5	18.2	0.98
22:25:00	2780.0	3.00	93.0	18.1	0.98
22:35:00	2790.0	3.01	93.5	18.2	0.98
22:45:00	2800.0	3.02	94.0	18.3	0.99
22:55:00	2810.0	3.03	94.0	18.3	0.99
23:05:00	2820.0	3.05	94.0	18.3	0.99
23:15:00	2830.0	3.06	94.5	18.4	1.00
23:25:00	2840.0	3.07	94.5	18.4	1.00
23:35:00	2850.0	3.08	94.5	18.4	1.00
23:45:00	2860.0	3.09	94.0	18.3	0.99
23:55:00	2870.0	3.10	94.5	18.4	1.00
00:05:00	2880.0	3.11	94.5	18.4	1.00
00:15:00	2890.0	3.12	94.5	18.4	1.00
00:25:00	2900.0	3.13	94.5	18.4	1.00
00:35:00	2910.0	3.14	94.5	18.4	1.00
00:45:00	2920.0	3.15	94.5	18.4	1.00
00:55:00	2930.0	3.16	94.5	18.4	1.00
01:05:00	2940.0	3.17	94.5	18.4	1.00
01:15:00	2950.0	3.19	94.5	18.4	1.00
01:25:00	2960.0	3.20	94.5	18.4	1.00
01:35:00	2970.0	3.21	94.5	18.4	1.00
01:45:00	2980.0	3.22	94.5	18.4	1.00
01:55:00	2990.0	3.23	94.5	18.4	1.00
02:05:00	3000.0	3.24	94.5	18.4	1.00
02:15:00	3010.0	3.25	94.5	18.4	1.00
02:25:00	3020.0	3.26	94.5	18.4	1.00
02:35:00	3030.0	3.27	94.5	18.4	1.00
02:45:00	3040.0	3.28	94.5	18.4	1.00
02:55:00	3050.0	3.29	94.5	18.4	1.00
03:05:00	3060.0	3.30	94.5	18.4	1.00
03:15:00	3070.0	3.32	94.5	18.4	1.00
03:25:00	3080.0	3.33	94.5	18.4	1.00
03:35:00	3090.0	3.34	94.5	18.4	1.00
03:45:00	3100.0	3.35	94.5	18.4	1.00
03:55:00	3110.0	3.36	94.5	18.4	1.00
04:25:00	3140.0	3.39	94.5	18.4	1.00

APPENDIX 2: WOLF - RESNICK MODEL

```
FILTERS AND CLEARWELL (140 ML/d)
WOLF-RESNICK MODEL: C/Co=1-exp( -A*(T-B))


ITERATION          LOSS           PARAMETER VALUES
    0         0.6302559D+00 0.1200D+01
    1         0.2539767D+00 0.2086D+01
    2         0.2079244D+00 0.1827D+01
    3         0.2076854D+00 0.1801D+01
    4         0.2076588D+00 0.1807D+01
    5         0.2076588D+00 0.1807D+01
    6         0.2076588D+00 0.1807D+01

DEPENDENT VARIABLE IS          C/Co

    SOURCE    SUM-OF-SQUARES      DF   MEAN-SQUARE

 REGRESSION             27.999     1        27.999
   RESIDUAL              0.208    41         0.005

      TOTAL             29.008    42
  CORRECTED              4.137    41

       RAW R-SQUARED (1-RESIDUAL/TOTAL)      =            0.993
CORRECTED R-SQUARED (1-RESIDUAL/CORRECTED) =            0.950


PARAMETER          ESTIMATE
          A              1.807       (NON LINEAR REGRESSION)
          B              0.73        (DETERMIDE GRAPHICALLY)
```

```
FILTERS AND CLEARWELL (180 ML/d)
WOLF-RESNICK MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION          LOSS          PARAMETER VALUES
    0          0.2041478D+00  0.1200D+01
    1          0.2041135D+00  0.1191D+01
    2          0.2040987D+00  0.1194D+01
    3          0.2040987D+00  0.1194D+01

DEPENDENT VARIABLE IS           C/Co

    SOURCE    SUM-OF-SQUARES      DF   MEAN-SQUARE

  REGRESSION          29.776       1        29.776
    RESIDUAL           0.204      45         0.005

       TOTAL          27.329      46
   CORRECTED           3.266      45

       RAW R-SQUARED  (1-RESIDUAL/TOTAL)       =            0.993
CORRECTED R-SQUARED  (1-RESIDUAL/CORRECTED)   =            0.938


PARAMETER            ESTIMATE
         A               1.194        (NON LINEAR REGRESSION)
         B               0.62         (DETERMINED GRAPHICALLY)
```

```
CLARIFIER NO.2  (180  ML/d)
WOLF-RESNICK  MODEL:  C/Co=1-exp(-A*(T-B))


ITERATION          LOSS          PARAMETER  VALUES
    0         0.2672162D-01  0.1600D+01
    1         0.2669448D-01  0.1606D+01
    2         0.2669416D-01  0.1605D+01
    3         0.2669416D-01  0.1605D+01

DEPENDENT  VARIABLE  IS            C/Co

    SOURCE    SUM-OF-SQUARES      DF   MEAN-SQUARE

 REGRESSION            11.397      1        11.397
   RESIDUAL             0.027     34         0.001

      TOTAL            11.799     35
  CORRECTED             3.049     34

      RAW  R-SQUARED  (1-RESIDUAL/TOTAL)          =          0.998
CORRECTED  R-SQUARED  (1-RESIDUAL/CORRECTED)  =              0.991


PARAMETER            ESTIMATE
        A               1.605       (NON LINEAR REGRESSION)
        B               0.22        (DETERMINED GRAPHICALLY)
```

```
RESERVOIR NO.2 (141 ML/d)
WOLF-RESNICK MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION          LOSS          PARAMETER VALUES
    0         0.2541460D+00  0.1530D+01
    1         0.2541207D+00  0.1542D+01
    2         0.2540645D+00  0.1537D+01
    3         0.2540638D+00  0.1537D+01
    4         0.2540638D+00  0.1537D+01

DEPENDENT VARIABLE IS           C/Co

    SOURCE     SUM-OF-SQUARES      DF   MEAN-SQUARE

 REGRESSION            52.801       1         52.801
   RESIDUAL             0.254      81          0.003

      TOTAL            52.409      82
  CORRECTED             4.466      81

      RAW R-SQUARED (1-RESIDUAL/TOTAL)         =          0.995
CORRECTED R-SQUARED (1-RESIDUAL/CORRECTED)     =          0.943


PARAMETER           ESTIMATE
        A              1.537    (NON LINEAR REGRESSION)
        B              0.04     (DETERMINED GRAPHICALLY)
```

```
RESERVOIR NO.2  (167 ML/d)
WOLF-RESNICK  MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION          LOSS         PARAMETER VALUES
    0          0.2472576D+00  0.1580D+01
    1          0.2471727D+00  0.1594D+01
    2          0.2471364D+00  0.1589D+01
    3          0.2471364D+00  0.1589D+01

DEPENDENT VARIABLE IS          C/Co

   SOURCE    SUM-OF-SQUARES      DF   MEAN-SQUARE

 REGRESSION           60.743      1          60.743
   RESIDUAL            0.247     87           0.003

      TOTAL           59.209     88
  CORRECTED            4.272     87

      RAW R-SQUARED  (1-RESIDUAL/TOTAL)         =          0.996
CORRECTED R-SQUARED  (1-RESIDUAL/CORRECTED)     =          0.942


PARAMETER            ESTIMATE
        A               1.589     (NON LINEAR REGRESSION)
        B               0.02      (DETERMINED GRAPHICALLY)
```

```
RESERVOIR NO.1  (180  ML/d)
WOLF-RESNICK  MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION          LOSS          PARAMETER  VALUES
     0         0.7437440D-01  0.1870D+01
     1         0.7436906D-01  0.1868D+01
     2         0.7436900D-01  0.1868D+01
     3         0.7436900D-01  0.1868D+01

DEPENDENT  VARIABLE  IS           C/Co

    SOURCE    SUM-OF-SQUARES      DF   MEAN-SQUARE

  REGRESSION           42.291      1        42.291
    RESIDUAL            0.074     67         0.001

       TOTAL           42.030     68
   CORRECTED            4.526     67

       RAW  R-SQUARED  (1-RESIDUAL/TOTAL)       =            0.998
CORRECTED  R-SQUARED  (1-RESIDUAL/CORRECTED)  =            0.984


PARAMETER          ESTIMATE
        A             1.868     (NON  LINEAR  REGRESSION)
        B             0.22      (DETERMINED  GRAPHICALLY)
```

```
RESERVOIR NO.1 (230 ML/d)
WOLF-RESNICK MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION         LOSS          PARAMETER VALUES
    0        0.9053236D-01  0.2220D+01
    1        0.9052473D-01  0.2224D+01
    2        0.9052469D-01  0.2224D+01
    3        0.9052469D-01  0.2224D+01

DEPENDENT VARIABLE IS          C/Co

    SOURCE    SUM-OF-SQUARES     DF   MEAN-SQUARE

  REGRESSION          33.572      1        33.572
    RESIDUAL           0.091     47         0.002

       TOTAL          33.557     48
   CORRECTED           2.693     47

       RAW R-SQUARED (1-RESIDUAL/TOTAL)       =            0.997
CORRECTED R-SQUARED (1-RESIDUAL/CORRECTED)    =            0.966


PARAMETER          ESTIMATE
        A             2.224    (NON LINEAR REGRESSION)
        B             0.16     (DETERMINED GRAPHICALLY)
```

```
RESERVOIR NO.3 (179 ML/d)
WOLF-RESNICK MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION         LOSS          PARAMETER VALUES
    0        0.1457287D+00 0.1680D+01
    1        0.1457164D+00 0.1685D+01
    2        0.1457131D+00 0.1683D+01
    3        0.1457131D+00 0.1683D+01

DEPENDENT VARIABLE IS          C/Co

    SOURCE    SUM-OF-SQUARES     DF   MEAN-SQUARE

 REGRESSION           55.877      1        55.877
   RESIDUAL            0.146     81         0.002

      TOTAL           56.396     82
  CORRECTED            4.808     81

       RAW R-SQUARED (1-RESIDUAL/TOTAL)      =             0.997
CORRECTED R-SQUARED (1-RESIDUAL/CORRECTED)   =             0.970


PARAMETER           ESTIMATE
        A              1.683    (NON LINEAR REGRESSION)
        B               0.01    (DETERMINED GRAPHICALLY)
```

```
RESERVOIR NO.3  (198 ML/d)
WOLF-RESNICK  MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION          LOSS          PARAMETER VALUES
    0         0.2035537D+00  0.1590D+01
    1         0.2029091D+00  0.1632D+01
    2         0.2025005D+00  0.1616D+01
    3         0.2025001D+00  0.1616D+01
    4         0.2025001D+00  0.1616D+01

DEPENDENT VARIABLE IS           C/Co

    SOURCE     SUM-OF-SQUARES      DF   MEAN-SQUARE

 REGRESSION            26.949       1         26.949
   RESIDUAL             0.203      57          0.004

      TOTAL            26.113      58
  CORRECTED             3.294      57

       RAW R-SQUARED (1-RESIDUAL/TOTAL)       =            0.992
CORRECTED R-SQUARED (1-RESIDUAL/CORRECTED)  =            0.939


PARAMETER           ESTIMATE
        A              1.616      (NON LINEAR REGRESSION)
        B              0.01       (DETERMINED GRAPHICALLY)
```

```
RESERVOIRS NOS. 1,2,3 (170 ML/d)
WOLF-RESNICK MODEL:  C/Co=1-exp(-A*(T-B))

ITERATION         LOSS          PARAMETER VALUES
    0          0.7016456D-01  0.1600D+01
    1          0.7008512D-01  0.1596D+01
    2          0.7008490D-01  0.1596D+01
    3          0.7008490D-01  0.1596D+01

DEPENDENT VARIABLE IS           C/Co

    SOURCE     SUM-OF-SQUARES      DF    MEAN-SQUARE

 REGRESSION            212.603      1          212.603
   RESIDUAL              0.070    298            0.000

      TOTAL            210.994    299
  CORRECTED             17.934    298

       RAW R-SQUARED  (1-RESIDUAL/TOTAL)      =             1.000
CORRECTED R-SQUARED  (1-RESIDUAL/CORRECTED)  =             0.996


PARAMETER            ESTIMATE
         A               1.596       (NON LINEAR REGRESSION)
         B               0.11        (DETERMINED GRAPHICALLY)
```

APPENDIX 3: REBHUN - ARGAMAN MODEL

FILTERS+CLEARWELL (140 ML/d) - REBHUN-ARGAMAN MODEL

REAL			CORRECTION	
C/Co	(To-Ti)/Td	log(1-C/Co)	(To-Ti)/Td	log(C/Co)
0.00	0.00	0.00	-0.73	0.62
0.00	0.19	0.00	-0.54	0.46
0.00	0.24	0.00	[illegible]	0.42
0.00	0.30	0.00	-0.43	0.37
0.00	0.35	0.00	-0.36	0.32
0.00	0.41	0.00	-0.32	0.28
0.00	0.46	0.00	-0.27	0.23
0.00	0.51	0.00	-0.22	0.18
0.00	0.57	0.00	-0.16	0.14
0.00	0.62	0.00	-0.11	0.09
0.00	0.68	0.00	-0.05	0.05
0.02	0.73	-0.01	0.00	0.00
0.04	0.78	-0.02	0.05	-0.05
0.14	0.84	-0.07	0.11	-0.09
0.14	0.89	-0.07	0.16	-0.14
0.18	0.95	-0.08	0.22	-0.18
0.27	1.00	-0.14	0.27	-0.23
0.33	1.05	-0.18	0.32	-0.28
0.46	1.11	-0.27	0.38	-0.32
0.56	1.16	-0.35	0.43	-0.37
0.58	1.22	-0.38	0.49	-0.42
0.66	1.27	-0.47	0.54	-0.46
0.69	1.32	-0.50	0.59	-0.51
0.56	1.38	-0.35	0.65	-0.55
0.74	1.43	-0.58	0.70	-0.60
0.83	1.49	-0.78	0.76	-0.65
0.76	1.54	-0.61	0.81	-0.69
0.90	1.59	-1.02	0.86	-0.74
0.87	1.65	-0.88	0.92	-0.78
0.95	1.70	-1.27	0.97	-0.83
0.94	1.76	-1.21	1.03	-0.88
0.95	1.89	-1.27	1.16	-0.99
0.87	2.03	-0.88	1.30	-1.11
0.85	2.16	-0.83	1.43	-1.22
1.01	2.30	-3.00	1.57	-1.34
0.96	2.43	-1.44	1.70	-1.45
1.02	2.57	-3.00	1.84	-1.57
1.02	2.70	-3.00	1.97	-1.68
1.02	2.84	-3.00	2.11	-1.80
0.98	2.97	-1.73	2.24	-1.91
0.91	3.16	-1.06	2.43	-2.08
0.98	3.24	-1.73	2.51	-2.15
0.95	3.38	-1.27	2.65	-2.26
0.96	3.65	-1.44	2.92	-2.49
0.97	3.78	-1.56	3.05	-2.61
1.07	3.92	-3.00	3.19	-2.72
1.08	4.05	-3.00	3.32	-2.84
1.08	4.15	-3.00	3.42	-2.92
1.09	4.32	-3.00	3.59	-3.07
0.89	4.46	-0.94	3.73	-3.18
1.00	4.59	-2.87	3.86	-3.30
1.00	4.86	-2.87	4.14	-3.53
1.04	4.97	-3.00	4.24	-3.62

CALCULATION

Regression: About 90% of the Data (Log 0.1=-1)
The Non-Zero C/Co Started at 0.03
Intercept=loge p/(1-p 0.6228 >>>>> p= 58.9%
slope=(-)loge /(1-d)(1-p)= -0.8536 >>>>> d= -23.8%

Regression Statistics

Multiple R	0.93
R Square	0.86
Adjusted R Squar	0.80
Standard Error	0.11
Observations	17.00

Analysis of Variance

	df	um of Square	Mean Square	F	ignificance F
Regression	1.00	1.15	1.15	101.46	4.54E-08
Residual	16.00	0.18	0.01		
Total	17.00	1.33			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.85	0.05	-16.76	0.00	-0.96158	-0.74569

FILTERS+CLEARWELL (180 ML/d) - REBHUN-ARGAMAN MODEL

REAL			CORRECTION	
C/Co	(To-Ti)/Td	log(1-C/Co)	(To-Ti)/Td	log(C/Co)
0.01	0.00	0.00	-0.62	0.30
0.01	0.07	0.00	-0.55	0.27
0.00	0.14	0.00	-0.48	0.24
0.00	0.21	0.00	-0.41	0.20
-0.01	0.28	0.00	-0.34	0.17
-0.01	0.34	0.00	-0.28	0.14
-0.01	0.41	0.00	-0.21	0.10
0.00	0.48	0.00	-0.14	0.07
0.00	0.55	0.00	-0.07	0.03
0.01	0.62	-0.01	0.00	0.00
0.05	0.69	-0.02	0.07	-0.03
0.11	0.76	-0.05	0.14	-0.07
0.17	0.83	-0.08	0.21	-0.10
0.19	0.90	-0.09	0.28	-0.14
0.29	0.97	-0.15	0.34	-0.17
0.39	1.03	-0.21	0.41	-0.20
0.48	1.10	-0.28	0.48	-0.24
0.46	1.17	-0.27	0.55	-0.27
0.59	1.24	-0.38	0.62	-0.30
0.61	1.31	-0.41	0.69	-0.34
0.67	1.38	-0.48	0.76	-0.37
0.59	1.45	-0.39	0.83	-0.41
0.74	1.52	-0.58	0.90	-0.44
0.79	1.59	-0.68	0.97	-0.47
0.67	1.66	-0.49	1.03	-0.51
0.74	1.72	-0.59	1.10	-0.54
0.82	1.79	-0.74	1.17	-0.58
0.82	1.86	-0.74	1.24	-0.61
0.79	1.93	-0.68	1.31	-0.64
0.81	2.00	-0.73	1.38	-0.68
0.81	2.07	-0.73	1.45	-0.71
0.87	2.24	-0.90	1.62	-0.80
0.88	2.41	-0.92	1.79	-0.88
0.83	2.59	-0.76	1.97	-0.97
0.89	2.76	-0.98	2.14	-1.05
0.85	2.93	-0.83	2.31	-1.13
0.93	3.10	-1.15	2.48	-1.22
0.93	3.28	-1.15	2.66	-1.30
0.93	3.45	-1.15	2.83	-1.39
0.87	3.62	-0.90	3.00	-1.47
0.87	3.79	-0.90	3.17	-1.56
0.90	3.97	-1.01	3.34	-1.64
0.92	4.14	-1.07	3.52	-1.73
0.85	4.31	-0.83	3.69	-1.81
0.92	4.48	-1.07	3.86	-1.90
0.95	4.66	-1.30	4.03	-1.98
0.96	4.83	-1.36	4.21	-2.07
0.96	5.00	-1.36	4.38	-2.15
0.92	5.17	-1.07	4.55	-2.24
0.98	5.34	-1.79	4.72	-2.32
0.90	5.52	-1.01	4.90	-2.41
0.94	5.69	-1.19	5.07	-2.49
0.90	5.86	-1.01	5.24	-2.57
0.87	6.03	-0.88	5.41	-2.66
0.85	6.21	-0.81	5.59	-2.74

CALCULATION

Regression: About 90% of the Data (Log 0.1=-1)
The Non-Zero C/Co Started at 0.03
Intercept=loge p/(1-p 0.3049 >>>>>> p= 41.2%
slope=(-)loge /(1-d)(1-p)= -0.4913 >>>>>> d= -50.5%

Regression Statistics

Multiple R	0.94
R Square	0.88
Adjusted R Squar	0.84
Standard Error	0.11
Observations	27.00

Analysis of Variance

	df	*Sum of Square*	*Mean Square*	*F*	*ignificance F*
Regression	1.00	2.11	2.11	186.82	0.00
Residual	26.00	0.29	0.01		
Total	27.00	2.40			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.49	0.02	-27.51	0.00	-0.53	-0.45

CLARIFIER NO.2 (180 ML/d) - REBHUN-ARGAMAN MODEL

REAL		CORRECTION		
C/Co	(To-Ti)/Td	log(1-C/Co)	(To-Ti)/Td	log(C/Co)
0.00	0.01	0.00	-0.22	0.16
0.00	0.03	0.00	-0.19	0.14
0.00	0.06	0.00	-0.16	0.12
0.01	0.08	0.00	-0.14	0.10
0.01	0.10	0.00	-0.12	0.08
0.00	0.13	0.00	-0.09	0.07
0.00	0.15	0.00	-0.07	0.05
0.00	0.17	0.00	-0.05	0.03
0.00	0.20	0.00	-0.02	0.02
0.02	0.22	-0.01	0.00	0.00
0.07	0.24	-0.03	0.02	-0.02
0.08	0.27	-0.03	0.05	-0.03
0.09	0.29	-0.04	0.07	-0.05
0.13	0.31	-0.06	0.09	-0.07
0.13	0.34	-0.06	0.12	-0.08
0.18	0.36	-0.08	0.14	-0.10
0.20	0.38	-0.10	0.16	-0.12
0.27	0.41	-0.14	0.19	-0.14
0.27	0.43	-0.14	0.21	-0.15
0.30	0.45	-0.15	0.23	-0.17
0.31	0.48	-0.16	0.26	-0.19
0.34	0.50	-0.18	0.28	-0.20
0.37	0.55	-0.20	0.33	-0.24
0.42	0.57	-0.23	0.35	-0.25
0.43	0.59	-0.24	0.37	-0.27
0.45	0.62	-0.26	0.40	-0.29
0.48	0.64	-0.29	0.42	-0.30
0.49	0.66	-0.30	0.44	-0.32
0.51	0.69	-0.31	0.47	-0.34
0.55	0.74	-0.35	0.52	-0.38
0.62	0.80	-0.41	0.58	-0.42
0.63	0.86	-0.43	0.64	-0.46
0.68	0.93	-0.50	0.71	-0.52
0.71	0.98	-0.54	0.76	-0.55
0.77	1.05	-0.64	0.83	-0.60
0.77	1.10	-0.64	0.88	-0.64
0.80	1.19	-0.70	0.97	-0.70
0.82	1.24	-0.75	1.02	-0.74
0.86	1.30	-0.85	1.08	-0.79
0.87	1.36	-0.88	1.14	-0.83
0.92	1.53	-1.11	1.31	-0.95
0.95	1.71	-1.26	1.49	-1.08
1.00	1.88	-3.00	1.66	-1.21
1.00	2.07	-3.00	1.85	-1.34

CALCULATION

Regression: About 90% of the Data (Log 0.1=-1)
The Non-Zero C/Co Started at 0.03

Intercept=loge p/(1-p	0.1562	>>>>> p=	26.5%
slope=(-)loge /(1-d)(1-p)=	-0.7263	>>>>> d=	18.7%

Regression Statistics

Multiple R	1.00
R Square	0.99
Adjusted R Squar	0.96
Standard Error	0.03
Observations	31.00

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*ignificance F*
Regression	1.00	1.96	1.96	3066.87	0.00
Residual	30.00	0.02	0.00		
Total	31.00	1.98			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.73	0.01	-88.52	0.00	-0.74	-0.71

RESERVOIR NO.2 (141 ML/d) - REBHUN-ARGAMAN MODEL

REAL DATA			CORRECTION	
C/Co	(Te-Ti)/Te	log(1-C/Co)	(Te-Ti)/Te	log(1-C/Co)
0.00	0.00	0.00	-0.04	0.02
0.00	0.00	0.00	-0.04	0.02
0.00	0.00	0.00	-0.04	0.01
0.00	0.00	0.00	-0.04	0.02
0.00	0.04	0.00	0.00	0.00
0.17	0.06	-0.08	0.03	-0.01
0.27	0.09	-0.14	0.06	-0.03
0.27	0.12	-0.14	0.09	-0.05
0.29	0.16	-0.15	0.12	-0.07
0.30	0.19	-0.16	0.15	-0.09
0.33	0.22	-0.18	0.18	-0.11
0.44	0.26	-0.25	0.21	-0.12
0.43	0.29	-0.24	0.25	-0.14
0.44	0.32	-0.25	0.28	-0.16
0.45	0.36	-0.26	0.31	-0.18
0.47	0.39	-0.27	0.35	-0.20
0.51	0.42	-0.31	0.38	-0.22
0.52	0.46	-0.32	0.42	-0.24
0.55	0.49	-0.34	0.45	-0.26
0.56	0.53	-0.36	0.49	-0.28
0.58	0.56	-0.38	0.52	-0.30
0.60	0.59	-0.39	0.55	-0.32
0.60	0.62	-0.40	0.58	-0.34
0.61	0.66	-0.41	0.62	-0.36
0.63	0.69	-0.43	0.65	-0.38
0.63	0.72	-0.43	0.68	-0.39
0.65	0.76	-0.46	0.72	-0.41
0.65	0.79	-0.46	0.75	-0.43
0.67	0.82	-0.48	0.79	-0.45
0.67	0.86	-0.49	0.82	-0.47
0.71	0.89	-0.53	0.86	-0.49
0.74	0.93	-0.58	0.94	-0.54
0.74	0.99	-0.58	0.96	-0.56
0.75	1.03	-0.60	0.99	-0.57
0.76	1.06	-0.62	1.02	-0.59
0.76	1.09	-0.62	1.06	-0.61
0.78	1.14	-0.66	1.10	-0.63
0.79	1.16	-0.67	1.12	-0.65
0.79	1.19	-0.69	1.15	-0.67
0.79	1.23	-0.69	1.19	-0.68
0.79	1.26	-0.69	1.22	-0.70
0.80	1.29	-0.70	1.26	-0.72
0.82	1.33	-0.74	1.29	-0.74
0.82	1.36	-0.74	1.32	-0.76
0.83	1.39	-0.78	1.36	-0.78
0.82	1.43	-0.74	1.39	-0.80
0.83	1.46	-0.78	1.42	-0.82
0.83	1.50	-0.76	1.46	-0.84
0.86	1.54	-0.86	1.50	-0.87
0.87	1.56	-0.90	1.52	-0.88
0.87	1.60	-0.87	1.56	-0.90
0.83	1.63	-0.78	1.60	-0.92
0.84	1.67	-0.80	1.63	-0.94
0.87	1.70	-0.87	1.66	-0.96
0.91	1.73	-1.06	1.69	-0.97
0.92	1.76	-1.10	1.72	-0.99
0.91	1.80	-1.06	1.76	-1.01
0.94	1.82	-1.20	1.79	-1.03
0.94	1.86	-1.26	1.82	-1.06
0.93	1.89	-1.15	1.86	-1.07
0.94	1.93	-1.26	1.89	-1.09
0.96	1.96	-1.40	1.92	-1.10
0.97	1.99	-1.50	1.95	-1.12
0.94	2.03	-1.26	1.99	-1.15
0.93	2.07	-1.15	2.03	-1.17
0.98	2.08	-1.62	2.04	-1.18
1.00	2.11	-3.00	2.07	-1.20
0.98	2.15	-1.80	2.11	-1.22
0.98	2.20	-1.62	2.16	-1.24
0.99	2.22	-2.10	2.18	-1.26
1.01	2.26	-3.00	2.21	-1.27
0.98	2.30	-1.80	2.26	-1.30
1.01	2.32	-3.00	2.28	-1.31
0.99	2.36	-2.10	2.32	-1.34
0.97	2.40	-1.50	2.36	-1.36
0.97	2.43	-1.50	2.39	-1.38
0.98	2.46	-1.62	2.42	-1.40
1.00	2.49	-3.00	2.45	-1.41
0.99	2.54	-2.10	2.50	-1.44
1.00	2.56	-3.00	2.52	-1.46
1.00	2.59	-3.00	2.56	-1.47
1.00	2.63	-3.00	2.59	-1.49
1.00	2.66	-3.00	2.62	-1.51
1.00	2.70	-3.00	2.66	-1.53
1.00	2.73	-3.00	2.69	-1.55
1.00	2.76	-3.00	2.71	-1.56

CALCULATION

Regression About 90% of the Data (Log 0 1e-1)
The Non-Zero C/Co Start at 0.83
Intercept=log p(1- 0.0202 >>>>>> p 4.48%
Slope=(-log (1-m)(1-p))= -0.5765 >>>>> m 21.16%

Regression Statistics	
Multiple R	0.97
R Square	0.93
Adjusted R Square	0.91
Standard Error	0.07
Observations	51.00

Analysis of Variance

	df	Sum of Squares	Mean Square	F	Significance F
Regression	1.00	2.96	2.96	682.13	0.00
Residual	50.00	0.22	0.00		
Total	51.00	3.17			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.58	0.01	-61.21	0.00	-0.60	-0.56

RESERVOIR NO.2 (167 ML/d) - RESHUN-ARGAMAN MODEL

REAL DATA			CORRECTION	
C/Co	(To-Ti)/Td	log(1-C/Co)	(To-Ti)/Td	log(1-C/Co)
0.00	0.00	0.00	-0.02	0.01
0.00	0.00	0.00	-0.02	0.01
0.00	0.00	0.00	-0.02	0.01
0.00	0.02	0.00	0.00	0.00
0.17	0.04	-0.08	0.02	-0.01
0.22	0.08	-0.11	0.06	-0.03
0.31	0.11	-0.16	0.09	-0.05
0.33	0.14	-0.18	0.13	-0.08
0.34	0.18	-0.18	0.16	-0.10
0.41	0.21	-0.23	0.20	-0.12
0.46	0.25	-0.27	0.23	-0.14
0.47	0.29	-0.28	0.27	-0.16
0.45	0.32	-0.26	0.30	-0.18
0.42	0.36	-0.29	0.34	-0.20
0.50	0.39	-0.30	0.38	-0.22
0.54	0.43	-0.34	0.41	-0.25
0.51	0.47	-0.31	0.45	-0.27
0.55	0.50	-0.35	0.48	-0.29
0.60	0.54	-0.40	0.52	-0.31
0.60	0.59	-0.40	0.57	-0.34
0.61	0.61	-0.41	0.59	-0.35
0.63	0.64	-0.43	0.63	-0.37
0.66	0.68	-0.47	0.66	-0.40
0.71	0.71	-0.54	0.70	-0.42
0.69	0.75	-0.51	0.73	-0.44
0.69	0.79	-0.51	0.77	-0.46
0.69	0.82	-0.51	0.80	-0.48
0.69	0.86	-0.51	0.84	-0.50
0.69	0.90	-0.51	0.88	-0.52
0.73	0.93	-0.57	0.91	-0.55
0.74	0.97	-0.58	0.95	-0.57
0.77	1.00	-0.64	0.98	-0.59
0.77	1.04	-0.64	1.02	-0.61
0.78	1.07	-0.66	1.05	-0.63
0.80	1.11	-0.69	1.09	-0.65
0.83	1.14	-0.77	1.12	-0.67
0.83	1.18	-0.77	1.17	-0.70
0.84	1.22	-0.80	1.21	-0.72
0.84	1.25	-0.80	1.23	-0.74
0.81	1.29	-0.73	1.27	-0.76
0.83	1.32	-0.77	1.30	-0.78
0.83	1.35	-0.77	1.34	-0.80
0.84	1.39	-0.80	1.37	-0.82
0.84	1.43	-0.80	1.41	-0.84
0.84	1.46	-0.80	1.44	-0.86
0.87	1.49	-0.87	1.48	-0.88
0.87	1.53	-0.87	1.51	-0.90
0.87	1.57	-0.87	1.55	-0.93
0.89	1.60	-0.96	1.59	-0.95
0.90	1.64	-1.00	1.62	-0.97
0.92	1.67	-1.08	1.65	-0.99
0.88	1.71	-0.93	1.69	-1.01
0.88	1.75	-0.93	1.72	-1.04
0.90	1.78	-1.00	1.76	-1.05
0.91	1.81	-1.04	1.79	-1.07
0.90	1.86	-1.00	1.84	-1.10
0.90	1.89	-1.00	1.87	-1.12
0.91	1.92	-1.04	1.90	-1.14
0.93	1.95	-1.16	1.93	-1.16
0.93	1.99	-1.16	1.97	-1.18
0.94	2.02	-1.24	2.00	-1.20
0.96	2.06	-1.40	2.04	-1.22
0.95	2.09	-1.31	2.07	-1.24
0.97	2.12	-1.50	2.10	-1.26
0.95	2.16	-1.31	2.15	-1.28
0.95	2.20	-1.31	2.18	-1.30
0.93	2.25	-1.13	2.24	-1.34
0.95	2.27	-1.31	2.25	-1.35
0.95	2.31	-1.31	2.29	-1.37
0.97	2.34	-1.50	2.32	-1.39
0.99	2.36	-1.85	2.34	-1.40
0.99	2.40	-1.85	2.38	-1.42
0.99	2.43	-2.24	2.41	-1.44
0.99	2.47	-2.24	2.45	-1.46
0.99	2.51	-1.85	2.49	-1.49
0.99	2.54	-1.85	2.53	-1.51
0.99	2.58	-2.24	2.56	-1.53
0.97	2.63	-1.50	2.61	-1.56
0.96	2.67	-1.40	2.65	-1.58
0.96	2.70	-1.40	2.68	-1.61
0.96	2.74	-1.40	2.72	-1.63
0.95	2.78	-1.31	2.76	-1.65
0.97	2.81	-1.50	2.79	-1.67
0.97	2.84	-1.50	2.83	-1.69
0.99	2.87	-1.85	2.85	-1.71
0.99	2.90	-2.24	2.88	-1.72
0.99	2.94	-2.24	2.92	-1.75
0.99	2.98	-1.85	2.96	-1.77
0.99	3.01	-2.24	2.99	-1.79
1.00	3.04	-3.00	3.03	-1.81
1.00	3.08	-3.00	3.06	-1.83

CALCULATION

Regression About 90% of the Data (Log 0.1~-1)
The Non-Zero C/Co Start at 0.03

Intercept=loge p/(1-p)	0.0108	>>>>> p=	2.43%
Slope=(-)loge /(1-d)(1-p)=	-0.5979	>>>>> d=	25.55%

Regression Statistics

Multiple R	0.97
R Square	0.94
Adjusted R Square	0.92
Standard Error	0.07
Observations	55.00

Analysis of variance

	df	Sum of Square	Mean Square	F	Significance F
Regression	1.00	4.39	4.39	857.30	0.00
Residual	54.00	0.28	0.01		
Total	55.00	4.67			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.60	0.01	-66.25	0.00	-0.62	-0.58

RESERVOIR NO.1 (180 ML/d) - REBHUN-ARGAMAN MODEL

REAL			CORRECTION	
C/Co	(Te-Ti)/Td	log(1-C/Co)	(Te-Ti)/Td	log(C/Co)
0.00	0.00	0.00	-0.22	0.18
0.00	0.00	0.00	-0.22	0.18
0.00	0.02	0.00	-0.20	0.15
0.00	0.06	0.00	-0.17	0.12
0.00	0.09	0.00	-0.13	0.10
0.00	0.12	0.00	-0.10	0.07
0.02	0.14	-0.01	-0.08	0.06
0.00	0.16	0.00	-0.07	0.05
0.01	0.17	0.00	-0.06	0.04
0.02	0.19	-0.01	-0.03	0.02
0.02	0.22	-0.01	0.00	0.00
0.07	0.26	-0.03	0.03	-0.02
0.11	0.27	-0.05	0.06	-0.03
0.15	0.29	-0.07	0.08	-0.05
0.22	0.31	-0.11	0.09	-0.07
0.27	0.35	-0.14	0.12	-0.09
0.35	0.38	-0.18	0.16	-0.12
0.34	0.41	-0.18	0.19	-0.14
0.39	0.44	-0.21	0.22	-0.16
0.47	0.47	-0.27	0.26	-0.19
0.45	0.51	-0.26	0.29	-0.21
0.49	0.54	-0.30	0.32	-0.24
0.50	0.57	-0.30	0.35	-0.26
0.56	0.61	-0.36	0.39	-0.29
0.59	0.66	-0.38	0.43	-0.32
0.58	0.67	-0.38	0.45	-0.33
0.59	0.71	-0.39	0.48	-0.36
0.60	0.74	-0.40	0.52	-0.38
0.62	0.77	-0.43	0.55	-0.41
0.63	0.80	-0.44	0.58	-0.43
0.65	0.84	-0.46	0.61	-0.46
0.66	0.87	-0.47	0.65	-0.48
0.72	0.89	-0.56	0.67	-0.50
0.72	0.92	-0.56	0.70	-0.52
0.74	0.96	-0.59	0.73	-0.54
0.76	0.99	-0.61	0.78	-0.57
0.78	1.02	-0.66	0.80	-0.59
0.79	1.06	-0.68	0.83	-0.62
0.80	1.09	-0.69	0.86	-0.64
0.76	1.12	-0.61	0.90	-0.67
0.78	1.16	-0.66	0.93	-0.69
0.81	1.19	-0.71	0.96	-0.71
0.81	1.22	-0.73	1.00	-0.74
0.85	1.26	-0.81	1.03	-0.76
0.86	1.29	-0.84	1.06	-0.79
0.87	1.31	-0.89	1.09	-0.81
0.86	1.36	-0.84	1.14	-0.86
0.87	1.38	-0.89	1.16	-0.88
0.88	1.41	-0.92	1.19	-0.90
0.88	1.45	-0.92	1.23	-0.93
0.89	1.51	-0.96	1.29	-0.96
0.87	1.56	-0.89	1.33	-0.98
0.87	1.58	-0.89	1.36	-1.01
0.89	1.61	-0.96	1.39	-1.03
0.89	1.64	-0.96	1.42	-1.06
0.91	1.67	-1.05	1.45	-1.08
0.90	1.71	-1.02	1.49	-1.10
0.93	1.74	-1.15	1.52	-1.12
0.94	1.77	-1.20	1.55	-1.15
0.95	1.80	-1.26	1.58	-1.17
0.93	1.84	-1.15	1.62	-1.20
0.95	1.86	-1.33	1.64	-1.22
0.95	1.90	-1.33	1.68	-1.24
0.95	1.93	-1.33	1.71	-1.27
0.95	1.96	-1.33	1.74	-1.29
0.95	2.00	-1.33	1.78	-1.32
0.95	2.03	-1.33	1.81	-1.34
0.98	2.03	-1.67	1.81	-1.34
0.98	2.07	-1.67	1.84	-1.37
1.04	2.07	-3.00	1.86	-1.37
1.01	2.10	-3.00	1.88	-1.40
1.01	2.14	-3.00	1.92	-1.42
1.01	2.17	-3.00	1.96	-1.45
0.99	2.21	-2.29	1.99	-1.48
0.99	2.26	-2.29	2.02	-1.50
0.98	2.30	-1.67	2.08	-1.54
1.00	2.31	-3.00	2.09	-1.56
0.99	2.36	-2.29	2.13	-1.58

CALCULATION

Regression: About 80% of the Data (Log 0.1=-1)
The Non-Zero C/Co Started at 0.03
Intercept=-log(p)/(1- 0.1830 >>>>> p= 27.4%
slope=(-1)/log(1-d)(1-p)= -0.7411 >>>>> d= 19.3%

Regression Statistics

Multiple R	0.99
R Square	0.97
Adjusted R Squar	0.96
Standard Error	0.05
Observations	47.00

Analysis of Variance

	df	Sum of Square	Mean Square	F	gnificance F
Regression	1.00	4.21	4.21	1519.30	0.00
Residual	46.00	0.13	0.00		
Total	47.00	4.33			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.74	0.01	-81.19	0.00	-0.76	-0.72

RESERVOIR NO.3 (179 ML/d) - REBHUN-ARGAMAN MODEL

REAL DATA C/Co	(Te-Tl)/Td	log(1-C/Co)	CORRECTION (Te-Tl)/Td	CORRECTION log(1-C/Co)
0.00	0.00	0.00	-0.01	0.01
0.00	0.00	0.00	-0.01	0.01
0.00	0.01	0.00	0.00	0.00
0.10	0.04	-0.05	0.03	-0.02
0.25	0.07	-0.12	0.06	-0.04
0.26	0.11	-0.13	0.09	-0.06
0.26	0.15	-0.13	0.13	-0.09
0.32	0.18	-0.17	0.16	-0.11
0.36	0.21	-0.19	0.20	-0.13
0.43	0.25	-0.24	0.23	-0.15
0.43	0.28	-0.24	0.27	-0.18
0.47	0.32	-0.27	0.30	-0.20
0.50	0.36	-0.30	0.34	-0.23
0.53	0.39	-0.33	0.37	-0.25
0.53	0.42	-0.33	0.41	-0.27
0.52	0.46	-0.32	0.44	-0.29
0.56	0.49	-0.36	0.48	-0.32
0.57	0.52	-0.37	0.51	-0.34
0.59	0.56	-0.39	0.54	-0.36
0.61	0.59	-0.41	0.58	-0.39
0.64	0.63	-0.44	0.61	-0.41
0.67	0.66	-0.48	0.65	-0.43
0.69	0.70	-0.51	0.68	-0.45
0.68	0.73	-0.50	0.72	-0.48
0.70	0.77	-0.53	0.75	-0.50
0.72	0.80	-0.56	0.79	-0.53
0.73	0.85	-0.57	0.84	-0.56
0.74	0.87	-0.59	0.86	-0.57
0.78	0.91	-0.66	0.89	-0.59
0.76	0.94	-0.62	0.93	-0.62
0.76	0.98	-0.62	0.96	-0.64
0.76	1.01	-0.62	1.00	-0.66
0.77	1.05	-0.64	1.03	-0.69
0.78	1.08	-0.66	1.07	-0.71
0.82	1.12	-0.74	1.10	-0.73
0.79	1.15	-0.68	1.14	-0.76
0.78	1.19	-0.66	1.18	-0.78
0.79	1.22	-0.68	1.21	-0.80
0.86	1.25	-0.85	1.24	-0.82
0.87	1.29	-0.89	1.27	-0.84
0.88	1.32	-0.92	1.31	-0.87
0.88	1.36	-0.92	1.34	-0.89
0.90	1.39	-1.01	1.38	-0.92
0.88	1.43	-0.92	1.42	-0.94
0.89	1.46	-0.96	1.45	-0.96
0.88	1.50	-0.92	1.48	-0.98
0.89	1.53	-0.96	1.52	-1.01
0.92	1.56	-1.10	1.55	-1.03
0.90	1.60	-1.01	1.59	-1.06
0.90	1.64	-1.01	1.62	-1.08
0.91	1.67	-1.05	1.65	-1.10
0.91	1.70	-1.05	1.69	-1.12
0.96	1.72	-1.37	1.71	-1.14
0.97	1.75	-1.48	1.74	-1.16
0.97	1.79	-1.48	1.77	-1.18
0.97	1.82	-1.48	1.81	-1.20
0.98	1.85	-1.61	1.84	-1.22
0.98	1.88	-1.61	1.87	-1.24
0.98	1.91	-1.82	1.90	-1.26
1.01	1.93	-3.00	1.92	-1.28
0.99	1.97	-2.22	1.96	-1.30
0.99	2.01	-2.22	1.99	-1.33
1.00	2.04	-3.00	2.02	-1.35
1.01	2.07	-3.00	2.06	-1.37
1.01	2.11	-3.00	2.10	-1.39
0.98	2.16	-1.82	2.14	-1.43
0.98	2.20	-1.61	2.19	-1.46
0.98	2.23	-1.61	2.22	-1.48
0.99	2.26	-2.22	2.24	-1.49
0.99	2.29	-2.22	2.28	-1.51
0.98	2.33	-1.82	2.32	-1.54
1.00	2.36	-3.00	2.34	-1.56
1.00	2.39	-3.00	2.38	-1.58
1.02	2.43	-3.00	2.41	-1.61
1.02	2.46	-3.00	2.45	-1.63
1.02	2.50	-3.00	2.48	-1.66
1.03	2.53	-3.00	2.52	-1.68
1.03	2.57	-3.00	2.55	-1.70
1.04	2.60	-3.00	2.59	-1.72
1.03	2.64	-3.00	2.63	-1.75
1.02	2.67	-3.00	2.66	-1.77
0.98	2.73	-1.61	2.72	-1.81
1.01	2.75	-3.00	2.73	-1.82
1.01	2.78	-3.00	2.77	-1.84

CALCULATION

Regression: About 90% of the Data (Log 0 1=-1)

The Non-Zero C/Co Start at 0.03

Intercept=log p(1-φ 0.0004 >>>>> p= 2.12%

slope=(-1/log e)(1-m)(1-p)= -0.6650 >>>>> m 33.30%

Regression Statistics

Multiple R	0.98
R Square	0.96
Adjusted R Squar	0.94
Standard Error	0.06
Observations	48.00

Analysis of Variance

	df	Sum of Square	Mean Square	F	ignificance F
Regression	1.00	4.00	4.00	1221.79	0.00
Residual	47.00	0.15	0.00		
Total	48.00	4.15			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.67	0.01	-75.57	0.00	-0.68	-0.65

RESERVOIR NO. 1 (230 ML/d) - REBHUN-ARGAMAN MODEL

REAL DATA			CORRECTION	
C/Ce	(Te-T)/Td	log(1-C/Ce)	(Te-T)/Td	log(1-C/Ce)
0.00	0.00	0.00	-0.16	0.15
0.00	0.00	0.00	-0.16	0.15
0.01	0.03	0.00	-0.14	0.13
0.00	0.07	0.00	-0.09	0.08
0.00	0.12	0.00	-0.05	0.04
0.00	0.16	0.00	0.00	0.00
0.18	0.20	-0.09	0.04	-0.03
0.40	0.24	-0.22	0.08	-0.07
0.37	0.31	-0.20	0.15	-0.13
0.41	0.38	-0.23	0.21	-0.20
0.46	0.42	-0.27	0.26	-0.24
0.51	0.47	-0.31	0.30	-0.28
0.53	0.51	-0.33	0.35	-0.32
0.61	0.55	-0.41	0.39	-0.36
0.63	0.60	-0.44	0.44	-0.40
0.64	0.65	-0.44	0.48	-0.45
0.66	0.69	-0.48	0.53	-0.49
0.68	0.74	-0.49	0.57	-0.53
0.72	0.78	-0.56	0.62	-0.57
0.75	0.82	-0.60	0.66	-0.61
0.76	0.87	-0.63	0.70	-0.66
0.78	0.91	-0.66	0.75	-0.69
0.84	0.95	-0.80	0.79	-0.73
0.85	1.05	-0.82	0.89	-0.82
0.85	1.09	-0.82	0.93	-0.86
0.86	1.13	-0.86	0.97	-0.90
0.86	1.17	-0.86	1.01	-0.93
0.90	1.22	-1.02	1.05	-0.97
0.90	1.26	-0.99	1.10	-1.02
0.93	1.31	-1.14	1.14	-1.06
0.95	1.35	-1.30	1.19	-1.10
0.95	1.40	-1.30	1.23	-1.14
0.93	1.44	-1.18	1.28	-1.18
0.95	1.49	-1.30	1.32	-1.22
0.90	1.53	-1.02	1.37	-1.27
0.93	1.58	-1.18	1.41	-1.31
0.95	1.62	-1.30	1.46	-1.36
0.95	1.67	-1.30	1.50	-1.39
0.96	1.71	-1.38	1.55	-1.43
0.97	1.75	-1.52	1.59	-1.47
0.97	1.80	-1.47	1.64	-1.51
0.98	1.84	-1.73	1.67	-1.56
0.99	1.88	-1.98	1.72	-1.59
1.00	1.92	-2.61	1.76	-1.63
1.00	1.97	-3.00	1.80	-1.67
1.01	2.01	-3.00	1.85	-1.71
1.00	2.06	-3.00	1.90	-1.76
1.00	2.11	-2.61	1.94	-1.80
1.00	2.15	-3.00	1.99	-1.84
1.00	2.20	-2.61	2.03	-1.88
1.00	2.26	-2.61	2.10	-1.94
1.00	2.29	-2.61	2.12	-1.96
0.99	2.34	-1.98	2.17	-2.01

CALCULATION

Regression: About 90% of the Data (Log 0.1e-1)
The Non-Zero C/Ce Start at 0.03
intercept=loge p/(1-p 0.1614 >>>>>> p= 26.85%
slope=(-)loge ((1-m)(1-p)= -0.8245 >>>>>> m= 36.65%

Regression Statistics

Multiple R	0.99
R Square	0.97
Adjusted R Squar	0.93
Standard Error	0.06
Observations	24.00

Analysis of Variance

	df	Sum of Squares	Mean Square	F	Significance F
Regression	1.00	1.92	1.92	862.22	0.00
Residual	23.00	0.06	0.00		
Total	24.00	1.97			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.92	0.02	-41.49	0.00	-0.96	-0.88

RESERVOIR NO. 3 (1[illegible] Ml/d) - REBHUN-ARGAMAN MODEL

REAL DATA			CORRECTION	
C/Co	(Te-T)/Td	log(1-C/Co)	(Te-T)/Td	log(1-C/Co)
0.00	0.00	0.00	-0.03	0.02
0.00	0.00	0.00	-0.03	0.02
0.00	0.00	0.00	-0.03	0.02
0.00	0.00	0.00	-0.03	0.02
0.00	0.00	0.00	-0.03	0.02
0.01	0.01	0.00	-0.01	0.01
0.03	0.03	-0.01	0.00	0.00
0.15	0.04	-0.07	0.01	-0.01
0.24	0.05	-0.12	0.02	-0.02
0.24	0.07	-0.12	0.04	-0.03
0.26	0.08	-0.13	0.06	-0.03
0.27	0.10	-0.14	0.07	-0.04
0.27	0.13	-0.14	0.10	-0.06
0.29	0.16	-0.15	0.13	-0.08
0.33	0.19	-0.17	0.16	-0.10
0.40	0.22	-0.22	0.20	-0.13
0.39	0.26	-0.22	0.23	-0.15
0.41	0.27	-0.23	0.24	-0.16
0.42	0.33	-0.23	0.30	-0.19
0.46	0.34	-0.27	0.32	-0.20
0.52	0.37	-0.32	0.35	-0.22
0.53	0.41	-0.33	0.38	-0.24
0.54	0.44	-0.34	0.41	-0.26
0.55	0.45	-0.34	0.43	-0.27
0.58	0.50	-0.38	0.47	-0.30
0.59	0.53	-0.38	0.50	-0.32
0.62	0.56	-0.42	0.53	-0.34
0.61	0.59	-0.41	0.57	-0.36
0.63	0.62	-0.43	0.60	-0.38
0.63	0.64	-0.43	0.61	-0.39
0.65	0.69	-0.46	0.66	-0.42
0.68	0.72	-0.49	0.69	-0.44
0.66	0.75	-0.47	0.72	-0.46
0.68	0.78	-0.50	0.75	-0.48
0.72	0.81	-0.55	0.78	-0.50
0.70	0.84	-0.52	0.81	-0.52
0.72	0.89	-0.55	0.86	-0.56
0.73	0.90	-0.57	0.88	-0.56
0.77	0.93	-0.63	0.91	-0.58
0.76	0.96	-0.62	0.94	-0.60
0.76	1.00	-0.62	0.97	-0.62
0.78	1.03	-0.66	1.00	-0.63
0.80	1.07	-0.70	1.05	-0.66
0.79	1.09	-0.68	1.06	-0.67
0.79	1.12	-0.68	1.09	-0.69
0.80	1.15	-0.70	1.12	-0.71
0.80	1.18	-0.70	1.16	-0.73
0.81	1.21	-0.73	1.19	-0.75
0.81	1.24	-0.73	1.22	-0.77
0.83	1.27	-0.77	1.25	-0.79
0.83	1.31	-0.77	1.28	-0.81
0.84	1.34	-0.79	1.31	-0.83
0.85	1.37	-0.82	1.34	-0.85
0.86	1.40	-0.85	1.37	-0.87
0.88	1.43	-0.92	1.40	-0.89
0.88	1.46	-0.92	1.43	-0.91
0.88	1.49	-0.92	1.46	-0.93
0.89	1.52	-0.96	1.49	-0.95
0.89	1.55	-0.96	1.53	-0.97
0.90	1.59	-0.98	1.56	-0.99
0.89	1.63	-0.96	1.60	-1.02
0.90	1.65	-0.98	1.62	-1.03
0.89	1.67	-0.96	1.64	-1.04

CALCULATION

Regression Up to 99% of the Data (Log 0 1e-1)
The Non-Zero C/Co Start at 0.03
Intercept=log p/(1-p 0.0167 >>>>> p= 3.71%
Slope=(-)log 1/(1-m)(1-p)= -0.6380 >>>>> m= 38.97%

Regression Statistics

Multiple R	0.98
R Square	0.96
Adjusted R Squar	0.95
Standard Error	0.06
Observations	68.00

Analysis of Variance

	df	Sum of Square	Mean Square	F	ignificance F
Regression	1.00	4.53	4.53	14[illegible]	0.00
Residual	67.00	0.17	0.00		
Total	68.00	4.71			

	Coefficients	Standard Error	t Statistic	P-value	Lower 95%	Upper 95%
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.63	0.01	-81.13	0.00	-0.65	-0.62

RESERVOIRS NOS. 1,2,3 (170 ML/d) - REBHUN-ARGAMAN MODEL

REAL C/Co	(To-Ti)/Td	log(1-C/Co)	CORRECTION (To-Ti)/Td	log(C/Co)
0.01	0.00	0.00	-0.10	0.07
0.00	0.00	0.00	-0.10	0.07
0.00	0.01	0.00	-0.09	0.06
0.00	0.02	0.00	-0.08	0.06
0.01	0.03	0.00	-0.07	0.05
0.01	0.05	0.00	-0.05	0.03
0.01	0.06	0.00	-0.04	0.03
0.00	0.07	0.00	-0.03	0.02
0.01	0.08	0.00	-0.02	0.01
0.00	0.09	0.00	-0.01	0.01
0.00	0.10	0.00	0.00	0.00
0.04	0.12	-0.02	0.02	-0.01
0.04	0.12	-0.02	0.02	-0.01
0.08	0.13	-0.04	0.03	-0.02
0.11	0.14	-0.05	0.04	-0.03
0.09	0.15	-0.04	0.05	-0.03
0.11	0.16	-0.05	0.06	-0.04
0.11	0.17	-0.05	0.07	-0.05
0.11	0.18	-0.05	0.08	-0.06
0.10	0.19	-0.05	0.09	-0.06
0.14	0.20	-0.07	0.10	-0.07
0.14	0.22	-0.07	0.12	-0.08
0.18	0.23	-0.09	0.13	-0.09
0.20	0.24	-0.10	0.14	-0.10
0.20	0.25	-0.10	0.15	-0.10
0.22	0.26	-0.11	0.16	-0.11
0.22	0.27	-0.11	0.17	-0.12
0.23	0.28	-0.11	0.18	-0.13
0.23	0.29	-0.11	0.19	-0.13
0.28	0.30	-0.14	0.20	-0.14
0.28	0.31	-0.14	0.21	-0.15
0.29	0.32	-0.15	0.22	-0.15
0.29	0.33	-0.15	0.23	-0.16
0.34	0.34	-0.18	0.24	-0.17
0.34	0.35	-0.18	0.25	-0.17
0.39	0.36	-0.21	0.26	-0.18
0.39	0.37	-0.21	0.27	-0.19
0.39	0.39	-0.21	0.29	-0.20
0.39	0.40	-0.21	0.30	-0.21
0.41	0.41	-0.23	0.31	-0.22
0.43	0.42	-0.24	0.32	-0.22
0.43	0.43	-0.24	0.33	-0.23
0.44	0.44	-0.25	0.34	-0.24
0.43	0.45	-0.24	0.35	-0.24
0.43	0.46	-0.24	0.36	-0.25
0.44	0.47	-0.25	0.37	-0.26
0.43	0.48	-0.24	0.38	-0.26
0.47	0.49	-0.28	0.39	-0.27
0.48	0.50	-0.28	0.40	-0.28
0.50	0.51	-0.30	0.41	-0.29
0.49	0.52	-0.29	0.42	-0.29
0.50	0.54	-0.30	0.44	-0.31
0.51	0.55	-0.31	0.45	-0.31
0.52	0.56	-0.32	0.46	-0.32
0.53	0.57	-0.33	0.47	-0.33
0.51	0.58	-0.31	0.48	-0.33
0.52	0.59	-0.32	0.49	-0.34
0.53	0.60	-0.33	0.50	-0.35
0.54	0.61	-0.34	0.51	-0.36
0.59	0.62	-0.39	0.52	-0.36
0.60	0.63	-0.40	0.53	-0.37
0.61	0.64	-0.41	0.54	-0.38
0.61	0.65	-0.41	0.55	-0.38
0.61	0.66	-0.41	0.56	-0.39
0.61	0.67	-0.41	0.57	-0.40
0.62	0.69	-0.42	0.59	-0.41
0.63	0.70	-0.43	0.60	-0.42
0.63	0.71	-0.43	0.61	-0.42
0.63	0.72	-0.43	0.62	-0.43
0.63	0.73	-0.43	0.63	-0.44
0.65	0.74	-0.46	0.64	-0.45
0.65	0.75	-0.46	0.65	-0.45
0.64	0.76	-0.44	0.66	-0.46
0.67	0.77	-0.48	0.67	-0.47
0.68	0.79	-0.49	0.69	-0.48
0.68	0.79	-0.49	0.69	-0.48
0.69	0.80	-0.51	0.70	-0.49
0.70	0.81	-0.52	0.71	-0.49
0.70	0.83	-0.52	0.73	-0.51
0.70	0.84	-0.52	0.74	-0.52
0.71	0.85	-0.54	0.75	-0.52
0.71	0.86	-0.54	0.76	-0.53

CALCULATION

Regression About 90% of the Data (Log 0.1=-1)
The Non-Zero C/Co Started at 0.03
Intercept=log p/(1-p) 0.0697 >>>>> p= 13.8%
slope=(-)log ((1-d)(1-p))= -0.6967 >>>>> d= 27.7%

0.71	0.87	-0.54	0.77	-0.54
0.72	0.88	-0.55	0.78	-0.54
0.73	0.89	-0.57	0.79	-0.55
0.71	0.90	-0.54	0.80	-0.56
0.74	0.91	-0.59	0.81	-0.56
0.74	0.92	-0.59	0.82	-0.57
0.73	0.93	-0.57	0.83	-0.58
0.74	0.94	-0.59	0.84	-0.59
0.77	0.95	-0.64	0.85	-0.59
0.79	0.98	-0.68	0.88	-0.61
0.79	0.99	-0.68	0.89	-0.62
0.77	1.00	-0.64	0.90	-0.63
0.78	1.01	-0.66	0.91	-0.63
0.79	1.02	-0.68	0.92	-0.64
0.79	1.03	-0.68	0.93	-0.65
0.79	1.04	-0.68	0.94	-0.65
0.81	1.05	-0.72	0.95	-0.66
0.82	1.06	-0.74	0.96	-0.67
0.82	1.07	-0.74	0.97	-0.68
0.82	1.08	-0.74	0.98	-0.68
0.82	1.09	-0.74	0.99	-0.69
0.83	1.10	-0.77	1.00	-0.70
0.82	1.12	-0.74	1.02	-0.71
0.84	1.13	-0.80	1.03	-0.72
0.85	1.14	-0.82	1.04	-0.72
0.85	1.15	-0.82	1.06	-0.73
0.83	1.16	-0.77	1.06	-0.74
0.84	1.17	-0.80	1.07	-0.75
0.84	1.18	-0.80	1.08	-0.75
0.84	1.19	-0.80	1.09	-0.76
0.85	1.20	-0.82	1.10	-0.77
0.84	1.21	-0.80	1.11	-0.77
0.83	1.22	-0.77	1.12	-0.78
0.85	1.23	-0.82	1.13	-0.79
0.84	1.24	-0.80	1.14	-0.79
0.85	1.25	-0.82	1.15	-0.80
0.84	1.27	-0.80	1.17	-0.82
0.85	1.28	-0.82	1.18	-0.82
0.86	1.29	-0.85	1.19	-0.83
0.88	1.30	-0.92	1.20	-0.84
0.88	1.31	-0.92	1.21	-0.84
0.88	1.32	-0.92	1.22	-0.85
0.87	1.33	-0.89	1.23	-0.86
0.88	1.34	-0.92	1.24	-0.86
0.87	1.35	-0.89	1.25	-0.87
0.85	1.36	-0.82	1.26	-0.88
0.85	1.37	-0.82	1.27	-0.88
0.85	1.38	-0.82	1.28	-0.89
0.87	1.39	-0.89	1.29	-0.90
0.88	1.40	-0.92	1.30	-0.91
0.88	1.42	-0.92	1.32	-0.92
0.88	1.43	-0.92	1.33	-0.93
0.88	1.44	-0.92	1.34	-0.93
0.88	1.45	-0.92	1.35	-0.94
0.88	1.46	-0.92	1.36	-0.95
0.88	1.47	-0.92	1.37	-0.95
0.88	1.48	-0.92	1.38	-0.96
0.88	1.49	-0.92	1.39	-0.97
0.88	1.50	-0.92	1.40	-0.98
0.88	1.51	-0.92	1.41	-0.98
0.88	1.52	-0.92	1.42	-0.99
0.90	1.53	-1.00	1.43	-1.00
0.90	1.54	-1.00	1.44	-1.00
0.88	1.56	-0.92	1.46	-1.02
0.88	1.57	-0.92	1.47	-1.02
0.90	1.58	-1.00	1.48	-1.03
0.89	1.59	-0.96	1.49	-1.04
0.89	1.60	-0.96	1.50	-1.05
0.88	1.61	-0.92	1.51	-1.05
0.89	1.62	-0.96	1.52	-1.06
0.90	1.63	-1.00	1.53	-1.07
0.90	1.64	-1.00	1.54	-1.07
0.91	1.65	-1.05	1.55	-1.08
0.91	1.66	-1.05	1.56	-1.09
0.90	1.67	-1.00	1.57	-1.09
0.91	1.68	-1.05	1.58	-1.10
0.91	1.69	-1.05	1.59	-1.11
0.91	1.71	-1.05	1.61	-1.12
0.91	1.72	-1.05	1.62	-1.13
0.91	1.73	-1.05	1.63	-1.14
0.93	1.75	-1.15	1.65	-1.15
0.93	1.76	-1.15	1.66	-1.16
0.92	1.77	-1.10	1.67	-1.16
0.92	1.78	-1.10	1.68	-1.17
0.92	1.79	-1.10	1.69	-1.18
0.92	1.80	-1.10	1.70	-1.18
0.90	1.81	-1.00	1.71	-1.19

0.91	1.82	-1.05	1.72	-1.20
0.93	1.83	-1.15	1.73	-1.21
0.93	1.85	-1.15	1.75	-1.22
0.93	1.86	-1.15	1.76	-1.23
0.92	1.87	-1.10	1.77	-1.23
0.92	1.88	-1.10	1.78	-1.24
0.92	1.89	-1.10	1.79	-1.25
0.93	1.90	-1.15	1.80	-1.25
0.92	1.91	-1.10	1.81	-1.26
0.94	1.92	-1.22	1.82	-1.27
0.94	1.93	-1.22	1.83	-1.27
0.94	1.94	-1.22	1.84	-1.28
0.95	1.95	-1.30	1.85	-1.29
0.94	1.96	-1.22	1.86	-1.30
0.95	1.97	-1.30	1.87	-1.30
0.94	1.99	-1.22	1.89	-1.32
0.95	2.00	-1.30	1.90	-1.32
0.95	2.01	-1.30	1.91	-1.33
0.95	2.02	-1.30	1.92	-1.34
0.94	2.03	-1.22	1.93	-1.34
0.93	2.04	-1.15	1.94	-1.35
0.95	2.05	-1.30	1.95	-1.36
0.95	2.06	-1.30	1.96	-1.37
0.95	2.07	-1.30	1.97	-1.37
0.95	2.08	-1.30	1.98	-1.38
0.95	2.09	-1.30	1.99	-1.39
0.96	2.10	-1.40	2.00	-1.39
0.95	2.12	-1.30	2.02	-1.41
0.94	2.13	-1.22	2.03	-1.41
0.95	2.14	-1.30	2.04	-1.42
0.95	2.15	-1.30	2.05	-1.43
0.95	2.16	-1.30	2.06	-1.44
0.95	2.17	-1.30	2.07	-1.44
0.95	2.18	-1.30	2.08	-1.45
0.95	2.19	-1.30	2.09	-1.46
0.95	2.20	-1.30	2.10	-1.46
0.95	2.21	-1.30	2.11	-1.47
0.95	2.22	-1.30	2.12	-1.48
0.95	2.23	-1.30	2.13	-1.48
0.95	2.24	-1.30	2.14	-1.49
0.95	2.26	-1.30	2.16	-1.50
0.95	2.27	-1.30	2.17	-1.51
0.95	2.28	-1.30	2.18	-1.52
0.95	2.29	-1.30	2.19	-1.53
0.95	2.30	-1.30	2.20	-1.53
0.95	2.31	-1.30	2.21	-1.54
0.95	2.32	-1.30	2.22	-1.55
0.96	2.33	-1.40	2.23	-1.55
0.96	2.34	-1.40	2.24	-1.56
0.96	2.35	-1.40	2.25	-1.57
0.95	2.36	-1.30	2.26	-1.57
0.96	2.37	-1.40	2.27	-1.58
0.96	2.38	-1.40	2.28	-1.59
0.96	2.40	-1.40	2.30	-1.60
0.96	2.41	-1.40	2.31	-1.61
0.96	2.42	-1.40	2.32	-1.62
0.96	2.43	-1.40	2.33	-1.62
0.96	2.44	-1.40	2.34	-1.63
0.97	2.45	-1.52	2.35	-1.64
0.96	2.47	-1.40	2.37	-1.65
0.96	2.48	-1.40	2.38	-1.66
0.96	2.48	-1.40	2.38	-1.66
0.97	2.50	-1.52	2.40	-1.67
0.96	2.51	-1.40	2.41	-1.68
0.97	2.52	-1.52	2.42	-1.69
0.97	2.54	-1.52	2.44	-1.70
0.98	2.55	-1.70	2.45	-1.71
0.98	2.56	-1.70	2.46	-1.71
0.98	2.58	-1.70	2.48	-1.73
0.96	2.59	-1.40	2.49	-1.73
0.97	2.60	-1.52	2.50	-1.74
0.98	2.61	-1.70	2.51	-1.75
0.98	2.62	-1.70	2.52	-1.76
0.98	2.63	-1.70	2.53	-1.76
0.97	2.64	-1.52	2.54	-1.77
0.97	2.65	-1.52	2.55	-1.78
0.98	2.66	-1.70	2.56	-1.78
0.98	2.68	-1.70	2.58	-1.80
0.98	2.69	-1.70	2.59	-1.80
0.98	2.70	-1.70	2.60	-1.81
0.98	2.71	-1.70	2.61	-1.82
0.98	2.72	-1.70	2.62	-1.83
0.98	2.73	-1.70	2.63	-1.83
0.98	2.74	-1.70	2.64	-1.84
0.98	2.75	-1.70	2.65	-1.85
0.99	2.76	-2.00	2.66	-1.85
0.98	2.77	-1.70	2.67	-1.86

0.98	2.78	-1.70	2.68	-1.87
0.99	2.79	-2.00	2.69	-1.87
0.99	2.80	-2.00	2.70	-1.88
0.98	2.82	-1.70	2.72	-1.89
0.98	2.83	-1.70	2.73	-1.90
0.98	2.84	-1.70	2.74	-1.91
0.98	2.85	-1.70	2.75	-1.92
0.98	2.86	-1.70	2.76	-1.92
0.98	2.87	-1.70	2.77	-1.93
0.99	2.88	-2.00	2.78	-1.94
0.99	2.89	-2.00	2.79	-1.94
0.98	2.90	-1.70	2.80	-1.95
0.99	2.91	-2.00	2.81	-1.96
0.98	2.92	-1.70	2.82	-1.96
0.98	2.93	-1.70	2.83	-1.97
0.98	2.95	-1.70	2.85	-1.99
0.98	2.96	-1.70	2.86	-1.99
0.98	2.97	-1.70	2.87	-2.00
0.98	2.98	-1.70	2.88	-2.01
0.98	2.99	-1.70	2.89	-2.01
0.99	3.00	-2.00	2.90	-2.02
0.99	3.01	-2.00	2.91	-2.03
0.99	3.02	-2.00	2.92	-2.03
1.00	3.03	-3.00	2.93	-2.04
1.00	3.04	-3.00	2.94	-2.05
1.00	3.05	-3.00	2.95	-2.06
0.99	3.06	-2.00	2.96	-2.06
1.00	3.07	-3.00	2.97	-2.07
1.00	3.09	-3.00	2.99	-2.08
1.00	3.10	-3.00	3.00	-2.09
1.00	3.11	-3.00	3.01	-2.10
1.00	3.12	-3.00	3.02	-2.10
1.00	3.13	-3.00	3.03	-2.11
1.00	3.14	-3.00	3.04	-2.12
1.00	3.15	-3.00	3.05	-2.12
1.00	3.16	-3.00	3.06	-2.13
1.00	3.17	-3.00	3.07	-2.14
1.00	3.18	-3.00	3.08	-2.15
1.00	3.19	-3.00	3.09	-2.15
1.00	3.20	-3.00	3.10	-2.16
1.00	3.21	-3.00	3.11	-2.17
1.00	3.23	-3.00	3.13	-2.18
1.00	3.24	-3.00	3.14	-2.19
1.00	3.25	-3.00	3.15	-2.19
1.00	3.26	-3.00	3.16	-2.20
1.00	3.27	-3.00	3.17	-2.21
1.00	3.28	-3.00	3.18	-2.22
1.00	3.29	-3.00	3.19	-2.22
1.00	3.30	-3.00	3.20	-2.23
1.00	3.31	-3.00	3.21	-2.24
1.00	3.32	-3.00	3.22	-2.24
1.00	3.33	-3.00	3.23	-2.25
1.00	3.37	-3.00	3.27	-2.28

Regression Statistics	
Multiple R	0.99
R Square	0.98
Adjusted R Square	0.98
Standard Error	0.04
Observations	144.00

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*	*F*	*Significance F*
Regression	1.00	13.48	13.48	8806.28	0.00
Residual	143.00	0.22	0.00		
Total	144.00	13.70			

	Coefficients	*Standard Error*	*t Statistic*	*P-value*	*Lower 99%*	*Upper 99%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A
x1	-0.70	0.00	-190.22	0.00	-0.70	-0.69

APPENDIX 4: JET MODEL

RESERVOIR NO. 2 (141 ML/d) - JET MODEL

vol. of tank	28570	m3
qo(initial flow)	97.92	m3/min
do(imagnery pipe diam)	1.00	m
Ao(m^2)	0.79	m^2
uo(initial velocity)	124.73	m/min

JETS

x1 (core length) = 18*ro	9.00	m
imagnery plane=	145	m
water level=	3.9	m
angle for jet core =	2	

ux = 9* (do/x)*uo *exp(-74 * (r/x)^2)

Cx =Co* 7* (do/x) * exp(-54* (r/x)^2)

		x (m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
angle (deg)	0.0	x'(m)=	0.0	10.0	15.0	20.0	25.0	30.0	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		ux(m/min)=	124.7	112.3	74.8	56.1	44.9	37.4	32.1	28.1	24.9	22.5	20.4	18.7	17.3	16.0	15.0	14.0
		dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.4	1.6	1.9	2.2	2.5	2.9
	1.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4
		ux(m/min)=	124.7	109.8	73.2	54.9	43.9	36.6	31.4	27.4	24.4	22.0	20.0	18.3	16.9	15.7	14.6	13.7
		dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.4	1.7	2.0	2.3	2.6	2.9
	2.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8
		ux(m/min)=	124.7	102.6	68.4	51.3	41.0	34.2	29.3	25.6	22.8	20.5	18.7	17.1	15.8	14.7	13.7	12.8
		dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.8	3.1
	3.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.1	3.4	3.7	3.9	4.2
		ux(m/min)=	124.7	91.6	61.1	45.8	36.7	30.5	26.2	22.9	20.4	18.3	16.7	15.3	14.1	13.1	12.2	11.5
		dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4
		tx(min)=	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.7	3.1	3.5
	4.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2	5.6
		ux(m/min)=	124.7	78.2	52.1	39.1	31.3	26.1	22.3	19.6	17.4	15.6	14.2	13.0	12.0	11.2	10.4	9.8
		dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5
		tx(min)=	0.0	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.3	1.6	2.0	2.3	2.7	3.2	3.6	4.1
	5.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.9	1.3	1.7	2.2	2.6	3.1	3.5	3.9	4.4	4.8	5.2	5.7	6.1	6.6	7.0
		ux(m/min)=	124.7	63.8	42.5	31.9	25.5	21.3	18.2	15.9	14.2	12.8	11.6	10.6	9.8	9.1	8.5	8.0
		dt x(min)=	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6
		tx(min)=	0.0	0.1	0.2	0.3	0.5	0.7	1.0	1.3	1.6	2.0	2.4	2.8	3.3	3.9	4.4	5.0
	6.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3	6.8	7.4	7.9	8.4
		ux(m/min)=	124.7	49.6	33.1	24.8	19.8	16.5	14.2	12.4	11.0	9.9	9.0	8.3	7.6	7.1	6.6	6.2
		dt x(min)=	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8
		tx(min)=	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.0	2.5	3.1	3.6	4.3	5.0	5.7	6.5
	7.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	66	71	76	81
		r(m)=	0.0	1.2	1.8	2.5	3.1	3.7	4.3	4.9	5.5	6.1	6.7	7.4	8.0	8.6	9.2	9.8
		ux(m/min)=	124.7	36.8	24.6	18.4	14.7	12.3	10.5	9.2	8.2	7.4	6.7	6.1	5.7	5.3	4.9	4.6
		dt x(min)=	0.0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.1
		tx(min)=	0.0	0.1	0.3	0.5	0.8	1.2	1.6	2.2	2.7	3.4	4.1	4.9	5.7	6.7	7.7	8.7
	8.0	x'(m)=	0	10	15	20	25	30	35	40	45	51	56	61	66	71	76	81
		r(m)=	0.0	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2
		ux(m/min)=	124.7	124.7	17.4	13.0	10.4	8.7	7.4	6.5	5.8	5.2	4.7	4.3	4.0	3.7	3.5	3.3
		dt x(min)=	0.0	0.1	0.1	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
		tx(min)=	0.0	0.1	0.2	0.5	0.9	1.4	2.1	2.8	3.6	4.5	5.5	6.7	7.9	9.2	10.6	12.1
	9.0	x'(m)=	0	10	15	20	25	30	35	41	46	51	56	61	66	71	76	81
		r(m)=	0.0	1.6	2.4	3.2	4.0	4.7	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.1	11.9	12.7
		ux(m/min)=	124.7	17.6	11.7	8.8	7.0	5.9	5.0	4.4	3.9	3.5	3.2	2.9	2.7	2.5	2.3	2.2
		dt x(min)=	0.0	0.1	0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	1.9	2.1	2.2
		tx(min)=	0.0	0.1	0.5	1.0	1.6	2.4	3.3	4.4	5.6	7.0	8.5	10.2	12.0	13.9	16.0	18.2
	10.0	x'(m)=	0	10	15	20	25	30	36	41	46	51	56	61	66	71	76	81
		r(m)=	0.0	1.8	2.6	3.5	4.4	5.3	6.2	7.0	7.9	8.8	9.7	10.6	11.5	12.3	13.2	14.1
		ux(m/min)=	124.7	11.3	7.5	5.6	4.5	3.8	3.2	2.8	2.5	2.3	2.0	1.9	1.7	1.6	1.5	1.4
		dt x(min)=	0.0	0.1	0.5	0.8	1.0	1.2	1.5	1.7	1.9	2.1	2.4	2.6	2.8	3.0	3.3	3.5
		tx(min)=	0.0	0.1	0.7	1.5	2.5	3.7	5.2	6.8	8.7	10.9	13.2	15.8	18.6	21.7	24.9	28.4

85	90	95	100	105	110	115	120	125	130	135	140	145
85	90	95	100	105	110	115	120	125	130	135	140	145
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0
13.2	12.5	11.8	11.2	10.7	10.2	9.8	9.4	9.0	8.64	8.3	8.0	7.7
0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.57	0.6	0.6	0.6
3.2	3.6	4.0	4.5	4.9	5.4	5.9	6.4	7.0	7.6	8.1	8.8	9.4
85	90	95	100	105	110	115	120	125	130	135	140	145
1.5	1.6	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.27	2.4	2.4	2.5
12.9	12.2	11.6	11.0	10.5	10.0	9.5	9.1	8.8	8.44	8.1	7.8	7.6
0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.58	0.6	0.6	0.6
3.3	3.7	4.1	4.6	5.0	5.5	6.1	6.6	7.1	7.7	8.3	9.0	9.6
85	90	95	100	105	110	115	120	125	130	135	140	145
3.0	3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.54	4.7	4.9	5.1
12.1	11.4	10.8	10.3	9.8	9.3	8.9	8.5	8.2	7.89	7.6	7.3	7.1
0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.62	0.6	0.7	0.7
3.6	4.0	4.4	4.9	5.4	5.9	6.5	7.0	7.6	8.3	8.9	9.6	10.3
85	90	95	100	105	110	115	120	125	130	135	140	145
4.5	4.7	5.0	5.2	5.5	5.8	6.0	6.3	6.5	6.81	7.1	7.3	7.6
10.8	10.2	9.8	9.2	8.7	8.3	8.0	7.6	7.3	7.05	6.8	6.5	6.3
0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.70	0.7	0.8	0.8
4.0	4.4	5.0	5.5	6.0	6.6	7.2	7.9	8.6	9.3	10.0	10.7	11.5
85	90	95	100	105	110	115	120	125	130	135	140	145
5.9	6.3	6.6	7.0	7.3	7.7	8.0	8.4	8.7	9.09	9.4	9.8	10.1
9.2	8.7	8.2	7.8	7.4	7.1	6.8	6.5	6.3	6.02	5.8	5.6	5.4
0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.82	0.8	0.9	0.9
4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.2	10.0	10.8	11.7	12.6	13.5
85	90	95	100	105	110	115	120	126	131	136	141	146
7.4	7.9	8.3	8.7	9.2	9.6	10.1	10.5	10.9	11.37	11.8	12.2	12.7
7.5	7.1	6.7	6.4	6.1	5.8	5.5	5.3	5.1	4.90	4.7	4.6	4.4
0.6	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.00	1.0	1.1	1.1
5.7	6.4	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.3	14.4	15.4	16.6
85	91	96	101	106	111	116	121	126	131	136	141	146
8.9	9.5	10.0	10.5	11.0	11.6	12.1	12.6	13.1	13.66	14.2	14.7	15.2
5.8	5.5	5.2	5.0	4.7	4.5	4.3	4.1	4.0	3.82	3.7	3.5	3.4
0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.29	1.3	1.4	1.4
7.3	8.2	9.1	10.1	11.2	12.3	13.4	14.6	15.8	17.1	18.5	19.9	21.3
86	91	96	101	106	111	116	121	126	131	136	141	146
10.4	11.0	11.7	12.3	12.9	13.5	14.1	14.7	15.3	15.95	16.6	17.2	17.8
4.3	4.1	3.9	3.7	3.5	3.3	3.2	3.1	2.9	2.83	2.7	2.6	2.5
1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.74	1.8	1.9	1.9
9.8	11.0	12.3	13.6	15.0	16.5	18.0	19.7	21.3	23.1	24.9	26.8	28.7
86	91	96	101	106	111	116	121	126	131	136	141	147
11.9	12.6	13.3	14.0	14.7	15.5	16.2	16.9	17.6	18.26	19.0	19.7	20.4
3.1	2.9	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.01	1.9	1.9	1.8
1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.47	2.6	2.7	2.8
13.7	15.4	17.2	19.1	21.0	23.1	25.3	27.6	29.9	32.4	35.0	37.6	40.4
86	91	96	101	106	111	117	122	127	132	137	142	147
13.5	14.2	15.0	15.8	16.6	17.4	18.2	19.0	19.8	20.58	21.4	22.2	23.0
2.1	2.0	1.8	1.8	1.7	1.6	1.5	1.5	1.4	1.35	1.3	1.3	1.2
2.4	2.5	2.7	2.8	3.0	3.1	3.2	3.4	3.5	3.67	3.8	4.0	4.1
20.6	23.1	25.8	28.6	31.6	34.7	37.9	41.3	44.8	48.5	52.3	56.3	60.4
86	91	97	102	107	112	117	122	127	132	137	142	147
15.0	15.9	16.7	17.6	18.5	19.4	20.3	21.1	22.0	22.91	23.8	24.7	25.6
1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.87	0.8	0.8	0.8
3.7	3.9	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.75	6.0	6.2	6.4
32.1	36.1	40.3	44.6	49.3	54.1	59.2	64.5	70.0	75.7	81.7	87.9	94.3

Inlet

Outlet at 145m

angle (deg)=	0.0	1.0	2.0	3.0	4.0
r(m)=	0.0	2.5	5.1	7.6	10.1
1/2 A(m^2)=	0.1	10.0	30.2	50.4	70.7
ux(m/min)=	7.7	7.6	7.1	6.3	5.4
tx(min)=	9.4	9.6	10.3	11.5	13.5

T inlet	C/Co	Toutlet	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass
17	0.00	26	0.00	26	0.00												
18	0.00	27	0.00	27	0.00	0.00	27	-0.01	0.00	27	-0.03						
19	0.00	28	0.00	28	0.00	0.00	28	-0.01	0.00	28	-0.03						
20	0.00	29	0.00	29	0.00	0.00	29	-0.01	0.00	29	-0.03	0.00	29	-0.04			
21	0.00	30	0.00	30	0.00	0.00	30	-0.01	0.00	30	-0.03	0.00	30	-0.04	0.00	30	-0.05
22	0.00	31	0.00	31	0.00	0.00	31	-0.01	0.00	31	-0.03	0.00	31	-0.04	0.00	31	-0.05
23	0.00	32	0.00	32	0.00	0.00	32	-0.01	0.00	32	-0.03	0.00	32	-0.04	0.00	32	-0.05
24	0.00	33	0.00	33	0.00	0.00	33	-0.01	0.00	33	-0.03	0.00	33	-0.04	0.00	33	-0.05
25	0.00	34	0.00	34	0.00	0.00	34	-0.01	0.00	34	-0.03	0.00	34	-0.04	0.00	34	-0.05
26	0.06	35	0.00	35	0.00	0.00	35	0.11	0.00	35	-0.03	0.00	35	-0.04	0.00	35	-0.05
27	0.12	36	0.01	36	0.00	0.00	36	0.34	0.00	36	0.63	0.00	36	0.45	0.00	36	-0.05
28	0.17	37	0.01	37	0.00	0.01	37	0.55	0.01	37	1.27	0.00	37	0.92	0.00	37	-0.05
29	0.29	38	0.01	38	0.01	0.01	38	0.88	0.01	38	1.80	0.00	38	1.77	0.00	38	0.51
30	0.34	39	0.02	39	0.01	0.01	39	1.20	0.01	39	3.07	0.01	39	3.14	0.00	39	1.53
31	0.42	40	0.02	40	0.01	0.02	40	1.45	0.02	40	3.58	0.01	40	3.89	0.00	40	2.44
32	0.50	41	0.03	41	0.01	0.02	41	1.75	0.02	41	4.44	0.01	41	5.39	0.01	41	3.89
33	0.60	42	0.03	42	0.01	0.02	42	2.09	0.02	42	5.29	0.01	42	6.37	0.01	42	5.26
34	0.68	43	0.03	43	0.01	0.03	43	2.44	0.03	43	6.34	0.02	43	7.73	0.01	43	6.38
35	0.76	44	0.04	44	0.01	0.03	44	2.74	0.03	44	7.19	0.02	44	8.94	0.02	44	7.69
36	0.78	45	0.04	45	0.02	0.04	45	2.93	0.04	45	8.03	0.03	45	10.29	0.02	45	9.19
37	0.82	46	0.04	46	0.02	0.04	46	3.04	0.04	46	8.25	0.03	46	11.02	0.02	46	10.68
38	0.84	47	0.04	47	0.02	0.04	47	3.16	0.04	47	8.67	0.03	47	11.91	0.03	47	12.01
39	0.88	48	0.04	48	0.02	0.04	48	3.27	0.04	48	8.88	0.03	48	12.21	0.03	48	12.81
40	0.91	49	0.05	49	0.02	0.04	49	3.40	0.04	49	9.30	0.03	49	12.81	0.03	49	13.32
41	0.92	50	0.05	50	0.02	0.04	50	3.48	0.04	50	9.62	0.04	50	13.19	0.03	50	13.81
42	0.92	51	0.05	51	0.02	0.05	51	3.50	0.04	51	9.73	0.04	51	13.56	0.03	51	14.32
43	0.96	52	0.05	52	0.02	0.05	52	3.58	0.04	52	9.73	0.04	52	13.77	0.03	52	14.89
44	0.97	53	0.05	53	0.02	0.05	53	3.67	0.04	53	10.15	0.04	53	14.16	0.03	53	15.22
45	0.98	54	0.05	54	0.02	0.05	54	3.71	0.05	54	10.25	0.04	54	14.24	0.03	54	15.29
46	0.99	55	0.05	55	0.02	0.05	55	3.75	0.05	55	10.36	0.04	55	14.60	0.03	55	15.85
47	0.99	56	0.05	56	0.02	0.05	56	3.76	0.05	56	10.47	0.04	56	14.75	0.04	56	16.05
48	1.00	57	0.05	57	0.02	0.05	57	3.78	0.05	57	10.47	0.04	57	14.83	0.04	57	16.21
49	1.00	58	0.05	58	0.02	0.05	58	3.80	0.05	58	10.57	0.04	58	14.98	0.04	58	16.38
50	1.00	59	0.05	59	0.02	0.05	59	3.80	0.05	59	10.57	0.04	59	14.98	0.04	59	16.46
51	1.00	60	0.05	60	0.02	0.05	60	3.80	0.05	60	10.57	0.04	60	15.05	0.04	60	16.55
52	1.00	61	0.05	61	0.02	0.05	61	3.80	0.05	61	10.57	0.04	61	15.05	0.04	61	16.62
53	1.00	62	0.05	62	0.02	0.05	62	3.80	0.05	62	10.57	0.04	62	15.05	0.04	62	16.62
END		63	0.05		0.02	0.05	63	3.80	0.05	63	10.57	0.04	63	15.05	0.04	63	16.62
		64	0.05		0.02	0.05		3.80	0.05		10.57	0.04	64	15.05	0.04	64	16.62
		65	0.05		0.02	0.05		3.80	0.05		10.57	0.04	65	15.05	0.04	65	16.62
		66	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04	66	16.62
		67	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		68	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		69	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		70	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		71	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		72	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		73	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		74	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		75	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		76	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		77	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		78	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		79	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		80	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		81	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		82	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		83	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		84	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		85	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		86	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		87	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		88	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		89	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		90	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		91	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		92	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		93	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		94	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		95	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		96	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62
		97	0.05		0.02	0.05		3.80	0.05		10.57	0.04		15.05	0.04		16.62

98	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
99	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
100	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
101	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
102	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
103	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
104	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
105	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
106	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
107	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
108	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
109	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
110	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
111	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
112	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
113	05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
114	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
115	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
116	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
117	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
118	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
119	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
120	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
121	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
122	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
123	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
124	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
125	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
126	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
127	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
128	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
129	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
130	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
131	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
132	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
133	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
134	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
135	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
136	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
137	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
138	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62
139	0.05	0.02	0.05	3.80	0.05	10.57	0.04	15.05	0.04	16.62

5.0 12.7 91.2 4.4 16.6			6.0 15.2 111.9 3.4 21.3			7.0 17.8 132.9 2.5 28.7			8.0 20.4 154.2 1.8 40.4			9.0 23.0 175.9 1.2 60.4			10.0 25.6 198.0 0.8 94.3			Complete Total Flux		Jet Core (2") Total Flux	
C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Mass	C/Co	Mass
																		0.00	0.0	0.00	0.00
																		0.00	0.0	0.00	-0.04
																		0.00	0.0	0.00	-0.04
																		0.00	-0.1	0.00	-0.04
																		0.00	-0.1	0.00	-0.04
																		0.00	-0.1	0.00	-0.04
																		0.00	-0.1	0.00	-0.04
																		0.00	-0.1	0.00	-0.04
0.00	34	-0.04																0.00	-0.2	0.00	-0.04
0.00	35	-0.04																0.00	-0.1	0.00	0.08
0.00	36	-0.04																0.01	1.3	0.01	0.98
0.00	37	-0.04																0.03	2.7	0.02	1.82
0.00	38	-0.04	0.00	38	-0.04													0.05	4.9	0.03	2.88
0.00	39	0.48	0.00	39	-0.04													0.10	9.4	0.04	4.27
0.00	40	0.99	0.00	40	-0.04													0.13	12.3	0.05	5.06
0.00	41	1.41	0.00	41	-0.04													0.17	16.8	0.06	6.20
0.00	42	2.42	0.00	42	-0.04													0.22	21.4	0.08	7.39
0.00	43	3.29	0.00	43	0.40													0.27	26.6	0.09	8.79
0.00	44	4.39	0.00	44	0.83													0.32	31.8	0.10	9.94
0.01	45	5.42	0.00	45	1.18													0.38	37.1	0.11	10.98
0.01	46	7.12	0.00	46	2.02	0.00	46	-0.03										0.43	42.1	0.12	11.30
0.01	47	8.15	0.00	47	2.73	0.00	47	0.30										0.48	46.9	0.12	11.84
0.01	48	9.40	0.00	48	3.64	0.00	48	0.62										0.52	50.8	0.12	12.17
0.02	49	10.14	0.00	49	4.49	0.00	49	0.88										0.56	54.4	0.13	12.72
0.02	50	11.19	0.01	50	5.89	0.00	50	1.50										0.60	58.7	0.13	13.12
0.02	51	11.93	0.01	51	6.74	0.00	51	1.76										0.63	61.5	0.14	13.24
0.02	52	12.84	0.01	52	7.76	0.00	52	2.18										0.66	64.8	0.14	13.32
0.03	53	13.24	0.01	53	8.36	0.00	53	2.60										0.69	67.4	0.14	13.84
0.03	54	13.61	0.02	54	9.22	0.00	54	3.12										0.71	69.5	0.14	13.98
0.03	55	13.75	0.02	55	9.82	0.00	55	3.80										0.73	71.7	0.14	14.12
0.03	56	14.37	0.02	56	10.56	0.00	56	4.47										0.76	74.5	0.15	14.25
0.03	57	14.67	0.02	57	10.69	0.00	57	4.78	0.00	57	0.59							0.78	76.2	0.15	14.27
0.03	58	14.83	0.02	58	11.19	0.01	58	5.48	0.00	58	1.01							0.80	78.3	0.15	14.39
0.03	59	14.91	0.02	59	11.30	0.01	59	5.80	0.00	59	1.18							0.81	79.0	0.15	14.39
0.03	60	15.20	0.02	60	11.82	0.01	60	6.34	0.00	60	1.46							0.83	80.6	0.15	14.39
0.03	61	15.36	0.02	61	12.06	0.01	61	6.82	0.00	61	1.74							0.84	82.0	0.15	14.39
0.03	62	15.43	0.02	62	12.19	0.01	62	7.29	0.00	62	2.09							0.85	83.1	0.15	14.39
0.03	63	15.50	0.02	63	12.26	0.01	63	7.62	0.00	63	2.37							0.86	83.8	0.15	14.39
0.03	64	15.50	0.03	64	12.49	0.02	64	8.16	0.00	64	2.65							0.87	84.9	0.15	14.39
0.03	65	15.57	0.03	65	12.62	0.02	65	8.30	0.00	65	2.72							0.87	85.3	0.15	14.39
0.03	66	15.57	0.03	66	12.67	0.02	66	8.51	0.00	66	3.03							0.88	85.8	0.15	14.39
0.03	67	15.57	0.03	67	12.73	0.02	67	8.65	0.00	67	3.25							0.88	86.3	0.15	14.39
0.03	68	15.57	0.03	68	12.73	0.02	68	8.81	0.00	68	3.53							0.89	86.7	0.15	14.39
0.03	69	15.57	0.03	69	12.79	0.02	69	8.99	0.00	69	3.95							0.89	87.4	0.15	14.39
0.03	70	15.57	0.03	70	12.79	0.02	70	9.03	0.01	70	4.12							0.89	87.6	0.15	14.39
0.03		15.57	0.03	71	12.79	0.02	71	9.03	0.01	71	4.33							0.90	87.8	0.15	14.39
0.03		15.57	0.03	72	12.79	0.02	72	9.20	0.01	72	4.69							0.90	88.3	0.15	14.39
0.03		15.57	0.03	73	12.79	0.02	73	9.24	0.01	73	4.99							0.91	88.7	0.15	14.39
0.03		15.57	0.03	74	12.79	0.02	74	9.28	0.01	74	5.24							0.91	88.9	0.15	14.39
0.03		15.57	0.03		12.79	0.02	75	9.32	0.01	75	5.49							0.91	89.2	0.15	14.39
0.03		15.57	0.03		12.79	0.02	76	9.32	0.01	76	5.54							0.91	89.3	0.15	14.39
0.03		15.57	0.03		12.79	0.02	77	9.36	0.01	77	5.68	0.00	77	1.73				0.93	91.2	0.15	14.39
0.03		15.57	0.03		12.79	0.02	78	9.36	0.01	78	5.73	0.00	78	1.77				0.93	91.3	0.15	14.39
0.03		15.57	0.03		12.79	0.02	79	9.36	0.01	79	5.84	0.00	79	1.85				0.93	91.5	0.15	14.39
0.03		15.57	0.03		12.79	0.02	80	9.36	0.01	80	5.92	0.00	80	1.92				0.94	91.6	0.15	14.39
0.03		15.57	0.03		12.79	0.02	81	9.36	0.01	81	5.95	0.00	81	1.94				0.94	91.7	0.15	14.39
0.03		15.57	0.03		12.79	0.02	82	9.36	0.01	82	5.95	0.00	82	1.94				0.94	91.7	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	83	6.05	0.00	83	2.02				0.94	91.8	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	84	6.08	0.00	84	2.04				0.94	91.9	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	85	6.11	0.00	85	2.06				0.94	92.0	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	86	6.13	0.00	86	2.18				0.94	92.1	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	87	6.13	0.00	87	2.27				0.94	92.2	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	88	6.16	0.00	88	2.37				0.94	92.3	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	89	6.16	0.00	89	2.56				0.94	92.5	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	90	6.16	0.00	90	2.64				0.95	92.6	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	91	6.16	0.00	91	2.76				0.95	92.7	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	92	6.16	0.01	92	2.88				0.95	92.8	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02	93	6.16	0.01	93	3.04				0.95	93.0	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02		6.16	0.01	94	3.16				0.95	93.1	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02		6.16	0.01	95	3.29				0.95	93.2	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02		6.16	0.01	96	3.32				0.95	93.3	0.15	14.39
0.03		15.57	0.03		12.79	0.02		9.36	0.02		6.16	0.01	97	3.38				0.95	93.3	0.15	14.39

0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	98	3.41				0.95	93.4	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	99	3.47				0.95	93.4	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	100	3.52				0.95	93.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	101	3.54				0.95	93.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	102	3.54				0.96	93.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	103	3.60				0.96	93.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	104	3.61				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01	105	3.63				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63				0.96	93.6	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	111	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	112	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	113	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	114	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	115	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	116	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	117	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	118	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	119	1.13	0.97	94.7	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	120	1.18	0.97	94.8	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	121	1.23	0.97	94.8	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	122	1.27	0.97	94.8	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	123	1.37	0.97	94.9	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	124	1.41	0.97	95.0	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	125	1.47	0.97	95.1	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	126	1.54	0.97	95.1	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.00	127	1.62	0.97	95.2	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	126	1.68	0.97	95.3	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	129	1.75	0.97	95.3	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	130	1.77	0.97	95.3	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	131	1.80	0.97	95.4	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	132	1.81	0.97	95.4	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	133	1.85	0.97	95.4	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	134	1.87	0.97	95.4	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	135	1.88	0.97	95.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	136	1.88	0.97	95.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	137	1.91	0.98	95.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	138	1.92	0.98	95.5	0.15	14.39
0.03	15.57	0.03	12.79	0.02	9.36	0.02	6.16	0.01		3.63	0.01	139	1.93	0.98	95.5	0.15	14.39

RESERVOIR NO. 2 (167 ML/d) - JET MODEL

vol. of tank	32050	m3
qo(initial flow)	115.97	m3/min
do(imaginary pipe diam)	1.10	m
Ao(m^2)	0.95	m^2
uo(initial velocity)	122.10	m/min
JETS		
x1 (core length) = 18*ro =	9.90	m
imaginary plane=	145	m
water level=	4.0	m
angle for jet core =	2	

ux = 9* (do/x)*uo *exp(-74 * (r/x)^2)

Cx =Co* 7* (do/x) * exp(-64* (r/x)^2)

		x (m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
angle (deg)	0.0	x'(m)=	0.0	10.0	15.0	20.0	25.0	30.0	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		ux(m/min)=	122.1	122.1	80.6	60.4	48.3	40.3	34.5	30.2	26.9	24.2	22.0	20.1	18.6	17.3	16.1	15.1
		d x(min)=	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.8	2.1	2.4	2.7
	1.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4
		ux(m/min)=	122.1	122.1	78.8	59.1	47.3	39.4	33.8	29.5	26.3	23.6	21.5	19.7	18.2	16.9	15.8	14.8
		d x(min)=	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6	1.8	2.1	2.4	2.7
	2.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8
		ux(m/min)=	122.1	122.1	73.6	55.2	44.2	36.8	31.6	27.6	24.5	22.1	20.1	18.4	17.0	15.8	14.7	13.8
		d x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	0.9	1.2	1.4	1.7	1.9	2.2	2.6	2.9
	3.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.1	3.4	3.7	3.9	4.2
		ux(m/min)=	122.1	122.1	65.8	49.3	39.5	32.9	28.2	24.7	21.9	19.7	17.9	16.4	15.2	14.1	13.2	12.3
		d x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
		tx(min)=	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	1.0	1.3	1.5	1.8	2.2	2.5	2.9	3.3
	4.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2	5.6
		ux(m/min)=	122.1	122.1	56.1	42.1	33.7	28.1	24.1	21.1	18.7	16.8	15.3	14.0	13.0	12.0	11.2	10.5
		d x(min)=	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5
		tx(min)=	0.0	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.2	1.5	1.8	2.1	2.5	2.9	3.3	3.8
	5.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	0.9	1.3	1.7	2.2	2.6	3.1	3.5	3.9	4.4	4.8	5.2	5.7	6.1	6.6	7.0
		ux(m/min)=	122.1	122.1	45.8	34.3	27.5	22.9	19.6	17.2	15.3	13.7	12.5	11.4	10.6	9.8	9.2	8.6
		d x(min)=	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6
		tx(min)=	0.0	0.1	0.1	0.3	0.4	0.6	0.9	1.1	1.4	1.8	2.2	2.6	3.1	3.5	4.1	4.6
	6.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
		r(m)=	0.0	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3	6.8	7.4	7.9	8.4
		ux(m/min)=	122.1	122.1	35.6	26.7	21.4	17.8	15.3	13.4	11.9	10.7	9.7	8.9	8.2	7.6	7.1	6.7
		d x(min)=	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7
		tx(min)=	0.0	0.1	0.1	0.3	0.5	0.8	1.1	1.4	1.8	2.3	2.8	3.3	3.9	4.5	5.2	5.9
	7.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	66	71	76	81
		r(m)=	0.0	1.2	1.8	2.5	3.1	3.7	4.3	4.9	5.5	6.1	6.7	7.4	8.0	8.6	9.2	9.8
		ux(m/min)=	122.1	122.1	26.4	19.8	15.9	13.2	11.3	9.9	8.8	7.9	7.2	6.6	6.1	5.7	5.3	5.0
		d x(min)=	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1.0
		tx(min)=	0.0	0.1	0.2	0.4	0.7	1.0	1.4	1.9	2.4	3.0	3.7	4.4	5.2	6.1	7.0	8.0
	8.0	x'(m)=	0	10	15	20	25	30	35	40	45	51	56	61	66	71	76	81
		r(m)=	0.0	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2
		ux(m/min)=	122.1	122.1	18.7	14.0	11.2	9.4	8.0	7.0	6.2	5.6	5.1	4.7	4.3	4.0	3.7	3.5
		d x(min)=	0.0	0.1	0.1	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.4
		tx(min)=	0.0	0.1	0.2	0.5	0.9	1.4	1.9	2.6	3.4	4.2	5.2	6.2	7.3	8.5	9.8	11.2
	9.0	x'(m)=	0	10	15	20	25	30	35	41	46	51	56	61	66	71	76	81
		r(m)=	0.0	1.6	2.4	3.2	4.0	4.7	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.1	11.9	12.7
		ux(m/min)=	122.1	122.1	12.6	9.5	7.6	6.3	5.4	4.7	4.2	3.8	3.4	3.2	2.9	2.7	2.5	2.4
		d x(min)=	0.0	0.1	0.1	0.5	0.6	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.7	1.8	1.9	2.1
		tx(min)=	0.0	0.1	0.2	0.6	1.2	1.9	2.8	3.8	4.9	6.2	7.6	9.1	10.8	12.6	14.6	16.6
	10.0	x'(m)=	0	10	15	20	25	30	36	41	46	51	56	61	66	71	76	81
		r(m)=	0.0	1.8	2.6	3.5	4.4	5.3	6.2	7.0	7.9	8.8	9.7	10.6	11.5	12.3	13.2	14.1
		ux(m/min)=	122.1	122.1	8.1	6.1	4.9	4.0	3.5	3.0	2.7	2.4	2.2	2.0	1.9	1.7	1.6	1.5
		d x(min)=	0.0	0.1	0.1	0.7	0.9	1.1	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
		tx(min)=	0.0	0.1	0.2	0.9	1.8	3.0	4.3	5.9	7.6	9.6	11.8	14.2	16.8	19.7	22.7	25.9

85	90	95	100	105	110	115	120	125	130	135	140	145
85	90	95	100	105	110	115	120	125	130	135	140	145
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.2	13.4	12.7	12.1	11.5	11.0	10.5	10.1	9.7	9.3	9.0	8.6	8.3
0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6
3.0	3.4	3.8	4.2	4.6	5.0	5.5	6.0	6.5	7.0	7.6	8.1	8.7
85	90	95	100	105	110	115	120	125	130	135	140	145
1.5	1.6	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.4	2.5
13.9	13.1	12.4	11.8	11.3	10.7	10.3	9.8	9.5	9.1	8.8	8.4	8.2
0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6
3.1	3.5	3.8	4.3	4.7	5.1	5.6	6.1	6.6	7.2	7.7	8.3	8.9
85	90	95	100	105	110	115	120	125	130	135	140	145
3.0	3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4.9	5.1
13.0	12.3	11.6	11.0	10.5	10.0	9.6	9.2	8.8	8.5	8.2	7.9	7.6
0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6
3.3	3.7	4.1	4.6	5.0	5.5	6.0	6.5	7.1	7.7	8.3	8.9	9.5
85	90	95	100	105	110	115	120	125	130	135	140	145
4.5	4.7	5.0	5.2	5.5	5.8	6.0	6.3	6.5	6.8	7.1	7.3	7.6
11.6	11.0	10.4	9.9	9.4	9.0	8.6	8.2	7.9	7.6	7.3	7.0	6.8
0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7
3.7	4.1	4.6	5.1	5.6	6.1	6.7	7.3	7.9	8.6	9.3	10.0	10.7
85	90	95	100	105	110	115	120	125	130	135	140	145
5.9	6.3	6.6	7.0	7.3	7.7	8.0	8.4	8.7	9.1	9.4	9.8	10.1
9.9	9.4	8.9	8.4	8.0	7.7	7.3	7.0	6.7	6.5	6.2	6.0	5.8
0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8
4.3	4.8	5.4	5.9	6.6	7.2	7.9	8.6	9.3	10.0	10.8	11.7	12.5
85	90	95	100	105	110	115	120	126	131	136	141	146
7.4	7.9	8.3	8.7	9.2	9.6	10.1	10.5	10.9	11.4	11.8	12.2	12.7
8.1	7.6	7.2	6.9	6.5	6.2	6.0	5.7	5.5	5.3	5.1	4.9	4.7
0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0
5.2	5.9	6.6	7.3	8.0	8.8	9.6	10.5	11.4	12.3	13.3	14.3	15.3
85	91	96	101	106	111	116	121	126	131	136	141	146
8.9	9.5	10.0	10.5	11.0	11.6	12.1	12.6	13.1	13.7	14.2	14.7	15.2
6.3	5.9	5.6	5.3	5.1	4.9	4.6	4.5	4.3	4.1	4.0	3.8	3.7
0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3
6.7	7.5	8.4	9.3	10.3	11.3	12.4	13.5	14.6	15.8	17.1	18.4	19.7
86	91	96	101	106	111	116	121	126	131	136	141	146
10.4	11.0	11.7	12.3	12.9	13.5	14.1	14.7	15.3	16.0	16.6	17.2	17.8
4.7	4.4	4.2	4.0	3.8	3.6	3.4	3.3	3.2	3.1	2.9	2.8	2.7
1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.7	1.8
9.0	10.1	11.3	12.5	13.8	15.2	16.6	18.1	19.7	21.3	23.0	24.7	26.5
86	91	96	101	106	111	116	121	126	131	136	141	147
11.9	12.6	13.3	14.0	14.7	15.5	16.2	16.9	17.6	18.3	19.0	19.7	20.4
3.3	3.1	3.0	2.8	2.7	2.6	2.4	2.3	2.2	2.2	2.1	2.0	1.9
1.5	1.6	1.7	1.8	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6
12.7	14.3	16.0	17.7	19.6	21.5	23.5	25.6	27.8	30.1	32.5	35.0	37.5
86	91	96	101	106	111	117	122	127	132	137	142	147
13.5	14.2	15.0	15.8	16.6	17.4	18.2	19.0	19.8	20.6	21.4	22.2	23.0
2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.8
18.8	21.2	23.7	26.3	29.0	31.9	34.9	38.0	41.3	44.7	48.3	52.0	55.8
86	91	97	102	107	112	117	122	127	132	137	142	147
15.0	15.9	16.7	17.6	18.5	19.4	20.3	21.1	22.0	22.9	23.8	24.7	25.6
1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8
3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.8	6.0
29.4	33.0	36.9	41.0	45.3	49.8	54.5	59.4	64.5	69.9	75.4	81.2	87.1

Outlet at 145m					
angle (deg)=	0.0	1.0	2.0	3.0	4.0
r(m)=	0.0	2.5	5.1	7.6	10.1
1/2 A(m^2)=	0.1	10.0	30.2	50.4	70.7
us(m/min)=	8.3	8.2	7.6	6.8	5.8
tx(min)=	8.7	8.9	9.5	10.7	12.6

Inlet																	
T inlet	C/Co	Toutlet	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass
17	0.00	26	0.00	26	0.00	0.00	26	-0.01									
18	0.01	27	0.00	27	0.00	0.00	27	0.03	0.00	27	0.02						
19	0.01	28	0.00	28	0.00	0.00	28	0.08	0.00	28	0.13	0.00	28	0.03			
20	0.01	29	0.00	29	0.00	0.00	29	0.03	0.00	29	0.12	0.00	29	0.16			
21	0.01	30	0.00	30	0.00	0.00	30	0.06	0.00	30	0.13	0.00	30	0.17	0.00	30	0.12
22	0.03	31	0.00	31	0.00	0.00	31	0.14	0.00	31	0.29	0.00	31	0.16	0.00	31	0.11
23	0.11	32	0.01	32	0.00	0.01	32	0.48	0.00	32	0.89	0.00	32	0.41	0.00	32	0.28
24	0.19	33	0.01	33	0.00	0.01	33	0.84	0.01	33	1.66	0.00	33	1.28	0.00	33	0.38
25	0.23	34	0.01	34	0.01	0.01	34	1.03	0.01	34	2.80	0.01	34	2.66	0.00	34	1.27
26	0.45	35	0.02	35	0.01	0.02	35	2.03	0.01	35	4.29	0.01	35	3.71	0.00	35	2.23
27	0.61	36	0.03	36	0.01	0.03	36	2.73	0.02	36	6.64	0.01	36	6.16	0.00	36	3.38
28	0.71	37	0.04	37	0.02	0.04	37	3.19	0.03	37	8.24	0.02	37	8.48	0.01	37	6.43
29	0.79	38	0.04	38	0.02	0.04	38	3.54	0.04	38	9.37	0.03	38	11.76	0.01	38	8.44
30	0.79	39	0.04	39	0.02	0.04	39	3.54	0.04	39	9.84	0.03	39	13.35	0.02	39	11.58
31	0.81	40	0.04	40	0.02	0.04	40	3.66	0.04	40	9.99	0.04	40	14.00	0.03	40	13.81
32	0.84	41	0.06	41	0.02	0.06	41	3.78	0.04	41	10.33	0.04	41	14.23	0.03	41	14.78
33	0.87	42	0.06	42	0.02	0.06	42	3.92	0.04	42	10.71	0.04	42	14.72	0.03	42	15.72
34	0.90	43	0.06	43	0.02	0.06	43	4.06	0.04	43	11.09	0.04	43	15.26	0.03	43	16.04
35	0.92	44	0.06	44	0.02	0.06	44	4.14	0.06	44	11.40	0.04	44	15.79	0.03	44	16.58
36	0.93	45	0.06	45	0.02	0.06	45	4.19	0.06	45	11.58	0.04	45	16.23	0.03	45	17.17
37	0.94	46	0.06	46	0.02	0.06	46	4.23	0.06	46	11.71	0.04	46	16.49	0.04	46	17.66
38	0.95	47	0.06	47	0.02	0.06	47	4.28	0.06	47	11.83	0.04	47	16.67	0.04	47	18.03
39	0.96	48	0.06	48	0.02	0.06	48	4.32	0.06	48	11.98	0.04	48	16.86	0.04	48	18.32
40	0.97	49	0.06	49	0.02	0.06	49	4.37	0.06	49	12.09	0.04	49	17.03	0.04	49	18.52
41	0.98	50	0.06	50	0.02	0.06	50	4.41	0.06	50	12.21	0.06	50	17.20	0.04	50	18.72
42	0.98	51	0.05	51	0.02	0.06	51	4.41	0.06	51	12.27	0.05	51	17.38	0.04	51	18.91
43	0.98	52	0.06	52	0.02	0.05	52	4.41	0.06	52	12.27	0.06	52	17.47	0.04	52	19.11
44	0.99	53	0.05	53	0.02	0.05	53	4.46	0.06	53	12.33	0.06	53	17.47	0.04	53	19.20
45	0.99	54	0.06	54	0.02	0.05	54	4.48	0.05	54	12.40	0.05	54	17.56	0.04	54	19.30
46	0.99	55	0.05	55	0.02	0.06	55	4.48	0.06	55	12.40	0.05	55	17.65	0.04	55	19.40
47	0.99	56	0.05	56	0.02	0.06	56	4.48	0.06	56	12.40	0.05	56	17.65	0.04	56	19.40
48	0.99	57	0.05	57	0.02	0.05	57	4.48	0.06	57	12.40	0.06	57	17.65	0.04	57	19.49
49	0.99	58	0.05	58	0.02	0.06	58	4.48	0.06	58	12.40	0.05	58	17.66	0.04	58	19.49
50	0.99	59	0.06	59	0.02	0.06	59	4.48	0.06	59	12.40	0.06	59	17.66	0.04	59	19.49
51	0.99	60	0.05	60	0.02	0.06	60	4.48	0.06	60	12.40	0.06	60	17.66	0.04	60	19.49
52	0.99	61	0.05	61	0.07	0.06	61	4.48	0.06	61	12.40	0.06	61	17.66	0.04	61	19.49
53	1.00	62	0.06	62	0.02	0.06	62	4.50	0.06	62	12.48	0.06	62	17.66	0.04	62	19.49
END		63	0.06		0.02	0.06		4.50	0.06	63	12.52	0.06	63	17.74	0.04	63	19.49
		64	0.06		0.02	0.06		4.50	0.06		12.52	0.06	64	17.82	0.04	64	19.60
		65	0.06		0.02	0.06		4.50	0.05		12.52	0.06		17.82	0.04	65	19.60
		66	0.06		0.02	0.05		4.50	0.05		12.52	0.06		17.82	0.04	66	19.69
		67	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		68	0.06		0.02	0.05		4.50	0.06		12.52	0.05		17.82	0.04		19.69
		69	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		70	0.06		0.02	0.06		4.50	0.06		12.52	0.05		17.82	0.04		19.69
		71	0.06		0.02	0.06		4.50	0.06		12.52	0.05		17.82	0.04		19.69
		72	0.06		0.02	0.06		4.50	0.06		12.52	0.05		17.82	0.04		19.69
		73	0.06		0.02	0.06		4.50	0.05		12.52	0.06		17.82	0.04		19.69
		74	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		75	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		76	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		77	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		78	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		79	0.06		0.02	0.06		4.50	0.05		12.52	0.06		17.82	0.04		19.69
		80	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		81	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		82	0.06		0.02	0.06		4.50	0.05		12.52	0.06		17.82	0.04		19.69
		83	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		84	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		85	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		86	0.06		0.02	0.05		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		87	0.06		0.02	0.06		4.50	0.06		12.52	0.05		17.82	0.04		19.69
		88	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		89	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		90	0.06		0.02	0.05		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		91	0.06		0.02	0.05		4.5	0.06		12.52	0.06		17.82	0.04		19.69
		92	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		93	0.06		0.02	0.05		4.50	0.06		12.52	0.06		17.82	0.04		19.69
		94	0.06		0.02	0.06		4.50	0.06		12.52	0.06		17.82	0.04		19.69

95	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
96	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
97	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
98	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
99	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
100	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
101	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
102	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
103	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
104	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
105	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
106	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
107	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
108	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
109	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
110	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
111	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
112	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
113	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
114	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
115	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
116	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
117	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
118	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
119	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
120	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
121	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
122	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
123	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69
124	0.08	0.02	0.06	4.50	0.06	12.52	0.06	17.82	0.04	19.69

5.0 12.2 74.1 4.9 14.3			6.0 15.2 120.0 3.7 19.7			7.0 17.8 132.9 2.7 28.5			8.0 20.4 154.2 1.9 37.5			9.0 23.0 175.9 1.3 55.8			10.0 25.8 196.0 0.8 87.1			Complete Total Flux		Jet Core (2") Total Flux	
C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Mass	C/Co	Mass
																		0.00	0.0	0.00	0.0
																		0.00	0.0	0.00	0.0
																		0.00	0.2	0.00	0.2
																		0.00	0.3	0.00	0.1
																		0.00	0.5	0.00	0.2
0.00	31	0.03																0.01	0.8	0.00	0.4
0.00	32	0.10																0.02	2.2	0.01	1.4
0.00	33	0.15																0.04	4.6	0.02	2.7
0.00	34	0.16																0.07	7.7	0.03	3.8
0.00	35	0.36																0.11	12.6	0.06	6.3
0.00	36	1.12																0.17	20.0	0.08	9.4
0.00	37	2.31	0.00	37	1.07													0.27	30.8	0.10	11.8
0.01	38	3.22	0.00	38	1.92													0.33	38.3	0.11	12.9
0.01	39	5.36	0.00	39	2.42													0.40	46.1	0.12	13.4
0.02	40	8.24	0.00	40	4.60													0.47	54.3	0.12	13.7
0.02	41	10.19	0.00	41	6.22													0.51	59.5	0.12	14.1
0.03	42	11.57	0.00	42	7.39													0.55	64.1	0.13	14.6
0.03	43	12.13	0.00	43	8.79													0.58	67.4	0.13	15.2
0.03	44	12.33	0.01	44	9.41	0.00	44	1.14										0.61	70.8	0.13	15.6
0.03	45	12.75	0.01	45	10.00	0.00	45	1.44										0.63	73.4	0.14	15.8
0.03	46	13.21	0.01	46	12.09	0.00	46	2.86										0.67	78.3	0.14	16.0
0.03	47	13.67	0.02	47	13.63	0.00	47	3.78										0.71	81.9	0.14	16.1
0.03	48	14.08	0.02	48	14.76	0.00	48	4.45										0.73	84.7	0.14	16.3
0.03	49	14.28	0.02	49	15.59	0.00	49	5.02										0.75	86.9	0.14	16.5
0.03	50	14.44	0.02	50	15.69	0.00	50	5.39										0.76	88.1	0.14	16.6
0.03	51	14.59	0.02	51	15.98	0.00	51	5.92										0.77	89.5	0.14	16.7
0.03	52	14.75	0.02	52	16.32	0.01	52	6.32										0.78	90.7	0.14	16.7
0.03	53	14.90	0.03	53	16.67	0.01	53	7.60										0.80	92.6	0.15	16.8
0.04	54	15.05	0.03	54	17.01	0.01	54	8.54										0.81	94.3	0.15	16.9
0.04	55	15.13	0.03	55	17.27	0.02	55	9.17	0.00	55	2.92							0.85	98.4	0.15	16.9
0.04	56	15.13	0.03	56	17.35	0.02	56	9.61	0.00	56	3.27							0.86	99.3	0.15	16.9
0.04	57	15.21	0.03	57	17.43	0.02	57	9.67	0.00	57	3.30							0.86	99.6	0.15	16.9
0.04	58	15.28	0.03	58	17.61	0.02	58	9.85	0.00	58	3.37							0.86	100.1	0.15	16.9
0.04	59	15.28	0.03	59	17.69	0.02	59	10.06	0.00	59	3.52							0.87	100.6	0.15	16.9
0.04	60	15.28	0.03	60	17.77	0.02	60	10.27	0.00	60	3.70							0.87	101.0	0.15	16.9
0.04	61	15.28	0.03	61	17.85	0.02	61	10.47	0.00	61	4.07							0.88	101.7	0.15	16.9
0.04	62	15.28	0.03	62	17.85	0.02	62	10.57	0.00	62	4.39							0.88	102.2	0.15	17.0
0.04	63	15.28	0.03	63	17.85	0.02	63	10.62	0.00	63	4.57							0.88	102.6	0.15	17.0
0.04	64	15.28	0.03	64	17.93	0.02	64	10.73	0.01	64	5.32							0.89	103.7	0.15	17.0
0.04	65	15.28	0.03	65	17.93	0.02	65	10.78	0.01	65	5.84							0.90	104.3	0.15	17.0
0.04	66	15.36	0.03	66	17.93	0.02	66	10.83	0.01	66	6.21							0.90	104.9	0.15	17.0
0.04	67	15.43	0.03	67	18.03	0.02	67	10.88	0.01	67	6.50							0.91	106.4	0.15	17.0
0.04		15.43	0.03	68	18.03	0.02	68	10.93	0.01	68	6.54							0.91	106.5	0.15	17.0
0.04		15.43	0.03	69	18.03	0.02	69	10.93	0.01	69	6.61							0.91	106.6	0.15	17.0
0.04		15.43	0.03	70	18.03	0.02	70	10.93	0.01	70	6.71							0.91	106.7	0.15	17.0
0.04		15.43	0.03	71	18.03	0.02	71	10.98	0.02	71	6.84							0.91	106.9	0.15	17.0
0.04		15.43	0.03	72	18.03	0.02	72	10.98	0.02	72	6.94							0.91	106.9	0.15	17.0
0.04		15.43	0.03	73	18.11	0.02	73	11.04	0.02	73	7.00	0.00	73	2.29				0.94	108.4	0.15	17.0
0.04		15.43	0.03		18.11	0.02	74	11.04	0.02	74	7.03	0.00	74	2.33				0.94	108.5	0.15	17.0
0.04		15.43	0.03		18.11	0.02	75	11.04	0.02	75	7.06	0.00	75	2.36				0.94	108.6	0.15	17.0
0.04		15.43	0.03		18.11	0.02	76	11.04	0.02	76	7.10	0.00	76	2.38				0.94	108.6	0.15	17.0
0.04		15.43	0.03		18.11	0.02	77	11.04	0.02	77	7.13	0.00	77	2.43				0.94	108.7	0.15	17.0
0.04		15.43	0.03		18.11	0.02	78	11.04	0.02	78	7.16	0.00	78	2.48				0.94	108.8	0.15	17.0
0.04		15.43	0.03		18.11	0.02	79	11.04	0.02	79	7.19	0.00	79	2.65				0.94	109.0	0.15	17.0
0.04		15.43	0.03		18.11	0.02	80	11.09	0.02	80	7.23	0.00	80	2.79				0.94	109.2	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	81	7.23	0.00	81	2.87				0.94	109.3	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	82	7.26	0.01	82	3.30				0.96	109.8	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	83	7.26	0.01	83	3.59				0.95	110.0	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	84	7.26	0.01	84	3.77				0.96	110.2	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	85	7.26	0.01	85	3.92				0.95	110.4	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	86	7.26	0.01	86	3.92				0.96	110.4	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	87	7.26	0.01	87	3.96				0.96	110.4	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	88	7.26	0.01	88	4.02				0.96	110.5	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	89	7.26	0.01	89	4.07				0.95	110.5	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	90	7.26	0.01	90	4.13				0.95	110.6	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02	91	7.30	0.01	91	4.19				0.96	110.7	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02		7.30	0.01	92	4.21				0.96	110.7	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02		7.30	0.01	93	4.22				0.96	110.7	0.15	17.0
0.04		15.43	0.03		18.11	0.02		11.09	0.02		7.30	0.01	94	4.24				0.96	110.7	0.15	17.0

0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	95	4.28				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	96	4.28				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	97	4.30				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	98	4.30				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	99	4.30				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	100	4.32				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	101	4.32				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	102	4.32				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	103	4.32				0.96	110.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	104	4.32	0.00	104	1.35	0.97	112.2	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	105	4.32	0.00	105	1.36	0.97	112.2	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	106	4.32	0.00	106	1.37	0.97	112.2	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	107	4.32	0.00	107	1.38	0.97	112.2	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	108	4.32	0.00	108	1.37	0.97	112.2	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01	109	4.33	0.00	109	1.40	0.97	112.2	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.00	110	1.47	0.97	112.3	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.00	111	1.55	0.97	112.4	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.00	112	1.69	0.97	113.4	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.00	113	1.80	0.97	112.6	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	114	1.96	0.97	112.8	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	115	2.06	0.97	112.9	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	116	2.12	0.97	113.0	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	117	2.12	0.97	113.0	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	118	2.15	0.97	113.0	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	119	2.18	0.97	113.0	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	120	2.21	0.97	113.0	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	121	2.23	0.97	113.1	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	122	2.25	0.98	113.1	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	123	2.26	0.98	113.1	0.15	17.0
0.04	15.43	0.03	18.11	0.02	11.09	0.02	7.30	0.01		4.33	0.01	124	2.27	0.98	113.1	0.15	17.0

RESERVOIR NO. 3 (179 ML/d) - JET MODEL

vol of tank	35178	m3
qo(initial flow)	124.31	m3/min
do(imagnery pipe diam)	0.70	m
Ao(m^2)	0.38	m^2
uo(initial velocity)	323.17	m/min
JETS		
x1 (core length) = 18*ro	6.30	m
imagnery plane=	175	m
water level=	3.6	m
angle for jet core =	2	

ux = 9* (do/x)*uo *exp(-74 * (r/x)^2)
Cx =Co* 7* (do/x) * exp(-64* (r/x)^2)

		x (m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
angle (deg)	0.0	x'(m)=	0.0	10.0	15.0	20.0	25.0	30.0	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		ux(m/min)=	323.2	203.6	135.7	101.8	81.4	67.9	58.2	50.9	45.2	40.7	37.0	33.9	31.3	29.1	27.1	25.4	24.0
		dt x(min)=	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
		tx(min)=	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.4	1.6	1.8
	1.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5
		ux(m/min)=	323.2	199.1	132.7	99.5	79.6	66.4	56.9	49.8	44.2	39.8	36.2	33.2	30.6	28.4	26.5	24.9	23.4
		dt x(min)=	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
		tx(min)=	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.6	1.8
	2.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0
		ux(m/min)=	323.2	186.0	124.0	93.0	74.4	62.0	53.2	46.5	41.3	37.2	33.8	31.0	28.6	26.6	24.8	23.3	21.9
		dt x(min)=	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
		tx(min)=	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.5	1.7	1.9
	3.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.1	3.4	3.7	3.9	4.2	4.5
		ux(m/min)=	323.2	166.2	110.8	83.1	66.5	55.4	47.5	41.5	36.9	33.2	30.2	27.7	25.6	23.7	22.2	20.8	19.6
		dt x(min)=	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		tx(min)=	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.7	1.9	2.2
	4.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2	5.6	5.9
		ux(m/min)=	323.2	141.8	94.6	70.9	56.7	47.3	40.5	35.5	31.5	28.4	25.8	23.6	21.8	20.3	18.9	17.7	16.7
		dt x(min)=	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3
		tx(min)=	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	2.0	2.3	2.6
	5.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	0.9	1.3	1.7	2.2	2.6	3.1	3.5	3.9	4.4	4.8	5.2	5.7	6.1	6.6	7.0	7.4
		ux(m/min)=	323.2	115.6	77.1	57.8	46.2	38.5	33.0	28.9	25.7	23.1	21.0	19.3	17.8	16.5	15.4	14.5	13.6
		dt x(min)=	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
		tx(min)=	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.6	1.8	2.1	2.4	2.8	3.1
	6.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
		r(m)=	0.0	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3	6.8	7.4	7.9	8.4	8.9
		ux(m/min)=	323.2	90.0	60.0	45.0	36.0	30.0	25.7	22.5	20.0	18.0	16.4	15.0	13.8	12.9	12.0	11.2	10.6
		dt x(min)=	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5
		tx(min)=	0.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.7	3.1	3.6	4.0
	7.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	66	71	76	81	86
		r(m)=	0.0	1.2	1.8	2.5	3.1	3.7	4.3	4.9	5.5	6.1	6.7	7.4	8.0	8.6	9.2	9.8	10.4
		ux(m/min)=	323.2	66.8	44.5	33.4	26.7	22.3	19.1	16.7	14.8	13.4	12.1	11.1	10.3	9.5	8.9	8.3	7.9
		dt x(min)=	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6
		tx(min)=	0.0	0.1	0.1	0.3	0.4	0.6	0.9	1.2	1.5	1.8	2.2	2.7	3.1	3.7	4.2	4.8	5.4
	8.0	x'(m)=	0	10	15	20	25	30	35	40	45	51	56	61	66	71	76	81	86
		r(m)=	0.0	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2	11.9
		ux(m/min)=	323.2	47.3	31.5	23.6	18.9	15.8	13.5	11.8	10.5	9.5	8.6	7.9	7.3	6.8	6.3	5.9	5.6
		dt x(min)=	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9
		tx(min)=	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.1	2.6	3.2	3.8	4.4	5.2	5.9	6.8	7.6
	9.0	x'(m)=	0	10	15	20	25	30	35	41	46	51	56	61	66	71	76	81	86
		r(m)=	0.0	1.6	2.4	3.2	4.0	4.7	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.1	11.9	12.7	13.5
		ux(m/min)=	323.2	31.9	21.2	15.9	12.7	10.6	9.1	8.0	7.1	6.4	5.8	5.3	4.9	4.6	4.2	4.0	3.7
		dt x(min)=	0.0	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.2	1.3
		tx(min)=	0.0	0.1	0.2	0.5	0.9	1.3	1.8	2.4	3.1	3.8	4.7	5.6	6.8	7.6	8.8	10.0	11.3
	10.0	x'(m)=	0	10	15	20	25	30	36	41	46	51	56	61	66	71	76	81	86
		r(m)=	0.0	1.8	2.6	3.5	4.4	5.3	6.2	7.0	7.9	8.8	9.7	10.6	11.5	12.3	13.2	14.1	15.0
		ux(m/min)=	323.2	11.9	13.6	10.2	8.2	6.8	5.8	5.1	4.5	4.1	3.7	3.4	3.1	2.9	2.7	2.6	2.4
		dt x(min)=	0.0	0.1	0.4	0.4	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0
		tx(min)=	0.0	0.1	0.5	0.9	1.4	2.1	2.9	3.8	4.9	6.1	7.4	8.8	10.4	12.0	13.8	15.8	17.8

90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.8	21.4	20.4	19.4	18.5	17.7	17.0	16.3	15.7	15.1	14.5	14.0	13.6	13.1	12.7	12.3	12.0	11.6
0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
2.0	2.2	2.5	2.7	3.0	3.3	3.5	3.8	4.2	4.5	4.8	5.2	5.5	5.9	6.3	6.7	7.1	7.5
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
1.6	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
22.1	21.0	19.9	19.0	18.1	17.3	16.6	15.9	15.3	14.7	14.2	13.7	13.3	12.8	12.4	12.1	11.7	11.4
0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
2.0	2.3	2.5	2.8	3.0	3.3	3.6	3.9	4.3	4.6	4.9	5.3	5.7	6.0	6.4	6.8	7.3	7.7
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.8	5.9	6.1
20.7	19.6	18.6	17.7	16.9	16.2	15.5	14.9	14.3	13.8	13.3	12.8	12.4	12.0	11.6	11.3	10.9	10.6
0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
2.2	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.9	5.3	5.7	6.1	6.5	6.9	7.3	7.8	8.2
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
4.7	5.0	5.2	5.5	5.8	6.0	6.3	6.5	6.8	7.1	7.3	7.6	7.9	8.1	8.4	8.6	8.9	9.2
18.5	17.5	16.6	15.8	15.1	14.5	13.8	13.3	12.8	12.3	11.9	11.5	11.1	10.7	10.4	10.1	9.8	9.5
0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5
2.4	2.7	3.0	3.3	3.6	4.0	4.3	4.7	5.1	5.5	5.9	6.3	6.8	7.2	7.7	8.2	8.7	9.2
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
6.3	6.6	7.0	7.3	7.7	8.0	8.4	8.7	9.1	9.4	9.8	10.1	10.5	10.8	11.2	11.5	11.9	12.2
15.8	14.9	14.2	13.5	12.9	12.3	11.8	11.3	10.9	10.5	10.1	9.8	9.5	9.2	8.9	8.6	8.3	8.1
0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
2.9	3.2	3.5	3.9	4.3	4.7	5.1	5.5	6.0	6.4	6.9	7.4	7.9	8.5	9.0	9.6	10.2	10.8
90	95	100	105	110	115	120	126	131	136	141	146	151	156	161	166	171	176
7.9	8.3	8.7	9.2	9.6	10.1	10.5	10.9	11.4	11.8	12.2	12.7	13.1	13.5	14.0	14.4	14.9	15.3
12.8	12.2	11.6	11.0	10.5	10.1	9.6	9.2	8.9	8.6	8.3	8.0	7.7	7.5	7.2	7.0	6.8	6.6
0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
3.5	3.9	4.3	4.8	5.2	5.7	6.2	6.8	7.3	7.9	8.5	9.1	9.8	10.4	11.1	11.8	12.5	13.3
91	96	101	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176
9.5	10.0	10.5	11.0	11.6	12.1	12.6	13.1	13.7	14.2	14.7	15.2	15.8	16.3	16.8	17.3	17.9	18.4
10.0	9.5	9.0	8.6	8.2	7.8	7.5	7.2	6.9	6.7	6.4	6.2	6.0	5.8	5.6	5.5	5.3	5.1
0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0
4.5	5.0	5.6	6.1	6.7	7.4	8.0	8.7	9.4	10.2	10.9	11.7	12.6	13.4	14.3	15.2	16.1	17.1
91	96	101	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176
11.0	11.7	12.3	12.9	13.5	14.1	14.7	15.3	16.0	16.6	17.2	17.8	18.4	19.0	19.6	20.2	20.9	21.5
7.4	7.0	6.7	6.4	6.1	5.8	5.6	5.3	5.1	4.9	4.8	4.6	4.5	4.3	4.2	4.0	3.9	3.8
0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3
6.1	6.3	7.5	8.3	9.1	9.9	10.8	11.7	12.7	13.7	14.7	15.8	16.9	18.1	19.3	20.5	21.8	23.1
91	96	101	106	111	116	121	126	131	136	141	147	152	157	162	167	172	177
12.6	13.3	14.0	14.7	15.5	16.2	16.9	17.6	18.3	19.0	19.7	20.4	21.1	21.8	22.5	23.2	23.9	24.6
5.3	5.0	4.7	4.5	4.3	4.1	3.9	3.8	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9	2.8	2.7
0.9	1.0	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8
8.6	9.6	10.6	11.7	12.8	14.0	15.3	16.6	18.0	19.4	20.9	22.4	24.0	25.6	27.3	29.0	30.8	32.6
91	96	101	106	111	117	122	127	132	137	142	147	152	157	162	167	172	177
14.2	15.0	15.8	16.6	17.4	18.2	19.0	19.8	20.6	21.4	22.2	23.0	23.7	24.5	25.3	26.1	26.9	27.7
3.5	3.4	3.2	3.0	2.9	2.8	2.7	2.5	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.9	1.8
1.4	1.5	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.7
12.7	14.2	15.7	17.4	19.1	20.9	22.7	24.7	26.7	28.8	31.0	33.3	35.6	38.0	40.5	43.1	45.8	48.5
91	97	102	107	112	117	122	127	132	137	142	147	152	158	163	168	173	178
15.9	16.7	17.6	18.5	19.4	20.3	21.1	22.0	22.9	23.8	24.7	25.6	26.4	27.3	28.2	29.1	30.0	30.8
2.3	2.2	2.0	1.9	1.9	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
2.2	2.3	2.4	2.5	2.7	2.8	2.9	3.0	3.2	3.3	3.4	3.5	3.7	3.8	3.9	4.0	4.2	4.3
20.0	22.3	24.7	27.2	29.9	32.7	35.6	38.7	41.8	45.1	48.5	52.1	55.8	59.5	63.5	67.5	71.7	75.9

Inlet			Outlet at 175m																
			angle (deg)=	0.0			1.0			2.0			3.0			4.0			
			r(m)=	0.0			3.1			6.1			9.2			12.2			
			1/2 A(m^2)=	0.1			14.6			43.9			73.4			102.9			
			ux(m/min)=	11.6			11.4			10.6			9.5			8.1			
			tx(min)=	7.5			7.7			8.2			9.2			10.8			
T inlet	C/Co	Toutlet		C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co
17	0.00	25		0.00	25	0.00	0.00	25	0.00	0.00	25	0.00							
18	0.00	26		0.00	26	0.00	0.00	26	0.00	0.00	26	0.00	0.00	26	0.00				
19	0.00	27		0.00	27	0.00	0.00	27	0.00	0.00	27	0.00	0.00	27	0.00				
20	0.00	28		0.00	28	0.00	0.00	28	0.00	0.00	28	0.00	0.00	28	0.00	0.00	28	0.00	
21	0.00	29		0.00	29	0.00	0.00	29	0.00	0.00	29	0.00	0.00	29	0.00	0.00	29	0.00	
22	0.05	30		0.00	30	0.00	0.00	30	0.26	0.00	30	0.69	0.00	30	0.51	0.00	30	0.00	0.00
23	0.15	31		0.00	31	0.00	0.00	31	0.74	0.00	31	2.06	0.00	31	1.90	0.00	31	0.67	0.00
24	0.28	32		0.01	32	0.00	0.01	32	1.29	0.01	32	3.67	0.00	32	4.04	0.00	32	1.71	0.00
25	0.38	33		0.01	33	0.00	0.01	33	1.78	0.01	33	4.94	0.01	33	6.06	0.00	33	3.46	0.00
26	0.50	34		0.01	34	0.00	0.01	34	2.47	0.01	34	6.66	0.01	34	8.43	0.00	34	5.60	0.00
27	0.62	35		0.02	35	0.01	0.02	35	3.07	0.02	35	8.50	0.01	35	10.96	0.01	35	8.29	0.00
28	0.72	36		0.02	36	0.01	0.02	36	3.58	0.02	36	9.67	0.02	36	13.06	0.01	36	10.66	0.00
29	0.80	37		0.02	37	0.01	0.02	37	3.88	0.02	37	10.97	0.02	37	14.62	0.01	37	13.20	0.00
30	0.86	38		0.03	38	0.01	0.03	38	4.26	0.02	38	11.79	0.02	38	16.16	0.01	38	15.31	0.01
31	0.88	39		0.03	39	0.01	0.03	39	4.35	0.02	39	12.07	0.02	39	16.94	0.02	39	16.99	0.01
32	0.90	40		0.03	40	0.01	0.03	40	4.45	0.02	40	12.34	0.02	40	17.33	0.02	40	18.02	0.01
33	0.92	41		0.03	41	0.01	0.03	41	4.55	0.03	41	12.62	0.02	41	17.71	0.02	41	18.65	0.01
34	0.94	42		0.03	42	0.01	0.03	42	4.65	0.03	42	12.89	0.02	42	18.10	0.02	42	19.27	0.01
35	0.95	43		0.03	43	0.01	0.03	43	4.70	0.03	43	13.03	0.02	43	18.39	0.02	43	19.70	0.02
36	0.95	44		0.03	44	0.01	0.03	44	4.70	0.03	44	13.03	0.02	44	18.48	0.02	44	20.02	0.02
37	0.96	45		0.03	45	0.01	0.03	45	4.75	0.03	45	13.17	0.02	45	18.59	0.02	45	20.22	0.02
38	0.96	46		0.03	46	0.01	0.03	46	4.75	0.03	46	13.17	0.02	46	18.68	0.02	46	20.43	0.02
39	0.96	47		0.03	47	0.01	0.03	47	4.75	0.03	47	13.17	0.02	47	18.68	0.02	47	20.43	0.02
40	0.96	48		0.03	48	0.01	0.03	48	4.75	0.03	48	13.17	0.02	48	18.68	0.02	48	20.53	0.02
41	0.96	49		0.03	49	0.01	0.03	49	4.75	0.03	49	13.17	0.02	49	18.68	0.02	49	20.53	0.02
42	0.97	50		0.03	50	0.01	0.03	50	4.80	0.03	50	13.30	0.02	50	18.78	0.02	50	20.53	0.02
43	0.97	51		0.03	51	0.01	0.03	51	4.80	0.03	51	13.30	0.02	51	18.87	0.02	51	20.64	0.02
44	0.98	52		0.03	52	0.01	0.03	52	4.85	0.03	52	13.44	0.02	52	18.98	0.02	52	20.64	0.02
45	0.98	53		0.03	53	0.01	0.03	53	4.85	0.03	53	13.44	0.02	53	19.07	0.02	53	20.86	0.02
46	0.99	54		0.03	54	0.01	0.03	54	4.90	0.03	54	13.58	0.02	54	19.17	0.02	54	20.86	0.02
47	0.99	55		0.03	55	0.01	0.03	55	4.90	0.03	55	13.58	0.02	55	19.28	0.02	55	21.07	0.02
48	0.99	56		0.03	56	0.01	0.03	56	4.90	0.03	56	13.58	0.02	56	19.28	0.02	56	21.07	0.02
49	1.00	57		0.03	57	0.01	0.03	57	4.95	0.03	57	13.71	0.02	57	19.38	0.02	57	21.17	0.02
50	1.00	58		0.03	58	0.01	0.03	58	4.95	0.03	58	13.71	0.03	58	19.46	0.02	58	21.28	0.02
51	1.00	59		0.03	59	0.01	0.03	59	4.95	0.03	59	13.71	0.03	59	19.46	0.02	59	21.28	0.02
52	1.00	60		0.03	60	0.01	0.03	60	4.95	0.03	60	13.71	0.03	60	19.46	0.02	60	21.38	0.02
53	1.00	61		0.03	61	0.01	0.03	61	4.95	0.03	61	13.71	0.03	61	19.46	0.02	61	21.38	0.02
END		62		0.03		0.01	0.03		4.95	0.03		13.73	0.03	62	19.46	0.02	62	21.38	0.02
		63		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02	63	21.38	0.02
		64		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02	64	21.38	0.02
		65		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		66		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		67		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		68		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		69		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		70		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		71		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		72		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		73		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		74		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		75		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		76		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		77		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		78		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		79		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		80		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		81		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		82		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		83		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		84		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		85		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		86		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		87		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		88		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		89		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		90		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		91		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		92		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		93		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		94		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		95		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		96		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		97		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02
		98		0.03		0.01	0.03		4.95	0.03		13.73	0.03		19.46	0.02		21.38	0.02

99	0.03	0.01	0.03	4.86	0.03	13.73	0.03	19.46	0.02	21.38	0.02
100	0.03	0.01	0.03	4.86	0.03	13.73	0.03	19.46	0.02	21.38	0.02
101	0.03	0.01	0.03	4.86	0.03	13.73	0.03	19.46	0.02	21.38	0.02
102	0.03	0.01	0.03	4.86	0.03	13.73	0.03	19.46	0.02	21.38	0.02
103	0.03	0.01	0.03	4.86	0.03	13.73	0.03	19.46	0.02	21.38	0.02

5.0 15.3 132.8 6.6 13.3			6.0 18.4 163.0 5.1 17.1			7.0 21.5 193.5 3.8 23.1			8.0 24.6 224.6 2.7 32.6			9.0 27.7 258.2 1.8 48.5			10.0 30.8 288.5 1.2 79.9		Complete Total Flux		Jet Core (2") Total Flux	
Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Mass	C/Co	Mass
																	0.00	0.0	0.00	0.0
																	0.00	0.0	0.00	0.0
																	0.00	0.0	0.00	0.0
																	0.00	0.0	0.00	0.0
																	0.00	0.0	0.00	0.0
30	0.00																0.01	1.4	0.01	0.9
31	0.00																0.04	5.4	0.02	2.8
32	0.00																0.09	10.6	0.04	4.9
33	0.54																0.14	18.8	0.06	6.7
34	1.82	0.00	34	0.00													0.20	26.0	0.08	9.3
35	3.28	0.00	35	0.45													0.28	34.5	0.09	11.6
36	5.25	0.00	36	1.34													0.35	43.8	0.11	13.4
37	7.78	0.00	37	2.32													0.43	53.0	0.12	14.9
38	9.98	0.00	38	3.22													0.49	60.7	0.13	16.1
39	12.32	0.00	39	4.83													0.54	67.5	0.13	16.4
40	14.27	0.00	40	6.83	0.00	40	0.99										0.60	74.0	0.14	16.8
41	15.83	0.00	41	8.32	0.00	41	1.71										0.64	78.8	0.14	17.2
42	16.78	0.01	42	9.78	0.00	42	2.37										0.67	83.8	0.14	17.5
43	17.54	0.01	43	11.32	0.00	43	3.29										0.71	88.0	0.14	17.7
44	17.94	0.01	44	12.37	0.00	44	4.08										0.73	90.6	0.14	17.7
45	18.34	0.01	45	13.27	0.00	45	5.00										0.75	93.3	0.14	17.9
46	18.63	0.01	46	14.03	0.00	46	6.04										0.77	95.7	0.14	17.9
47	18.81	0.01	47	14.65	0.00	47	7.00										0.78	97.5	0.14	17.9
48	19.01	0.01	48	14.88	0.00	48	7.65										0.79	98.7	0.14	17.9
49	19.01	0.01	49	15.03	0.01	49	8.50										0.80	99.7	0.14	17.9
50	19.10	0.01	50	15.26	0.01	50	9.25	0.00	50	2.70							0.83	103.7	0.15	18.1
51	19.10	0.01	51	15.41	0.01	51	9.90	0.00	51	3.13							0.85	106.2	0.15	18.1
52	19.10	0.01	52	15.48	0.01	52	10.38	0.00	52	3.46							0.86	106.4	0.15	18.3
53	19.21	0.01	53	15.48	0.01	53	10.69	0.00	53	3.74							0.86	107.3	0.15	18.3
54	19.21	0.01	54	15.55	0.01	54	10.88	0.00	54	3.83							0.87	108.0	0.15	18.5
55	19.41	0.01	55	15.64	0.01	55	10.96	0.00	55	4.08							0.88	108.9	0.15	18.5
56	19.41	0.01	56	15.64	0.01	56	11.06	0.00	56	4.50							0.88	109.4	0.15	18.5
57	19.60	0.01	57	15.73	0.01	57	11.17	0.00	57	4.94							0.89	110.7	0.15	18.7
58	19.60	0.01	58	15.73	0.01	58	11.22	0.00	58	5.32							0.90	111.3	0.15	18.7
59	19.70	0.01	59	15.90	0.01	59	11.28	0.00	59	5.78							0.90	112.1	0.15	18.7
60	19.80	0.01	60	15.90	0.01	60	11.34	0.01	60	6.21							0.91	112.8	0.15	18.7
61	19.80	0.01	61	15.97	0.01	61	11.40	0.01	61	6.54							0.91	113.2	0.15	18.7
62	19.89	0.01	62	16.06	0.01	62	11.40	0.01	62	6.80							0.91	113.7	0.15	18.7
63	19.89	0.02	63	16.13	0.01	63	11.47	0.01	63	7.00							0.92	114.0	0.15	18.7
64	19.89	0.02	64	16.13	0.01	64	11.47	0.01	64	7.06							0.92	114.1	0.15	18.7
65	19.89	0.02	65	16.13	0.01	65	11.52	0.01	65	7.17							0.92	114.2	0.15	18.7
66	19.89	0.02	66	16.20	0.01	66	11.59	0.01	66	7.24	0.00	66	2.39				0.94	116.6	0.15	18.7
	19.89	0.02	67	16.20	0.01	67	11.64	0.01	67	7.35	0.00	67	2.44				0.94	117.0	0.15	18.7
	19.89	0.02	68	16.20	0.01	68	11.64	0.01	68	7.38	0.00	68	2.46				0.94	117.1	0.15	18.7
	19.89	0.02	69	16.20	0.01	69	11.69	0.01	69	7.42	0.00	69	2.48				0.94	117.2	0.15	18.7
	19.89	0.02	70	16.20	0.01	70	11.69	0.01	70	7.46	0.00	70	2.49				0.94	117.3	0.15	18.7
	19.89	0.02		16.20	0.01	71	11.69	0.01	71	7.46	0.00	71	2.58				0.94	117.4	0.15	18.7
	19.89	0.02		16.20	0.01	72	11.74	0.01	72	7.50	0.00	72	2.77				0.95	117.6	0.15	18.7
	19.89	0.02		16.20	0.01	73	11.74	0.01	73	7.50	0.00	73	2.98				0.95	117.8	0.15	18.7
	19.89	0.02		16.20	0.01	74	11.74	0.01	74	7.50	0.00	74	3.17				0.95	118.0	0.15	18.7
	19.89	0.02		16.20	0.01	75	11.74	0.01	75	7.53	0.00	75	3.46				0.95	118.4	0.15	18.7
	19.89	0.02		16.20	0.01	76	11.74	0.01	76	7.53	0.00	76	3.68				0.95	118.6	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	77	7.57	0.00	77	3.89				0.96	118.8	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	78	7.57	0.01	78	4.04				0.96	119.0	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	79	7.60	0.01	79	4.18				0.96	119.1	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	80	7.60	0.01	80	4.22				0.96	119.2	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	81	7.60	0.01	81	4.26				0.96	119.2	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	82	7.63	0.01	82	4.32				0.96	119.3	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	83	7.63	0.01	83	4.36				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	84	7.63	0.01	84	4.38				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.31	85	7.63	0.01	85	4.38				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01	86	7.63	0.01	86	4.40				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	87	4.40				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	88	4.40				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	89	4.40				0.96	119.4	0.15	18.7
	19.86	0.02		16.20	0.01		11.74	0.01		7.63	0.01	90	4.40				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	91	4.42				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	92	4.42				0.96	119.4	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	93	4.43	0.00	93	1.37	0.97	120.6	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	94	4.43	0.00	94	1.37	0.97	120.8	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	95	4.45	0.00	95	1.38	0.97	120.8	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	96	4.45	0.00	96	1.38	0.97	120.8	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	97	4.45	0.00	97	1.38	0.97	120.8	0.15	18.7
	19.89	0.02		16.20	0.01		11.74	0.01		7.63	0.01	98	4.47	0.00	98	1.45	0.97	120.9	0.15	18.7

19.80	0.02	16.30	0.01	11.74	0.01	7.63	0.01	99	4.47	0.00	99	1.54	0.97	121.0	0.15	18.7
19.80	0.02	16.20	0.01	11.74	0.01	7.63	0.01	100	4.47	0.00	100	1.65	0.97	121.1	0.15	18.7
19.80	0.02	16.20	0.01	11.74	0.01	7.63	0.01	101	4.47	0.00	101	1.75	0.98	121.2	0.15	18.7
19.80	0.02	16.20	0.01	11.74	0.01	7.63	0.01	102	4.47	0.00	102	1.88	0.98	121.4	0.15	18.7
19.80	0.02	16.20	0.01	11.74	0.01	7.63	0.01		4.47	0.00	103	2.00	0.98	121.5	0.15	18.7

RESERVOIR NO. 3 (198 ML/d) - JET MODEL

vol. of tank 43782 m3
qo(initial flow) 137.50 m3/min
do(imaginary pipe diam) 1.20 m
Ao(m^2) 1.13 m^2
uo(initial velocity) 121.64 m/min
JETS
x1 (core length) = 18*ro 10.80 m
imaginary plane= 175 m
water level= 4.2 m
angle for jet core = 2 -
ux = 9* (do/x)*uo *exp(-74 * (r/x)^2)
Cx =Co*7* (do/x) * exp(-64* (r/x)^2)

	x (m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
angle (deg) 0.0	x'(m)=	0.0	10.0	15.0	20.0	25.0	30.0	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ux(m/min)=	121.6	121.6	87.6	65.7	52.5	43.8	37.5	32.8	29.2	26.3	23.9	21.9	20.2	18.8	17.5	16.4	15.5
	dt x(min)=	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
	tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.9	2.2	2.5	2.8
1.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5
	ux(m/min)=	121.6	121.6	85.6	64.2	51.4	42.8	36.7	32.1	28.5	25.7	23.4	21.4	19.8	18.3	17.1	16.1	15.1
	dt x(min)=	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
	tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.7	1.9	2.2	2.5	2.8
2.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0
	ux(m/min)=	121.6	121.6	80.0	60.0	48.0	40.0	34.3	30.0	26.7	24.0	21.8	20.0	18.5	17.1	16.0	15.0	14.1
	dt x(min)=	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
	tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.8	2.1	2.4	2.7	3.0
3.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.1	3.4	3.7	3.9	4.2	4.5
	ux(m/min)=	121.6	121.6	71.5	53.6	42.9	35.7	30.6	26.8	23.8	21.4	19.5	17.9	16.5	15.3	14.3	13.4	12.6
	dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
	tx(min)=	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.4	1.7	2.0	2.3	2.6	3.0	3.4
4.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2	5.6	5.9
	ux(m/min)=	121.6	121.6	61.0	45.8	36.6	30.5	26.1	22.9	20.3	18.3	16.6	15.3	14.1	13.1	12.2	11.4	10.8
	dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5
	tx(min)=	0.0	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.3	2.7	3.1	3.5	4.0
5.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	0.9	1.3	1.7	2.2	2.6	3.1	3.5	3.9	4.4	4.8	5.2	5.7	6.1	6.6	7.0	7.4
	ux(m/min)=	121.6	121.6	49.7	37.3	29.8	24.9	21.3	18.7	16.6	14.9	13.6	12.4	11.5	10.7	9.9	9.3	8.8
	dt x(min)=	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6
	tx(min)=	0.0	0.1	0.1	0.3	0.4	0.6	0.8	1.1	1.3	1.7	2.0	2.4	2.8	3.3	3.8	4.3	4.8
6.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	r(m)=	0.0	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3	6.8	7.4	7.9	8.4	8.9
	ux(m/min)=	121.6	121.6	38.7	29.0	23.2	19.4	16.6	14.5	12.9	11.6	10.6	9.7	8.9	8.3	7.7	7.3	6.8
	dt x(min)=	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7
	tx(min)=	0.0	0.1	0.1	0.3	0.5	0.7	1.0	1.3	1.7	2.1	2.6	3.1	3.6	4.2	4.8	5.5	6.2
7.0	x'(m)=	0	10	15	20	25	30	35	40	45	50	55	60	66	71	76	81	86
	r(m)=	0.0	1.2	1.8	2.5	3.1	3.7	4.3	4.9	5.5	6.1	6.7	7.4	8.0	8.6	9.2	9.8	10.4
	ux(m/min)=	121.6	121.6	28.7	21.6	17.2	14.4	12.3	10.8	9.6	8.6	7.8	7.2	6.6	6.2	5.7	5.4	5.1
	dt x(min)=	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0
	tx(min)=	0.0	0.1	0.1	0.4	0.6	0.9	1.3	1.7	2.2	2.8	3.4	4.1	4.8	5.6	6.4	7.3	8.3
8.0	x'(m)=	0	10	15	20	25	30	35	40	45	51	56	61	66	71	76	81	86
	r(m)=	0.0	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2	11.9
	ux(m/min)=	121.6	121.6	20.3	15.3	12.2	10.2	8.7	7.6	6.8	6.1	5.5	5.1	4.7	4.4	4.1	3.8	3.6
	dt x(min)=	0.0	0.1	0.1	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	1.4
	tx(min)=	0.0	0.1	0.2	0.4	0.8	1.3	1.8	2.4	3.1	3.9	4.8	5.7	6.7	7.9	9.1	10.3	11.7
9.0	x'(m)=	0	10	15	20	25	30	35	41	46	51	56	61	66	71	76	81	86
	r(m)=	0.0	1.6	2.4	3.2	4.0	4.7	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.1	11.9	12.7	13.5
	ux(m/min)=	121.6	121.6	13.7	10.3	8.2	6.9	5.9	5.1	4.6	4.1	3.7	3.4	3.2	2.9	2.7	2.6	2.4
	dt x(min)=	0.0	0.1	0.1	0.4	0.5	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.7	1.8	1.9	2.0
	tx(min)=	0.0	0.1	0.2	0.6	1.1	1.8	2.6	3.5	4.6	5.7	7.[illegible]	8.4	10.0	11.6	13.4	15.3	17.3
10.0	x'(m)=	0	10	15	20	25	30	36	41	46	51	56	61	66	71	76	81	86
	r(m)=	0.0	1.8	2.6	3.5	4.4	5.3	6.2	7.0	7.9	8.8	9.7	10.6	11.5	12.3	13.2	14.1	15.0
	ux(m/min)=	121.6	121.6	8.8	6.6	5.3	4.4	3.8	3.3	2.9	2.6	2.4	2.2	2.0	1.9	1.8	1.6	1.6
	dt x(min)=	0.0	0.1	0.1	0.7	0.9	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2
	tx(min)=	0.0	0.1	0.2	0.8	1.7	2.7	4.0	5.4	7.0	8.9	10.9	13.1	15.5	18.1	20.9	23.9	27.0

90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.6	13.8	13.1	12.5	11.9	11.4	10.9	10.5	10.1	9.7	9.4	9.1	8.8	8.5	8.2	8.0	7.7	7.5
0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7
3.1	3.5	3.8	4.2	4.6	5.1	5.5	6.0	6.5	7.0	7.5	8.0	8.6	9.2	9.8	10.4	11.0	11.7
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
1.6	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
14.3	13.5	12.8	12.2	11.7	11.2	10.7	10.3	9.9	9.5	9.2	8.9	8.6	8.3	8.0	7.8	7.6	7.3
0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7
3.2	3.5	3.9	4.3	4.7	5.2	5.6	6.1	6.6	7.1	7.7	8.2	8.8	9.4	10.0	10.6	11.3	12.0
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.8	5.9	6.1
13.3	12.6	12.0	11.4	10.9	10.4	10.0	9.6	9.2	8.9	8.6	8.3	8.0	7.7	7.5	7.3	7.1	6.9
0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
3.4	3.8	4.2	4.6	5.1	5.5	6.0	6.5	7.1	7.6	8.2	8.8	9.4	10.0	10.7	11.4	12.1	12.8
90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
4.7	5.0	5.2	5.5	5.8	6.0	6.3	6.5	6.8	7.1	7.3	7.6	7.9	8.1	8.4	8.6	8.9	9.2
11.9	11.3	10.7	10.2	9.7	9.3	8.9	8.6	8.2	7.9	7.7	7.4	7.1	6.9	6.7	6.5	6.3	6.1
0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8
3.8	4.2	4.7	5.2	5.7	6.2	6.7	7.3	7.9	8.5	9.2	9.8	10.5	11.2	12.0	12.7	13.5	14.3
[illegible]	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
6.3	6.6	7.0	7.3	7.7	8.0	8.4	8.7	9.1	9.4	9.8	10.1	10.5	10.8	11.2	11.5	11.9	12.2
10.2	9.6	9.2	8.7	8.3	8.0	7.6	7.3	7.0	6.8	6.5	6.3	6.1	5.9	5.7	5.5	5.4	5.2
0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9
4.4	4.9	5.5	6.0	6.6	7.2	7.9	8.6	9.3	10.0	10.7	11.5	12.3	13.2	14.0	14.9	15.8	16.8
90	95	100	105	110	115	120	126	131	136	141	146	151	156	161	166	171	176
7.9	8.3	8.7	9.2	9.6	10.1	10.5	10.9	11.4	11.8	12.2	12.7	13.1	13.6	14.0	14.4	14.9	15.3
8.3	7.9	7.5	7.1	6.8	6.5	6.2	6.0	5.7	5.5	5.3	5.1	5.0	4.8	4.7	4.5	4.4	4.3
0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.2
5.4	6.0	6.7	7.4	8.1	8.9	9.7	10.5	11.3	12.2	13.2	14.1	15.1	16.1	17.2	18.3	19.4	20.6
91	96	101	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176
9.5	10.0	10.5	11.0	11.6	12.1	12.6	13.1	13.7	14.2	14.7	15.2	15.8	16.3	16.8	17.3	17.9	18.4
6.5	6.1	5.8	5.5	5.3	5.0	4.8	4.6	4.5	4.3	4.1	4.0	3.9	3.7	3.6	3.5	3.4	3.3
0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.5
6.9	7.7	8.6	9.5	10.4	11.4	12.4	13.5	14.6	15.7	16.9	18.1	19.4	20.7	22.1	23.5	25.0	26.5
91	96	101	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176
11.0	11.7	12.3	12.9	13.5	14.1	14.7	15.3	16.0	16.6	17.2	17.8	18.4	19.0	19.6	20.2	20.9	21.5
4.8	4.5	4.3	4.1	3.9	3.7	3.6	3.4	3.3	3.2	3.1	3.0	2.9	2.8	2.7	2.6	2.5	2.5
1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0
9.3	10.4	11.6	12.8	14.0	15.3	16.7	18.1	19.6	21.2	22.8	24.4	26.2	27.9	29.8	31.7	33.6	35.7
91	96	101	106	111	116	121	126	131	136	141	147	152	157	162	167	172	177
12.6	13.3	14.0	14.7	15.5	16.2	16.9	17.6	18.3	19.0	19.7	20.4	21.1	21.8	22.5	23.2	23.9	24.6
3.4	3.2	3.1	2.9	2.8	2.7	2.5	2.4	2.3	2.3	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7
1.4	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.9
13.2	14.7	16.3	18.0	19.8	21.6	23.6	25.6	27.7	29.9	32.2	34.6	37.0	39.5	42.1	44.8	47.6	50.5
91	96	101	106	111	117	122	127	132	137	142	147	152	157	162	167	172	177
14.2	15.0	15.8	16.6	17.4	18.2	19.0	19.8	20.6	21.4	22.2	23.0	23.7	24.5	25.3	26.1	26.9	27.7
2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.6	3.8	3.9	4.0	4.1	4.2
19.5	21.8	24.2	26.7	29.4	32.1	35.0	38.0	41.2	44.4	47.8	51.3	55.0	58.7	62.6	66.6	70.7	75.0
91	97	102	107	112	117	122	127	132	137	142	147	152	158	163	168	173	178
15.9	16.7	17.6	18.5	19.4	20.3	21.1	22.0	22.9	23.8	24.7	25.6	26.4	27.3	28.2	29.1	30.0	30.8
1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
3.4	3.6	3.8	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.3	6.5	6.6
30.4	34.0	37.7	41.7	45.8	50.1	54.7	59.4	64.3	69.4	74.7	80.2	85.9	91.7	97.8	104.1	110.5	117.2

Inlet

Outlet at 175m

			angle (deg)=	0.0			1.0			2.0			3.0			4.0			
			r(m)=	0.0			3.1			6.1			9.2			12.2			
			1/2 A(m^2)=	0.1			14.6			43.9			73.4			102.9			
			us(m/min)=	7.5			7.3			6.9			6.1			5.2			
			tc(min)=	11.7			12.0			12.8			14.3			16.8			
T inlet	C/Co	Toutlet		C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co	Tout	Mass	C/Co
17	0.03	29		0.00	29	0.00	0.00	29	0.16										
18	0.03	30		0.00	30	0.00	0.00	30	0.17	0.00	30	0.46							
19	0.02	31		0.00	31	0.00	0.00	31	0.11	0.00	31	0.38	0.00	31	0.65				
20	0.02	32		0.00	32	0.00	0.00	32	0.11	0.00	32	0.30	0.00	32	0.63				
21	0.02	33		0.00	33	0.00	0.00	33	0.11	0.00	33	0.30	0.00	33	0.43				
22	0.02	34		0.00	34	0.00	0.00	34	0.11	0.00	34	0.30	0.00	34	0.43	0.00	34	0.58	
23	0.10	35		0.01	35	0.00	0.00	35	0.58	0.00	35	0.93	0.00	35	0.43	0.00	35	0.58	
24	0.25	36		0.01	36	0.00	0.01	36	1.39	0.00	36	2.89	0.00	36	1.33	0.00	36	0.47	
25	0.38	37		0.02	37	0.00	0.02	37	2.00	0.01	37	4.86	0.00	37	3.84	0.00	37	1.48	
26	0.50	38		0.03	38	0.00	0.02	38	2.78	0.02	38	6.86	0.01	38	6.62	0.00	38	3.37	0.00
27	0.67	39		0.04	39	0.01	0.03	39	3.72	0.02	39	8.91	0.02	39	9.32	0.00	39	4.78	0.00
28	0.76	40		0.04	40	0.01	0.04	40	4.22	0.03	40	10.87	0.02	40	12.88	0.00	40	7.40	0.00
29	0.78	41		0.04	41	0.01	0.04	41	4.33	0.04	41	11.88	0.03	41	15.43	0.01	41	11.20	0.00
30	0.85	42		0.04	42	0.01	0.04	42	4.72	0.04	42	12.38	0.03	42	16.58	0.01	42	13.55	0.00
31	0.88	43		0.05	43	0.01	0.04	43	4.89	0.04	43	13.13	0.03	43	17.68	0.02	43	16.35	0.00
32	0.90	44		0.05	44	0.01	0.04	44	5.00	0.04	44	13.50	0.04	44	18.63	0.03	44	18.12	0.00
33	0.86	45		0.05	45	0.01	0.04	45	4.78	0.04	45	13.34	0.04	45	19.16	0.03	45	19.49	0.01
34	0.94	46		0.05	46	0.01	0.05	46	5.22	0.04	46	13.87	0.04	46	18.92	0.03	46	19.98	0.01
35	0.97	47		0.05	47	0.01	0.05	47	5.39	0.04	47	14.49	0.04	47	19.41	0.03	47	20.23	0.02
36	0.96	48		0.05	48	0.01	0.05	48	5.33	0.05	48	14.84	0.04	48	20.57	0.03	48	21.57	0.02
37	0.96	49		0.05	49	0.01	0.05	49	5.33	0.05	49	14.98	0.04	49	20.78	0.03	49	22.17	0.02
38	0.98	50		0.05	50	0.01	0.05	50	5.33	0.05	50	14.56	0.04	50	20.88	0.03	50	21.80	0.02
39	0.95	51		0.05	51	0.01	0.05	51	5.28	0.05	51	14.48	0.04	51	20.88	0.04	51	22.49	0.03
40	0.95	52		0.05	52	0.01	0.05	52	5.28	0.04	52	14.41	0.04	52	20.65	0.04	52	22.82	0.03
41	0.96	53		0.05	53	0.01	0.05	53	5.33	0.04	53	14.49	0.04	53	20.45	0.04	53	22.58	0.03
42	0.97	54		0.05	54	0.01	0.05	54	5.39	0.05	54	14.84	0.04	54	20.58	0.04	54	22.58	0.03
43	0.98	55		0.05	55	0.01	0.05	55	5.45	0.05	55	14.79	0.04	55	20.77	0.04	55	22.71	0.03
44	1.00	56		0.05	56	0.01	0.05	56	5.56	0.05	56	15.02	0.04	56	20.99	0.04	56	22.72	0.03
45	1.00	57		0.05	57	0.01	0.05	57	5.56	0.05	57	15.17	0.04	57	21.32	0.04	57	22.85	0.03
46	1.00	58		0.05	58	0.01	0.05	58	5.56	0.05	58	15.17	0.04	58	21.52	0.04	58	23.21	0.03
47	1.00	59		0.05	59	0.01	0.05	59	5.56	0.05	59	15.17	0.04	59	21.52	0.04	59	23.32	0.03
48	1.00	60		0.05	60	0.01	0.05	60	5.56	0.05	60	15.17	0.04	60	21.52	0.04	60	23.43	0.03
49	1.00	61		0.05	61	0.01	0.05	61	5.56	0.05	61	15.17	0.04	61	21.52	0.04	61	23.65	0.03
50	1.00	62		0.05	62	0.01	0.05	62	5.56	0.05	62	15.17	0.04	62	21.52	0.04	62	23.65	0.03
51	1.00	63		0.05	63	0.01	0.05	63	5.56	0.05	63	15.17	0.04	63	21.52	0.04	63	23.65	0.03
52	1.00	64		0.05	64	0.01	0.05	64	5.56	0.05	64	15.17	0.04	64	21.52	0.04	64	23.65	0.03
53	1.00	65		0.05	65	0.01	0.05	65	5.56	0.05	65	15.17	0.04	65	21.52	0.04	65	23.65	0.03
END		66		0.05		0.01	0.05		5.56	0.05	66	15.17	0.04	66	21.52	0.04	66	23.65	0.03
		67		0.05		0.01	0.05		5.56	0.05		15.17	0.04	67	21.52	0.04	67	23.65	0.03
		68		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04	68	23.65	0.03
		69		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04	69	23.65	0.03
		70		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04	70	23.65	0.03
		71		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		72		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		73		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		74		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		75		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		76		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		77		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		78		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		79		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		80		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		81		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		82		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		83		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		84		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		85		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		86		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		87		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		88		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		89		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		90		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		91		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		92		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		93		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		94		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		95		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		96		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		97		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		98		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		99		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		100		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		101		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03
		102		0.05		0.01	0.05		5.56	0.05		15.17	0.04		21.52	0.04		23.65	0.03

103	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
104	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
105	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
106	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
107	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
108	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
109	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
110	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
111	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
112	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
113	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
114	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
115	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
116	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
117	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
118	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
119	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
120	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
121	0.06	0.01	0.06	5.56	0.05	15.17	0.04	21.52	0.04	23.65	0.03
122	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
123	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
124	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
125	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
126	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
127	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
128	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
129	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
130	0.05	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
131	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
132	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
133	0.05	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
134	0.05	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
135	0.05	0.01	0.05	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
136	0.06	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
137	0.06	0.01	0.05	5.56	0.05	15.17	0.04	21.52	0.04	23.65	0.03
138	0.05	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
139	0.05	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
140	0.05	0.01	0.06	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
141	0.06	0.01	0.05	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
142	0.05	0.01	0.05	5.56	0.06	15.17	0.04	21.52	0.04	23.65	0.03
143	0.05	0.01	0.06	5.56	0.05	15.17	0.04	21.52	0.04	23.65	0.03
144	0.05	0.01	0.06	5.56	0.05	15.17	0.04	21.52	0.04	23.65	0.03

5.0 15.3 132.8 4.3 20.6		6.0 18.4 163.0 3.3 28.5			7.0 21.5 193.5 2.5 36.7			8.0 24.6 224.6 1.7 50.5			9.0 27.7 266.2 1.2 75.0			10.0 30.8 308.5 0.6 117.2			Complete Total Flux		Jet Core (2") Total Flux	
Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Tau	Mass	C/Co	Mass	C/Co	Mass
																	0.00	0.2	0.00	0.2
																	0.00	0.6	0.00	0.6
																	0.01	1.1	0.00	0.5
																	0.01	0.9	0.00	0.4
																	0.01	0.8	0.00	0.4
																	0.01	1.4	0.00	0.4
																	0.02	2.8	0.01	1.5
																	0.04	5.9	0.03	4.1
																	0.09	12.0	0.06	6.7
38	0.54																0.14	18.9	0.07	9.3
39	0.54																0.20	27.3	0.09	12.6
40	1.39																0.27	38.6	0.11	15.1
41	3.18																0.33	45.8	0.12	16.0
42	4.49																0.38	51.7	0.12	17.1
43	6.18	0.00	43	0.44													0.42	57.6	0.13	18.0
44	9.00	0.00	44	1.23													0.48	65.5	0.13	18.5
45	11.58	0.00	45	2.83													0.52	71.0	0.13	18.1
46	12.93	0.00	46	3.72													0.54	74.4	0.14	18.9
47	15.18	0.00	47	5.10													0.58	79.8	0.14	19.9
48	17.25	0.00	48	6.78													0.63	86.1	0.15	20.0
49	18.39	0.00	49	8.31													0.65	89.5	0.14	19.9
50	18.12	0.01	50	9.72													0.66	90.0	0.14	19.9
51	19.78	0.01	51	11.29													0.68	94.0	0.14	19.6
52	20.44	0.01	52	12.72													0.70	98.2	0.14	19.7
53	20.52	0.02	53	14.28	0.00	53	5.05										0.75	102.7	0.14	19.8
54	20.12	0.02	54	14.61	0.00	54	5.71										0.76	103.6	0.15	20.0
55	20.92	0.02	55	15.56	0.00	55	5.79										0.77	106.0	0.15	20.2
56	21.11	0.02	56	16.42	0.00	56	6.30										0.79	108.1	0.15	20.6
57	21.01	0.02	57	16.56	0.00	57	6.52										0.79	109.0	0.15	20.7
58	21.13	0.02	58	16.72	0.00	58	6.67										0.80	110.0	0.15	20.7
59	21.24	0.02	59	16.40	0.00	59	6.83										0.80	110.1	0.15	20.7
60	21.26	0.02	60	16.95	0.01	60	8.27										0.82	112.2	0.15	20.7
61	21.50	0.03	61	17.19	0.01	61	9.12										0.83	113.7	0.15	20.7
62	21.60	0.02	62	17.21	0.01	62	9.84										0.83	114.6	0.15	20.7
63	21.70	0.02	63	17.30	0.01	63	10.81										0.84	115.7	0.15	20.7
64	21.80	0.02	64	17.40	0.02	64	11.33										0.85	116.4	0.15	20.7
65	22.01	0.02	65	17.52	0.02	65	11.37										0.85	116.8	0.15	20.7
66	22.01	0.02	66	17.52	0.02	66	11.77										0.85	117.2	0.15	20.7
67	22.01	0.02	67	17.60	0.02	67	12.01	0.00	67	4.35							0.89	121.9	0.15	20.7
68	22.01	0.03	68	17.68	0.02	68	12.20	0.00	68	4.44							0.89	122.2	0.15	20.7
69	22.01	0.03	69	17.76	0.02	69	12.04	0.00	69	4.21							0.89	121.9	0.15	20.7
70	22.01	0.03	70	17.92	0.02	70	12.64	0.00	70	4.60							0.90	123.1	0.15	20.7
71	22.01	0.03	71	17.92	0.02	71	12.81	0.00	71	4.74							0.90	123.4	0.15	20.7
72	22.01	0.03	72	17.92	0.02	72	12.76	0.00	72	4.70							0.90	123.3	0.15	20.7
73	22.01	0.03	73	17.92	0.02	73	12.76	0.00	73	4.99							0.90	123.6	0.15	20.7
74	22.01	0.03	74	17.92	0.02	74	12.76	0.00	74	5.53							0.90	124.1	0.15	20.7
	22.01	0.03	75	17.92	0.02	75	12.70	0.01	75	5.88							0.90	124.4	0.15	20.7
	22.01	0.03	76	17.92	0.02	76	12.70	0.01	76	6.39							0.91	124.9	0.15	20.7
	22.01	0.03	77	17.92	0.02	77	12.76	0.01	77	7.05							0.91	125.7	0.15	20.7
	22.01	0.03	78	17.92	0.02	78	12.81	0.01	78	7.43							0.92	126.1	0.15	20.7
	22.01	0.03	79	17.92	0.02	79	12.87	0.01	79	7.55							0.92	126.3	0.15	20.7
	22.01	0.03		17.92	0.02	80	12.99	0.01	80	7.90							0.92	126.7	0.15	20.7
	22.01	0.03		17.92	0.02	81	12.99	0.01	81	8.01							0.92	126.8	0.15	20.7
	22.01	0.03		17.92	0.02	82	12.99	0.01	82	8.08							0.92	126.9	0.15	20.7
	22.01	0.03		17.92	0.02	83	12.90	0.01	83	7.93							0.92	126.8	0.15	20.7
	22.01	0.03		17.92	0.02	84	12.99	0.01	84	8.22							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02	85	12.99	0.01	85	8.33							0.92	127.2	0.15	20.7
	22.01	0.03		17.92	0.02	86	12.99	0.01	86	8.30							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02	87	12.99	0.01	87	8.30							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02	88	12.99	0.01	88	8.30							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02	89	12.99	0.01	89	8.28							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.01	90	8.28							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.01	91	8.30							0.92	127.1	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.01	92	8.33	0.00	92	2.85				0.96	130.0	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	93	8.37	0.00	93	2.88				0.96	130.1	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	94	8.44	0.00	94	2.91				0.96	130.2	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	95	8.44	0.00	95	2.91				0.95	130.2	0.15	20.7
	22.01	0.03		17.92	0.02		12.90	0.02	96	8.44	0.00	96	2.91				0.95	130.2	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	97	8.44	0.00	97	2.91				0.96	130.2	0.15	20.7
	22.01	0.03		17.92	0.02		12.90	0.02	98	8.44	0.00	98	3.08				0.96	130.3	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	99	8.44	0.00	99	3.39				0.95	130.7	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	100	8.44	0.00	100	3.62				0.95	130.9	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	101	8.44	0.01	101	3.91				0.95	131.2	0.15	20.7
	22.01	0.03		17.92	0.02		12.99	0.02	102	8.44	0.01	102	4.26				0.96	131.5	0.15	20.7

22.01	0.03	17.92	0.02	12.99	0.02	103	8.44	0.01	103	4.45				0.98	131.7	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	104	4.49				0.98	131.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	105	4.64				0.98	131.9	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	106	4.70				0.98	132.0	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	107	4.74				0.98	132.0	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	108	4.80				0.98	131.9	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	109	4.82				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	110	4.88				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	111	4.88				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	112	4.88				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	113	4.88				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	114	4.84				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	115	4.84				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	116	4.88				0.98	132.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	117	4.88				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	118	4.91				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	119	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	120	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	121	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	122	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	123	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	124	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	125	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	126	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	127	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01	128	4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96				0.98	132.2	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96	0.00	134	1.58	0.97	133.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96	0.00	135	1.58	0.97	133.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.95	0.00	136	1.57	0.97	133.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.95	0.00	137	1.57	0.97	133.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96	0.00	138	1.57	0.97	133.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96	0.00	139	1.57	0.97	133.8	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.96	0.00	140	1.65	0.97	133.9	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.95	0.00	141	1.81	0.97	134.0	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.95	0.00	142	1.93	0.98	134.1	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.95	0.00	143	2.08	0.98	134.3	0.15	20.7
22.01	0.03	17.92	0.02	12.99	0.02		8.44	0.01		4.95	0.01	144	2.26	0.98	134.5	0.15	20.7

APPENDIX 5: FLOW SPLIT CALCULATION

FLOW SPLIT ANALYSES FOR RESERVOIR NOS. 1, 2, AND 3.

Note
1) all of measurements for Length and Area are based on site plan drawing
2) travel time based on t50

INLET ANALYSES

Inlet1

Flow=	170.0	ML/d	
=	118.1	m^3/min	

Inlet 2

L of pipe=	340	m	(from Inlet1 to Inlet2)
D of pipe=	2.1	m	
A of pipe=	3.5	m^2	
Time travel=	12.5	min.	(t50 Inlet2 - t50 Inlet1)
Velocity=	27.2	m/min	
Flow=	94.2	m^3/min	

Flow Split

Cell 1=	23.9	m^3/min.	20	%
Cell 2&3=	94.2	m^3/min.	80	%

Assume= 1) split Cell 2&3 = 38% & 42% (check the assumption later)
2) inlet profile 3= inlet profile 2 with shift

Inlet 3

L of pipe=	5.0	m	(from Inlet2 to Inlet3)
D of pipe=	2.1	m	
A of pipe=	3.5	m^2	
Flow=	49.6	m^3/min.	
Velocity=	14.3	m/min	
Time travel=	0.3	min	(shift of inlet 2 and inlet 3)

Time Analyses

T10 from Convergence		=	137	min			
Time Travel							
Pipe System-Inlet1	70	m			Total Volume=	2631	m^3
Pipe Inlet1-Otlet2	340	m			Pipe Td=	22.3	min
Pipe Outlet 2&3-Outlet1	270	m					
Pipe Outlet 1-Convergence	80	m					
Td		=	903.3				
		Total=	926	min			

OUTLET ANALYSES (CHECK THE ASSUMPTION)

Convergence

t50=	488	min

Outlet 1

L of pipe=	80	m	(from Outlet1 to Convergence)	
A of pipe=	3.5	m^2		
Flow=	23.6	m^3/min	(assumed Flow Inlet = Outlet)	
Velocity=	6.8	m/min		
Time travel=	11.7	min		
Checking Time=	488.0	min.		
Correction Time=	476.3	min ——	C/Co=	0.61

Outlet 2

L of pipe=	340	m	(from Outlet 2 to Convergence)	
A of pipe=	2.1	m^2		
Flow=	44.9	m^3/min		
Velocity=	21.4	m/min		
Time travel=	15.9	min		
Checking Time=	488.0	min		
Correction Time=	472.1	min ——	C/Co=	0.57

Outlet 3

L of pipe=	350	m	(from Outlet 3 to Convergence)			
A of pipe=	2.1	m^2				
Flow=	49.3	m^3/min				
Velocity=	23.5	m/min				
Time travel=	14.9	min				
Checking Time=	488	min				
Correction Time=	473.1	min ——	C/Co=	0.52	or	0.48

Total C/Co= %Flow(1)xC/Co(1) + %Flow(2) x C/Co(2) + %Flow(3) x C/Co(3)
= 0.56 ——— error = 11 %
(out of 0.50) (assumption accepted !)

Note assuming an error data at t=355 min , taking interpolation for data between t=335 min (C/Co=0.44) and 594 min (C/Co=0.53)at t=47 gives C/Co = 0.48

Total C/Co= 0.54 ——— error = 7 %
(out of 0.50)

APPENDIX 6: INSTRUMENT STANDARD DEVIATION

STANDARD Na SOLUTION TEST

Reading No.	0 mg/L Na	5 mg/ L Na	10 mg/ L Na	15 mg/ L Na	20 mg/ L Na
1	0.0	32.5	58.5	81.5	98.5
2	0.0	32.5	58.5	80.5	99.0
3	0.0	33.0	58.5	81.0	99.0
4	0.0	33.0	58.0	81.0	98.5
5	0.0	32.5	58.5	80.5	99.5
6	0.0	33.0	58.0	80.5	99.5
7	0.0	32.5	59.0	81.5	99.0
8	0.0	33.0	58.5	81.0	99.5
9	0.0	33.0	58.5	81.0	98.5
10	0.0	33.5	58.5	81.0	99.0
11	0.0	33.0	58.5	80.5	98.5
12	0.0	33.0	59.0	80.0	99.0
13	0.0	33.0	58.5	81.0	98.5
14	0.0	33.5	59.0	81.0	99.5
15	0.0	33.5	58.5	81.0	99.0
16	0.0	33.5	58.5	81.5	98.5
17	0.0	33.0	58.5	80.5	99.5
18	0.0	33.0	59.0	81.0	99.5
19	0.0	32.5	59.0	81.5	99.5
20	0.0	33.5	59.5	81.0	99.0
21	0.0	33.5	59.0	81.5	99.5
22	0.0	33.0	59.0	81.5	99.0
23	0.0	33.5	59.0	81.5	100.0
24	0.0	33.0	58.5	82.0	99.0
25	0.0	33.0	59.0	81.0	98.5
26	0.0	32.5	58.5	81.0	98.5
27	0.0	33.0	58.5	80.5	98.5
28	0.0	33.0	59.0	81.0	99.0
29	0.0	33.5	59.0	81.0	99.0
30	0.0	33.5	59.5	81.0	99.5
Average	**0.0**	**33.1**	**58.7**	**81.0**	**99.0**
Stand. Dev	**0.00**	**0.36**	**0.36**	**0.43**	**0.43**

UNIVERSITY OF ALBERTA

A Methodology for Designing Local Area ATM Networks

By

Chu-Kiat Lim

A thesis
submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree
of Master of Science

Department of Computing Science

Edmonton, Alberta
Fall 1994

National Library of Canada
Acquisitions and Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale du Canada
Direction des acquisitions et des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

ISBN 0-315-95069-2

Canada

Name CHU-KIAT LIM

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

COMPUTER SCIENCE
SUBJECT TERM

0 9 8 4
SUBJECT CODE

U·M·I

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS

Architecture	0729
Art History	0377
Cinema	0900
Dance	0378
Fine Arts	0357
Information Science	0723
Journalism	0391
Library Science	0399
Mass Communications	0708
Music	0413
Speech Communication	0459
Theater	0465

EDUCATION

General	0515
Administration	0514
Adult and Continuing	0516
Agricultural	0517
Art	0273
Bilingual and Multicultural	0282
Business	0688
Community College	0275
Curriculum and Instruction	0727
Early Childhood	0518
Elementary	0524
Finance	0277
Guidance and Counseling	0519
Health	0680
Higher	0745
History of	0520
Home Economics	0278
Industrial	0521
Language and Literature	0279
Mathematics	0280
Music	0522
Philosophy of	0998
Physical	0523
Psychology	0525
Reading	0535
Religious	0527
Sciences	0714
Secondary	0533
Social Sciences	0534
Sociology of	0340
Special	0529
Teacher Training	0530
Technology	0710
Tests and Measurements	0288
Vocational	0747

LANGUAGE, LITERATURE AND LINGUISTICS

Language	
General	0679
Ancient	0289
Linguistics	0290
Modern	0291
Literature	
General	0401
Classical	0294
Comparative	0295
Medieval	0297
Modern	0298
African	0316
American	0591
Asian	0305
Canadian (English)	0352
Canadian (French)	0355
English	0593
Germanic	0311
Latin American	0312
Middle Eastern	0315
Romance	0313
Slavic and East European	0314

PHILOSOPHY, RELIGION AND THEOLOGY

Philosophy	0422
Religion	
General	0318
Biblical Studies	0321
Clergy	0319
History of	0320
Philosophy of	0322
Theology	0469

SOCIAL SCIENCES

American Studies	0323
Anthropology	
Archaeology	0324
Cultural	0326
Physical	0327
Business Administration	
General	0310
Accounting	0272
Banking	0770
Management	0454
Marketing	0338
Canadian Studies	0385
Economics	
General	0501
Agricultural	0503
Commerce-Business	0505
Finance	0508
History	0509
Labor	0510
Theory	0511
Folklore	0358
Geography	0366
Gerontology	0351
History	
General	0578
Ancient	0579
Medieval	0581
Modern	0582
Black	0328
African	0331
Asia, Australia and Oceania	0332
Canadian	0334
European	0335
Latin American	0336
Middle Eastern	0333
United States	0337
History of Science	0585
Law	0398
Political Science	
General	0615
International Law and Relations	0616
Public Administration	0617
Recreation	0814
Social Work	0452
Sociology	
General	0626
Criminology and Penology	0627
Demography	0938
Ethnic and Racial Studies	0631
Individual and Family Studies	0628
Industrial and Labor Relations	0629
Public and Social Welfare	0630
Social Structure and Development	0700
Theory and Methods	0344
Transportation	0709
Urban and Regional Planning	0999
Women's Studies	0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES

Agriculture	
General	0473
Agronomy	0285
Animal Culture and Nutrition	0475
Animal Pathology	0476
Food Science and Technology	0359
Forestry and Wildlife	0478
Plant Culture	0479
Plant Pathology	0480
Plant Physiology	0817
Range Management	0777
Wood Technology	0746
Biology	
General	0306
Anatomy	0287
Biostatistics	0308
Botany	0309
Cell	0379
Ecology	0329
Entomology	0353
Genetics	0369
Limnology	0793
Microbiology	0410
Molecular	0307
Neuroscience	0317
Oceanography	0416
Physiology	0433
Radiation	0821
Veterinary Science	0778
Zoology	0472
Biophysics	
General	0786
Medical	0760

EARTH SCIENCES

Biogeochemistry	0425
Geochemistry	0996
Geodesy	0370
Geology	0372
Geophysics	0373
Hydrology	0388
Mineralogy	0411
Paleobotany	0345
Paleoecology	0426
Paleontology	0418
Paleozoology	0985
Palynology	0427
Physical Geography	0368
Physical Oceanography	0415

HEALTH AND ENVIRONMENTAL SCIENCES

Environmental Sciences	0768
Health Sciences	
General	0566
Audiology	0300
Chemotherapy	0992
Dentistry	0567
Education	0350
Hospital Management	0769
Human Development	0758
Immunology	0982
Medicine and Surgery	0564
Mental Health	0347
Nursing	0569
Nutrition	0570
Obstetrics and Gynecology	0380
Occupational Health and Therapy	0354
Ophthalmology	0381
Pathology	0571
Pharmacology	0419
Pharmacy	0572
Physical Therapy	0382
Public Health	0573
Radiology	0574
Recreation	0575
Speech Pathology	0460
Toxicology	0383
Home Economics	0386

PHYSICAL SCIENCES

Pure Sciences

Chemistry	
General	0485
Agricultural	0749
Analytical	0486
Biochemistry	0487
Inorganic	0488
Nuclear	0738
Organic	0490
Pharmaceutical	0491
Physical	0494
Polymer	0495
Radiation	0754
Mathematics	0405
Physics	
General	0605
Acoustics	0986
Astronomy and Astrophysics	0606
Atmospheric Science	0608
Atomic	0748
Electronics and Electricity	0607
Elementary Particles and High Energy	0798
Fluid and Plasma	0759
Molecular	0609
Nuclear	0610
Optics	0752
Radiation	0756
Solid State	0611
Statistics	0463

Applied Sciences

Applied Mechanics	0346
Computer Science	0984
Engineering	
General	0537
Aerospace	0538
Agricultural	0539
Automotive	0540
Biomedical	0541
Chemical	0542
Civil	0543
Electronics and Electrical	0544
Heat and Thermodynamics	0348
Hydraulic	0545
Industrial	0546
Marine	0547
Materials Science	0794
Mechanical	0548
Metallurgy	0743
Mining	0551
Nuclear	0552
Packaging	0549
Petroleum	0765
Sanitary and Municipal	0554
System Science	0790
Geotechnology	0428
Operations Research	0796
Plastics Technology	0795
Textile Technology	0994

PSYCHOLOGY

General	0621
Behavioral	0384
Clinical	0622
Developmental	0620
Experimental	0623
Industrial	0624
Personality	0625
Physiological	0989
Psychobiology	0349
Psychometrics	0632
Social	0451

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: *Chu-Kiat Lim*

TITLE OF THESIS: *A Methodology for Designing Local Area ATM Networks*

DEGREE: *Master of Science*

YEAR THIS DEGREE GRANTED: *1994*

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as hereinbefore provided neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

(Signed) Lim Chu Kiat

Permanent Address:
20, Solok Piggot,
Pulau Pinang,
10450, Malaysia

Date: Oct 4th 1994

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *A Methodology for Designing Local Area ATM Networks* submitted by *Chu-Kiat Lim* in partial fulfillment of the requirements for the degree of Masters of Science.

J. Harms
Supervisor: J. Harms

Examiner: P. Gburzynski

External: B. Schmuland (Mathematical Sciences)

Chairperson: R. Elio

Date: Oct 4th, 1994

To my parents
Mr. and Mrs. Lim Yoke Kwai,

My brothers
Lim Chu-Keong, Lim Chu-Kim, and Lim Chu-Wai

and
All my friends in Edmonton

Abstract

In a local area Asynchronous Transfer Mode network (LATM), interconnections of switches using high-speed links make up the topology of the network. As the number of variables involved is quite large and the interconnection of these switches is quite complex, a method has to be devised so that a topology that satisfies traffic requirements and is cost effective can be obtained.

This thesis describes a method for designing the topology of a local area ATM network. The method is based on the concept of an ATM pipe. Using these ATM pipes, a logical LATM topology is first created, from which the final physical LATM topology is derived. An advantage of this method is that it produces a topology that satisfies given traffic requirements while trying to minimize the cost of the network. This method consists of two parts. The first part involves the calculation of the ATM pipe sizes. A Multiclass Heterogeneous On/Off Sources Fluid Flow model (MCFF) is used for this calculation. The second part is the derivation of the actual physical topology. The main technique used here is heuristic-based algorithms. The effectiveness of both part one and two are examined, and their results presented.

This method successfully generates network topologies for LATM networks.

Acknowledgements

I would like to extend my greatest gratitude to my supervisor Dr. Janelle Harms, for her guidance and support (especially financially!). Without her unfailing support, this thesis would not be possible. Thank you Janelle.

I am also grateful to the members of my examining committee: Dr. Pawel Gburzynski, Dr B. Schmuland and Dr. Renee Elio for their precious time spent in reviewing this work. I am also indebted to the members of the network group, especially Srinivasan Ramaswamy, Kannan Thiruvengadam, and Xiaofan Guo for their valuable suggestions and support.

I would like to thank all my friends in the Computing Science Department, especially Vikas Nehru (we have been friends for a long time), Sydney Lee, Collins Chien, Kacheong Yeung, Magued Fahim, Lettice Tse (thank you for all the conversations). Special thanks also to Dr. Hong Zhang and Dr. Ahmed Kamal for their encouragements that led to my graduate studies. Also to Prof. Ursula Maydell for her guidance and support in publishing my first paper.

Thank you all.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Since the invention of the telephone, the world has taken a great leap forward in communications. At present, millions of miles of communication lines span the entire globe serving billions of people in hundreds of countries. And with the advent of present day technologies in digital computing, the world of communication is witnessing a transition from the old low-bandwidth voice-based networks to high-bandwidth multipurpose all digital networks. No longer are the networks carrying only voice traffic; data, still images, and video as well as other multimedia traffic is becoming a vital and integral part of everyday traffic that is being sent over communication networks. This is evident as the number of voice network users grow at an annual rate of 3% whereas data network users increase at an astonishing 20% annually [37].

With this explosion in the number of new users and thus new networks, present day communication networks are getting more and more complex as more and more networks of different technologies and functionalities are being deployed. Network planning and designing is no longer an exclusive role to large corporations or telephone service providers, but an important and vital part to all organizations however big or small, that envisage the use of communication networks. Foresight, expertise, and careful planning is indispensable so that the communication network that results satisfies not only present day requirements but future usages and/or expansions as well.

This thesis is about network design, specifically for obtaining the topology for local area Asynchronous Transfer Mode (LATM) networks. We shall begin with this chapter, by discussing some general topics on network design. Next, a brief overview on Asynchronous Transfer Mode is given. Finally, the problem definition and an objective to this thesis will be presented.

1.1 Network Planning and Design Issues

The role of network design involves various issues. Although every organization is different in terms of size, usages and requirements, several issues are common to many of them. A good reference that discusses these issues can be found in [16]. We present a brief discussion of the network planning and design issues here.

1.1.1 Justification

Before a new network is installed, it is important that the need for such a network is justified. Various facts needs to be considered to justify owning a new network, including costs of hardware, installation, network maintenance technicians and administrator, as well as the forecasted network usage. For example, it might be more economical for certain organizations to lease services or lines from common carrier companies, instead of owning one themselves. This is especially true for organizations that are geographically wide-spread; installing long distance cables and equipment just to serve a single organization may very well be too expensive.

Often alternative solutions exit in lieu of installing a network. A network designer should always forecast the would-be traffic usage for the new network carefully. If the projected traffic is too small, applying alternative solutions might be better than purchasing a new network. For example, for rare transfers of small amounts of data, one can download them with a modem or even transfer them physically in magnetic tapes or diskettes.

1.1.2 Security

As organizations put more and more computers onto their network, unauthorized individuals no longer need to have access physically to a machine to gain access to restricted information. Information theft may cause serious harm to the well-being of a company, for example, a financial institution. A culprit may log on to a machine from far away, or even out of the country to attempt to gain unauthorized access into the system. It becomes harder to bring the culprits to justice, even if they have been discovered in their act, since they are physically far away.

Therefore, security measurements have to be taken to ensure the privacy of the networks. For example, more stringent access validation systems can be employed, and traffic to and from network gateways can be monitored. Repeated login failures should flag an alert to the system administrators for possible unauthorized entry.

In addition, care has to be exercised in choosing the type of network that is acquired. Some types of networks are more susceptible to unauthorized access than others. As a rule of thumb, networks that broadcasts wirelessly, for example radio networks and satellite links can be eaves-dropped easily, and thus is more susceptible to security problems.

1.1.3 Network Architecture

As there are a wide variety of network technologies in the market, it becomes hard to choose a network architecture to use. Each of the network architecture has advantages and disadvantages of their own. Each of them differs in functionality and price.

As to which architecture is the most suitable, there is no specific answer to this question. Some applications can only run on certain types of network architecture, while others work on a wide range of different networks. For example, constant bit rate voice works best with networks that support synchronous transfers such as the Fiber Distributed Data Interface II Network (FDDI-II); it does not work well with networks that exhibit variable delays (for example, Ethernet).

Another factor to consider is expandability of the network architecture. Some networks can be expanded (scaled) more easily than others with increase demands on traffic. One such network is the switched Asynchronous Transfer Mode (ATM) networks, where the aggregate bandwidth of the network can be expanded easily by adding in new switches and links, as compared to a DQDB network where the extension of bandwidth can only be done by obtaining another network and connecting these networks by bridges.

1.1.4 Manageability

As networks grow bigger and more complex, the need for a network architecture that is manageable becomes crucial to the everyday operations of the network. A network that is assembled from too many types of equipment from multiple vendors with different standards and formats may become too complex in order to function effectively. Segmentation and assembly of packets may be performed more often than necessary due to the different formats and standards of different equipment. Hence, the increase in overhead, and subsequently the degrading in network performance. A network having too many different types of equipment also needs more staff to maintain the network, since more people need to be trained to handle different types of network components. This represents more cost to maintaining the network.

1.1.5 Reliability

While most networks sold today are relatively reliable compared to a couple of decades back, questions of reliability of networks are still important for certain kinds of networks. In fact, reliability in local networks is becoming a more and more important consideration [25]. As an example, airline flight control equipment requires availability 99.99999% of the time. That means communication networks for flight control equipment has to achieve a downtime of less than 4 seconds per year. Other organizations that rely heavily on the usage of networks may find that reliability of their networks is important. A network failure can possibly result in a loss of thousands or even millions of dollars in business.

Some networks on the market are more reliable than others. For example, FDDI with its dual ring architecture is able to reconfigure the secondary ring in case the primary ring fails. Also, mesh networks can be more reliable than fixed topology networks (ring or star) since a link failure in a mesh network can be easily coped by rerouting the traffic via other paths to the destination. It is up to the network designer to determine which level of reliability is needed, and hence which network is more suitable.

1.1.6 Cost

Perhaps the one of the most important factors in influencing the decision of purchasing which type of network is cost. It is one of the major issues in network design [28]. The actual cost of acquiring a network can be quite complex. However, the cost can be divided into the following categories:

- **Hardware Cost.** Depending on the technology in use, this can be the cost for switches, multiplexers,concentrators, terminators, diagnostic equipment, copper wire, fiber-optic cables, coaxial cable bridges and gateways, etc.
- **Software Cost.** To have the network operational, certain software has to be installed. For example, communication software, network monitoring software, network administration software, etc.
- **Installation Cost.** Included in this category is the cost related for installing hardware and links. This includes labor cost as well as other costs related to installation. For example, putting up conduits or special encasements for fiber-optic cables, or installing fire-proof material to protect communication lines.
- **Facility Cost.** This category includes the cost for locating hardware or links at premises. For example, a room with special ventilation for locating switches, or wiring closets for link distribution. Sometimes, this cost can be the dominant cost for the network. An example is if rights of way over other peoples property have to be purchased in order to install links/equipment.
- **Maintenance Cost** With the network in place, regular maintenance is required to keep the network functioning effectively. The maintenance cost includes the cost of employing/training maintenance technicians as well as replacements of failed or unfunctional equipment.

1.2 Network Planning and Design Life-cycle

Figure 1 shows a diagram of the life-cycle of network planning and design. This life-cycle can be divided into two parts: long term planning and design, and short term planning and design. Long term planning and design involves planning and designing aspects of the network that exerts long lasting effects to the operations or structure of the network, whereas short term planning and design mainly deals with semi-temporary redesigning or reconfiguration of the network to satisfy short term changing traffic usage requirements.

1.2.1 Long Term Planning and Design

Long term network planning and design starts with forecasting the usage characteristics of the network in the long term. Usage characteristics include what applications will be used, and the type and amount of bandwidth that is required to run these applications as well as any other service requirements associated with these applications. Usage characteristics also include the expected number of users in the long run. Other issues such as reliability, security and manageability are considered as well.

After the long term forecasting or planning stage, the network designer surveys the available technologies or soon to be available technologies (for reasons of future compatibility). Information on prices and functions of each types of technology is collected and considered. Questions to be considered include compatibility between existing standards and equipment and/or future standards and equipment.

With one or a collection of desired technologies in mind, the network designer sets out to design the network. Simple networks such as a token ring network or an ethernet network do not require much designing except for the wiring plan for terminals and peripherals that connect onto the network. Other more complex networks such as switched ATM networks or interconnection of networks require more designing to yield a network with the desired functions. Various tools and techniques such as simulation tools, queueing theory and optimization techniques are applied to assist in the designing process. The focus of this thesis is here,

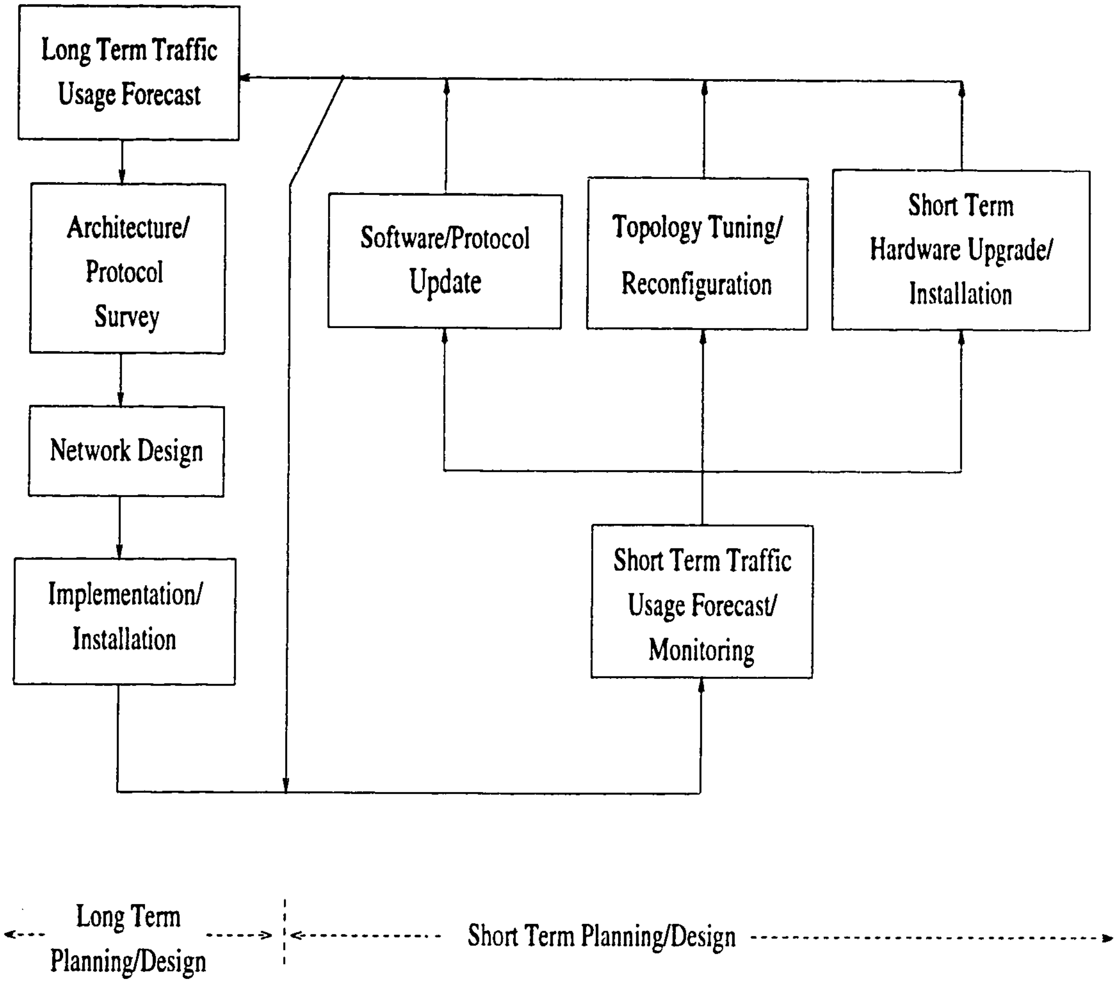


Figure 1: *The Network Planing and Design Life-cycle*

specifically on topology design for switched LATM networks.

Next, the actual purchasing, implementation and installation of the network is done. Some testing is also done in this phase to ensure that the newly installed network is functioning properly.

1.2.2 Short Term Planning and Design

Short term network planning and design, on the other hand is performed in an ongoing basis. This process begins with the regular monitoring or short term forecast of network usage statistics. Changes in usage statistics or network requirements are mostly short-lived but the need to fine tune the network persists.

The short term network planning and design process can be divided to the following:

- *Software Update.* By updating or fine-tuning of the software in the topology, some improvements in network performance is achievable. For example, by using software to changing the buffer configuration or cell priority scheme, network efficiency can be improved.

- *Topology Tuning/Reconfiguration* This involves a small change to the network topology, physical or logical. Physical changes include non-major rewiring of the topology. Logical changes include optimization and rerouting traffic to new paths. Some work has been done in this area for ATM networks. Interested readers can refer to [24, 32]

- *Short Term Hardware Upgrade/Installation* Work in this category involves putting in temporary hardware to support short-term increase in traffic or workload. For example, additional multiplexers and concentrators can be installed in to improve link utilization, or adding in additional links to increase bandwidth. Typically, this involves a minor reconfiguration of the topology as well.

1.3 ATM: The Asynchronous Transfer Mode

The Asynchronous Transfer Mode (ATM) is a fast packet switching transfer mode promising great flexibility and support for future bandwidth demanding applications. Since the CCITT (The International Consultative Committee for Telecommunications and Telegraphy) adopted it as the transfer mode for Broadband Integrated Services Digital Networks (B-ISDN) [6], much attention has been focused on research in this area.

B-ISDN is perceived to be an all purpose network [31], promising support for traffic of all bandwidths, including low bandwidth traffic (e.g., voice, telefax, low-speed data, etc.), medium bandwidth traffic (e.g., video telephony, hi-fi sound, etc.) and high bandwidth traffic (e.g.,medical imaging [27], high-quality video distribution, etc).

A characteristic of ATM is its small cell size (53 bytes). Having a small cell size permits statistical multiplexing, hence more efficient utilization of the links. Also, small cell size reduces packetization delay. Another characteristic of ATM is that it is connection-oriented, that is, prior to sending traffic, a virtual channel (VC) is set-up between the source host and the destination host. A virtual channel identifier (VCI) is allocated, and switches route cells based on this VCI. Another identifier is also used along with the VCI. It is the virtual path identifier (VPI). A virtual path is essentially a predefined path in an ATM network. Virtual channels can join in a virtual path so that they can be switched more efficiently as one.

1.3.1 The ATM Layers

The ATM functionality can be divided into three layers [5]:

1. *The Physical Layer.* The first function of the physical layer is to ensure that bits are transmitted correctly onto or received correctly from the physical medium while the second function involves mapping the reconstructed bits to the transmission system used.

2. *The ATM Layer.* This layer is responsible for multiplexing and demultiplexing of cells, cell header addition and extraction, VCI translation and

access flow control.

3. *The ATM Adaption Layer* The main function of the adaptation layer is to provide additional service on top of that already provided by the lower layers. The main aim is to be able to provide different quality of services for different traffic.

1.3.2 Quality of Service

One of the most powerful features of ATM is its ability to provide different quality of services (QOS), that is providing different levels of services for different traffic. For example, voice traffic which is more tolerant to cell loss can specify a higher degree of cell loss, as compared to data traffic. In addition, some traffic requires slightly different services than others. For example, video or voice traffic are sensitive to cell delay jitter, whereas users of data traffic may not care about the jitter in cell delay as long as all the cells arrive within a reasonable time. Basically, QOS can belong to one of three types [3]: deterministic (e.g., maximum delay time to be 500ms), statistical (e.g., cell loss rate to be 10^{-6}) and best effort (e.g, unguaranteed cell delivery).

1.3.3 ATM Hardware

ATM is mainly a switched network, although some proposals have been made for a ring ATM network [34]. Links connect switches with hosts or other switches. ATM links transmit at a certain fixed speed, for example 155Mbps. However, multiples of the link speed can be achieved by combining more than one links together. Each ATM switch contains a number of input ports, where cells arrive, and a number of output ports where cells are sent. At the heart of the switch is the switch fabric that takes care of routing which cell to which output port. Since more than one cell can contend for the same output port, buffers are built in to temporarily store the cells that awaits their turns to be sent. Figure 2 shows a conceptual diagram of an ATM switch with output buffering. For a good introduction to ATM switches, interested readers can refer to [37, 33].

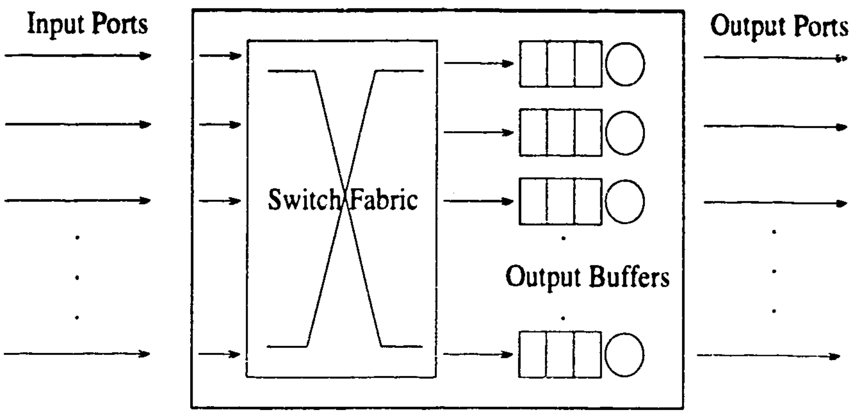


Figure 2: *A Conceptual Diagram of an ATM Switch with Output Buffering*

1.3.4 Local Area ATM Networks

The ATM standard is still evolving. With many aspects of ATM still being unclear it is not surprising that the earliest deployment of ATM networks will be in the local area. As local area networks are usually owned by a single organization, certain functions of the network can be relaxed, for example, congestion control or traffic policing. In addition, the number of users in a local area network environment is smaller, and the amount of traffic is less. Therefore, implementations in a smaller scale are usually done first in a local area environment prior to the metropolitan or wide area networks environments. Because of this, local area ATM Networks are receiving considerable attention, and some first-generation LATM products have already appeared in the market.

1.4 Thesis Objective

Consider the following scenario:

> A network designer is faced with the challenge of designing a local area network. Due to the flexibility and power of ATM he has decided to use ATM as the transfer mode for his local area network. With past usage statistics and careful forecast, he has projected the would-be

> traffic requirements (most traffic are multimedia, each with different QOS requirements). He has also obtained information about the cost and characteristics of the LATM switches and links currently on the market. After much consideration, he has decided that the 16x16 and 32x32 switches from company x, and the 64x64 switches from company y are the best buy, and therefore should be used. He has also found out other information on costs, such as labor cost for installing links, and cost for putting in conduits to protect the fiber-optic links. His company has also allocated a few locations specifically for locating the switches for this new network. Under direct orders from the Chief Executive Officer, his network must cost as little as possible while satisfying all traffic requirements. He sits down and begins to ponder on some questions in his mind: How many switches shall he purchase, and which ones? How can he connect the switches so that the desired traffic requirements can be satisfied? And the most important of all, how can the resultant topology be both functional and as cheap as possible? After a while, he realizes he has the answer to the above questions in one of the books on his shelf. He walks to the shelf, reaches out and pulls out the thesis entitled ..... 'A Methodology for Designing Local Area ATM Networks'.

The objective of this thesis is to propose a methodology for solving such a problem. Specifically, this method enables a designer to design a LATM topology that is cost effective while satisfying the requirements of complex ATM traffic.

1.4.1 Problem Formulation

Given the above objective, we can formulate the LATM network design problem as an optimization problem as follows:

Given:

1. Network traffic requirements.
2. Information on usable ATM switches, for example, the switch sizes and costs.

3. Information on ATM transmission links.
4. Locations of user sites.
5. Candidate location sites for switches.
6. The cost associated with installing these switches and links.

Minimize:

1. Total Topology Cost z,
   where z is the cost of switches and links in the topology plus the cost of installing these switches and links.

Over The Variables:

1. Switch number and their corresponding sizes.
2. The location of these switches.
3. The number of links in the network and the interconnection of the switches with these links.
4. The paths that route the traffic.

1.5 Thesis Organization

This thesis is organized as follows. In the following chapter, Chapter 2, a review on some past literature in the area of topology design is given. Several distinctive methods of topology design are outlined there. Next, Chapter 3 presents an outline of our proposed method for LATM topology design. Phase I of our proposed method is included in that chapter. Some results of verifying our Phase I method is presented and discussed. In Chapter 4, the second half of our proposed method, Phase II is presented. The effectiveness of our Phase II method is also examined in this chapter by the discussion of experimental results that we have performed. The conclusions arrived at due to this work are presented in Chapter 5. The pros and cons of our proposed method is discussed along with possible improvements and future works. Finally, appendices are included at the end of this thesis for interested readers.

1.6 Summary

In this chapter, an introduction to network planning and design was given. Various aspects and issues of network planning and design were discussed. We have also given an overview of the Asynchronous Transfer Mode, which is the type of transfer mode used in the networks targeted in this thesis. The scope and objective of this thesis was also presented alongside a formulation of the problem to be solved in this thesis.

Chapter 2

Related Work

While there is little literature for topology design in LATM, much literature exists in the area of topology design in general. In this chapter, we present an overview of several papers that include a wide variety of approaches and techniques for topology design. A brief discussion of each paper is done in relation to their suitability for usage in designing switched LATM networks.

2.1 Topology Design using the Steepest Descent Method

In [11], Gerla, Monteiro and Pazos proposed a method for designing a packet-switched network embedded in a backbone network, and later for reconfiguration of ATM networks [32]. This method involves a concept called "express pipes". An "express pipe" is a logical concatenation of several links that carries traffic from a source node and a destination node. These pipes are derived from the underlying backbone network.

The problem is formulated as an optimization problem, where the variables are the routing of the "express pipes" and the capacities of these pipes, subject to the capacity constraints imposed by the underlying facility network. Gerla, Monteiro and Pazos chose to optimize the average delay of packets in the network. In doing so, they used an M/M/1 model for modeling both the trunk queuing delays and switch delays. By modeling the switches as two nodes of infinite capacity joined by a link of capacity equal to the switch capacity multiplied by the average packet length, the average delay of the topology is approximated by

$$z = \frac{1}{\lambda}\sum_{u=1}^{\bar{M}} \frac{\bar{f}}{\bar{C}_u - \bar{f}_u} \tag{2.1}$$

where $\bar{M}$ is the number "express pipes", $\bar{f}_u$ is the flow on pipe u, and $\bar{C}_u$ is the capacity of pipe u. This objective function is minimized with the the constraints imposed by the underlying backbone. Using Frank-Wolfe's steepest descent method [29] , the best feasible direction of descent can be found taking the gradient of the objective function, that is

$$\min \nabla_z (\bar{C}^1, \bar{f}^1) \cdot (\bar{C}, \bar{f}) \tag{2.2}$$

where $(\bar{C}^{K-1}, \bar{f}^{K-1})$ is an initial solution of pipe capacities $\bar{C}$ and pipe flow $\bar{f}$. The gradient [30] of a function is the vector of partial derivatives of that function. By rewriting the equation with the constraints, the problem boils down to a minimum path problem. Gerla, Monteiro and Pazos subsequently applies a modified version of Dijkstra's [2, 14] minimum path algorithm to solve the problem.

2.1.1 Analysis

Using the Steepest Descent optimization technique, Gerla, Monteiro and Pazos in [11] succeed in deriving a logical ATM network (Express Pipe) topology from an underlying ATM backbone network while minimizing the total delay for the network. The delay is calculated from the delays in the links and switches. Although this work deals with ATM topology design, it does not build a network from scratch since they assume that there is an underlying backbone network on which the new topology is derived.

A major drawback of their work is that the links and switches in the network are modeled using M/M/1 queues in order to make the problem more tractable. This is inaccurate for ATM traffic, as ATM traffic is highly complex. The delay in most ATM switches are more accurately modeled by M/D/1, G/D/1 or other queueing models as found in [33, 22, 8, 7, 20, 38, 13, 4, 36]. Another downside to this work is that there is no exact concept of virtual circuits being incorporated into the design process. The traffic from one host can travel to another host via more than one route. As mentioned in the previous chapter, ATM is a connection oriented protocol, cells belong to a single session are not allowed to travel by multiple routes to the destination. This is necessary so that the cell arrival sequence can be maintained.

In general, this work produces topologies that are optimal. However, due to some of the assumptions that are made, their method is not suitable for our ATM networks.

2.2 The Mentor Algorithm for Topology Design

Kershenbaum, Kermani and Grover in [17] provide a different, more heuristic approach to topology design. Although the solution is not specifically for ATM networks, it is for mesh networks and ATM networks that utilize switches do turn out to be meshes in general. Given the locations of the nodes and the traffic requirements between each source and destination, the algorithm comes up with a minimal cost topology. Unlike the work of Gerla, Monteiro and Pazos in their work in the previous section, who chose to optimize on a performance measure. Kershenbaum, Kermani and Grover try to minimize the cost of the topology instead, assuming that the performance of the network is 'satisfied' by allowing the capacity of the links to be utilized up to a certain level as defined by the topology designer. The reason is that bottlenecks occur and performance deteriorates when links are over-utilized. By keeping the traffic flowing in the links under an acceptable level, reasonably good network performance can be expected.

The first step of Kershenbaum, Kermani and Grover's method is to come up with an initial topology. This topology is an appropriate spanning tree that results in the total link lengths of the network as well as the individual path lengths of destinations being reasonably low. As pointed out by the authors, the networks with the shortest total lengths (minimum spanning trees) will usually result in networks that have longer individual path lengths [16, 17]. while networks with the shortest individual path lengths will usually have a higher shortest total lengths. A special heuristic algorithm has been devised to balance out these two effects, so that both individual path lengths and shortest total lengths of a network can be kept low at the same time. The heuristic algorithm is a modification of Prim's Minimum Spanning Tree (MST) [2, 14] algorithm and Dijkstra's minimum path algorithm. Given a node as the center of the topology, the algorithm selects candidate nodes to be included into the tree starting at the center node like the Prim's MST algorithm. However, instead of including nodes that have the shortest link l from the edge of the tree, the algorithm includes the node that has the shortest link plus α times the distance from the center node. The center node is determined as the node having the least center of mass

$$M_i = \sum_j c_{ij} w_j \tag{2.3}$$

where c_{ij} is the cost of connecting nodes i and j, and

$$w_j = \sum_k r_{jk} + r_{kj} \tag{2.4}$$

is defined as the total traffic requirements in and out of node j.

The next step involves changing the topology by putting in direct links. A direct link between a source and destination is warranted if the total traffic that flows between this source and destination (link utilization) reaches a minimal level, defined as a portion of a link capacity. If the flows exceed a certain level, more links will be added or alternately a portion of the traffic will be routed by another path. However, since the utilization levels of links depends on the routes of many source-destination pairs, the traffic requirements are sequenced by using a dependency matrix [17].

2.2.1 Analysis

In this work, a heuristic method is applied to successfully create a topology that attempts to minimize both the shortest total lengths and individual path lengths at the same time. The heuristic that they apply is a modification of Prim's MST algorithm and Dijkstra's minimum path algorithm.

While this work manages to generate a topology that is low cost, the cost function in [17] is a little too simple, as it considers the cost of the links as the only cost. Other cost such as switching components, or installation costs are not considered. Another downside to this work is that the authors assume that the switches in the network can be connected with any number of links, that is the switches have unlimited capacity. In reality, we know that this is impossible. Furthermore, like the previous paper, the traffic from one host to a destination can travel through multiple paths to a destination.

In conclusion, this work utilizes a simple heuristic method to design a network topology. However, since the method is not specifically geared for ATM networks, we can not apply this work to solve our problem.

2.3 The Simulated Annealing Optimization Technique

In [9], Ersoy and Panwar propose a method for designing interconnected LAN-MAN networks. The objective is to find a minimum delay spanning tree topology for interconnected networks. Instead of using M/M/1 to model the delay of the network, Ersoy and Panwar use $M^x/M/1$ queues [12] with batch Poisson Arrivals. The objective function to minimize is

$$T = \frac{1}{\gamma}\left(\sum_{i=1}^{N} \lambda_i X E[T_i] + \sum_{i=1}^{N}\sum_{j=1}^{N} x_{ij}\lambda_{ij} X E[T_{ij}]\right) \tag{2.5}$$

where $E[T_i]$ is the expected delay in LAN i, $E[T_{ij}]$ is the expected delay in the bridge connecting LAN i and LAN j, and $x_{ij} = 1$ if LAN i and j is connected and equals to zero otherwise. X is mean number of packets in a batch arrival. The expected value of delay for each $M^x/M/1$ queue is

$$E[T] = \frac{X}{\mu(1 - \frac{\lambda X}{\mu})} \tag{2.6}$$

where λ and μ are the arrival rate and service rate respectively.

Ersoy and Panwar proposed the Simulated Annealing Optimization Technique to be used for searching for the solution to this problem. Annealing is a thermal process for obtaining low energy states of a melted solid by slowly cooling the solid. Kirkpatrik, Gelatt and Vecchi [18] first applied an algorithm simulating the annealing process to a combinatorial algorithm. The advantage of the simulated annealing technique is that it avoids getting caught in a local minima by accepting a cost-increasing transition in the search process. That is, in searching for the global minima, a transition from solution i to j is accepted with probability

$$p = \exp(\frac{-[\mathrm{Cost}(j) - \mathrm{Cost}(i)]}{c}) \tag{2.7}$$

where c is a control parameter that regulates the probability of acceptance. By reducing c towards zero gradually, the probability of accepting a cost-increasing solution decreases. The stopping criterion for simulated annealing is that when the cost does not change after decrementing the control parameter a fixed number of times. This number has to be large enough so that a good part of the search space has been visited.

2.3.1 Analysis

Ersoy and Panwar in their work [9] provide a very elegant method to avoid getting stuck in local minimas using the Simulated Annealing method. This method is generally applicable to any problem that involves searching through a state space to locate a solution. However, like [11] a major downside to their method is the usage of a batch arrival $M^x/M/1$ queue instead of more complex ATM queueing models [33, 22, 8, 7, 20, 38, 13, 4, 36] to model the traffic behavior in the network.

In, short, since this work is mainly for interconnection of MAN LANs with bridges, it cannot be applied directly to solve our problem. However, the Simulated Annealing method is a general search algorithm. Therefore the chances of adapting it into a design problem, including that for ATM networks, is promising.

2.4 The Add Heuristic and Cluster Heuristic for Topology Design

The Add algorithm [16] is a classic algorithm for topology design, initially for attacking the celebrated warehouse location problem. Hsieh, Gerla, McGregor and Eckl adopted and modified this algorithm in [15] for designing the backbone of large packet networks. Specifically, it was used for optimal location of backbone switches in these networks. Given the location of user sites and relevant traffic requirements for each user site, the problem involves determining the number and location of switches to which user sites connect so that the cost of the backbone topology is minimized. The cost function given by [15] is:

$$D = \sum_i \sum_j \frac{c r_{ij} R(1+b)}{\rho} + N \times F \tag{2.8}$$

where c is the cost per mile per unit bandwidth per month, r_{ij} is the traffic requirement from i to j, b is the line overhead (protocols, etc.), R is an estimate of the average link length, ρ is average utilization, N the number of switches, and F is the average fixed cost per switch.

The modified add algorithm works by weighing the savings achievable by homing a user site to a switch candidate location, instead of homing the user site to an imaginary site which is the center of mass[16] (COM) of the un-homed sites. At each iteration, a new center of mass is calculated, and with it the sites that have positive savings are homed to a new switch which is located at the switch candidate location that achieves the most savings. The homing process during an iteration of the add algorithm will stop when the switch to which the homing is done, is full. The center of mass of two sites[16] is calculated by:

$$\begin{aligned} x_k &= \frac{w_i x_i + w_j x_j}{w_i + w_j} \\ y_k &= \frac{w_i y_i + w_j y_j}{w_i + w_j} \end{aligned} \tag{2.9}$$

where (x_k, y_k) denotes the COM location of sites located at (x_i, y_i) and (x_j, y_j). w_r denotes the traffic weight of site r, which is simply the total traffic that flows in and out of site r.

A second algorithm that is proposed in [15] is the cluster algorithm. The cluster algorithm attempts to minimize the cost of the whole backbone topology by minimizing the local access cost of each site. By partitioning the user sites into N clusters, the sites can be homed to a switch located at the COM of the partition containing the sites. At the beginning of the algorithm, the two sites that are closest together are clustered and located at the COM of the two sites, then at each iteration, the same process is applied to the clusters that are closest together. To avoid having clusters that are too big or too small, a threshold Z is defined. The merging of clusters is only allowed if the merging does not exceed a threshold Z. At the end of the algorithm, sites that are belong to one cluster will be served by a switch dedicated to that cluster.

2.4.1 Analysis

In this work [15], Hsieh, Gerla, McGregor and Eckl used two very simple heuristics to produce the topology of a network. The Add Heuristic incrementally chooses the best location to home a switch, whereas the Cluster Heuristic attempts to produce a low cost backbone network by minimizing the local access cost for each site. These algorithms are good for their simplicity. However, this is also the downside. This is especially true for the cluster algorithm, where sites are homed to switches without really considering where the traffic needs to be sent.

Unlike the work from the previous sections [11, 9, 17], The authors utilize a more realistic cost function that takes into consideration link and switch costs. However, like [17, 11, 9] a drawback of [15] is that the traffic is too simple compared to current ATM traffic. Traffic is merely specified as some amounts of bandwidth. Another drawback to this work is that the links that they assumed are bidirectional, which is not true for ATM networks.

In general, this work has some good points, specifically the relatively realistic cost function, and simple heuristical algorithms. However, problems do exist for applying this method to an ATM environment.

2.5 Summary

In this chapter, we have presented some research work in the area of topology design each with their own distinctive solution techniques. The solutions presented in these related works are not immediately applicable to the problem that we are pursuing because

- The topology design methods are based on either very simple traffic requirements or none at all. Most papers assume that some r traffic units are needed for some source-destination pairs without really providing any reason. This is not adequate as traffic that flows in an ATM network consists of different traffic types each with its distinct requirement.

- Traffic behaviors in the networks are approximated using M/M/1 queueing models which is inaccurate in the ATM environment. This is especially undesirable when the objective cost function which is based on the M/M/1 model is optimized to produce the final topology.
- Non-ATM specific hardware is assumed. Most papers assume that switches have infinite capacity, that is, infinite number of links can be connected to the switch. Some methods assume that the links are bidirectional, which is untrue in ATM networks.
- Possible multiple paths exists for ATM traffic. In ATM, to maintain correct sequence of delivery, traffic belonging to one session is required to travel in a single path. Most papers in topology design have no mechanism to incorporate this requirement, hence allowing more than one path to carry traffic of one session to the destination.

Nevertheless, these works are valuable to us, as we have learnt many fundamental ideas from them. Specifically we adopted the idea of a pipe logical network as the starting point for topology design. We also design our heuristic programs to be greedy, similar to the heuristics in the previous work.

Chapter 3

The Pipe Based LATM Topology Design Methodology

3.1 Introduction

Using the problem formulation in Chapter 1 we present here a novel approach for designing a switched local area ATM network topology. This approach is unique compared to past related work in that it produces a low-cost LATM network while guaranteeing certain quality of service requirements much needed by complex multimedia ATM traffic.

There are two phases to our method. Phase I of our method deals with determining the effective multiplexed traffic for each source host-destination host pair. With the knowledge of the effective multiplexed traffic, the quality of service requirements can be guaranteed. The main QOS measurement that we use is cell loss probability. Each source-destination host pair sends traffic down a logical channel, which we termed an ATM pipe. A network of these ATM pipes will be fed into Phase II as input. Phase II generates the actual switched ATM network. It consists of three heuristic-based optimization techniques which attempt to minimize the cost of the final topology.

In Section 3.3, we will describe Phase I of our Pipe-based LATM Design Methodology. This is an analytical method and we call this the Multiclass Heterogeneous On/Off Sources Fluid-flow Model. We will present the details of this method in Section 3.4. We will also present the results of the simulation study that we have carried out to verify the correctness of this analytical method.

3.2 The ATM Pipe, What is It?

An ATM pipe is a logical, unidirectional pipe that delivers ATM traffic from one host machine to another (Figure 1). It is analogous to a water pipe in everyday life. At one end of this pipe, water (ATM traffic) enters the pipe through the opening and exits at the other end. Since there is only one opening, the amount of fluid in the pipe is directly proportional to the rate of inflow into the pipe. Let's say that congestion in the pipe will cause leakage and hence fluid loss. With knowledge of the pipe size and rate of inflow, the amount of fluid loss will be determinable. Therefore, by using pipes with the right sizes, we can determine the exact fluid loss that may occur.

Using this concept, we can assign an[1] ATM pipe to each source-destination pair to carry traffic. Since the amount of traffic that travels in the pipes is unique to each source-destination pair, the pipe sizes are also different for each source-destination pair. Similarly each source-destination pair may have a different loss rate. An example of a network consisting of ATM pipes is shown in Figure 2. This is a network that consists of 4 hosts, and each host communicates with each other, hence, the fully connected graph.

Before the ATM pipe network can be used, a corresponding physical LATM network has to be designed (Figure 3). Since more than one physical network can be created from a single ATM pipe logical network (using different combinations of switches and wiring of the links, etc.), techniques have to be applied is that the physical network that is created is both functionally equivalent to the logical network and cost effective. In devising this physical LATM network, special attention is made to utilize ATM-specific components (for example, ATM switches and point to point links). This is essential as our aim is to produce a truly ATM network.

In the physical LATM network, the logical ATM pipes are essentially imple-

---

[1] Theoretically, more than one pipe can be assigned to each source-destination host pair

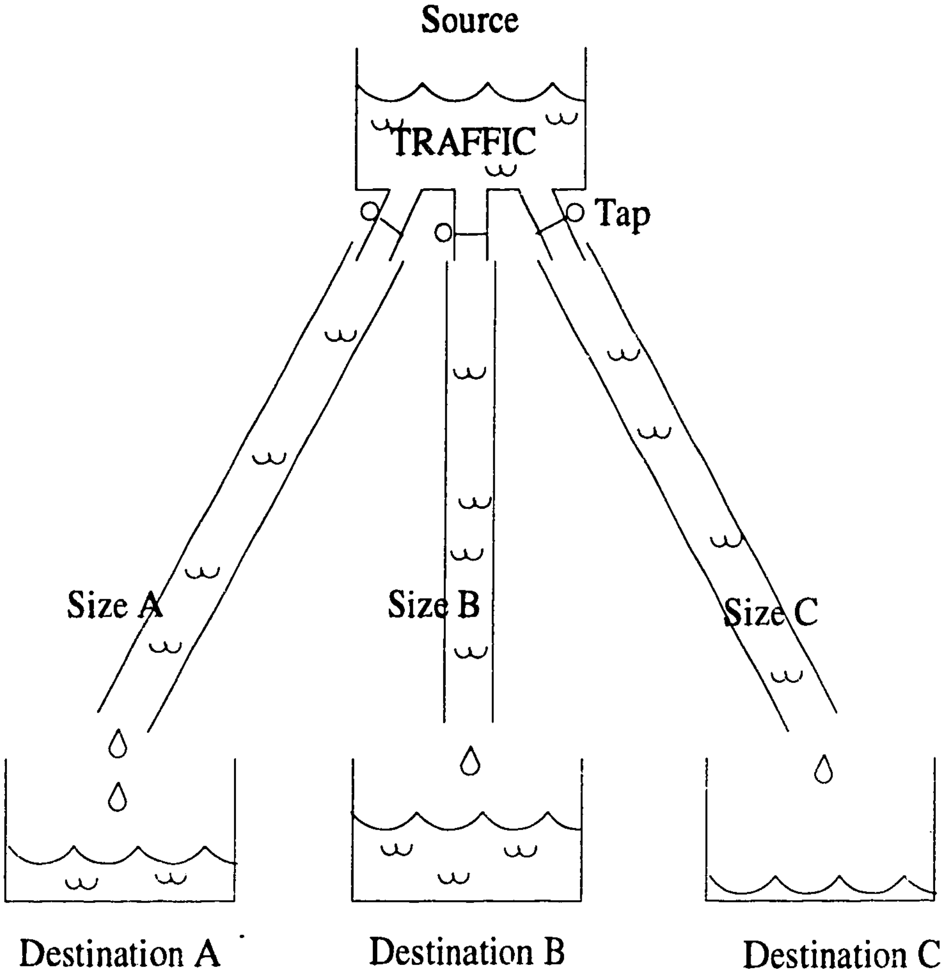


Figure 1: *The ATM Pipe Concept*

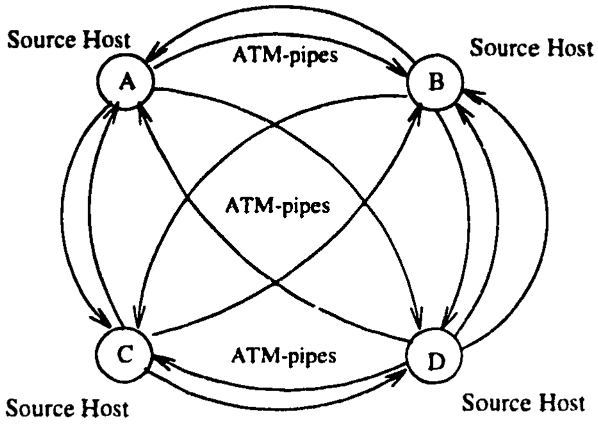


Figure 2: *A 4 Host ATM Pipe Network*

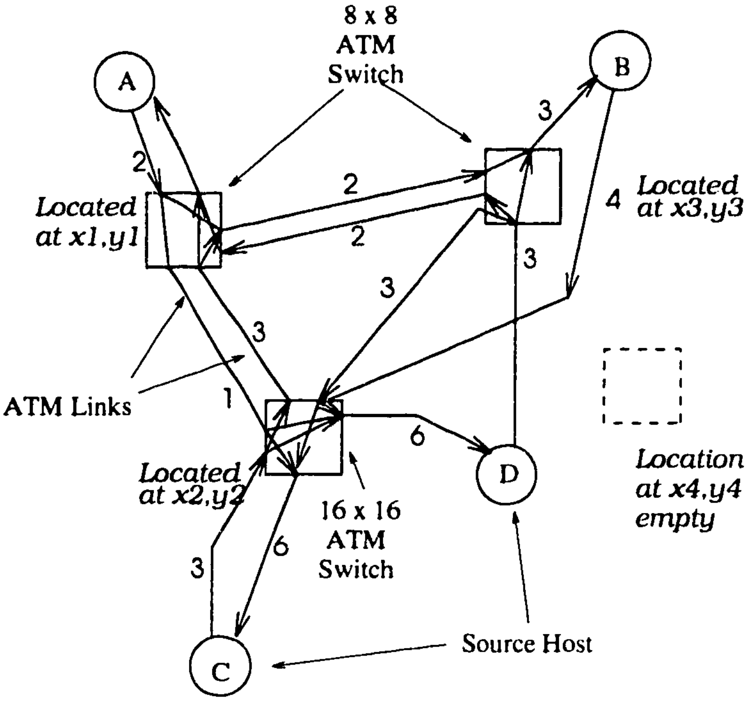


Figure 3: *A Corresponding LATM Network*

mented as permanent virtual paths. With these virtual paths, a set of links or a concatenation of links and switch ports are dedicated to serving each virtual path, so that the effective bandwidth is equivalent to the pipe size. Hence, given the ATM pipe network, the physical topology construction algorithm then decides on the number and dimensions of the switches and the interconnection of these switches with other switches/hosts. The routing of the virtual paths are also computed alongside.

The Power of the ATM Pipe Concept

The power of the ATM pipe concept is its ability to separate the performance aspects and the topology optimization aspects for building a network. While it is not uncommon for topology designers to optimize on performance [16, 9] rather than the cost of hardware, we have chosen the latter as it is hard to optimize on both performance and cost at the same time. By having a pipe between a source and destination, and producing a network based on these pipes, we are essentially producing a 'no wait' network since there is always enough bandwidth (because of the pipes) to handle the traffic, as long as all the hosts do not transmit beyond their pipe sizes. Since all traffic goes in its own pipe, there will essentially be no congestion at all. Furthermore, some other QOS requirements can be implicitly solved. For example, the delay jitter (that is caused by cells' contention for the same output port) will be virtually eliminated. Within the network, delay is limited to fixed delays of switching time and propagation delay in the links.

In this work, we will adopt the traffic loss probability as our main QOS requirement (as our network is a local area network, we assume that the end-to-end delay is satisfied, since it is extremely small). This loss probability will be specified by the network designer when he/she calculates the required pipe sizes.

3.3 PHASE I: Generating the ATM Pipe Network

The ATM pipe Network is simple. It can be represented by a graph $G =< V, E >$, where $V = \{v_i | i = 1, 2, ...N\}$ is the set of vertices, and $E = \{e_j | j = 1, 2, ...M\}$ is the set of directed edges for graph G. Each vertex v_i corresponds to a host machine, and each edge e_j corresponds to an ATM pipe that flows from a source $s(e_j)$ to a destination $d(e_j)$. Each ATM pipe e_j has a capacity denoted by $c(e_j)$. In practice, graph G will most likely turn out to be a fully connected graph, since all hosts will most likely wish to communicate with all other hosts. Figure 2 is an example of a fully connected ATM pipe network G.

To complicate things a little, the traffic from a host machine to a destination machine is a multiplexed stream of traffic produced by possibly more than one process in that host. Also each stream of traffic generated by these processes are non-identical. In order to produce the right pipe size for the edges, we propose an analytical method to determine the pipe sizes. We call this method the Multiclass Heterogeneous On/Off Fluid Flow Model.

3.4 The MCFF Fluid-flow Model

The Multiclass Heterogeneous On/Off Sources Fluid Flow Model (hereinafter referred to in short form as MCFF) is a burst scale model of traffic generated by multiple sources. It approximates the arrival of data cells as continuous streams of fluid which arrive at fixed rates. The fluid is then 'drained', at a rate determined by the size of the pipe through which these streams of fluid flow[2]. Since the arrival and service rate of this fluid is fixed, the Fluid-Flow Model is also known as the Uniform Arrival and Service (UAS) model.

The UAS Fluid-Flow model was first introduced in a paper by Kosten [20] in 1974, and later improved upon by Anick, Mitra and Sondhi in [1]. Since then, it has gradually gained popularity as a method for modelling traffic in communication networks, including ATM networks. Examples of such efforts can be found in [4, 39, 21, 26, 7].

In 1988, Tucker [39] applied the UAS Fluid-Flow model to model the effects of a speech multiplexer, specifically for obtaining the loss probability as well as the cumulative distribution function of the buffer queue-length. In Tucker's paper, a number of identical speech sources generate data that are fed into a multiplexer. We have adopted and modified Tucker's method to model the effects

---

[2] Hence, the name Fluid-Flow Model

of multiplexed ATM communication sessions, rather than that of multiplexed short talk-spurts as originally done by Tucker. During a communication session, a source transmits its data at a fixed rate. We call this rate of arrival the intensity of the flow. The major advantage of our method over Tucker's method is that sources can be non-identical, that is, heterogeneous instead of homogeneous. Essentially what that means is that sources can possess different traffic characteristics instead of being uniform. For comparison, a summary of Tucker's method is included in Appendix A.

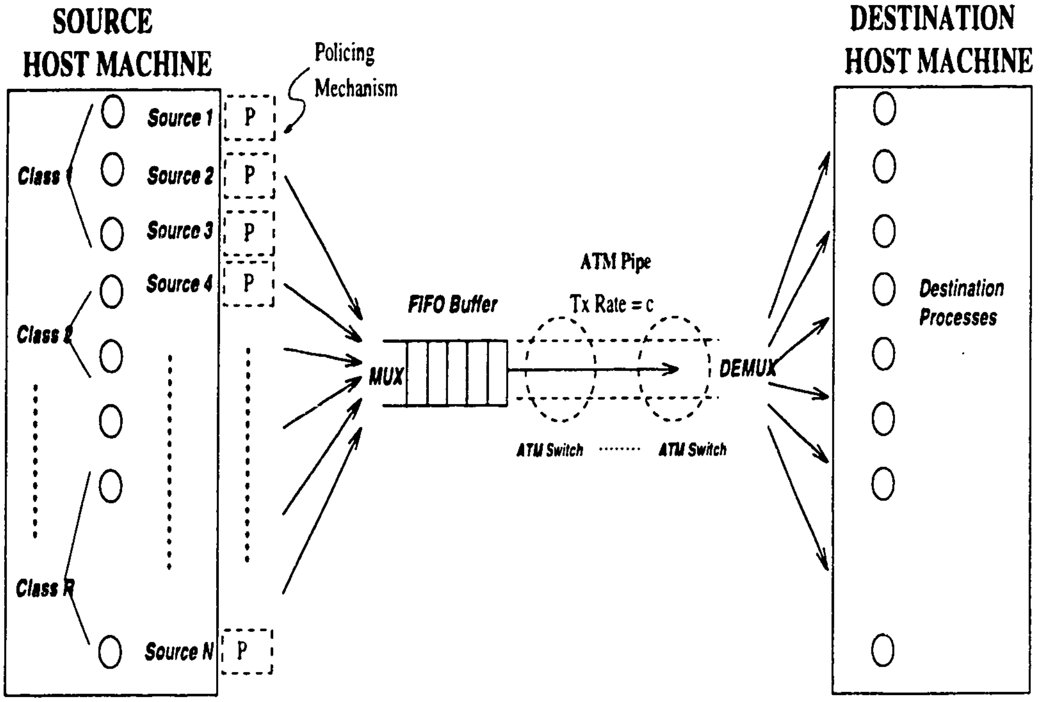


Figure 4: *The Fluid-Flow Model*

Figure 4 shows a conceptual diagram of the MCFF fluid-flow model. Sources at the entry end of the ATM pipe alternate between two states, that is the On state, and the Off state. We assume that the On and Off periods are exponentially distributed. During the On period, traffic flows through a policing mechanism, into a buffer, and then is transmitted onto an ATM pipe en route to the destination station. The function of these policing mechanisms is to ensure that sources do not violate the maximum bandwidth that they are supposed to transmit.

3.4.1 The Mathematical Analysis of MCFF

The main objective for the analysis of MCFF is to find out the size of the ATM pipe c that is just large enough to satisfy the usages of the traffic sources. With knowledge of the parameters for the sources and the classes to which they belong, and a particular c, we are then able to calculate the loss probability using MCFF. Ideally, we want to be able to calculate the pipe size given a loss probability, however through experimentations, we can find pairs of c and loss to obtain our desired pipe size.

This loss probability is expressed as a quality of service requirement by the pipe designers. Since MCFF approximates the traffic as fluid, there is no concept of packetization. Hence it cannot model the short-term fluctuations in the buffer into which cells arrive.

As shown by Tucker in [39], state equations that form Markov Chains are first derived while taking into account the fluid change in the buffer. At equilibrium probability, these state equations generate differential equations. These differential equations are then solved, and subsequently used to calculate the loss probability of the fluid.

Parameters

Given N traffic sources, each of which belongs to one of R classes such as voice, video and data, we can model the arrival of the traffic from these sources as individual bursts with the following parameters:

$$\begin{aligned} \text{Mean on period} &= \mu_u^{-1} && (3.1) \\ \text{Mean off period} &= \lambda_u^{-1} && (3.2) \\ \text{Flow intensity} &= i_u && (3.3) \end{aligned}$$

where u is the class to which each these sources belong. Note that a burst is actually a communication session and the intensity of the flow denotes the amount of bandwidth (in Mbps) dedicated for use by that session.

The MCFF Markov Chain

The Markov Chain [19] has been used widely to study exponentially distributed analytic problems. Figure 5 shows a diagram of the transitions in and out of a state in the Markov Chain used in MCFF. The Markov chain models the On/Off sources as a birth-death process, where a state in the Markov chain describing the number of On sources in each class can move to another state with certain rates, prompted by an arrival (birth) and departure (death) of an On period. Let

$$S = \{s_1, s_2, s_3, \dots, s_R\} \tag{3.4}$$

be a state S where $s_u, 1 \le u \le R$ denotes the number of traffic sources in class u that are in the On period. Relative to S, we define adjacent states to S as

$$\begin{aligned} S(s_u+) &= \{s_1, s_2, \dots, s_u + 1, \dots, s_R\}, \quad 1 \le u \le R \\ S(s_u-) &= \{s_1, s_2, \dots, s_u - 1 \dots, s_R\}, \quad 1 \le u \le R \end{aligned} \tag{3.5}$$

Let $r\{S_i, S_j\}$ =transition rate from state S_i to state S_j. Since the inverse of a mean is the rate, the birth and death rates of the Markov Chain can be defined as

$$\begin{aligned} r\{S(s_u+), S\} &= (s_u + 1)\mu_u \\ r\{S(s_u-), S\} &= (w_u - s_u + 1)\lambda_u \end{aligned}$$

or alternately,

$$\begin{aligned} r\{S, S(s_u-)\} &= s_u\mu_u \\ r\{S, S(s_u+)\} &= (w_u - s_u)\lambda_u \end{aligned}$$

where w_u denotes the number of sources belonging to class u. The flow rate out of state S would be the summation of all rates moving out of state S.

$$r^*\{S\} = \sum_{u=1}^{R}\{s_u\mu_u + (w_u - s_u)\lambda_u\}$$

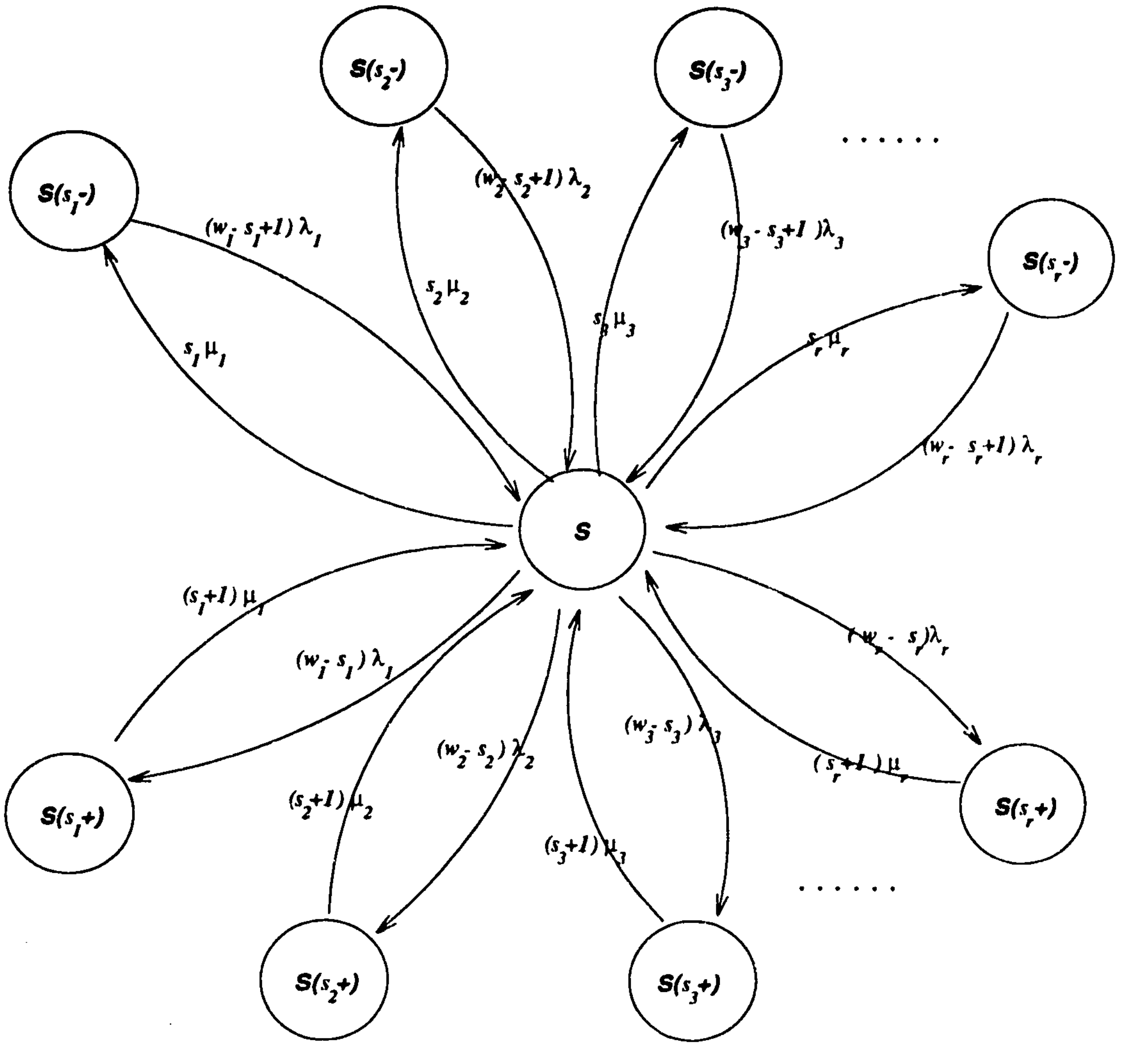


Figure 5: *The General Heterogeneous On/Off Sources Markov Chain*

Note that the birth and death rates prevent S from moving to an invalid state, that is a state where $(s_u - 1) \in S(s_u-)$ is less than zero or where $(s_u+1) \in S(s_u+)$ is greater than w_u. This is so because the transition rates $r\{S, S(s_u-)\} = 0$ when $s_u = 0$ and $r\{S, S(s_u+)\} = 0$ when $s_u = w_u$.

Deriving the State Equations

As mentioned in [39], the state equations are set by noting the buffer queue behaves in the following manner

1. If the fluid inflow rate > the outflow rate c, the buffer queue increases steadily at a rate of (inflow rate - c). When the queue limit m is reached, the queue will remain at its limit.
2. If the fluid inflow rate < the outflow rate c, the buffer queue decreases steadily at a rate of (c - inflow rate). When the queue reaches empty, it will stay empty.
3. If the fluid inflow = the outflow rate c, the queue level in the buffer does not change.

Define $P_S(t, x), \forall s_u \in S, 0 \leq s_u \leq w_u, 1 \leq u \leq R; t \geq 0; m > x > 0$ be the probability that given that the number of sources in the On state are S, the content of the buffer is not more than x at time t, with a buffer limit of m, we obtain,

$$\begin{aligned} P_S(t + \Delta t, x) = & \sum_{u=1}^{R} [P_{S(s_u-)}\{t, x - (B(S(s_u-)) - c)\Delta t\} r\{S(s_u-), S)\}\Delta t \\ & + P_{S(s_u+)}\{t, x - (B(S(s_u+)) - c)\Delta t\} r\{S(s_u+), S)\}\Delta t] \\ & + P_S\{t, x - (B(S) - c)\Delta t\}(1 - r^*\{S\}\Delta t) + o(\Delta t) \\ & 0 < x < m \end{aligned} \tag{3.6}$$

where $B(S)$ is the aggregate rate of input fluid. That is

$$B(S) = \sum_{u=1}^{R} s_u(i_u), s_u \in S$$

From (3.6). moving the $P_S\{t, x-(B(S)-c)\Delta t\}$ term to the left hand side, dividing both sides by Δt,

$$\begin{aligned}
&\frac{P_S(t+\Delta t, x)}{\Delta t} - \frac{P_S\{t, x-(B(S)-c)\Delta t\}}{\Delta t} = \\
&\sum_{u=1}^{R}[P_{S(s_u-)}\{t, x-(B(S(s_u-))-c)\Delta t\} r\{S(s_u-), S)\} \\
&+P_{S(s_u+)}\{t, x-(B(S(s_u+))-c)\Delta t\} r\{S(s_u+), S)\}] \\
&-P_S\{t, x-(B(S)-c)\Delta t\} r^*\{S\} \\
&0 < x < m \qquad (3.7)
\end{aligned}$$

approximating the L.H.S. and letting $\Delta t \rightarrow 0$, Equation (3.7) becomes

$$\begin{aligned}
\frac{\delta P_S(t,x)}{\delta t} + \frac{(B(S)-c)P_S(t,x)}{\delta x} &= \sum_{u=1}^{R}[P_{S(s_u+)}(t,x) r\{S(s_u+), S\} \\
&+P_{S(s_u-)}(t,x) r\{S(s_u-), S\}] \\
&-P_S(t,x) r^*\{S\} \\
&0 < x < m \qquad (3.8)
\end{aligned}$$

At equilibrium probability ($t \rightarrow \infty$), the first term on the L.H.S is equal to zero. Defining $F_S(x)$ as the equilibrium probability that with the number of On sources in each class $= s_u, s_u \in S$, the buffer content is less than or equal to x,

$$\begin{aligned}
(B(S)-c) dF_S/dx &= \sum_{u=1}^{R}[F_{S(s_u+)}(x) r\{S(s_u+), S\} \\
&+F_{S(s_u-)}(x) r\{S(s_u-), S\}] \\
&-F_S(x) r^*\{S\} \\
&0 < x < m \qquad (3.9)
\end{aligned}$$

State Equations in Matrix Form

Since the number of On sources in class $u, 1 \leq u \leq R$ can take a value from 0 to w_u, the total number of possible values for S is $z = \prod_{u=1}^{R}(w_u + 1)$. Therefore, we have a total of z differential equations. We can write the differential equations in matrix form,

$$\mathbf{D} d\mathbf{F}(x)/dx = \mathbf{M}\mathbf{F}(x) \quad 0 < x < m \qquad (3.10)$$

where $\mathbf{D} = \text{diag}(\mathbf{TH} - c)$. $\mathbf{T}$ is defined as a $z \times R$ matrix of all possible values for S. Each Column $\mathbf{T}_{.j}$ in $\mathbf{T}$ corresponds to class j of S. Hence, each row is a possible set S. Later, we shall use $\mathbf{T}_{i.}$ as a value of S interchangeably. We call the matrix $\mathbf{T}$ a Truth Matrix. One example for $\mathbf{T}$ can be

$$\mathbf{T} = \begin{bmatrix} 0 & 0 & 0 & & 0 \\ 1 & 0 & 0 & & 0 \\ 2 & 0 & 0 & & 0 \\ & & \vdots & \cdots & \\ w_1 & 0 & 0 & & 0 \\ 0 & 1 & 0 & & 0 \\ 1 & 1 & 0 & \cdots & 0 \\ & & \vdots & & \\ w_1 & w_2 & w_3 & \cdots & w_R \end{bmatrix} \tag{3.11}$$

$\mathbf{H}$ is an $R \times 1$ column matrix of intensities, i.e. $(i_1, i_2, \ldots, i_R)^T$, and c is the outflow rate.

$\mathbf{M}$, which is evident from equation (3.9) is a $z \times z$ matrix of inflow transition rates, that is

$$\mathbf{M}_{ij} = \begin{cases} r\{S(s_u-), S\}, & \text{if } \mathbf{T}_{i.} = S, \mathbf{T}_{j.} = S(s_u-) \\ r\{S(s_u+), S\}, & \text{if } \mathbf{T}_{i.} = S, \mathbf{T}_{j.} = S(s_u+) \\ -r^*(\mathbf{T}_{i.}), & \text{if } i = j \\ 0 & \text{otherwise} \end{cases}$$
$$1 \leq u \leq R \tag{3.12}$$

We can then use the eigenvalues and eigenvectors method to solve for $\mathbf{F}$.

Solving the State Equations

Eigenvalues and Eigenvectors An eigenvalue α is said to be a value that when multiplied with a vector $\mathbf{k}$ of size n, produces a result which is the product of an $n \times n$ matrix $\mathbf{A}$ multiplied with the vector $\mathbf{k}$. That is,

$$\alpha\mathbf{k} = \mathbf{Ak} \tag{3.13}$$

By rearranging (3.13) to

$$(\mathbf{A} - \alpha\mathbf{I})\mathbf{k} = 0 \tag{3.14}$$

where $\mathbf{I}$ is an identity matrix of size $n \times n$, we can find values for α and hence $\mathbf{k}$, by solving for the roots of the characteristic polynomial of equation (3.14), which is obtained from solving

$$\det(\mathbf{A} - \alpha\mathbf{I}) = 0 \tag{3.15}$$

The roots of the characteristic polynomial are the eigenvalues for (3.14). With each of these eigenvalue, a vector $\mathbf{k}$ can be computed from equation (3.14). This vector $\mathbf{k}$ is known as the eigenvector corresponding to the eigenvalue from which $\mathbf{k}$ is computed.

We rewrite equation (3.10) as

$$d\mathbf{F}(x)/dx = \mathbf{D}^{-1}\mathbf{M}\mathbf{F}(x) \quad 0 < x < m \tag{3.16}$$

By assuming F to be of the form $e^{\alpha x}\mathbf{k}$, we can obtain the eigenvalues and their corresponding eigenvectors by solving the characteristic equation

$$\det(\mathbf{D}^{-1}\mathbf{M} - \alpha\mathbf{I}) = 0 \tag{3.17}$$

The general solution as shown in [39] will be in the form of

$$\mathbf{F}(x) = a_1 e^{\alpha_1 x}\mathbf{k}_1 + a_2 e^{\alpha_2 x}\mathbf{k}_2 + a_3 e^{\alpha_3 x}\mathbf{k}_3 + \cdots + a_z e^{\alpha_z x}\mathbf{k}_z \quad 0 < x < m \tag{3.18}$$

By setting the proper values for the system of $\mathbf{F}(x)$'s, the coefficients a_j, $1 \leq j \leq z$ can be found by standard numerical algorithms. These values are defined by setting boundary conditions.

The Boundary Conditions

The contents of the buffer varies according to the rate of input of fluid, that is the rate of inflow of data into the buffer. Let us define $\hat{F}_S$ as the probability that the number of active sources in each class is S, and $\tilde{F}_S(x)$ as the probability that the contents of the buffer is greater than $x, 0 < x < m$, given that the number of active sources in each class is S. We also define $F_S(x)$ as the probability that the contents of the buffer is less than or equals $x, 0 < x < m$, given that the number of active sources in each class is S. We then get,

$$\hat{F}_S = \tilde{F}_S(x) + F_S(x) \tag{3.19}$$

$\hat{F}_S$ is simply

$$\hat{F}_S = \prod_{j=1}^{R} p_j^{s_j} q_j^{w_j - s_j} \begin{pmatrix} w_j \\ s_j \end{pmatrix}, \quad s_j \in S \tag{3.20}$$

where p_j is the probability that a source belonging to class j is on, and q_j is the probability that it is off, which can be specified as the ratio of the On or Off mean over the summation of the two. In other words

$$\begin{aligned} p_j &= \frac{\lambda_j}{\lambda_j + \mu_j} \\ q_j &= \frac{\mu_j}{\lambda_j + \mu_j} \\ &= 1 - p_j \end{aligned} \tag{3.21}$$

and $\begin{pmatrix} w_j \\ s_j \end{pmatrix}$ denotes w_j choose s_j.

By defining boundary conditions, the set of differential equations can be solved. The boundary conditions are set observing the fact that

1. If the rate of input is greater than the rate of output, that is $(\mathbf{T}_i.\mathbf{H} - c) > 0$ then the contents of the buffer will always be increasing. The buffer in this case will never reach its empty state. Therefore we can set $F_S(0) = 0$.

2. If the rate of input is less than the rate of output, that is $(\mathbf{T}_i.\mathbf{H} - c) < 0$ then the contents of the buffer will always be decreasing. The buffer in this case will never reach its limit. $\tilde{F}_S(x)$ will be $= 0$, hence $F_S(m^-) = \hat{F}_S$. Stirctly speaking, since the state equations does not apply when the buffer is at its limit m, we can set the x to $m^- = \lim_{x \to m}$. Nevertheless, we are able to calculate $F_S(m^-)$ by setting $x = m$ in (3.18).

Calculation of the Loss Probability

With the set of linear differential equations solved, the equilibrium rate of fluid loss can be obtained by simply multiplying the probability of the buffer held at its limit, for all possible combinations of S, with the net rate of inflow to the buffer.

$$\text{Total Loss} = \sum_{j=1}^{z} (\mathbf{T}_j.\mathbf{H} - c)\tilde{F}_{\mathbf{T}_j}(x) \tag{3.22}$$

The loss probability is expressed as the ratio of total rate of fluid loss over total rate of fluid inflow. Since each source belonging to class j is in the active state $\lambda_j/(\lambda_j + \mu_j)$ of the time, the total rate of inflow is

$$\text{Total Flow} = \sum_{j=1}^{R} (\frac{\lambda_j}{\lambda_j + \mu_j}) w_j i_j \tag{3.23}$$

Hence, the loss probability is obtained by

$$\text{Loss Probability} = \frac{\text{Total Loss}}{\text{Total Flow}} \tag{3.24}$$

3.4.2 The Computation of MCFF

The analysis of MCFF was computed on a Sun4 computer using the MATLAB math package. As pointed out by Tucker, the $e^{\alpha_j x}$ term can overflow easily for positive eigenvalues. This can avoided by solving for $a_j e^{\alpha_j}$ instead of just a_j in equation 3.18. This is alright because we need both a_j multiplied with e^{α_j} to calculate $F_S(x)$ in equation 3.18.

An advantage to using MATLAB is that computations can be programmed easily. However, the disadvantage is that we we have no knowledge to the algorithms and implementation of the routines. Thus, results might may be less accurate for extremely large or small numbers.

3.5 Simulation Study

To verify the accuracy of the MCFF mathematical analysis, we have performed a simulation study. In the simulations, the loss probability of the ATM pipes were recorded and compared with those obtained by the MCFF analysis.

We have chosen to model the arrival of ATM traffic in our simulations as continuous streams of fluid with no concept of cell packetization. The reason for doing this is two fold: The first reason is that since we are modelling entire communication sessions as a burst, where on average up to 1.8 Gigabytes of data can be transmitted. In this case, the effects caused by packetization at the physical layer is most likely negligible. The second reason is that we do not wish to assume any particular transmission scheme for the physical layer, since the packetization in these schemes vary extensively. For example, the SONET transmission scheme packs ATM cells into its 810-byte frames whereas TAXI transmits ATM cells raw without additional packetization. In future research, if the effects on the cell-scale as well as burst-scale need to be studied, additional analytic methods can be adapted. For example, Kroner, Eberspacher and Theimer [21] applied the fluid-flow approximation in conjunction with an *M/D/1-S* sub-model while Liao and Mason [26] used the fluid-flow approximation with a $G/D/1$ queuing sub-model for modelling the effects at both the burst and cell levels.

In each simulation run, over 10 million events are generated and the resultant loss probability measured. An event is essentially an arrival of an On or Off period for any of the N sources. We have divided each run into a hundred batches, and the loss probability in each batch is recorded. Since the simulations start with all sources being off and the buffer empty, a warm-up period of 3000 events is passed before any real measurements begin. This is done so that the system reaches a state of equilibrium and the transient effects eliminated. The mean loss probability $\bar{x}$ and its corresponding 95% confidence interval are subsequently calculated with the following formulas:

$$\begin{aligned}
\bar{x} &= \frac{\sum x_i}{n} \\
95\%\ \textit{Confidence Interval} &= \bar{x} \pm z_{1-\alpha/2} \cdot \frac{S_{\bar{x}}}{\sqrt{n}} \\
S_{\bar{x}}^2 &= \frac{\sum (x_i - \bar{x})^2}{n-1} \qquad (3.25)
\end{aligned}$$

where x_i the loss probability for batch i, $S_{\bar{x}}$ is the standard deviation associated with the mean $\bar{x}$, n is the number of batches which is 100, and for a 95% confidence interval $z_{1-\alpha/2}$ is equals to 1.96.

3.5.1 Simulation Parameters

The parameters involved in the simulations are:

- *Pipe Sizes.* This is the rate that the input traffic are transmitted onto the links, expressed in Megabits per second (Mbps).
- *Buffer Size.* This is the size of the buffer that holds the traffic before being sent out to the network, expressed in seconds[3].
- *Number of Classes and their Related Parameters.* In our case, the number of classes is 4, and the related parameters are the number of sources in a class, the mean On and Off periods in each class (in seconds), and the intensity for associated with a class(in Mbps).

The values for the pipe sizes range from 0.05 Mbps to 34 Mbps depending on the rate of inflow of the traffic. The values for the buffer size range from 0.5 to 3.0. However, since the buffer value directly determines the maximum queuing delay [4] possibly experienced by the traffic, we have chosen to fixed buffer size to 0.5 seconds for most simulations.

3.5.2 Class Parameters

To make our simulations as realistic as possible, we have chosen 4 of the most common types of traffic for ATM networks. They are:

- *File Transfers (FT)*
- *Constant Bit Rate Voice (CV)*
- *Video Telephony (VT)*
- *Video Retrieval (VR)*

---

[3] The equivalent buffer size in bits can be converted easily by multiplying the buffer size in seconds with the line transmission rate (i.e, the pipe size)

[4] Some traffic especially real-time traffic such as video and voice are sensitive to delays experienced in the transmission. These traffic will be rendered useless if they are kept too long in a buffer. Therefore, this value should not be too large.

The corresponding intensities and On/Off means for the above classes are presented in the following table. These parameters are taken from [35]. Note that the parameters vary greatly from one class to another. For example, the File Transfer class has a relatively short On mean of 1 second compared to the Video Retrieval class with an On mean of 3 minutes. In addition, the Video Transfer class has the highest intensity at 10Mbps, compared to the intensity for the Constant Bit Rate Voice class at 64kbps which is 156 times smaller.

Class Type	*On mean (s)*	*Off mean (s)*	*Intensity (Mbps)*
File Transfer (FT)	1	333.333333	2
Constant Bit Rate Voice (CV)	100	1250	0.064
Video Telephony (VT)	100	5000	10
Video Retrieval (VR)	180	1801.8018	10

Table 3.1: *The Four Traffic Classes*

3.6 Simulation Results

Simulations for multiclass traffic are run. A total of 8 mixes from 2 sets with different number of traffic sources are defined. Mixes in the first set contain a total of 6 traffic sources from the 4 classes, whereas the second set contains a total of 10 traffic sources. The number of sources in each of the 4 classes for set one is shown in Table 3.2, whereas the number of sources in each of the 4 classes for set two is shown in Table 3.3

Class Type	*Mix 1*	*Mix 2*	*Mix 3*	*Mix 4*
File Transfer (FT)	1	1	3	1
Constant Bit Rate Voice (CV)	1	1	1	3
Video Telephony (VT)	1	3	1	1
Video Retrieval (VR)	3	1	1	1

Table 3.2: *Set One Multiclass Traffic Mixes (6 sources)*

As we can see in Tables 3.2 and 3.3, the number of sources in each class are chosen so that one of the classes dominate the traffic. This is done so as to examine the effects these classes have on the loss probability.

Class Type	*Mix 1*	*Mix 2*	*Mix 3*	*Mix 4*
File Transfer (FT)	1	2	6	2
Constant Bit Rate Voice (CV)	1	1	1	6
Video Telephony (VT)	2	6	2	1
Video Retrieval (VR)	6	1	1	1

Table 3.3: *Set Two Multiclass Traffic Mixes (10 sources)*

The results of the simulation runs along the results obtained from the MCFF analysis for set 1 are shown in Figure 6 and set 2 in Figure 7. In these two figures, the traffic loss probability is plotted against the pipe sizes ranging from 6 Mbps to 20 Mbps. The buffer size is set at 5.0 seconds. As we can see, the graphs shows that the results from MCFF is extremely close to that obtained by simulation. All of the points generated with MCFF lie within their corresponding 95% confidence interval obtained from the simulation runs. This means that MCFF is very accurate.

It is interesting to note that in Figure 6 mixes 3 and 4 exhibit almost identical loss probabilities for the same pipe size. While Mix 3 and Mix 4 have the same composition for the VT and VR classes, Mix 3 has 3 sources in the FT class, and 1 in the CV class, whereas Mix 4 has only 1 in the FT class and 3 in the CV class (Table 3.2). With three sources in the FT class generating an intensity of 2 Mbps each, Mix 3 should exhibit more loss for the same pipe sizes as compared to Mix 4 which has three sources in the CV class generating at a mere 64kbps each. The reason lies in the lengths of the On mean and the Off means for the two classes. Although file transfers use up 2 Mbps each, their average session time is much shorter than that for the CBR Voice. In short, if we define the effective intensity of a class as the original intensity multiply by the fraction of the time a source is active, then the two mixes will show similar effective intensity. We show a calculation of this:

$$\text{Effective Intensity} = \text{Original Intensity} \times \text{Fraction of On Time} \quad (3.26)$$

where the fraction of On time is simply the probability of a source being On,

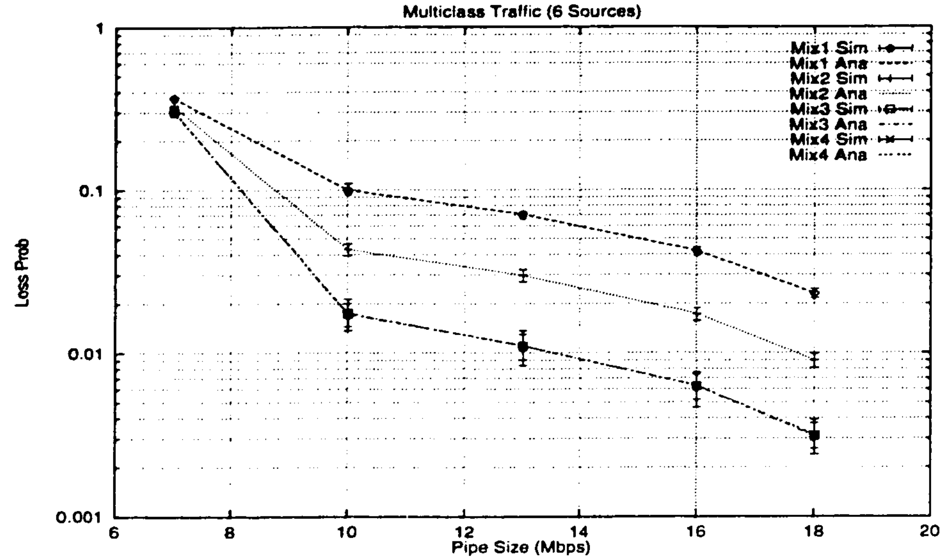


Figure 6: *Loss Probability vs Pipe Size for Multiclass Traffic (6 sources)*

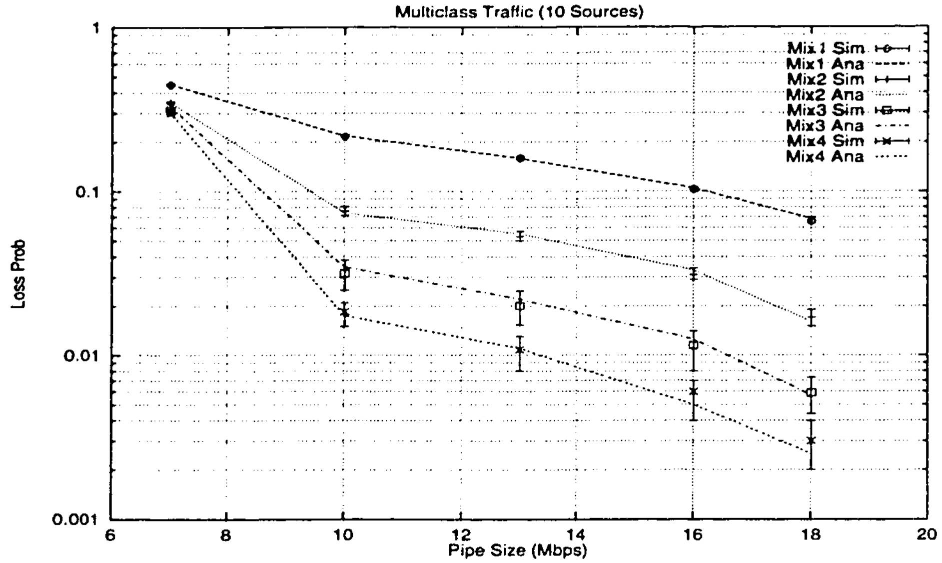


Figure 7: *Loss Probability vs Pipe Size for Multiclass Traffic (10 sources)*

which is

$$\textit{Fraction of On Time} = \frac{\textit{Mean On Period}}{\textit{Mean On Period} + \textit{Mean Off Period}} \quad (3.27)$$

The resultant fraction of on time for the FT class is 2.99×10^{-3} and that for the CV class is 0.074. Hence, the effective intensity for FT and CV are 5.98×10^{-3} and 4.74×10^{-3} respectively, which are very close. Table 3.4 shows the effective intensities for all classes. From Tables 3.2, 3.3, 3.4 and Figures 6 and 7, we can see that classes that have higher effective intensities have higher loss probabilities.

Class Type	*Effective Intensities (Mbps)*
File Transfer (FT)	5.982053×10^{-3}
Constant Bit Rate Voice (CV)	4.740740×10^{-3}
Video Telephony (VT)	0.1960784
Video Retrieval (VR)	0.9082644

Table 3.4: *The Effective Intensities for the Four Classes*

3.6.1 Single Class Traffic

To further examine the accuracy of MCFF, we have conducted simulations for the special case of one class, that is the case of homogeneous traffic. For each of the classes FT, CV, VT and VR, two sets of simulation runs are run with different pipe sizes. The first set contains 5 sources and the second contains 10 sources in a class. Again, the traffic loss probabilities in each run are obtained and subsequently plotted with the results from the MCFF computations.

In Figures 8 to 11, the results for homogeneous FT, CV, VT and VR traffic are plotted. Again, we find that the all loss probabilities computed with MCFF lie within their corresponding 95% confidence intervals obtained from the simulations. The results suggests that the MCFF mathematical analysis is indeed very accurate.

3.6.2 Effects of Pipe Multiplexing

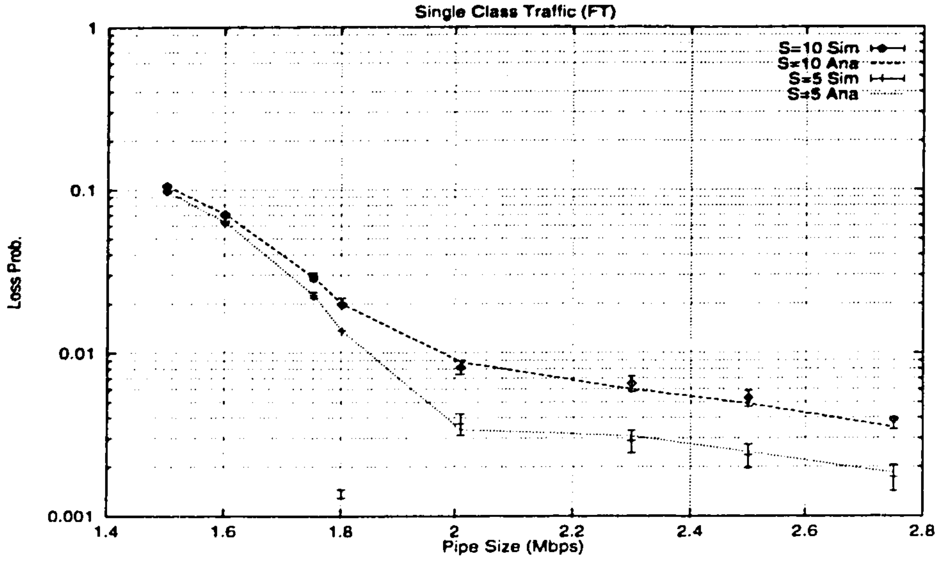


Figure 8: *Loss Probability vs Pipe Size for Single Class Traffic (File Transfer)*

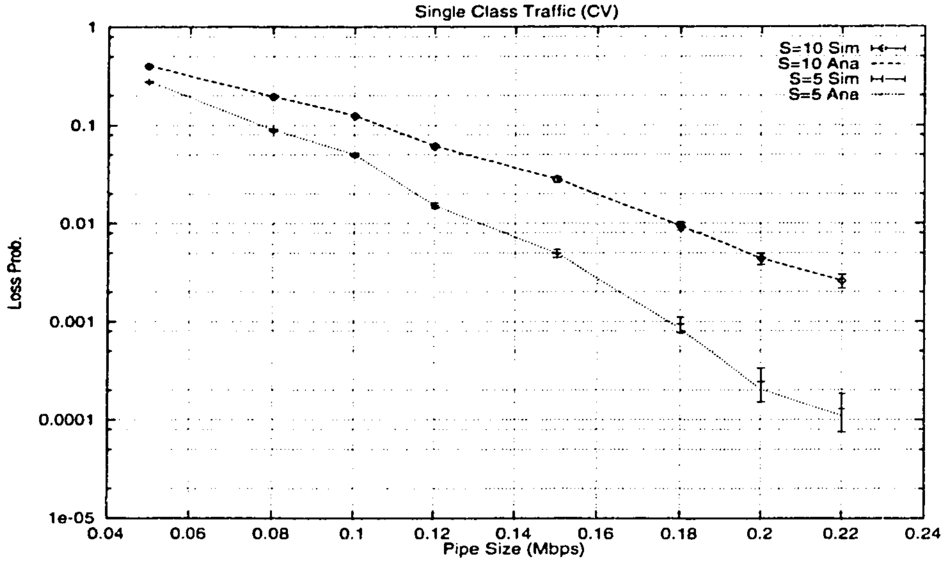


Figure 9: *Loss Probability vs Pipe Size for Single Class Traffic (CBR Voice)*

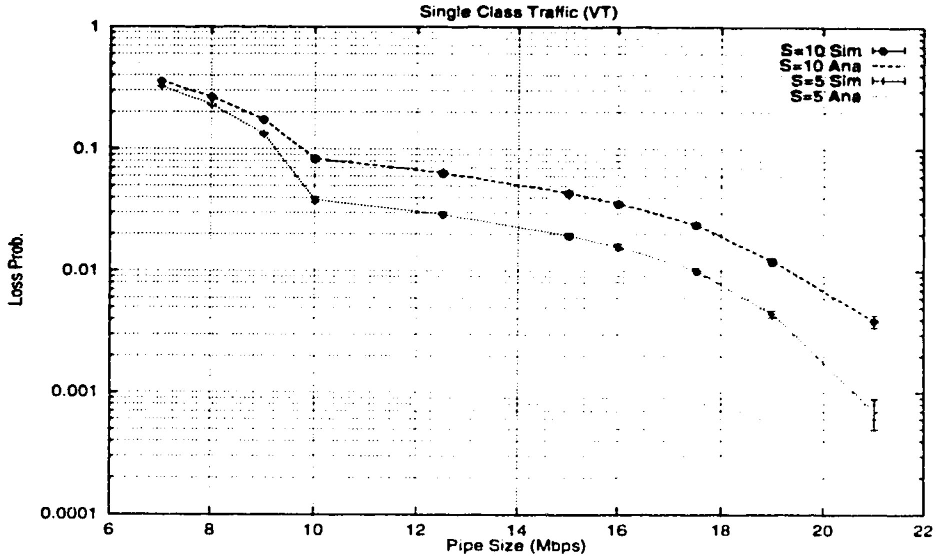


Figure 10: *Loss Probability vs Pipe Size for Single Class Traffic (Video Transfer)*

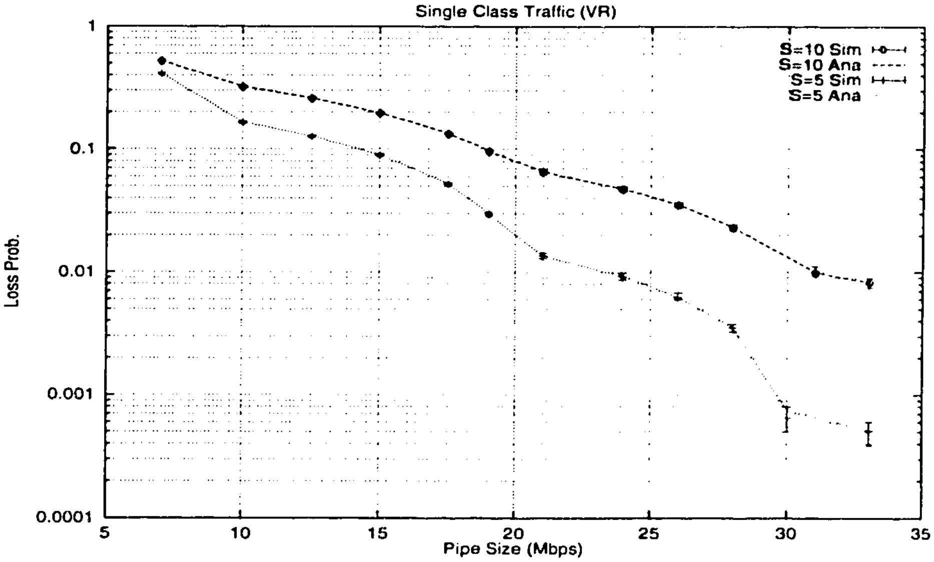


Figure 11: *Loss Probability vs Pipe Size for Single Class Traffic (Video Retrieval)*

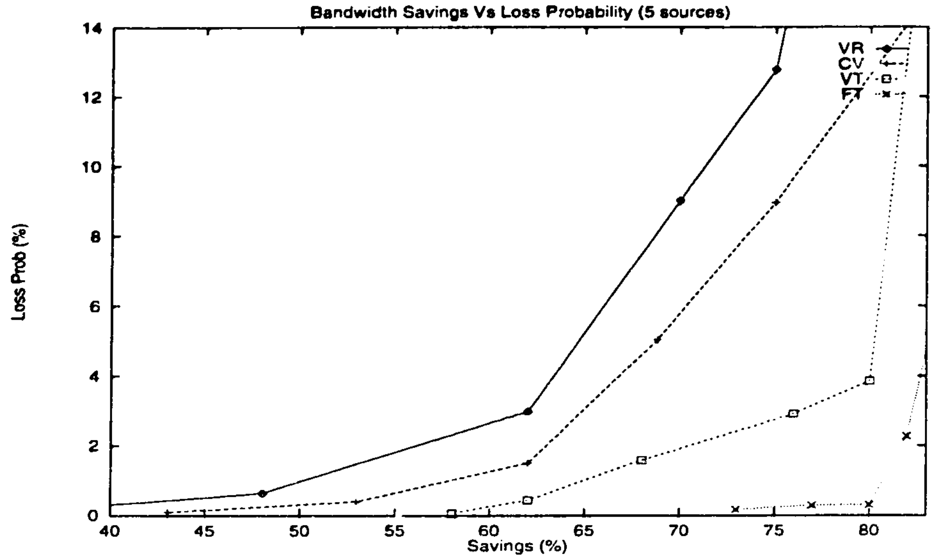


Figure 12: *Loss Probability vs Savings (5 sources)*

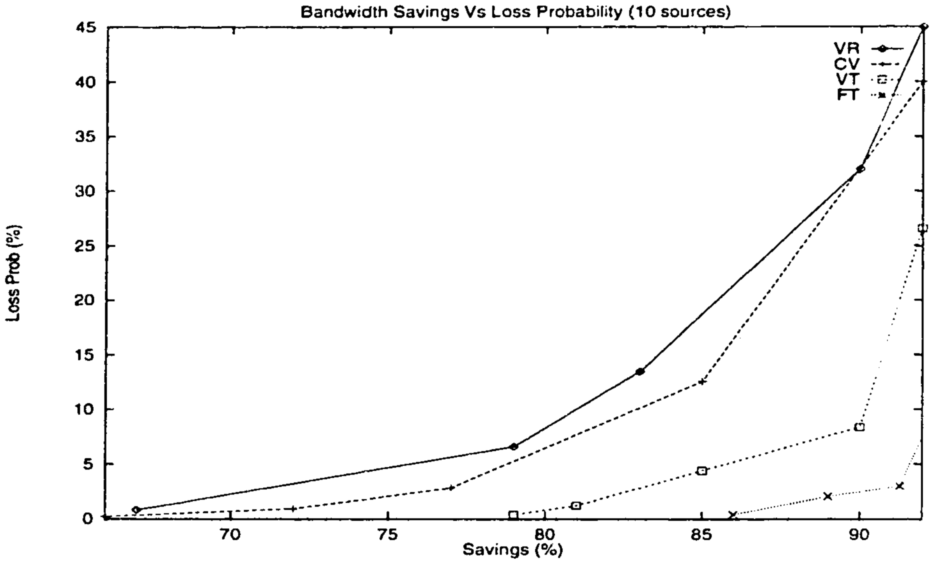


Figure 13: *Loss Probability vs Savings (10 sources)*

With the traffic from the various sources multiplexed onto the ATM pipe, the effective bandwidth will be less than that without multiplexing. This represents savings that is achieved by multiplexing traffic. We define the savings as the ratio between the multiplexed bandwidth i.e. the pipe size, and the unmultiplexed bandwidth, i.e. the aggregate intensities for all sources.

$$\text{Savings from Multiplexing} = \frac{c}{\sum_{u=1}^{R} s_u i_u} \tag{3.28}$$

where c denotes the pipe size, s_u denotes the number of sources in class u, and i_u denotes the intensity for class u. We have plotted the savings against the loss probability for the 5 source runs and the 10 source run for homogeneous traffic. They are shown in Figures 12 and 13.

As is evident from the graphs, the more savings that one desires, the more traffic losses will occur. In addition, the exponential shape of the savings curve suggests that the initial savings achieve the most reductions in traffic loss probabilities. Another interesting observation is that the more sources that share the same pipe, the more savings that one can achieve. This can be seen from the Figures 12 and 13. In Figure 12, where the traffic from 5 sources are multiplexed into a single pipe, for the loss probability of 5 % (VR traffic), the savings achieved is approximately 65%. However, at the same loss probability for the 10 source traffic multiplexing case (Figure 13), the achieved savings an increase of 10% to more at 75%. This can be explained by the individual buffer / shared buffer analogy. Multiplexing traffic sources is analogous to pooling buffers together for sharing. The more buffers that are pooled together the more efficient that the buffers can be utilized. Therefore, what this means is that unless for other reasons, one should always try to multiplex as many sources together in a single pipe, instead of multiplexing them in more than one pipe, as doing this will achieve more savings.

3.7 Limitations of the Verification

As is evident from the graphs that we have verified the loss probabilities of the MCFF model range down to about 10^{-3}, while ATM loss probabilities can be as low as 10^{-10}. The reason for this discrepancy is twofold: The first reason is that to verify the loss at the range of 10^{-10} will probably require special rare event simulation techniques so that meaningful results can be obtained. The second and probably the more dominant reason is that the we do not have a knowledge of how the computation package that we used, MATLAB, is implemented. For a set of differential equations, MATLAB generates only one eigenvalue with its corresponding eigenvector, while a set of differential equations can have more than one set of eigenvalue and eigenvector. We find that for small loss probabilities, we have to scale the eigenvalues and eigenvectors to obtain the loss probabilities that match the simulation results, hence, defying the whole purpose of verification.

3.8 Summary

In the chapter, we have presented an overview of the Pipe Based LATM Topology Design Methodology. A detailed description of Phase I of this methodology is also described. Phase I essentially deals with the calculation of the sizes of ATM pipes, which are the fundamental building block of our topology design methodology. We presented a analytical method, the Multiclass Heterogeneous Fluid-Flow model (MCFF), for calculating the pipe sizes.

Details of simulation runs for single class and multiclass traffic for verifying the correctness of MCFF were presented. And the results suggest that the MCFF analysis is very accurate, as all points calculated with MCFF lie within the 95% confidence interval of their corresponding simulation results.

Chapter 4

Phase II: Physical Topology Construction

4.1 Introduction

Given that the pipe sizes of each source-destination pair have been computed using the method presented in the previous chapter, and hence the ATM pipe network has been derived, we are set to construct a physical LATM topology based on these pipes. We present a method in this chapter for constructing such a topology.

4.2 Overview of Phase II

Phase II of the topology construction methodology applies a heuristical algorithmic approach to constructing a feasible topology. Heuristics, loosely defined as rule-of-thumbs have long been applied to topology design problems. [16] provides a overview to some heuristics algorithm used in topology design.

The physical topology construction algorithm starts off by generating a feasible topology based on the given pipe requirements. Then, applying heuristic algorithms, we try to improve the design of the initial topology by decreasing the cost of the topology. Note that the initial topology is already a feasible topology since it satisfies the given ATM pipe network. An advantage to this approach is that the topology is kept feasible throughout the whole process of Phase II. Therefore, no time is wasted on examining topologies that are non-feasible[1]. This dramatically cuts down on execution time.

Phase II can be divided into three parts. They are:

- *Part I: Initial Topology Construction.* In this part, an initial feasible topology is created given the pipe requirements. At this point, only the number, type and interconnections of these switches have been determined. As to the location of these switches, they will be handled by Part III.
- *Part II: Topology Improvement.* In this part, heuristical algorithms are applied to reduce the size of the initial topology, and hence the cost of the topology. Each iteration of the algorithm results in a topology that is feasible. We consider three different algorithms for this part. They are:
    1. *Random.*
    2. *Exhaustive.*
    3. *Neighborhood.*

  Each algorithm will be discussed in detail in Section 4.4.
- *Part III: Topology Location.* The resultant topology from Part II is a feasible topology at the logical level, that is each component of the topology has not been assigned a location in the real world. Since the location of these components directly affect the cost and the performance of the topology, their locations must be assigned in a way that is in some sense optimal. There are two algorithms considered for Topology Location. They are:
    1. *Random.*
    2. *Anchoring.*

  These algorithms will be presented in detail in Section 4.5.

---

[1] Topologies that do not satisfy the traffic constraints as defined by the given ATM pipe network

4.2.1 Switched ATM Network Requirement

The method that we present in this chapter is specifically for LATM networks, therefore certain assumptions exist so that the topology that is generated with this method is indeed an ATM network. In particular, the main network hardware consists of ATM switches. Links connect these switches with hosts or other switches. Each port on these switches is either an input port or an output port. The traffic that travels on these links goes only in one direction. We also assume that the multiplexed lines originate from or terminate at a switch or host, since if the multiplexed lines originate from or terminate at more than one switch or host, the cell sequence will not be maintained which is a violation of the requirement of ATM. All links in our topology have the same transmission speed, so that no additional buffers need be installed in the switches to prevent cell loss.

4.2.2 The Cost Function

Like [15], we choose the cost of hardware and links as the main costs for our topology. Note that theoretically the cost function can be anything subject to the definition of the network designer.

In this thesis, we have chosen to include the four most common cost for a network topology. That is, the switch cost and the cost for installing the switch, the link cost and the cost for installing the links.

Switch cost and link cost make up the hardware cost for the network. The link costs can include the cost of fiber-optic cables or unshielded twisted pair copper wires depending on the speed of transmission and the technology in use. Costs for installing links can include fiber splicing cost, as well as purchasing and installing conduits or any facilities to hold the links.

For the first two parts of the topology construction method, we defined the following formula for calculating the cost of the topology

$$z = \sum_{s} N_s C_s^T + \sum_{k=1}^{K} \mathrm{cap}(l_k) D_a C^L + I^L K + I^T \sum_{s} N_s \qquad (4.1)$$

The first two terms are the total switch and link costs, whereas the last two terms are the installation costs for the switches and links; N_s is the number of switches of type s, C_s^T is the cost of a single unit of switch type s, cap(l_k) is the capacity of link l_k, C^L is the cost per unit length per unit capacity of a link. I^L and I^T are the cost of installing a link and installing a switch respectively while K is the number of links in the whole topology, and S is the total number of switch types. A link is defined as a connection between a switch and a host machine, or in between switches. Therefore, a link can make up of physically one or more transmission lines. D_a is an approximated average length of a link in the topology. For Parts I and II, an approximation of the link lengths is used instead of the real link lengths since the locations of the switches in the topology will not be set until Part III. We define D_a to be simply the average link distance between hosts and switch candidate locations, and between switch candidate locations. It is given by :

$$D_a = \frac{\sum_h \sum_c d(h,c) + \sum_c \sum_c d(c,c)}{h \times c + c \times c} \tag{4.2}$$

where h is the number of hosts, c is the number of switch candidate locations, $d(i,j)$ is the distance in between switch candidate location i and switch candidate location j. Note that $d(r,r)$ is the distance between switches located at the same switch candidate location. In practice, this distance can never be zero, however, if the distances of $d(i,j), i \neq j$ is comparatively much larger, then we can approximate $d(r,r)$ with 0.

At the end of Part III, since the locations of all switches in the topology have been assigned, we can calculate the cost of the topology by the following rewritten form of equation 4.2:

$$z = \sum_s N_s C_s^T + \sum_{k=1}^{K} \text{cap}(l_k) d_k C^L + I^L K + I^T \sum_s N_s \tag{4.3}$$

where d_k is the real length of the link k.

4.3 PART I: Initial Topology Construction

The objective of the initial topology construction algorithm is to generate a local area ATM topology that satisfies the pipe requirements as given to it by the network designer. It works by creating an ATM subtopology for each source host and each destination host, and joins all these subtopologies into a larger functional ATM topology. Note that a source host and a destination host can be located on the same host machine, as typically a host machine does not only receive but send information as well. The root of this sub-topology is a source host or a destination host.

The initial topology construction algorithm starts by connecting a source host to a switch with a link. Note that this link can consist of more that one physical link depending on the bandwidth of each single physical link[2]. For example, if the total capacity needed for a link is 305 Mbps and the transmission speed for each physical link is 100 Mbps, then a total of 4 transmission lines giving a total of 400 Mbps is needed to implement this link. Inside each of these link flows the traffic of one or more pipes. The algorithm then tries to assign a separate link to each of the pipes that come out of the switch. If the number of desired output links exceeds the maximum allowable switch size, the algorithm will combine some of the pipes into a single link, attach the link to a new switch and attempt to separate the pipes there. The algorithm will repeat until all pipes are assigned to a single link. Figure 1 to 5 shows how this algorithm works.

Given that a source, say source host 1, needs to transmit traffic to all other hosts in a 5 host network, it sends its traffic in 4 ATM pipes (Figure 1). Each pipe(1,j), $2 \leq j \leq 5$ from source host 1 to destination host j has a size which is described in fractions of a transmission line. The algorithm first attaches a switch to the source host with a link as shown in Figure 2. Since all pipes originating from host 1 travel through this link, the capacity needed for this link is the summation of the capacities of all the pipes that flow in this link. The number of actual transmission lines required is the ceiling of the summation of all pipe sizes. In this example, the capacity required is 2.4, hence the number of transmission lines required is 3.

The algorithm then attempts to assign one link per pipe at the output ports of switch 1 (Figure 2). Since the total number of transmission lines required (summation of the ceiling of each pipe) is 5 which is greater than the largest

---

[2] to avoid confusion, we shall from now on refer to a physical link as a transmission line

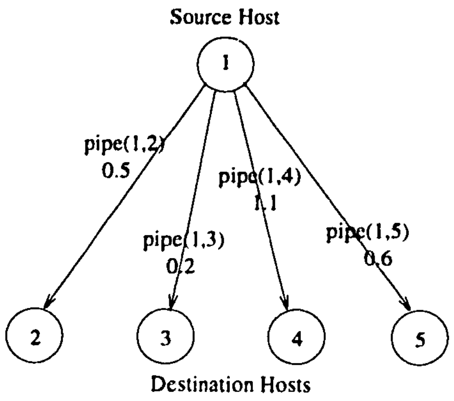


Figure 1: *Host 1 on a five host network needs to send traffic to the four other hosts (assuming no traffic to itself)*

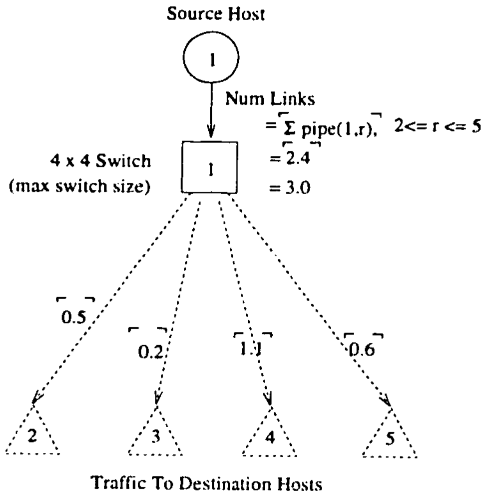


Figure 2: *Host 1 is attached to switch 1 and algorithm attempts to assign the each output pipe to a single link.*

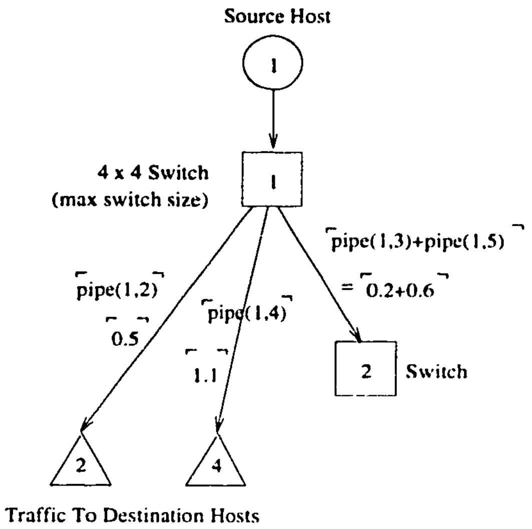


Figure 3: *The number of links required exceeds the maximum switch size, therefore a pipe combination heuristic is applied to combine some pipes together. A new switch is attached to the link that carries the combined pipe.*

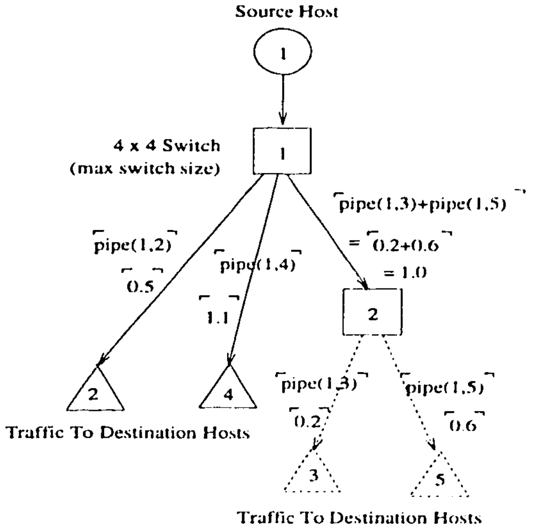


Figure 4: *Algorithm attempts to assign the output pipes to a single link and succeeds.*

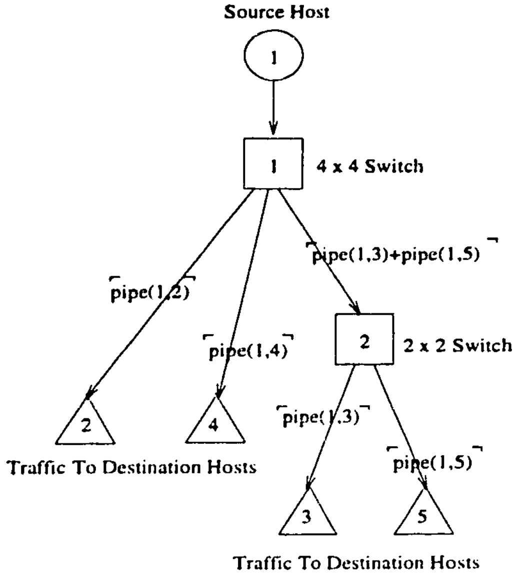


Figure 5: *The resultant subtopology for source host 1.*

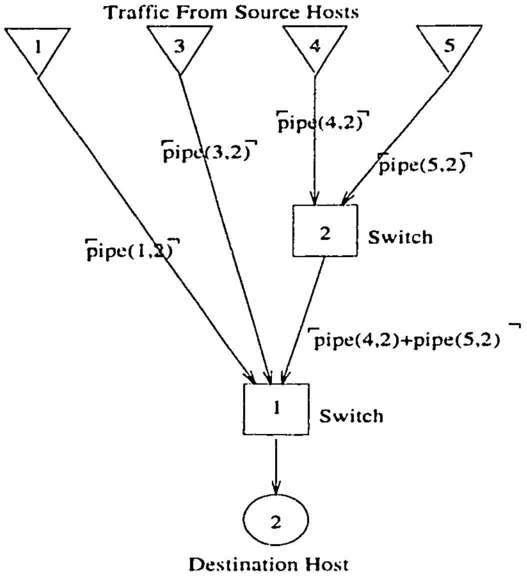


Figure 6: *The resultant subtopology for destination host 2.*

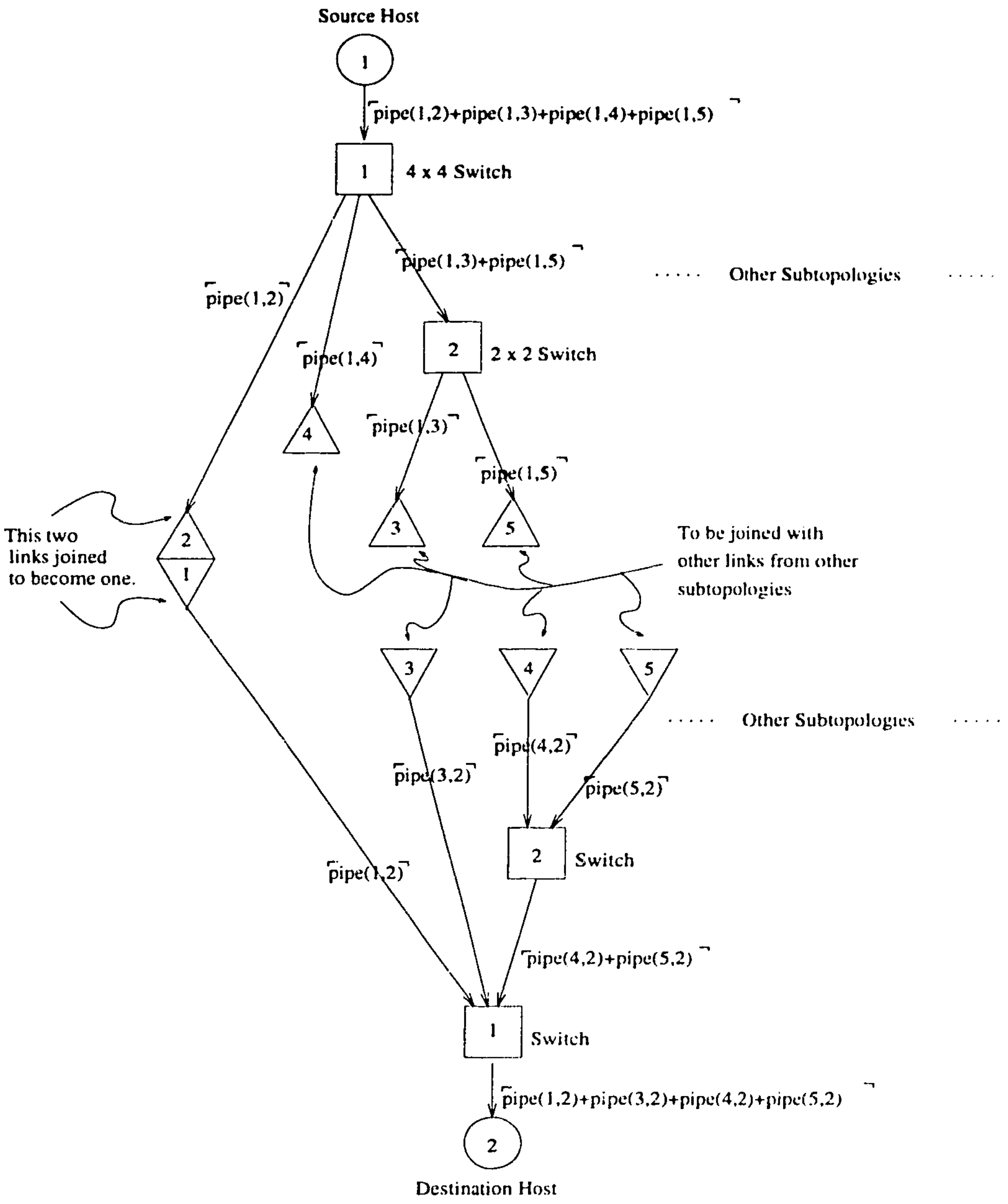


Figure 7: *Combining subtopologies together.*

available switch size (the largest allowable switch has only 4 input ports and 4 output ports), the algorithm combines more than 1 pipe into a link to reduce the number of required lines to fit switch 1. The choice of which pipes to combine is defined by an algorithm which will be described in the next subsection.

By combining pipe(1,3) with pipe(1,5), we reduce the total required output lines to 4, hence satisfying the constraint imposed by switch 1 (Figure 3). A new switch is attached to the link that contains pipe(1,3) and pipe(1,5), as shown in Figure 3. The algorithm then attempts to assign one pipe to a link for pipes (1,3) and (1,5) (Figure 4). Since the total required links is 2, which is smaller than 4, the algorithm succeeds. With only 2 input lines and 2 output lines used, switch 2 can be a 2 x 2 switch instead of a 4 x 4. The resultant subtopology is shown in Figure 5.

The algorithm is repeated for each source host and destination host. A subtopology for destination host 2 is shown in Figure 6. At the leaves of these subtopologies are links containing just one pipe each. Each of these links from a source host subtopology can be matched with a corresponding link from a destination host subtopology. In Figure 5, the leaf links containing pipe (1,2) corresponds to the leaf link containing pipe (1,2) in Figure 6. Therefore, when the topologies to which these links belong combine, these two links will be combined into one, as illustrated in Figure 7. The final combined topology for a 5 host network, can look like the topology in Figure 8. Each source host are labeled with a number preceeded by the letter 'S', each destination host by a 'D', each switch by the letters 'SW', and each link by the letters 'L'.

4.3.1 Choosing which pipes to combine

As mentioned in the previous subsection, if the number of transmission lines required exceeds the maximum allowable switch size, pipes that should normally flow separately in different links are put together in one link, so that the effective number of transmission lines fit within the maximum switch size constraint. We present the algorithm that we used to select which pipes to combine.

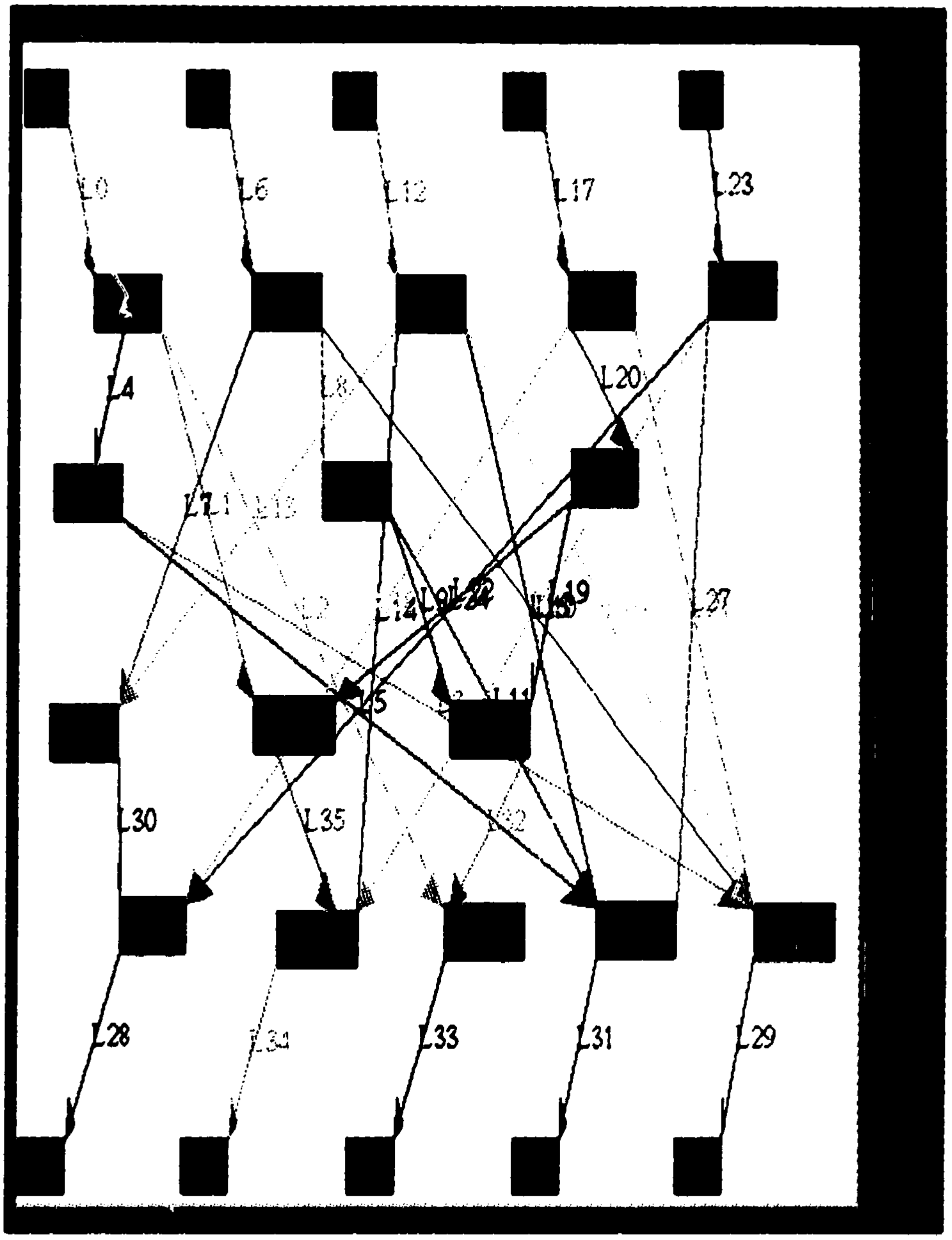


Figure 8: *A fully combined 5 host initial topology. Source hosts are labeled with numbers preceded with an 'S', destinations hosts with a 'D', and switches with an 'SW'.*

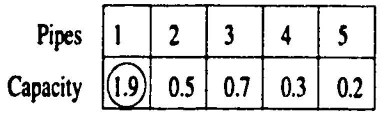
The Switch Combination Algorithm

The heuristic employed in this algorithm is that savings in the number of transmission lines can be achieved if two pipes whose fractional part of the pipe size when added together is at most one, are combined into one link. For example, given two pipes *a* and *b*, with *a* having pipe size 1.3 and *b* 2.5, if the two pipes are put into one link, then the total pipe size is 3.8, and hence the total transmission lines required will be the ceiling of 3.8. That is 4 lines. This represents a savings of one line, because if the two pipes were to put in separate links, then the effective transmission lines required will be the ceiling of 1.3 plus the ceiling of 2.5, which is 5 lines.

The algorithm starts by determining the desired savings needed. Then at each iteration, it chooses two pipes to combine. To increase its chances of combining pipes, the algorithm first chooses a pipe having the biggest fraction. It then looks for another pipe with the biggest fraction that when combined with the first pipe produces a savings of one line. The algorithm then repeats the previous procedure until the desired savings are achieved.

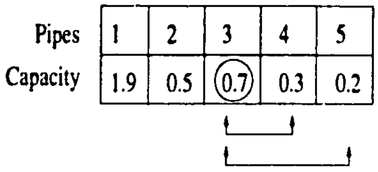
Figures 9 to 14 illustrates how this algorithm works. There are 5 pipes. The total number of transmission lines required is the summation of the ceilings of all the pipe sizes, that is 6 lines. Let's assume that the maximum allowable switch size is 4, a total of 2 savings are needed. The algorithm starts by looking for the pipe that has the biggest fraction. The algorithm finds pipe 1 which has size 1.9 (Figure 9). The algorithm tries to find another pipe that can be combined with pipe 1. Since none can be found, algorithm looks for the pipe that has the next biggest fraction. Pipe 3 which has a size of 0.7 is selected (Figure 10). There are two pipes, pipes 4 and 5 that can be combined with this pipe. Algorithm chooses the pipe 4 that has the bigger fraction and combines the two pipes (Figure 11). A savings of one line is achieved. The algorithm looks for a combinable pipe that has the biggest fraction. Pipe 2 is selected (Figure 12). This time only one pipe (pipe 5) can be combined. Therefore algorithm combines pipe 2 with pipe 5. A total desired savings of 2 lines are achieved. Therefore the algorithm exits.

In essence, this algorithm functions like the First-Fit Decreasing Bin Packing Algorithm [10] that packs to one unit. In general, the number of savings from



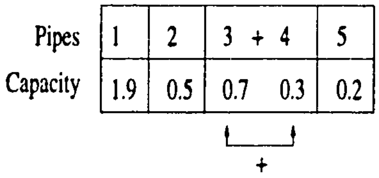
Pipes	1	2	3	4	5
Capacity	1.9	0.5	0.7	0.3	0.2

Figure 9: *Algorithm finds the pipe size (1.9) with the biggest fraction. This pipe is discarded as no other pipe can be combined with this.*



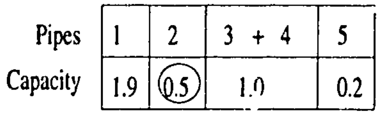
Pipes	1	2	3	4	5
Capacity	1.9	0.5	0.7	0.3	0.2

Figure 10: *Algorithm finds the pipe with the next biggest fraction (0.7). Two other pipes can be combined with this pipe (pipes 4 and 5).*



Pipes	1	2	3 + 4	5
Capacity	1.9	0.5	0.7 0.3	0.2

Figure 11: *Algorithm chooses pipe 4 as it has the bigger fraction among the two. The two pipes are combined.*



Pipes	1	2	3 + 4	5
Capacity	1.9	0.5	1.0	0.2

Figure 12: *Since desired total savings is not reached. Algorithm looks for the biggest combinable pipe.*

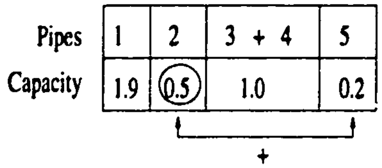


Figure 13: *Only one pipe (pipe 5) can be combined with the chosen pipe (pipe 2), therefore combine them.*

Pipes	1	3 + 4	2 + 5
Capacity	1.9	1.0	0.7

Figure 14: *A total of 2 savings is achieved. Therefore algorithm exits.*

combining of pipes can be further maximized when we pack to u units, where u is a non-zero positive integer. However, we did not implement this and this is left as future improvements.

4.4 PART II: Topology Improvement

The aim of the topology improvement part is to find an equivalent topology that is less expensive than that produced by the initial topology algorithm. An equivalent topology is defined as a topology that satisfies the same pipe specifications as the topology to which it equals.

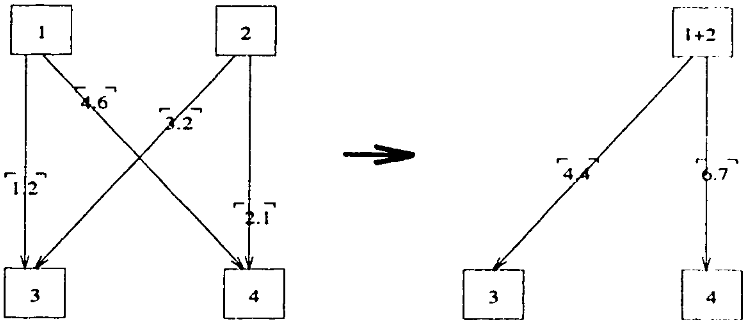
The topology improvement applies the concept of gradual improvement, that is at each iteration, the algorithm changes the topology according to some heuristics, so that some savings can be achieved. In essence, this concept is similar to the hill-climbing mathematical optimization method [30]. That is, with each iteration, the solution to the cost function gets closer to optimality. Topology changes are done through the intelligent combining of switches Savings are achieved when links rearrange or combine, and the number of switches reduces.

4.4.1 Savings Through Switch Combination

When switches combine, savings are achieved. Specifically

- Total switch cost is reduced as the total number of switches are reduced. Switches that have wasted capacity can be combined so that fewer switches are needed.

- The number of links are reduced when switches that have the same immediate descendants or ancestors combine. This can be seen in Figure 15. Switches 1 and 2 have the same immediate descendants, switches 3 and 4. The total output transmission lines required for switch 1 and 2 is 14. When the two switches 1 and 2 combine, since two of the links out of the four can be combined with the other two, the total required lines have fallen to 12



requires 2 less physical links

Figure 15: *Link capacities reduced when switches that have the same descendants combine.*

- Links are eliminated when switches combine with their immediate ancestors or descendants. For example, in Figure 16, when switch 1 combines with switch 2, the link carrying pipe a disappears. The total number links required in the topology is reduced.

- Links are eliminated and/or have their capacities reduced when self-loops that occur as a result of switches combining are stripped. This can be seen in Figure 17. When switch 1 combines with switch 3, a self-loop occurs with pipe b and c flowing out of the newly combined switch through switch 2, and back into the newly combined switch. This self loop is stripped and through stripping, links are either reduced in size or totally eliminated.

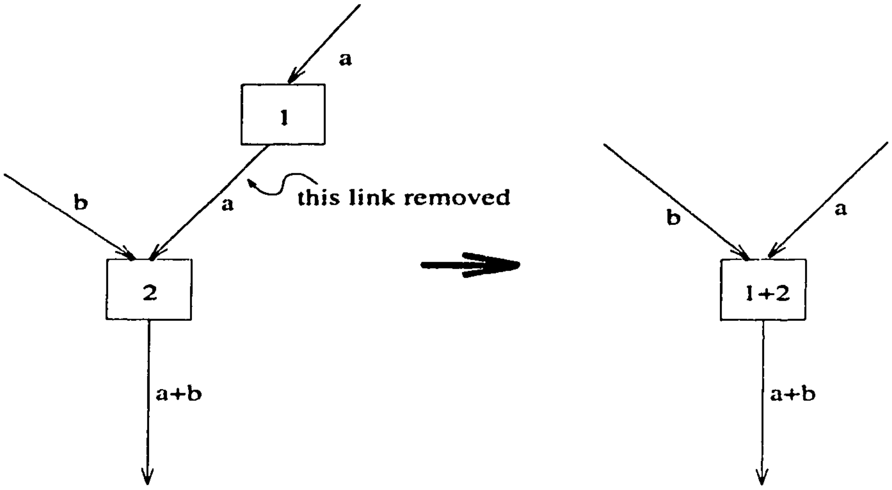


Figure 16: *Links eliminated when switches combine with immediate ancestors or descendants*

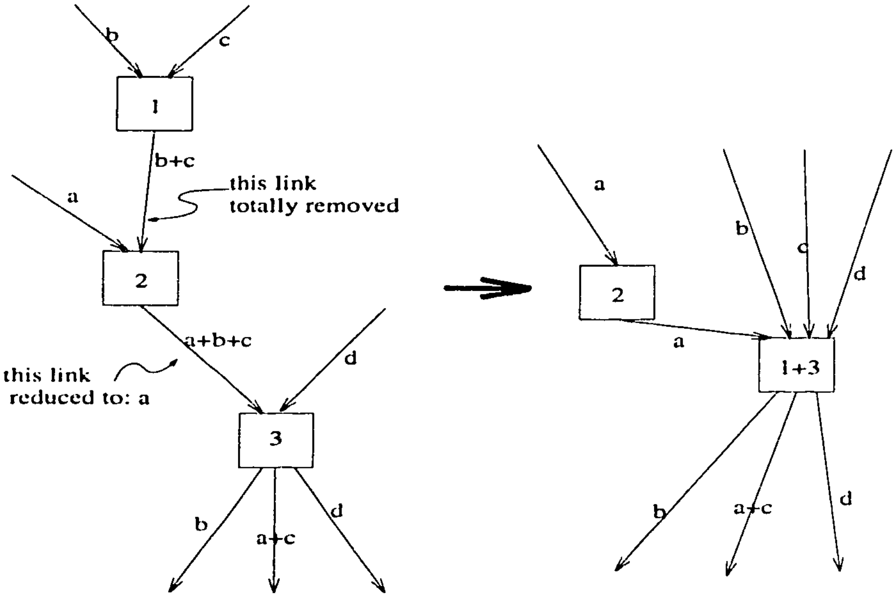


Figure 17: *Reduction of link size and elimination of links as a result of switches combining.*

4.4.2 Topology Improvement Algorithms

We have devised three algorithms to perform topology improvement. These programs each have their own way of choosing which switches to combine and hence the amount of savings achievable. Each algorithm is presented with its pseudocode.

1. **RANDOM.** The Random improvement algorithm essentially picks two switches randomly. Then it checks to see if the switches are combinable or not. If the switches are combinable, then they will be combined. The algorithm exits when x number of combining attempts results in failure.

   ```
   While(less than x iterations has elapsed since the last
         successful combination}{
              Randomly choose 2 switches in the topology;
              If(the two switches are combinable)
                        Combine them;
   }
   ```

2. **EXHAUSTIVE.** The Exhaustive algorithm in each iteration, finds the two switches that when combined will give the greatest savings. This is a greedy algorithm in that it attempts to achieve the most overall savings by maximizing on the savings in each iteration. This implies more intelligence in the algorithm for building the topology.

   ```
   While(last iterations successfully combines 2 switches){
         Find the savings achievable by all valid combinations of
           any two switches;
         Combine the two switches;
   }
   ```

3. **NEIGHBORHOOD.** The Neighborhood algorithm essentially combines a switch with another from its neighborhood that when combined will give the greatest savings. A neighborhood of a switch is defined as all immediate

ancestors and descendants of the switch, as well as the immediate descendants of these ancestors, and the immediate ancestors of these descendants. A switch can not be combined with itself.

The motivation behind the neighborhood algorithm is that combining switches with its neighbors can most likely result in more links being reduced in size or eliminated (as illustrated in the last section). This facilitates further combination with other switches may result in a cheaper topology.

```
While(less than x iterations has elapsed since the last
       successful combination){
            Randomly choose a switch in the topology;
            Find all the neighbors of this switch as defined
                 by the neighborhood function;
            Find the neighbor that when combined with the
                 switch will give the most savings;
            If(such neighbor is found) combine them;
}
```

4.5 PART III: Topology Location

The topology generated from Part II is a feasible topology. However, this topology is logical as the actual locations of the switches are not assigned yet. The topology location algorithm takes care of allocating the switches to the switch candidate locations. As the locations of this switch directly affect the lengths of the links to which this switch connects, the total cost of the topology is directly affected by the placement of these switches. Two algorithms are devised for performing this task.

- **RANDOM.** This algorithm randomly assigns a switch to a switch candidate locations. This algorithm is run as a basis for comparison.

```
While(not all switches have been assigned){
      Randomly choose a switch candidate location;
```

```
        Assign the switch to that location;
}
```

- **ANCHORING** An anchored switch is a switch that has been assigned a location. At each iteration of the anchoring algorithm, a to-be-anchored switch is chosen randomly. If there are links connecting this switch to other anchored switches, the total lengths of all these links are calculated, with the to-be-anchored switch taking the location of each of the switch candidate locations in turn. Otherwise, pick another unanchored switch. Hence, the location of the switch candidate location that produces the shortest total length will be chosen as the location to which the to-be-anchored switch will be anchored. A host is considered as an anchored switch.

```
While(not all switches have been anchored){
       Randomly choose one unanchored switch;
       If(there are at least one anchored switch
            connected to it){
            For all switch Candidate locations{
                 Find the total distances of all
                    links connecting the unanchored
                    switch with other anchored switch,
                    assuming that the unanchored
                    switch is located at the current
                    switch candidate locations;

            }
            Assign the unanchored switch to the
               location resulting in the shortest
               total distance.
        }
}
```

4.6 Experiments for Phase II

To evaluate the workings of the algorithms proposed for Phase II, we have implemented all of them, and combinations of them (meaning one from Part II and one from Part III) and in a program. With this program, we performed experiments to examine the effectiveness of these algorithms in accomplishing their functions.

4.6.1 Parameters

At the start of each program run, a number of parameters were read in. These parameters are:

- **Number of Hosts.** This is the number of hosts in the network. Values for this parameter are 5,10, or 15.
- **Pipe Sizes.** These are values calculated with the MCFF analytical method presented in the previous chapter. The pipes sizes are expressed in terms of multiples of the line transmission speed. For example, for a 45 Mbps pipe transmitted on a 150 Mbps link, the pipe size will be specified as 45/150=0.30. In the experiments, the smallest pipe size that we used is 0.1 and the largest is 18.3. The number of pipe sizes in a network of N hosts is $N \times (N - 1)$, assuming no self traffic.
- **Number of Types of Switches and Their Corresponding Sizes.** Currently, the switches are all symmetrical $n \times n$ types, that is, they have the same number of input and output ports. However, this can be changed easily to accommodate $n \times m$ switches. The Switch sizes that were used in our experiments range from 14 to 200 ports.
- **Switch Costs** As of the time of writing, most switches in the market are listed with the price per port (about \$1000 - \$2000). We have adopted this method of pricing our switches. However since prices change so rapidly, we have decided to omit real dollars as the unit of cost. Rather, we assign the cost for a port as 1 unit and price all other costs (e.g. switch installation, link costs, etc.) relative to that.

- **Switch Installation Cost.** The cost of installing switches. In practice, since this cost differs from case to case (for example, if special facilities such as air-conditioning need to be installed with the switch), we simply fix this value to 0.3.
- **Line Cost.** This is expressed as price per transmission line per meter. Again, this value can vary depending on the type of physical medium (twisted pair, fiber optics, etc) used. Here, we fix this value to 0.005 (for a $2000 per port switch, this works out to about $10 per meter).
- **Link Installation Cost.** Like the switch installation cost and link cost, the link installation cost also varies in real life. Here, we fix this to 0.1. Recall from the previous sections that a link can consist of more than one transmission line and normally they are installed as one. Therefore, we assume that the same link installation cost applies regardless of how many lines there are within the link.
- **Number of Switch Candidate Locations.** These are the places where switches can be installed. The number of switch candidate locations used ranges from to 3 to 8.
- **Distance Between Switches and Hosts or Other Switches.** This is the length of the cable that connects a host with a switch or a switch with another switch. The network designer determines the values for these. Although alternately we can take in actual coordinates of hosts and switch candidate locations as input and let the program calculate the distance, we chose not to do that, since a link often does not take the simplest route to its destination.

4.7 Experimental Results

Experiments of our Phase II program were run on a Silicon Graphics Iris Indigo Workstation. As mentioned before, we have examined 3 sizes of networks, namely, the 5-host network, 10-host network and 15-host network. For the 5-host and 10-host network, a total of 4 sets of runs were carried out. Each set contains two different classes of pipe parameters with the same mean pipe sizes. The pipe sizes in one class are skewed and the other are not skewed. This also applies for the 15-host network. The only difference is that instead of 4 sets, only 2 sets were run.

We calculate the skewness of the pipes with the following formula which was taken from [23]

$$v = \frac{E[(p_j - \bar{p})^3]}{(S^2)^{3/2}} \tag{4.4}$$

where p_j is a pipe size, $\bar{p}$ is the mean pipe size and S^2 is the variance of the pipe sizes. The pipe mean and skew values for the experiments are listed in Tables 4.1 and 4.2. Note that the smallest pipe mean is 0.5 and the largest is 3.0, whereas the smallest skew value is 2.68 and the largest is 4.593.

Set	*5 Hosts*		*10 Hosts*	
1.	Mean: 1.5 Skew: 3.112	Mean: 1.5 Skew: 0.0	Mean: 1.5 Skew: 3.217	Mean: 1.5 Skew: 0.0
2.	Mean: 3.0 Skew: 3.574	Mean: 3.0 Skew: 0.0	Mean: 3.5 Skew: 3.21	Mean: 3.5 Skew: 0.0
3.	Mean: 2.0 Skew: 2.68	Mean: 2.0 Skew: 0.0	Mean: 2.0 Skew: 2.808	Mean: 2.0 Skew: 0.0
4.	Mean: 0.5 Skew: 3.091	Mean: 0.5 Skew: 0.0	Mean: 0.5 Skew: 4.593	Mean: 0.5 Skew: 0.0

Table 4.1: *Pipe Mean and Skewness (5 and 10 Hosts)*

Set	*15 Hosts*	
1.	Mean: 1.5 Skew: 3.117	Mean: 1.5 Skew: 0.0
2.	Mean: 3.0 Skew: 3.542	Mean: 3.0 Skew: 0.0

Table 4.2: *Pipe Mean and Skewness (15 Hosts)*

4.7.1 Part I: The Initial Topology Construction

In each run, we recorded the cost of the initial topology. We find that in general, the more hosts there are in a network, the bigger the initial topology will turn out to be. This is so because more links and switches will result since the initial topology construction algorithm assigns a switch to each source host and destination host by default regardless of the input pipe sizes.

Figure 18 shows an example of an initial topology generated from one of our runs, that is the 5-host, Set 2, Skewed Pipe run. Each source host and each destination host is connected to a switch. Note that switch 4, which is not attached to any host, is part of the subtopology belonging to source host number 3. It is created because the total needed lines (for the output of switch 3) exceeded the maximum switch size.

At the conclusion of each experimental run, we have also verified links and paths to make sure that the initial topology is a feasible topology. That is, it contains all pipes that were given as the input, and that the maximum number of lines required for a switch does not exceed the maximum switch size. We find that the topologies that were generated by the initial topology algorithm are indeed feasible. As our algorithm is designed to maintain the feasibility of the topology, this checking is done mostly as a check on the implementation,

4.7.2 Effects of Skewness On the Initial Topology

Table 4.3 shows the initial topology costs gathered for the 5 and 10 host runs. In there, the results of both skewed and non-skewed costs are shown. The bigger cost of the two are enclosed in brackets.

From the table, we can see that number of times that the results from the skewed runs exceeds the results from the non-skewed runs are exactly the same as the other way round. This suggests that the skewness of the pipe sizes does not appear to have a direct influence over the cost of the initial topology. This is contrary to our intuition. One explanation could be that the difference in pipe sizes (hence the skewness) is not really the main factor that influences the number of switches and links that were used in the topology. The main factor is

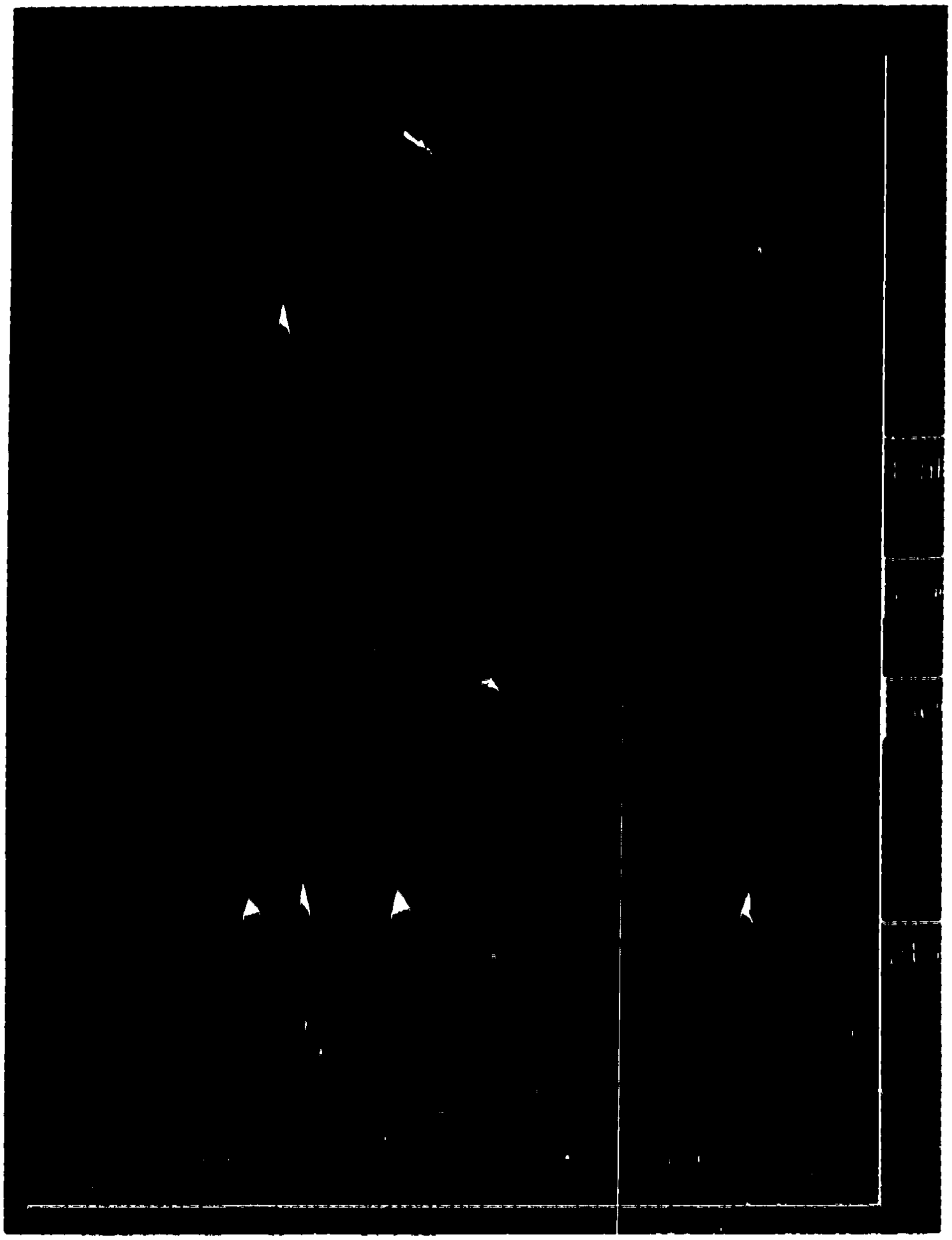


Figure 18: *The Initial Topology for the 5 Hosts,Set 2,Skewed Traffic Run*

	5 Hosts		*10 Hosts*	
	Skewed	*Non-Skewed*	*Skewed*	*Non-Skewed*
1.	36557	(37639)	179068	(183852)
2.	(38819)	36833	326597	(330553)
3.	47474	(48195)	(197312)	186395
4.	(12213)	11192	(76878)	75689

Table 4.3: *The Initial Topology Cost (The Bigger Cost is in Brackets)*

most likely dependent on the fractions of each pipe. For example, consider the following two sets of pipes $S_1 = \{1.0, 1.0, 1.0, 1.0, 1.0\}, S_2 = \{0.1, 0.1, 0.1, 0.1, 4.6\}$. Both sets have the same mean (1.0). The values in Set S_1 are identical (skewness 0), hence it has lower a skewness than Set S_2. The number of transmission lines needed for Set S_1 will be the summation of the ceiling of each pipe value, that is 5 lines. However, the number of transmission lines needed for Set S_2 is 9 lines. The more transmission lines needed the bigger the initial topology will most likely turn out to be, since more switch expansions need to be done (For example, if the maximum switch size is 8, then Set S_1 will be able to fit into one switch while Set S_2 will not). This is an example where a set of pipes with lower skewness results in a cheaper topology.

On the other hand, if we have a set of pipes, Set $S_3 = \{3.0, 0.5, 0.5, 0.5, 0.5\}$ and Set $S_4 = \{1.1, 1.1, 1.1, 1.1, 0.6\}$. Again, both of them have the same mean (1.0). However, S_3 with a higher skewness (the *minimum* difference of the individual pipes with the mean is 0.5 for Set S_3, whereas the *maximum* difference between the individual pipes and the mean for Set S_4 is only 0.4) requires 7 lines, whereas S_4 with a lower skewness requires a total of 9 lines. This is an example where the set of pipes with a higher skewness results in a cheaper topology. This is the opposite of the results that we get from the previous example.

4.7.3 Part II: Topology Improvement

In the experimental runs, we have examined the performance of the three topology improvement algorithms. Figures 19 to 21 show an example of the results obtained from applying these algorithms to the initial topology in Figure 18. From the figures, we can see that reduction in topology sizes have been achieved using the topology improvement algorithms. Both the Random and Exhaustive algorithms have managed to reduce the number of switches in the initial topology from a total of 11 to 6, whereas the Neighborhood algorithm managed to reduce it down to just 5 switches (Figure 21).

4.7.4 Repeated Calculation

Due to the fact that the both the Random and Neighborhood topology improvement algorithms depend on random selections of switches to combine, the resultant topologies generated with these two algorithms will vary from one run to another. Therefore to more accurately determine the performance of these two algorithms, we have applied the same algorithm a total of 70 times for each run. The mean and the 95% confidence interval of the topology cost are then obtained and plotted.

Figures 22 to 25 shows some of the plots that we have obtained. They are for the 5-host runs and 15-host runs. Since the results of the 10-host runs are identical to the 5-host runs, we chose not to include them. As evident from the figures, most of the time the Exhaustive algorithm produces the cheapest topology, followed by the Neighborhood algorithm, then the Random algorithm. This seems to confirm that the 'intelligence' that is built into the Exhaustive and Neighborhood does generate good topologies. Note that since the results in Figures 22 to 25 show that the confidence intervals of the bars in the same column do not overlap, we can be fairly sure that the differences are significant.

4.7.5 Part III: Topology Location

Like Part II, both of the topology location algorithms rely on random numbers to work. Therefore, we have run each Topology Location Algorithm 70 times for each input, so that the mean and 95% confidence interval can be obtained.

From the figures, we have found that in all cases the Anchoring algorithm produces a topology that is less costly than that produced by the Random topology location algorithm. This difference in performance can sometimes be as high as

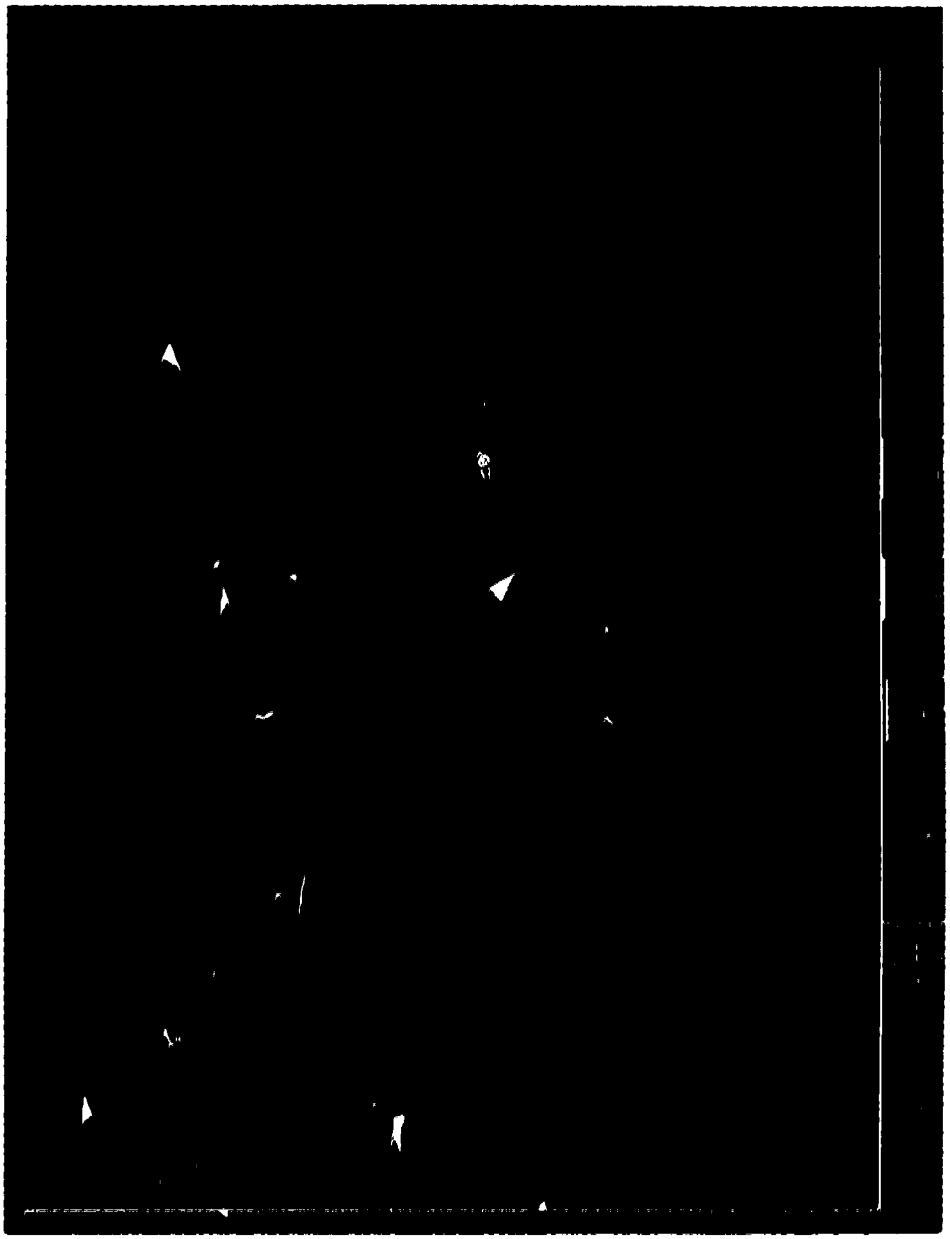


Figure 19: *The Improved Topology Using the Random Algorithm*

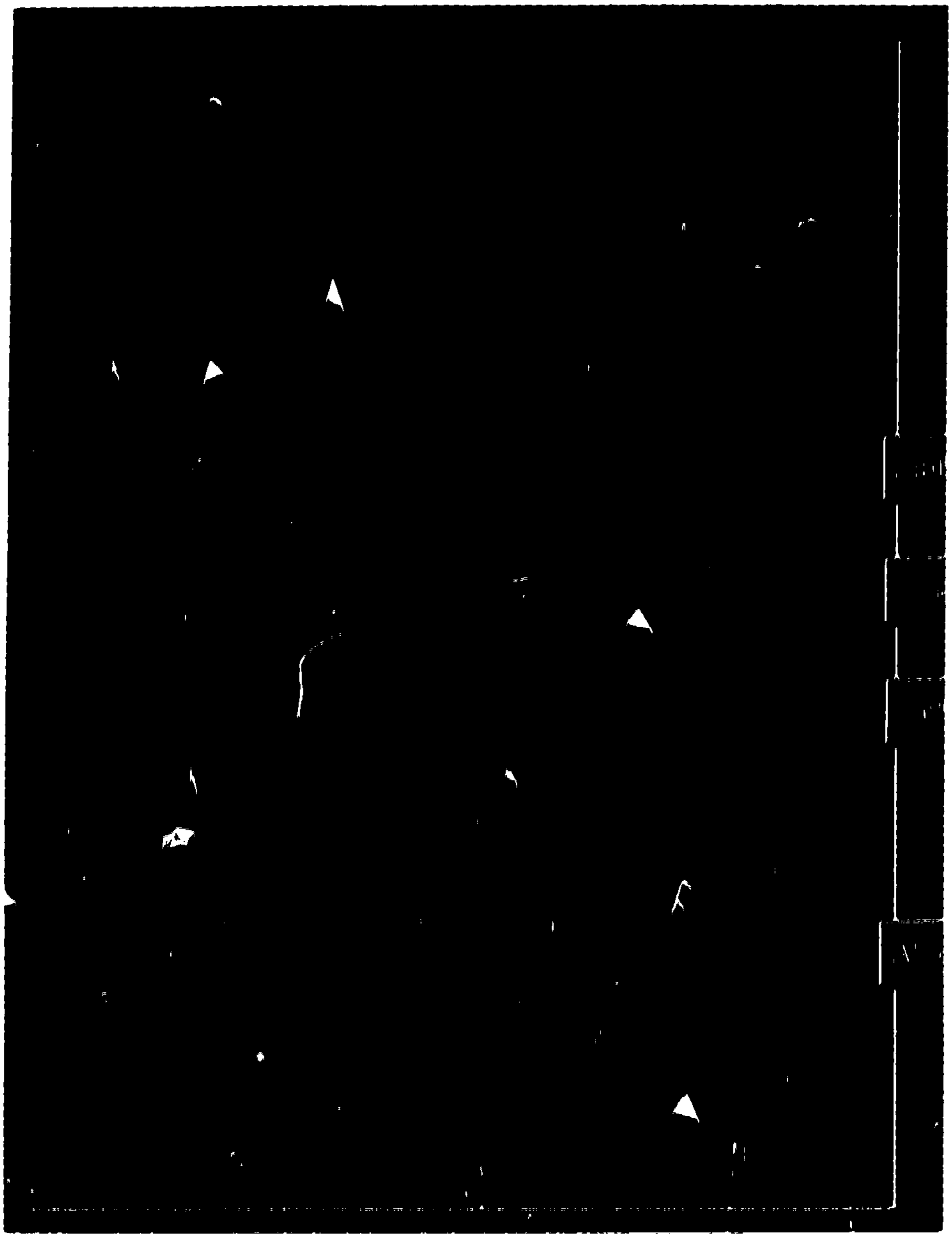


Figure 20: *The Improved Topology Using the Exhaustive Algorithm*

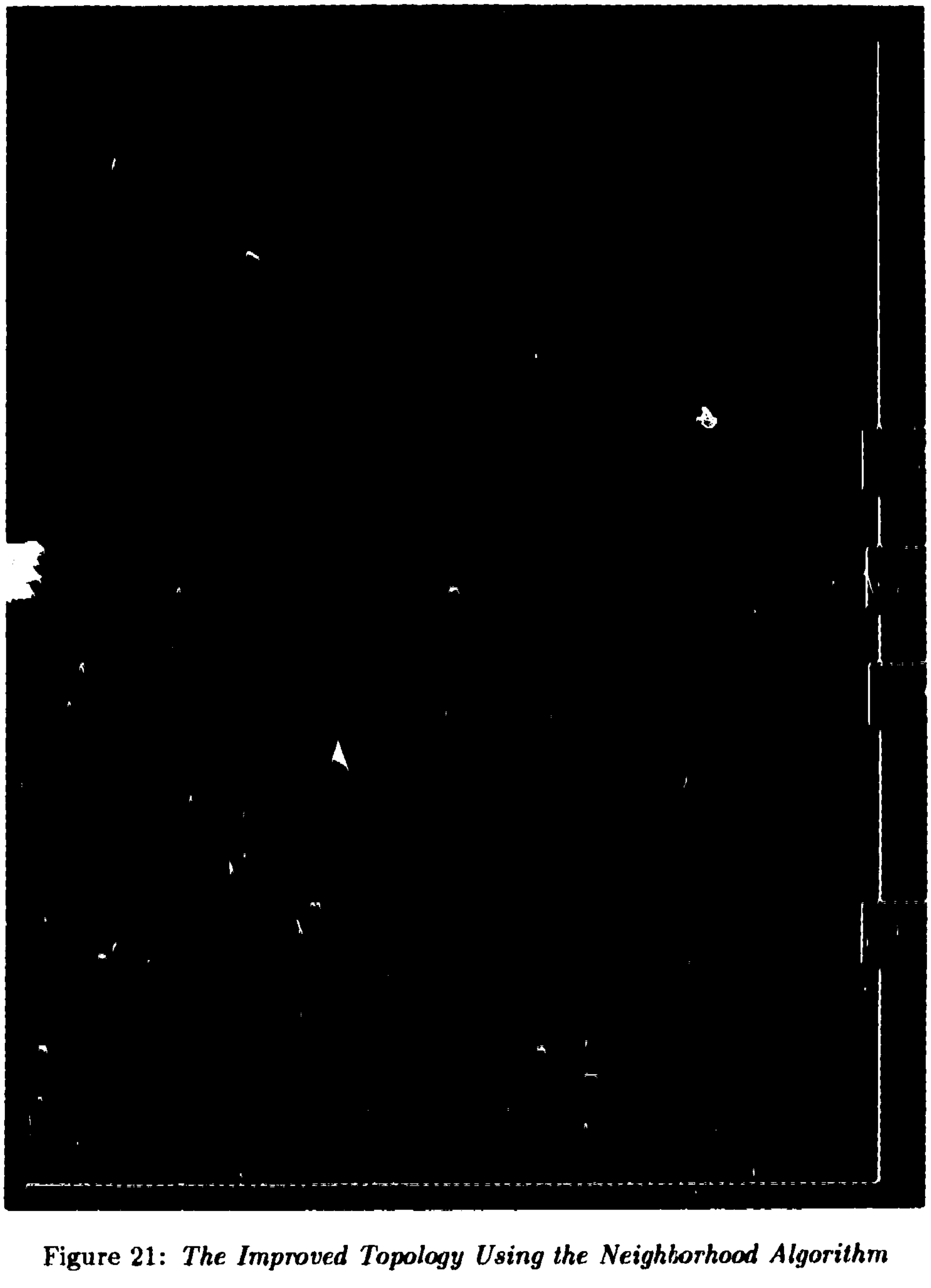


Figure 21: *The Improved Topology Using the Neighborhood Algorithm*

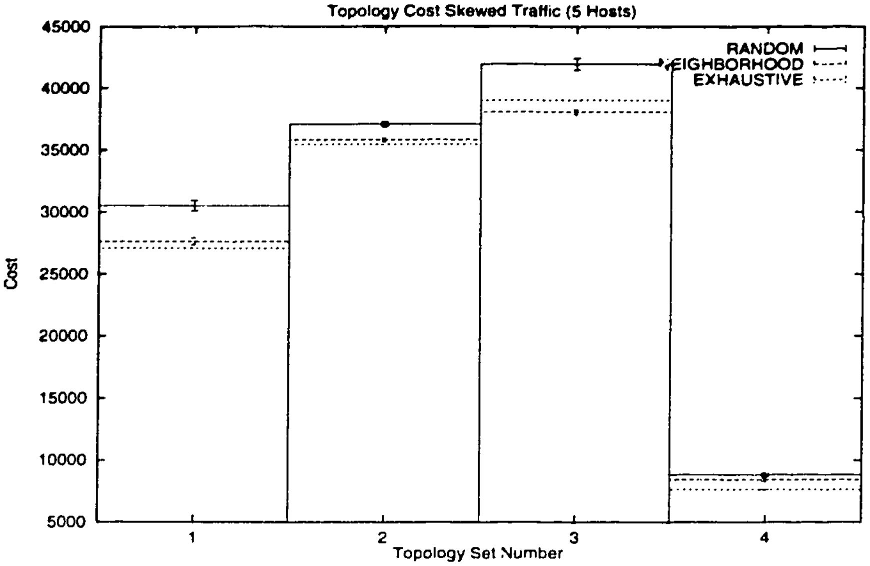


Figure 22: *Comparisons of the Topology Improvement algorithms for a 5 Host Network with Skewed Traffic*

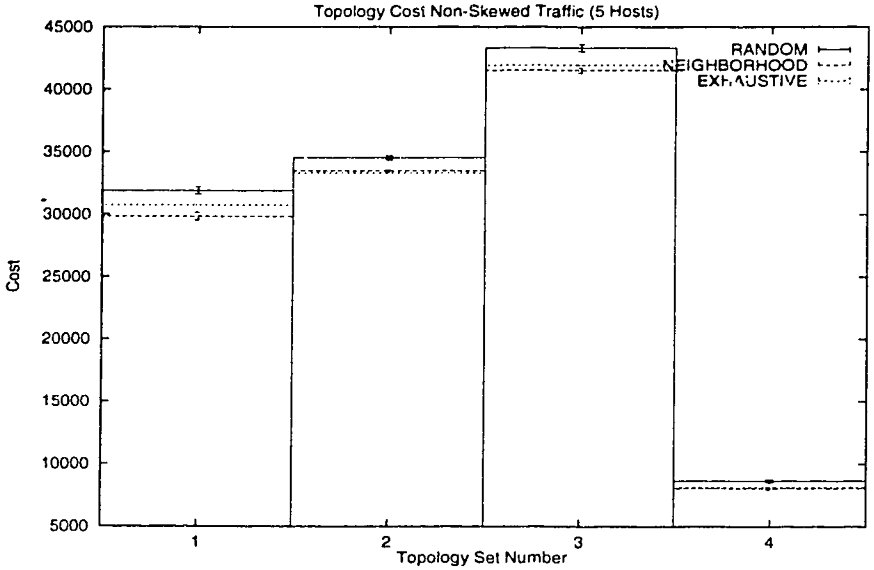


Figure 23: *Comparisons of the Topology Improvement Algorithms for a 5 Host Network with Non-Skewed Traffic*

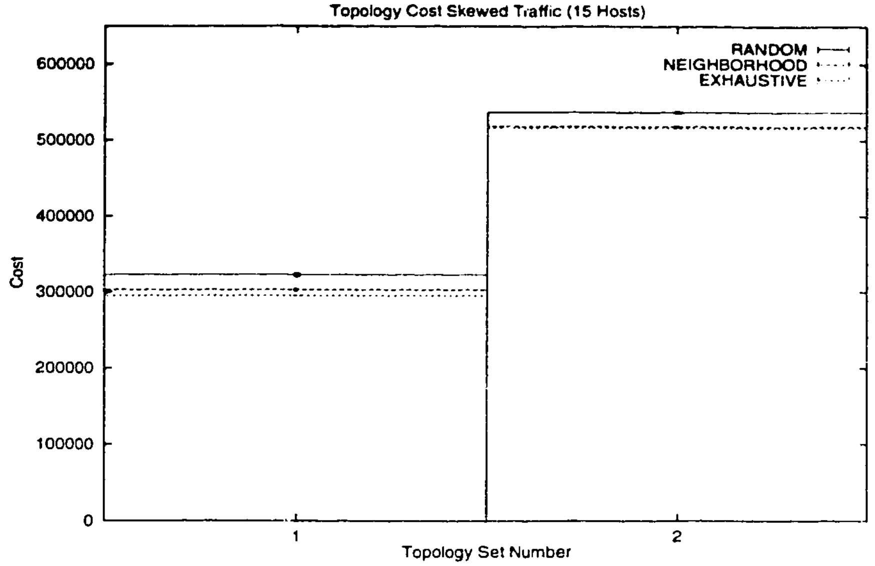


Figure 24: *Comparisons of the Topology Improvement Algorithms for a 15 Host Network with Skewed Traffic*

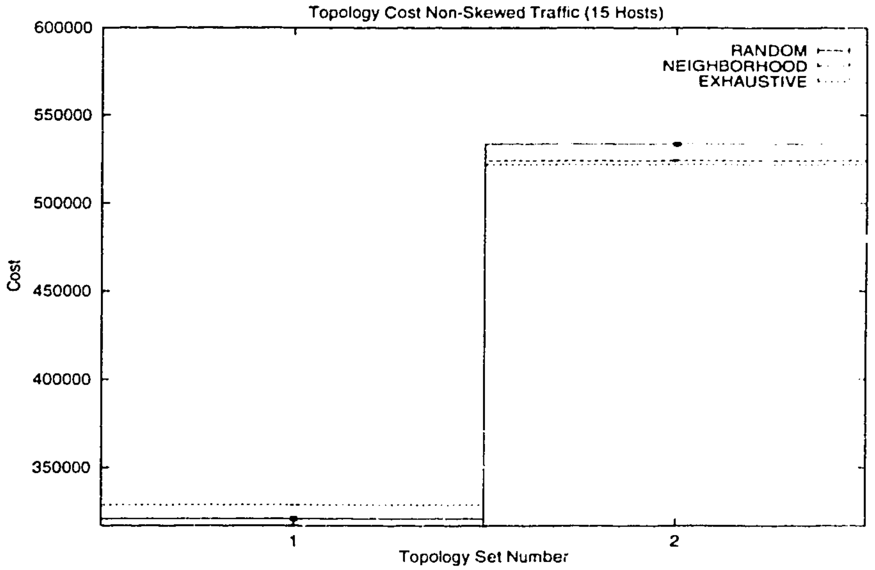


Figure 25: *Comparisons of the Topology Improvement Algorithms for a 15 Ho[illegible]work with Non-Skewed Traffic*