A GENERALIZED, STEADY-STATE SIMULATION

OF

WASTEWATER TREATMENT PLANTS
A GENERALIZED, STEADY-STATE SIMULATION
OF
WASTEWATER TREATMENT PLANTS

by
Patrick G. C. Tan, B.Eng.

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree
MASTER OF ENGINEERING

McMaster University
January, 1972
SCOPE AND CONTENTS:

Laboratory and field measurements were combined with theory in developing models for the various wastewater treatment processes. Some assumptions were made, both in an attempt to simplify the complex mechanisms encountered and to explain known experiences and observations.

Models for a primary settling tank, a secondary settling tank, a generalized aerobic biological sludge treatment scheme, an anaerobic digestion system and several other unit processes have been developed. The generalized aerobic biological sludge treatment scheme is an attempt to describe in one physical package, all the various activated sludge process modifications.

The executive system used is GEMCS, together with its library of subroutines, such as CONTL1, SEPA01, JUNCO1 and
and SETSPI, some of which have been modified slightly.

The models have been tested on the Drury Lane and the Skyway, Burlington, Sewage Treatment Plants, and have been found to agree very well with plant data. The former has a conventional activated sludge process, whilst the latter employs the extended aeration modification.

An interactive version has been developed, which requires the minimum knowledge of GEMCS for its use. This can be applied as a training and teaching tool for plant operators and students in the field.
ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to:

1. Dr. J. D. Norman, for his many ideas and contributions to the project, and for the interest and guidance he has shown throughout.

2. Dr. K. L. Murphy and Dr. A. Benedek for sharing their vast experience and knowledge.

3. Mr. K. Cronin, a fellow graduate student, for assistance in the field studies as well as in the laboratory.

4. Miss C. P. Lee, for help in the analyses and in the drawings and graphs for the thesis.

5. Miss I. Ellis for her patience in typing the manuscript.

6. Mr. C. Fiddy, Mr. G. Brewer, and all the operating personnel at the Dundas, Drury Lane and Skyway Water Pollution Control Plants for their kind co-operation.

7. The National Research Council of Canada for financial assistance provided during the course of this study.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
<th>PAGE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREFACE</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>CHAPTER 1 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER 2 LITERATURE REVIEW</td>
<td>4</td>
</tr>
<tr>
<td>CHAPTER 3 THE SIMULATION SYSTEM</td>
<td>11</td>
</tr>
<tr>
<td>3.1 The GEMCS Executive</td>
<td>11</td>
</tr>
<tr>
<td>3.2 The Stream List</td>
<td>14</td>
</tr>
<tr>
<td>CHAPTER 4 PRIMARY SEDIMENTATION</td>
<td>22</td>
</tr>
<tr>
<td>4.1 Theory</td>
<td>22</td>
</tr>
<tr>
<td>4.2 The Correlation of Batch Settling</td>
<td>29</td>
</tr>
<tr>
<td>Data</td>
<td></td>
</tr>
<tr>
<td>4.3 Deviations from Ideal &quot;Plug Flow&quot;</td>
<td>40</td>
</tr>
<tr>
<td>Settling</td>
<td></td>
</tr>
<tr>
<td>4.4 The Primary Settling Tank</td>
<td>44</td>
</tr>
<tr>
<td>Model - PRISET1</td>
<td></td>
</tr>
<tr>
<td>CHAPTER 5 AEROBIC BIOLOGICAL SLUDGE PROCESSES</td>
<td>46</td>
</tr>
<tr>
<td>5.1 The Bacteria and Its Activities</td>
<td>46</td>
</tr>
<tr>
<td>5.2 Chemostat Experiments</td>
<td>54</td>
</tr>
<tr>
<td>5.3 Aeration Studies of Activated Sludge</td>
<td>59</td>
</tr>
<tr>
<td>5.4 The Stripping Rate of Purgeable</td>
<td>75</td>
</tr>
<tr>
<td>Soluble Organics</td>
<td></td>
</tr>
<tr>
<td>5.5 Oxygen Transfer Efficiencies</td>
<td>81</td>
</tr>
<tr>
<td>5.6 Nutrient Balance</td>
<td>82</td>
</tr>
<tr>
<td>5.7 The Aerobic Biological Sludge</td>
<td></td>
</tr>
<tr>
<td>Process Model - ACTSL1 and</td>
<td>85</td>
</tr>
<tr>
<td>CSTR2</td>
<td></td>
</tr>
</tbody>
</table>

(vi)
<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>SECTION</th>
<th>PAGE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6.1</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>6.2</td>
<td>91</td>
</tr>
<tr>
<td>6</td>
<td>6.3</td>
<td>94</td>
</tr>
<tr>
<td>7</td>
<td>7.1</td>
<td>101</td>
</tr>
<tr>
<td>7</td>
<td>7.2</td>
<td>109</td>
</tr>
<tr>
<td>8</td>
<td>8.1</td>
<td>112</td>
</tr>
<tr>
<td>8</td>
<td>8.2</td>
<td>113</td>
</tr>
<tr>
<td>8</td>
<td>8.3</td>
<td>116</td>
</tr>
<tr>
<td>8</td>
<td>8.4</td>
<td>119</td>
</tr>
<tr>
<td>9</td>
<td>9.1</td>
<td>121</td>
</tr>
<tr>
<td>9</td>
<td>9.2</td>
<td>123</td>
</tr>
<tr>
<td>9</td>
<td>9.3</td>
<td>128</td>
</tr>
<tr>
<td>10</td>
<td>10.1</td>
<td>130</td>
</tr>
<tr>
<td>11</td>
<td>11.1</td>
<td>140</td>
</tr>
<tr>
<td>12</td>
<td>12.1</td>
<td>145</td>
</tr>
<tr>
<td>12</td>
<td>12.2</td>
<td>153</td>
</tr>
<tr>
<td>13</td>
<td>13.1</td>
<td>159</td>
</tr>
<tr>
<td>13</td>
<td>13.1.1</td>
<td>159</td>
</tr>
</tbody>
</table>

(vii)
13. 13.1.2 Tracer Studies of Primary Sedimentation Tanks 160
13.1.3 Data from the Chemostat Experiments 161
13.1.4 Data on the Aeration Studies of Activated Sludge 162
13.2 Discussion of Plant Simulations 164
13.2.1 Simulation of Drury Lane Plant 164
13.2.2 Simulation of Skyway Plant 170
CHAPTER 14 CONCLUSION 173
REFERENCES 174
APPENDIX A PRIMARY SETTLING DATA ON BATCH COLUMN 179
APPENDIX B EXIT AGE DISTRIBUTION OF PRIMARY TANKS 196
APPENDIX C DATA FROM THE CHEMOSTAT EXPERIMENTS 204
APPENDIX D EXTENDED AERATION STUDIES ON ACTIVATED SLUDGE 206
APPENDIX E DATA FOR THE STRIPPING RATE OF PURGEABLE SOLUBLE ORGANIC CARBON BY AERATION WITH AIR 213
APPENDIX F DATA OF ACTIVATED SLUDGE SETTLING FROM P. LEUNG 218
APPENDIX G ANAEROBIC DIGESTION DATA 221
APPENDIX H INTER-RELATIONSHIPS BETWEEN ORGANIC CARBON, BIOCHEMICAL OXYGEN DEMAND AND VOLATILE SUSPENDED SOLIDS 224
APPENDIX I SIMULATION DATA AND RESULTS FOR THE DRURY LANE, BURLINGTON SEWAGE TREATMENT PLANT 226 (viii)
APPENDIX J  SIMULATION DATA AND RESULTS FOR
THE SKYWAY, BURLINGTON,
SEWAGE TREATMENT PLANT 237

APPENDIX K  COMPUTER LISTINGS 247
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NUMBER</th>
<th>PAGE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1</td>
<td>INFORMATION FLOW WITHIN THE GEMCS EXECUTIVE</td>
</tr>
<tr>
<td>3.2.1</td>
<td>INTER-RELATIONSHIPS BETWEEN SOLID COMPONENTS</td>
</tr>
<tr>
<td>3.2.2</td>
<td>INTER-RELATIONSHIPS BETWEEN SOLUBLE COMPONENTS</td>
</tr>
<tr>
<td>4.1.1</td>
<td>SETTLING COLUMN</td>
</tr>
<tr>
<td>4.1.2</td>
<td>SETTLING VELOCITY ANALYSIS CURVE FOR SUSPENSIONS OF NON-FLOCCULATING PARTICLES</td>
</tr>
<tr>
<td>4.1.3</td>
<td>SETTLING CURVES FOR NON-FLOCCULATING SOLIDS</td>
</tr>
<tr>
<td>4.1.4</td>
<td>SETTLING CURVES FOR FLOCCULATING SOLIDS</td>
</tr>
<tr>
<td>4.2.1</td>
<td>FRACTION OF SETTLEABLE SOLIDS VERSUS DEPTH AND TIME - RUN #A.1</td>
</tr>
<tr>
<td>4.2.2</td>
<td>FRACTION OF SETTLEABLE SOLIDS VERSUS DEPTH AND TIME - RUN #A.2</td>
</tr>
<tr>
<td>4.2.3</td>
<td>FRACTION OF SETTLEABLE SOLIDS VERSUS DEPTH AND TIME - RUN #A.3</td>
</tr>
<tr>
<td>4.2.4</td>
<td>FRACTION OF SETTLEABLE SOLIDS VERSUS DEPTH AND TIME - RUN #A.4</td>
</tr>
<tr>
<td>4.2.5</td>
<td>COMPARISON OF REMOVALS OBTAINED FROM BATCH SETTLING AND FROM CORRELATION - RUN #A.1</td>
</tr>
<tr>
<td>412.6</td>
<td>COMPARISON OF REMOVALS OBTAINED FROM BATCH SETTLING AND FROM CORRELATION - RUN #A.2</td>
</tr>
</tbody>
</table>
4.2.7  COMPARISON OF REMOVALS OBTAINED FROM
       BATCH SETTLING AND FROM CORRELATION
       - RUN #A.3  37

4.2.8  COMPARISON OF REMOVALS OBTAINED FROM
       BATCH SETTLING AND FROM CORRELATION
       - RUN #A.4  38

5.1.1  A SCHEMATIC REPRESENTATION OF A
       BACTERIUM  47

5.2.1  A SCHEMATIC REPRESENTATION OF A
       CHEMOSTAT AND OPERATING VARIABLES  54

5.2.2  EXPERIMENTAL SET-UP FOR THE CHEMOSTAT  56

5.2.3  UNIT GROWTH RATE AS A FUNCTION OF
       SOLUBLE DEGRADABLE CARBON CONCENTRATION  57

5.3.1  VOLATILE SUSPENDED SOLIDS AS A FUNCTION
       OF AERATION TIME - RUN #D.1  61

5.3.2  OXYGEN UPTAKE RATE AS A FUNCTION OF
       AERATION TIME - RUN #D.1  62

5.3.3  SDOC AND SDOC VERSUS AERATION TIME
       - RUN #D.1  63

5.3.4  VOLATILE SUSPENDED SOLIDS AS A FUNCTION
       OF AERATION TIME - RUN #D.2  64

5.3.5  OXYGEN UPTAKE RATE AS A FUNCTION OF
       AERATION TIME - RUN #D.2  65

5.3.6  SDOC AND SDOC VERSUS AERATION TIME
       - RUN #D.2  66

5.3.7  SCHEMATIC REPRESENTATATION OF PARAMETER
       SEARCH  69

5.3.8  LOG (VSS) VERSUS TIME - RUN #D.1  72

5.3.9  LOG (VSS) VERSUS TIME - RUN #D.2  73

5.4.1  SEMI-LOG PLOT OF SPOC VERSUS TIME
       - RUN #E.1  77

(xi)
<table>
<thead>
<tr>
<th>FIGURE NUMBER</th>
<th>PAGE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.2</td>
<td>SEMI-LOG PLOT OF SPOC VERSUS TIME</td>
</tr>
<tr>
<td>- RUN #E.2</td>
<td>78</td>
</tr>
<tr>
<td>5.4.3</td>
<td>SEMI-LOG PLOT OF SPOC VERSUS TIME</td>
</tr>
<tr>
<td>- RUN #E.3</td>
<td>79</td>
</tr>
<tr>
<td>5.4.4</td>
<td>SEMI-LOG PLOT OF SPOC VERSUS TIME</td>
</tr>
<tr>
<td>- RUN #E.4</td>
<td>80</td>
</tr>
<tr>
<td>6.1.1</td>
<td>TRENDS OF CHANGES IN SVI AND XRSS WITH THE FOOD TO MICROORGANISMS RATIO</td>
</tr>
<tr>
<td>7.1.1</td>
<td>SCHEMATIC REPRESENTATION OF DIGESTION PROCESS</td>
</tr>
<tr>
<td>7.1.2</td>
<td>CONVENTIONAL DIGESTER CORRELATION</td>
</tr>
<tr>
<td>7.1.3</td>
<td>HIGH-RATE DIGESTER CORRELATION</td>
</tr>
<tr>
<td>8.1.1</td>
<td>SCREENINGS VOLUME AS A FUNCTION OF BAR SPACING</td>
</tr>
<tr>
<td>11.1</td>
<td>PROCESS FLOW DIAGRAM FOR THE INTER-ACTIVE VERSION</td>
</tr>
<tr>
<td>12.1.1</td>
<td>PROCESS FLOW DIAGRAM OF THE DRURY LANE PLANT</td>
</tr>
<tr>
<td>12.2.1</td>
<td>PROCESS FLOW DIAGRAM OF THE SKYWAY PLANT</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NUMBER</th>
<th>PAGE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2.1</td>
<td>15</td>
</tr>
<tr>
<td>4.2.1</td>
<td>39</td>
</tr>
<tr>
<td>4.3.1</td>
<td>43</td>
</tr>
<tr>
<td>5.3.1</td>
<td>70</td>
</tr>
<tr>
<td>5.3.2</td>
<td>74</td>
</tr>
<tr>
<td>5.4.1</td>
<td>81</td>
</tr>
<tr>
<td>5.5.1</td>
<td>83</td>
</tr>
<tr>
<td>5.6.1</td>
<td>83</td>
</tr>
<tr>
<td>8.3.1</td>
<td>119</td>
</tr>
<tr>
<td>10.1</td>
<td>132</td>
</tr>
<tr>
<td>10.2</td>
<td>133</td>
</tr>
<tr>
<td>10.3</td>
<td>138</td>
</tr>
<tr>
<td>10.4</td>
<td>139</td>
</tr>
<tr>
<td>12.1.1</td>
<td>151</td>
</tr>
</tbody>
</table>

(xiii)
<table>
<thead>
<tr>
<th>TABLE NUMBER</th>
<th>PAGE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1.2</td>
<td>SIMULATION OF THE DRURY LANE, BURLINGTON, WATER POLLUTION CONTROL PLANT</td>
</tr>
<tr>
<td>12.2.1</td>
<td>OPERATING CONDITIONS AND PARAMETERS USED IN THE SIMULATION OF THE SKYWAY PLANT</td>
</tr>
<tr>
<td>12.2.2</td>
<td>SIMULATION OF THE SKYWAY, BURLINGTON, WATER POLLUTION CONTROL PLANT</td>
</tr>
<tr>
<td>13.1.1</td>
<td>CORRELATIONS FOR THE BATCH SETTLING DATA, BASED ON TOTAL SOLIDS</td>
</tr>
<tr>
<td>13.2.1</td>
<td>EFFECT OF PLANT ALTERATIONS, AT THE SAME FLOW</td>
</tr>
<tr>
<td>13.2.2</td>
<td>EFFECT OF INCREASED PLANT FLOWS, WITH NO CHANGE IN PRESENT EQUIPMENT CAPACITIES</td>
</tr>
<tr>
<td>13.2.3</td>
<td>EFFECT OF INCREASED FEED FLOWS, AT THE SKYWAY PLANT</td>
</tr>
</tbody>
</table>
CHAPTER 1

1. INTRODUCTION

Although waste treatment practices have been known ever since the turn of the century, it was not until about the late 1940's that an effort was made to provide firm theoretical bases for design. Significant advances have been made in recent years, resulting in a better understanding of the complex variables affecting the operation of the various unit processes. It is now possible, where it would be beneficial, to bring together the models of the various waste treatment processes, to simulate the operation of full-scale plants, on a computer.

A successful simulation can have great potential applications, a few of which are:

(1) The performance of the individual units and of the plant as a whole can be predicted over a wide range of feed flows and operating conditions,

(2) The computer simulation can help in the selection of an optimal design for a plant to treat a given waste to a satisfactory level, at the least cost,

(3) It can be used effectively in the training of plant operators and as a valuable educational tool for students in the field, and

(4) It can be used for on-line process control purposes.
Several computer simulations have been attempted, both in the United States and in Canada, examples of which include those by Smith (46, 47), Silveston (40, 41), and by Fan and Erickson (10, 11). However, there is a severe limitation in their models for the activated sludge system. They have based their kinetics either on the entire sludge mass or on the volatile suspended matter in the sludge mass, when it is known that microorganisms are the only agents capable of stabilizing the waste. It is for this reason that their models break down when they are applied to the various modification of the conventional activated sludge process, as the composition of the sludge then changes.

One of the major objectives of this work is to develop a means by which the microbial mass may be estimated. The kinetic expressions can then be formulated around the physiological activities of the microorganisms, leading to a more meaningful model for the activated sludge process. This generalized model can then be applied to the various modifications of the activated sludge process.

As a great variety of raw wastes are encountered in wastewater treatment practice, it would be useful to develop generalized models that can handle all of them. However, the parameters pertaining to each type of waste will be different. Consequently, another objective of this work is to compile a series of experiments that can be used to
characterize a given wastewater and its treatability parameters. Although the work in this thesis is based primarily on domestic sewage, the same experiments used here may be performed on other wastewaters.

It is also realized that the complexity of a simulation system is discouraging its use by most plant operators or engineers. Furthermore, there is a tendency for interested parties to create their own simulation system rather than to try to understand and use other systems. It is for this reasons that we feel it necessary to develop an interactive version of the computer simulation which would require the minimum knowledge of the simulation system, for its use.
CHAPTER 2

2. LITERATURE REVIEW

The model for the primary settler proposed by R. Smith (46), was derived by plotting the data for suspended solids removal versus overflow rate for full-sized plants, as reported in "Sewage Treatment Plant Design", (38). He obtained the relationship

\[ FRPS = 0.82 \exp \left(-\frac{GPS}{2780}\right) \]  \hspace{1cm} (2.1)

where \( FRPS \) = fraction of solids removed
\( GPS \) = overflow rate usgpd/ft.\(^2\)

The fractional removal was applied to all classes of suspended solids, which may not be a valid assumption.

P. Silveston (41), tested the model on two Ontario plants and found that the effluent suspended solids predicted were about 25% higher than that actually observed. This led him to suggest that actual plant data have to be used to achieve a reasonable simulation. He proposed the relationship

\[ FRPS = 1 - \exp \left(-\frac{k}{GPS}\right) \]  \hspace{1cm} (2.2)

where \( k \) = constant fitted from plant data.

Both models, however, do not account for the effect of turbulence on the settling process. The constant \( k \) in Silveston's model could be interpreted to include both the effects of turbulence and the settling characteristics of the feed solids.
Camp (4) has developed a mechanistic model for discrete particle sedimentation in a continuous-flow tank. He first introduced the concept that a real settling tank may be divided into an inlet zone, a settling zone and an outlet zone. The actual sedimentation occurs in the middle zone, whilst turbulence at both the inlet and outlet zones prevent any further sedimentation from occurring. He also introduced the use of batch settling curves to predict the performance of a continuous-flow sedimentation tank.

Most of the models for the activated sludge process have evolved from the complete mixing model first presented by McKinney (25). The original paper was a little vague, and in a later discussion, Washington (47) corrected and clarified several points. However, his model can be interpreted as follows, noting that all the various forms of organic carbon are in their oxygen equivalents:

In the presence of unlimited food the rate of synthesis of the active solids is limited only by the concentration of the active solids, i.e.,

\[
\frac{d(MLVSS)}{dt} = k_s'MLVSS
\]  

(2.3)

But in the case of food-limiting situation, the rate becomes

\[
\frac{d(MLVSS)}{dt} = k_sC
\]  

(2.4)
where MLVSS = oxygen equivalent of active solids

\[ C = \text{oxygen equivalent of substrate} \]

\[ k_s, k'_s = \text{rate constants.} \]

He assumed that the volatile solids in the sludge is entirely active. He also proposed that the rate of substrate removal is proportional to the rate of synthesis of active solids, i.e.,

\[ \frac{dC}{dt} = -(1 + k_a) \frac{d(\text{MLVSS})}{dt} \quad (2.5) \]

The basal metabolism rate was also assumed to be proportional to the concentration of active solids, i.e.,

\[ \frac{d(\text{MLVSS})}{dt} = -kd(\text{MLVSS}) \quad (2.6) \]

By performing mass balances around the stirred tank reactor, he obtained, assuming a food-limiting situation:

\[ C_o = \frac{C_i}{1 + (1 + k_a) k_s \bar{t}} \quad (2.7) \]

and

\[ M_o = \frac{k_s C_o}{k_d + x \bar{t}} \quad (2.8) \]

where

\[ C_i = \text{influent substrate concentration} \]

\[ C_o = \text{effluent substrate concentration} \]

\[ M_o = \text{effluent active solids concentration} \]

\[ \bar{t} = \text{detention time} \]

and

\[ x = \text{fraction of sludge mass wasted.} \]
Estimated values of his constants were given as:

\[ k_a = 0.5 \]
\[ k_d = 0.006 \text{ hr}^{-1} \]
\[ k_s' = 15 \text{ hr}^{-1} \text{ (minimum)} \]
and \[ k_s = 7 \text{ hr}^{-1} \text{ (minimum)} \]

R. Smith (46) in his model, assumed that the rate of substrate removal is proportional to both the concentration of active solids and the substrate concentration, i.e.,

\[ \frac{dC}{dt} = -k_s'' C \text{ (MLSS)} \tag{2.9} \]

as contrasted to equations (2.3) and (2.4). \( k_s'' \) is a rate constant given by:

\[ k_s'' = 0.0001 (1.047)^{T-20} \text{ hr}^{-1} \text{ (mg/l)}^{-1} \tag{2.10} \]

Erickson, Ho and Fan (11) assumed Michaelis-Menten kinetics with the expression

\[ U = \frac{1}{U_{\text{max}}} \frac{dC}{dt} = - \frac{U_{\text{max}}}{Y (C^* + C)} \tag{2.11} \]

where \( U_{\text{max}} \) = maximum unit growth rate
\( C^* \) = value of C where \( U = \frac{1}{2} U_{\text{max}} \)
\( Y \) = yield factor.

It may be noted that equation (2.11) reverts to the form of equation (2.3) when \( C >> C^* \), and to the form of equation (2.9) when \( C << C^* \).
Little quantitative information exists on the operation of the secondary settler. The models proposed by Ott and Bogan (29), Erickson and Fan (10, 11), and Silveston (41), have assumed that a constant fraction \( \beta \), of the input solids escapes over the weir and that the underflow solids are compacted by a ratio \( C \). R. Smith (46) proposed a model, based on the data of Villiers (51) where

\[
\beta = \frac{556 \text{ (GPS)}^{0.494}}{\text{MLSS}^{1.82} \text{ (TA)}^{0.439}} \tag{2.12}
\]

\( \text{GPS} \) is the settler overflow rate (USgpd/ft.\(^2 \)), \( \text{MLSS} \) is the inlet mixed liquor suspended solids (mg/l), and \( \text{TA} \) the aeration time (hours). For some reason he later reverted back to the simple splitter model.

Anaerobic digestion is a complex operation involving several reaction stages and different microorganisms. An accurate description for the process is difficult to obtain. McCarty (24) using Michaelis-Menten kinetics and a completely stirred tank model, arrived at the relationship:

\[
\frac{k_{\text{max}} F}{F^* + F} = \frac{1}{t} \tag{2.13}
\]

where \( k_{\text{max}} = \) maximum unit growth rate constant
\( F^* = \) value of \( F \) at which unit growth rate is \( \frac{1}{2} k_{\text{max}} \)
\[ F = \text{concentration of biodegradable carbon in effluent} \]

and \( \bar{t} = \text{digester residence time}. \)

The reported values of \( k_{\text{max}} \) and \( F^* \) are:

\[ k_{\text{max}} = 0.28 \exp \left[-0.036 (35 - T)\right] \quad (2.14) \]

and \( F^* = 700 \exp \left[0.10 (35 - T)\right] \quad (2.15) \]

where \( T = \text{temperature of digestion, } ^\circ\text{C}. \)

His relationship implies that the effluent degradable carbon is independent of the influent value, but depends only on the detention time. He also suggested an expression to estimate the organic carbon of the volatile acids (VAC) in the effluent as:

\[ VAC = \frac{200 \exp \left[0.12 (35 - T)\right]}{1 + k_{\text{max}} \bar{t}} \quad (2.16) \]

Extensive cost information is available in the literature. R. Smith (45, 46) presented a thorough investigation of the capital and operating costs of domestic waste treatment unit processes. The capital and operating costs of a unit are calculated as a function of its most significant capacity variable. Michel et al. (26) reported on the total operating and maintenance costs of a treatment plant as a function of the waste flow and also of the population equivalent. Barnard and Eckenfelder (2) included industrial waste treatment costs in their report. A more complete list of references may be obtained from the above reports.
Several papers have been published on the optimization studies of wastewater treatment processes. Erickson and Fan (10) studied the optimization of the hydraulic regime of activated sludge systems. Erickson, Ho and Fan (11) later investigated the modelling and optimization of the step aeration processes, which consists of a series of completely mixed tanks. Shih and Krishnan (39) reported on their studies on the dynamic optimization of industrial waste treatment plant designs. Realizing that many design parameters are not accurate, Berthouex and Polkowski (3) studied the effect of such uncertainties on the optimal design of a treatment plant.

Further references from the literature will be made, as the thesis is developed.
3. THE SIMULATION SYSTEM

3.1 The GEMCS Executive

Any processing or manufacturing plant can be broken down into its component unit processes. The unit process is a basic operation within the framework of the plant, and can usually be identified with a distinct physical piece of equipment, examples of which are primary sedimentation, chlorination, drying, etc. The mathematical model of a unit process is known as a unit computation.

In a simulation system, it is necessary to have a master-mind to execute each unit computation in its logical sequence. Such is the purpose of the executive program. It should also supervise the flow of information between storage locations and the unit computations.

The Chemical Engineering Department of McMaster University, in co-operation with the Canadian General Electric Company, has developed a simple but yet very flexible executive program known as GEMCS (the General Electric-McMaster Simulator) for the simulation of steady-state processes. It has been used successfully in the simulation of several chemical process industries. The extensive work done is well summarized in the book "Chemical Plant Simulation" (5). Only a very brief description of the executive program will be attempted here.
Figure 3.1.1. Information Flow Within the GEMCS Executive
The aid of Figure 3.1.1 is invaluable. The executive program first calls an assistant subroutine DLOAD1 which reads in input streams, equipment parameters and an order of calculation in which to execute the unit computations. The information is then stored for subsequent use. The main program then prepares to execute the first unit computation in the plant. It retrieves the equipment parameters for the unit from the storage location, the EEN vector, via a linking subroutine DISKIO. It then places the equipment parameters (this is done directly by DISKIO) into a working equipment vector, the EN vector. The main program then retrieves from the storage location for the streams, the SN matrix, the input streams flowing into the unit computation. Subroutine STREAM(S) acts as the link between the SN matrix and the main program. The input streams are then placed in the working matrix, the SI matrix. The unit computation is then called and executed using information provided in the SI and EN via the subroutine MODULE(NT) locations. Any output streams generated by the unit computation are stored in the working matrix, the SO matrix, and which are then transferred by the main program into the SN storage matrix.

The other unit computations in the calculation order are similarly executed. In the case where there is a recycle of streams, a control subroutine must be placed in the calculation order to direct the main program to recalculate all the
unit computations within the recycle loop, until convergence is reached, within a specified tolerance.

It should be noted that the unit computations deal directly only with the working equipment vector and input and output stream matrices. This creates a uniform pattern whereby the unit computations may be constructed.

3.2 The Stream List

In every process simulation a list of components that will adequately describe any stream within the process has to be selected. Crowe et al (5) have listed several criteria for the selection of stream variables. They include

(1) The variables should be useful to satisfy the objectives of the simulation,

(2) All variables in recycle streams are usually important, and

(3) The unit computations must be able to manipulate the variables to an accuracy consistent throughout the whole system.

These criteria were used as an aid in the selection of the stream variables for the present generalized waste-water treatment plant simulation. In addition, the best features of the stream lists used by Smith (46) and Hoffman (20) were selected and in some cases modified. The stream list used is shown in Table 3.2.1.
<table>
<thead>
<tr>
<th>No.</th>
<th>Phase</th>
<th>Stream Variable</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Stream number</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>pH</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Total volumetric flow</td>
<td>gpm</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>5</td>
<td>Short List</td>
<td>Head</td>
<td>ft. of water</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Water</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Dissolved oxygen</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Total Organic Carbon (TOC = sum 15-22)</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Dissolved Organic Carbon (DOC = sum 20-22)</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Biochemical Oxygen Demand (BOD)</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Total Suspended Solids (TSS)</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Volatile Suspended Solids (VSS)</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>13</td>
<td>Suspended Solids Phase</td>
<td>Particulate settleable</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>Inorganics non-settleable</td>
<td>lbs/hr</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Microorganisms</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>Particulate settleable, biodegradable</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>Particulate settleable, non-biodegradable</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>Organics scum (floatable)</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Particulate non-settleable</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microorganisms</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suspended settleable, non-settleable</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>No.</td>
<td>Phase</td>
<td>Stream Variable</td>
<td>Units</td>
</tr>
<tr>
<td>-----</td>
<td>-----------</td>
<td>-----------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td><strong>Purgeable, biodegradable</strong></td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>21</td>
<td>Dissolved</td>
<td>Non-purgeable, biodegradable</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>22</td>
<td>Organics</td>
<td>Non-purgeable, non-biodegradable</td>
<td>lbsC/hr</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td><strong>Alkalinity, as CaCO₃</strong></td>
<td>lbs/hr</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
<td><strong>N in NH₃ (dissolved)</strong></td>
<td>lbs/hr</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td><strong>N in NO₂⁻ and NO₃⁻ (dissolved)</strong></td>
<td>lbs/hr</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td><strong>Dissolved P in all forms of phosphates</strong></td>
<td>lbs/hr</td>
</tr>
</tbody>
</table>

*Table 3.2.1 Stream List for Wastewater Simulation*
It may be noticed that the stream list is divided into three parts. The first part is a list of traditional variables commonly used in wastewater treatment practice. The second part covers the water-insoluble components normally found in wastewaters and the last category includes the water-soluble components. The second and third parts may be further sub-divided into an inorganic and an organic fraction.

The traditional variables in elements 8-12 are not fundamental components in the sense that they may be derived from the finer classification provided in elements 13-22. However, these are the variables that most operators and environmental engineers understand and hence are invaluable in our communication with them. Another reason for retaining these variables is that several of the correlations used in our simulation are expressed in terms of them. A simple simulation can be effected by the use of only these first twelve variables.

Suspended solids can either be organic or inorganic in nature. The inorganic portion is inert and does not take part in any biological processes, although chemically, it may be altered by a changing pH. However, we have to distinguish between a colloidal inorganic solid, which remain in suspension and a settleable inorganic solid which is removed in physical sedimentation.
For the organic suspended solids, we have to distinguish between the non-living organic objects from the living biomass which is active in bringing about the stabilization of the waste-load. The major portion of the non-living organic solids is biodegradable, while the remainder may be relatively non-biodegradable. The inertness may be due to several factors, one of which is a high degree of polymeric crosslinking. It is impossible to distinguish between the biodegradable portion from the non-biodegradable portion, and the distinction, although provided in the stream list is not used.

Physically, the non-living organic solids can be differentiated by their settling characteristics. We can distinguish a colloidal fraction, which remains in suspension, a settleable fraction and a scum (or floating) fraction.

Organics in solution can also be classified as biodegradable and non-biodegradable. Physically, certain organics in solution may be volatilized by purging with air. These are the solvents and other low molecular weight compounds. The non-biodegradable fraction, being largely composed of high molecular weight compounds, is relatively non-purgeable.

Soluble inorganics of interest include the nutrients phosphorus and nitrogen, and the alkalinity causing ion. Inorganic nitrogen is further subdivided into ammonia and the sum of nitrite and nitrate ions. Several blank spaces
are left in the soluble inorganics section to facilitate the addition of variables, should the simulation be extended to include tertiary treatment.

The units used are also shown in Table 3.2.1. It should be noted that concentration units facilitate the splitting of streams, while mass flow units facilitate the mixing of streams. A disadvantage of concentration units is that while concentrations based on unit volume are usually measured, the simulation system invariably has to use concentrations based on unit mass. Volumetric and mass concentrations are approximately equivalent under 1%, but become increasingly inaccurate above that. To avoid this complication, mass flow units are chosen.

As in Hoffman et al (20), the organic components are all measured in terms of the carbon content. This greatly facilitates the arithmetic of the biological processes.

The interplay being the variables is schematically represented in Figures 3.2.1 and 3.2.2, together with the analytical procedure followed. This is essentially the outline given by Hoffman et al with slight modifications. Further analytical details are given in "Standard Methods" (48).

The conversion of variables within our "finer" classification to the traditional variables is described in Section 9.1.
Figure 3.2.1. Inter-relationship Between Solid Components
filtrate

- dissolved inorganics
  - nitrogen
  - alkalinity
  - phosphorus

acidify and carbon analysis

- carbon analysis
  - total dissolved carbon
    - difference

- total dissolved organic carbon
  - purge with N₂ for 15 min.
    - remainder
      - non-purgeable dissolved organic carbon
  - purgeable dissolved organic carbon

- biochemical oxygen demand
  - degradable non-purgeable organic carbon
  - non-degradable non-purgeable organic carbon

---

Figure 3.2.2, Inter-relationship Between Dissolved Components
CHAPTER 4

4. PRIMARY SEDIMENTATION

The solid particles carried in suspension by wastewater flows can be partially removed by gravity settling in a relatively quiescent tank. The process, often called primary sedimentation, is used to reduce the sludge load downstream of the units. In the case where no further treatment is provided, primary sedimentation reduces the formation of sludge banks in the receiving waters. In most cases, it is used as a preliminary step ahead of biological treatment, to reduce the amount of solids being carried around in the latter system.

4.1 Theory

During sedimentation, the solid particles in a dilute suspension, may retain their individual shapes and sizes, and settle out as discrete particles. However, many other solids tend to flocculate (coalesce into a larger particle upon contact with each other), as they settle. This increases their settling velocities and hence the flocculation of the particles is a desirable property from this view-point.

The simpler case of discrete particle sedimentation will be dealt with first, and then it will be expanded to include the case of flocculent sedimentation.
A discrete particle, settling through a fluid, quickly reaches a terminal velocity. At this point, the gravitational force is exactly balanced by the buoyant and drag forces acting on the particle. This leads to the classical equation of discrete particle sedimentation

$$U_t = \left[ \frac{4}{3} g \left( \frac{P_s - P}{P} \right) D_p \right]^{\frac{1}{2}}$$  \hspace{1cm} (4.1.1)

where

- $U_t$ = terminal velocity (ft/sec)
- $g$ = acceleration due to gravity (ft/sec$^2$)
- $P_s$ = specific gravity of the solid particle
- $P$ = specific gravity of the fluid
- $C_D$ = drag coefficient
- $D_p$ = diameter of the particle (ft)

The drag coefficient $C_D$ is a function of the particle Reynolds Number and of the sphericity of the particle. This can be obtained from most standard texts on Fluid Mechanics.

Using the fact that a discrete particle quickly reaches a terminal velocity, during sedimentation, we can calculate the removal obtained in a batch settling test.

Consider the sketch of a batch settling column in Figure 4.1.1. If a dilute suspension of discrete particles occupies the entire volume uniformly, at the start of the test, then if a sample is drawn off at a depth $h$ at time $t$, it will not contain any particles with terminal velocities greater
Figure 4.1.1. Settling Column

Figure 4.1.2. Settling Velocity Analysis Curve for Suspensions of Non-Flocculating Particles
than \( U = h/t \). The fraction of the solids concentration in the sample to the original solids concentration will be the weight fraction of particles having terminal velocities \( U \leq h/t \). Let this weight fraction be represented by \( x \), and \( x = f(u) \) may be used to represent the settling characteristics of the particles. Figure 4.1.2 shows a typical settling velocity analysis curve for a suspension of non-flocculating particles.

If the liquid above a depth \( N_0 \) were to be decanted, at time \( t \), it will only contain particles with terminal velocities \( h_0/t = U_0 \). But particles with terminal velocities \( U \leq U_0 \) will have fallen through a distance \( h = Ut \), and hence only a fraction \( (h_0 - h)/h_0 = (U_0 - U)/U_0 \) of such particles will remain in the decanted liquid.

Hence the weight fraction of the solids in the decanted (or clarified) liquid will be

\[
W_C (U) = \int_0^{x_0} (U_0 - U)/U_0 \, dx
\]

\[
= x_0 - \int_0^{x_0} U/U_0 \, dx
\]

(4.1.2)

where \( W_C = \) weight fractions of solids in decanted liquid

\( x_0 = \) weight fraction of particles having terminal velocities \( U \leq U_0 \).

and \( U_0 = \) sometimes referred to as overflow velocity.
The weight fraction of solids not in the decanted liquid (or the weight fraction removal) is then given by

\[ W_r (U_o) = 1 - W_c (U_o) = (1 - x_o) + \int_0^{x_o} \frac{U}{U_o} \, dx \quad (4.1.3) \]

The integral may be approximated by a summation term and hence equations 4.1.2 and 4.1.3 may be rewritten as

\[ W_c (U_o) = x_o - \sum_{x=0}^{x=x_o} \frac{U}{U_o} \, \Delta x \quad (4.1.4) \]

and

\[ W_r (U_o) = (1 - x_o) + \sum_{x=0}^{x=x_o} \frac{U}{U_o} \, \Delta x \quad (4.1.5) \]

The integral or the summation term can be evaluated with the use of Figure 4.1.2.

If, during the batch settling test, samples are withdrawn at various depths and elapsed times, Figure 4.1.3 will result. The lines shown join points of equal weight-fraction. The slopes of the lines will give the associated terminal velocities.

The weight fraction of solids removed can also be evaluated from Figure 4.1.3. Equation 4.1.5 may be rewritten, for that purpose, as

\[ W_r (U_o) = (1 - x_o) + \sum_{x=0}^{x=x_o} \frac{h}{h_o} \, \Delta x \quad (4.1.6) \]

From Figure 4.1.3, if \( h_A \) is the average of \( h_o \) and \( h_1 \), \( h_B \) the average of \( h_1 \) and \( h_2 \), and so on, then the summation term can be evaluated as
Figure 4.1.3. Settling Curves for Non-Flocculating Solids

Figure 4.1.4. Settling Curves for Flocculating Solids
In the case where the particles tend to flocculate upon contact with each other, the settling velocities of the particles are increased, as sedimentation proceeds. Hence there is an added effect of the settling time.

The effect of flocculation is best seen in Figure 4.1.4, which is obtained in the same manner as Figure 4.1.3. The lines joining points of equal weight-fraction are no longer straight, as in the case of discrete particle sedimentation, but curved. The curvature reflects the increasing settling velocity, as the sedimentation proceeds.

Equation 4.1.2 to 4.1.6 still holds and may be used to evaluate the solids removal. Also, a similar procedure, as the one used in obtaining Equation 4.1.7, may be used as a graphical solution.

The batch settling test can be directly applied to a continuous flow primary settling tank, assuming plug flow conditions exist in the tank. The depth \( h_o \) refers directly to the depth of the tank and the time \( t \) is the residence time of the fluid in the tank. Deviations from plug flow conditions are treated in section 4.3.
4.2 The Correlation of Batch Settling Data

Raw sewage from the Drury Lane, Burlington and Dundas Sewage Treatment Plants were used in the settling experiments. The settling column is 8 in. in diameter and 8 ft. in height. The column has five sampling points, equally spaced 1 ft. apart.

The raw sewage was introduced into the column and allowed to equilibrate to room temperature for at least four hours. This was done to minimize thermal convection currents. Then the suspension was stirred up by blowing air into the sewage for one minute.

Samples were withdrawn initially, just after the mixing, and at regular time intervals from the five sampling ports. Prior to sampling, the sampling lines were flushed to wash out any accumulated solids. The column was also left for 24 hours, and the suspended solids determined. This represented the non-settleable or colloidal portion of the waste. The suspended solids of the samples were determined by vacuum filtration on 0.45 micron membrane filter papers. The papers were dried in an oven set at 103°C for at least half an hour. A Mettler balance with an accuracy of 0.1 mg was used for the weighing. All determinations were done in duplicate, and averaged.

The suspended solids data are given in Appendix A. Two previous runs, performed in 1969 and 1970, as part of a
wastewater course, using raw sewage from the Dundas Sewage Treatment Plant are also included. Figure 4.2.1 to 4.2.4 show the weight fraction of settleable solids in the samples withdrawn as a function of time and depth. Equation 4.1.6 was used to calculate the weight fraction of settleable solids removal as a function of depth and time, and the results are tabulated in Appendix A.

In the absence of theoretically derived expressions, empirical correlations had to be derived. However, we note that at constant $h_o$,

if $t \rightarrow \infty$, then $W_c \rightarrow 0$ or $W_r \rightarrow 1$ and if $t \rightarrow 0$, then $W_c \rightarrow 1$ or $W_r \rightarrow 0$. \hspace{2cm} (4.2.1)

Also that at constant $t$,

if $h_o \rightarrow \infty$, (or $U_o \rightarrow \infty$), then $W_c \rightarrow 1$ or $W_r \rightarrow 0$

and if $h_o \rightarrow 0$ (or $U_o \rightarrow 0$), then $W_c \rightarrow 0$ or $W_r \rightarrow 1$ \hspace{2cm} (4.2.2)

This suggests a relationship of the form

$$W_c = e^{-kt^\beta/h_o}$$ \hspace{2cm} (4.2.3)

or $$W_r = 1 - W_c = 1 - e^{-kt^\beta/h_o}$$ \hspace{2cm} (4.2.4)

By comparing Equations 4.2.4. and 4.2.2 we note the similarity between our model and Silveston's model. However, Silveston has assumed that $\alpha = \beta = 1$ (note: $GPS = \frac{h_o}{t}$).
Figure 4.2.1. Fraction of Settleable Solids Versus Depth and Time

RUN A.1
Figure 4.2.2. Fraction of Settleable Solids Versus Depth and Time

RUN A.2
Figure 4.2.3. Fraction of Settleable Solids Versus Depth and Time

RUN A.3
Figure 4.2.4. Fraction of Settleable Solids Versus Depth and Time

RUN A.4
Figure 4.2.5. Comparison of Removals Obtained from Batch Settling and from Correlation
Figure 4.2.6. Comparisons of Removals Obtained from Batch Settling and from Correlation
Figure 4.2.7. Comparison of Removals Obtained from Batch Settling and Correlation

RUN #A.3
Figure 4.2.8. Comparison of Removals Obtained from Batch Settling and Correlation

RUN #A.4

Removal Obtained from Batch Settling

Removal Calculated from Correlation
A three parameter search, using a SIMPLEX routine was then used to determine \( k, \alpha \) and \( \beta \). The objective function uses a least sum of squares criterion, the sum of squares being \( \sum (W_r \text{ experimental} - W_r \text{ correlation})^2 \). The values of \( k, \alpha \) and \( \beta \) are summarized in Table 4.2.1 and the correlated data are shown in Figures 4.2.5 to 4.2.8.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Source of Raw Waste</th>
<th>( k )</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>Dundas</td>
<td>0.215</td>
<td>0.473</td>
<td>0.233</td>
<td>0.95</td>
</tr>
<tr>
<td>A-2</td>
<td>Burlington</td>
<td>0.239</td>
<td>0.515</td>
<td>0.252</td>
<td>0.94</td>
</tr>
<tr>
<td>A-3</td>
<td>Dundas</td>
<td>0.238</td>
<td>0.513</td>
<td>0.251</td>
<td>0.94</td>
</tr>
<tr>
<td>A-4</td>
<td>Dundas</td>
<td>0.213</td>
<td>0.273</td>
<td>0.221</td>
<td>0.94</td>
</tr>
</tbody>
</table>

**TABLE 4.2.1. Parameters for Quiescent Settling Model**
(Note: \( t \) is in minutes and \( h_o \) is in feet.)

The correlations obtained are good and the closeness in the values of the parameters indicate that the raw waste from the two sources are not too different. The average values of \( k, \alpha \) and \( \beta \) obtained are 0.226, 0.494, and 0.239.
4.3 Deviations from Ideal "Plug Flow" Settling

Conditions in a primary settling tank are seldom of the ideal "plug flow" nature. Turbulence and short-circuiting in the flow can be caused by several factors, and their effects on sedimentation have to be accounted for.

Short-circuiting in the flow results mainly from density currents, which are bulk movements of fluids caused by density variations. Temperature differences between the feed and the water in the tank, or the presence of high suspended solids in the feed, will cause these density differences to occur.

Due to poor inlet design, the kinetic energy of the incoming flow can be quite considerable. The resulting energy dissipation can cause turbulent conditions to exist in the inlet zone. Inlet baffles, if properly designed, can reduce the kinetic energy to a large extent.

Several investigators have examined the effects of turbulence on settling. A very good summary of the various approaches used can be found in Fitz (15). Ensign Dobbins (6), starting from the Continuity Equation, made several assumptions and arrived at a simplified expression, for the case of discrete particle sedimentation

\[
\frac{dc}{dt} = e \frac{d^2c}{dy^2} + u \frac{dc}{dy} \quad (4.3.1)
\]
where \( C \) = concentration of solids having settling velocity \( U \)
\( U \) = settling velocity
\( y \) = depth
\( t \) = time

and \( e \) = eddy diffusivity.

Dobbins has obtained a solution for Equation 4.3.1, but it is too complex for use in a simulation model. A graphical solution of Equation 4.3.1 is available (4), and could be used in conjunction with the batch settling test as outlined in Section 4.2.

Another approach to the problem would be to obtain information on the flow patterns in the tank from a residence time distribution analysis. Fitz (15) used mixed models of combinations of stirred tanks, plug flow volumes and dead spaces to fit the residence time distributions thus obtained, to predict solids removal. His results were not too encouraging.

A dispersion model also does not appear to be promising as it rarely fits the observed exit age distributions. This is to be expected as the dispersion model assumes only relatively small deviations from plug flow with no gross short-circuiting or density currents.

In an attempt to estimate the degree of turbulence in the primary tanks of the Dundas and Drury Lane Water Pollution
Control Plants, tracer studies were carried out, using Rhodamine B dye and a Fluorometer, a Turner and Associates Model III. The experimental technique is well described by Wilson (49). The exit age distributions were followed for at least two residence times. Samples of the influent and effluent were collected during the tracer studies and analyzed for suspended solids.

Eight runs were made, four at Dundas and four at Drury Lane. Due to pump and recorder difficulties, two runs had to be discarded, one from each of the two plants. The exit age distributions are given in Appendix B. The tracer recoveries were poor and were approximately 80-85%. The calculated residence times from the exit age distributions were much lower than the actual fluid residence times. The tracer results are too unreliable for any use.

However, there seemed to be a consistent efficiency factor for each of the two plants, where the efficiency factor is defined as

\[
\phi = \frac{\text{observed} \% \text{ of settleable solids removed}}{\text{theoretical (batch)} \% \text{ of settleable solids removed}}
\]  

(4.3.2)

A high efficiency factor will indicate a low degree of turbulence or short-circuiting, while a low efficiency factor indicates a high level of turbulence or short-circuiting.
The theoretical or batch removal is calculated from the equation developed in Section 4.2. The efficiency factors obtained are summarized in the table below:

<table>
<thead>
<tr>
<th>Plant</th>
<th>Plant Flow (migd)</th>
<th>t (mins)</th>
<th>$\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dundas</td>
<td>2.1</td>
<td>66</td>
<td>0.62</td>
</tr>
<tr>
<td>(two tanks in parallel)</td>
<td>2.3</td>
<td>60</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>77</td>
<td>0.56</td>
</tr>
<tr>
<td>Drury Lane</td>
<td>2.2</td>
<td>84</td>
<td>0.83</td>
</tr>
<tr>
<td>(two tanks in parallel)</td>
<td>2.0</td>
<td>93</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>116</td>
<td>0.86</td>
</tr>
</tbody>
</table>

TABLE 4.3.1. Efficiency Factors for the Primary Sedimentation Tanks at the Dundas and Drury Lane Treatment Plants.

The average efficiency factor for the primary settlers at Dundas is 0.57 whilst that at Drury Lane is 0.85. The high degree of turbulence in the primary settling tank at Dundas is reflected in the low efficiency factor and is quite evident visually from the effluent turbidity.

Our overall correlation for the primary settler is then described by

$$W_r = \phi \left( - \exp \left( - k \frac{t^\alpha}{H^\beta} \right) \right)$$  \hspace{1cm} (4.3.3)
4.4 The Primary Settling Tank Model - PRISET1

A listing of the program is given in Appendix K.

The equipment vector for the model is reproduced below.

The computations carried out by the program can be explained in the following steps:

(1) The pH of the output streams is initially calculated.

(2) Input streams 2 and 3 are sludge streams carrying solids which have much higher settling velocities than the solids in the raw waste. Hence, the removal of the sludge solids is essentially complete. EN(22) provides
for the small fraction of the sludge solids which
do escape over the wiers due to short-circuiting or
turbulence.

(3) The removal of the solids in the raw waste is calculated
from Equation 4.3.3.

(4) The underflow is calculated from pump capacities. The
concentration of the underflow solids is then calculated,
for which a maximum value of 6% is assumed. If the
pump capacity is insufficient, excess solids over
6% is carried over to the effluent.

(5) The scum flow is then calculated, assuming 90%
removal of scum solids. The solids concentration
of the scum flow is specified by EN(20).

(6) Soluble components are then split according to
the split in water flow among the three output
streams.
CHAPTER 5

5. **AEROBIC BIOLOGICAL SLUDGE PROCESSES**

The theory here represents an attempt to model all aerobic biological sludge processes in one general package. Currently, all the various modifications of the activated sludge process, such as extended aeration, step aeration, contact stabilization and aerobic digestion, have been considered as separate processes. However, a bacterial cell does not know what hydraulic regime it is in, nor does it know what process it is supposed to work under. The kinetics describing the activity of the bacteria should be similar in all cases. The differences in rates observed with the various processes can only be due to differences in composition of the activated sludge mass.

5.1 **The Bacteria and its Activities**

The morphology of the bacteria is well described in any standard textbook on microbiology. A very brief description will be given here, while the physiological functions of the bacteria and their corresponding kinetic expressions will be described in more detail.

Bacterial cells are small and have sizes of the order of one micron. The cell shape may be spherical (coccus), rod-like (bacillus), or spirally-shaped (spirillum), and is defined to a large part by a relatively tough outer cell wall.
Figure 5.1.1. A Schematic Representation of Bacteria (a Procaryotic Cell)
Inside the cell wall is a semi-permeable cytoplasmic membrane, which is responsible for a selective transfer of nutrients and waste products into and out of the cell. The region within the cytoplasmic membrane includes the cytoplasm and the nuclear region. The cytoplasm is characterized by a relatively high concentration of ribonucleic acid (RNA), which is associated with protein synthesis. The nuclear region contains a high concentration of deoxyribonucleic acid (DNA). The genetic code is stored in the DNA. Some bacteria secrete slimy materials on their surfaces, creating a slimy layer outside the cell wall. A rough sketch of a bacterial cell is shown in Figure 5.1.1.

The activity of the bacteria will be described in the following four sections.

(a) **Metabolism:**

Bacterial cells, like all living cells are capable of feeding and growing. Soluble organic matter (substrate) diffuses into the bacterial cell where they are metabolized and converted partly into new cell matter. The remainder of the organic substrate is respired to provide energy for the cell. The respiration products are mainly carbon-dioxide and water.

Schematically, this may be represented as:

$$\text{soluble degradable organics} + \text{microorganisms} + O_2 \rightarrow \text{New cell matter}$$

$$\downarrow \quad \text{Respiration products}$$
The yield factor, $Y$, is defined as the fraction of soluble carbon metabolized which goes into new cell growth. The fraction $(1-Y)$ which is respired will require an equivalent amount of oxygen.

The rate of soluble carbon degradation can be written as

$$\text{rate} = \frac{dC}{dt} = -UM$$  \hfill (5.1.1)

where $C =$ concentration of soluble degradable carbon

$U = f(c) =$ unit growth rate

and $M =$ concentration of microorganisms

(as equivalent carbon)

For the case of a single substrate and a pure culture, the functional dependence of $u$ is described by Michaelis-Menton kinetics as

$$U = \frac{U_{max}C}{C^* + C}$$  \hfill (5.1.2)

where $U_{max} =$ maximum growth rate

and $C^* =$ constant = value of $C$ at which $U = \frac{1}{2}U_{max}$

However, in waste treatment, mixed substrates are generally encountered. Pure cultures are also difficult to maintain and is often less efficient than mixed cultures. Consequently, there is no need to restrict the description of $U$ by Michaelis-Menton kinetics. The measurements of
U and Y as described in Section 5.2 show that a linear correlation

\[ U = k_4 C \]  

is a better fit. It should also be noted that the Michaelis-Menton equation becomes linear when \( C \ll C^* \).

(b) **Endogenous Respiration**

Bacterial cells can also utilize stored food products (bacterial fat) to provide energy for its various physiological activities, especially in periods of low external food supplies. This is known as endogenous respiration or sometimes as basal metabolism.

Schematically, this may be represented as stored "bacterial fat" + \( O_2 \) ---?-- Respiration products  

\[ \text{stored "bacterial fat"} + O_2 \rightarrow \text{Respiration products} \]  

The rate of endogenous respiration should be proportional to the number of bacterial cells present, or is first order with respect to the bacterial concentration, namely,

\[ \text{rate} = \frac{dM}{dt} = -k_1 M \]  

where \( k_1 \) = endogenous respiration rate constant.

(c) **Death and Cell Lysis**

In cell lysis, the inner protoplasm of the cell is released to the surroundings through a breach in the cell wall. Part of the protoplasm is available as food for other microorganisms, while the remainder consists of relatively
non-biodegradable high molecular weight matter, schematically, this may be shown as

\[ \begin{align*}
\text{bacterial cells} & \xrightarrow{\alpha} \text{soluble degradable carbon} \\
& \xrightarrow{\beta} \text{soluble non-degradable carbon} \\
& \xrightarrow{(1-\alpha-\beta)} \text{particulate fragments}
\end{align*} \]  

(5.1.6)

\( \alpha \) is the fraction of soluble degradable carbon, and \( \beta \) is the fraction of soluble non-degradable carbon released during cell lysis. The remaining fraction \((1-\alpha-\beta)\) is particulate matter consisting of cell walls, slime layers, various membranes and so on, with varying degrees of biodegradability.

This process explains the build-up of soluble non-degradable carbon during the prolonged aeration of activated sludge.

The rate of death and subsequent cell lysis should also be proportional to the number of bacterial cells present:

\[ \text{rate} = \frac{dM}{dt} = -k_2M \]  

(5.1.7)

where \( k_2 \) = lysis rate constant.

(d) **Solubilization of Particulate Organics**

In general, solid organic matters have to be solubilized before they can be utilized by the bacteria. This process is speeded up by the secretion of exo-enzymes by the bacterial cells. The solubilized organic matter then diffuses back into the bacterial cell as substrate.
The rate of solubilization should be proportional to the concentration of the organic solids. It should also be proportional to the rate of release of exo-enzymes or equivalently, to the number of bacterial cells present:

\[ \text{rate} = \frac{dP}{dt} = -k_3PM \]  \hspace{1cm} (5.1.8)

where \( P \) = solid organics concentration (as equivalent carbon),
and \( k_3 \) = solubilization rate constant.

The four reactions proposed above involves principally five components, namely the microorganisms (M), the particulate organics other than microorganisms (P), soluble degradable organic carbon (SDOC), soluble non-degradable organic carbon (SNDOC) and carbon dioxide. However, carbon dioxide is partially purged from the system by the air and hence is difficult to monitor. But, it can always be obtained from a mass balance on carbon.

The total soluble organic carbon, SDOC+SNDOC, can be determined by means of the carbon analyzer. The soluble degradable organic carbon can be obtained from the Biochemical Oxygen Demand of the filtrate, using the relationship

\[ \text{SDOC} = \frac{\text{BOD (filtrate)}}{1.9} \]  \hspace{1cm} (5.1.9)

This is discussed in Section 9.1. The SNDOC is then obtained by difference.
The total concentration of microorganisms and particulate solids, \( M + P \), can be obtained from the volatile suspended solids using the relationship (see also Section 9.1)

\[
M + P = \frac{VSS}{2.1} \tag{5.1.10}
\]

The concentration of microorganisms alone can be indirectly measured from its oxygen uptake rate. In addition to the oxygen required for the carbon respired, oxygen is also consumed in the nitrification of ammonia-nitrogen associated with the sludge. A chemical analysis of activated sludge reports an average composition of \( C_5H_7O_2N \) (54). The oxidation reaction can then be written as:

\[
C_5H_7O_2N + 7O_2 \rightarrow 5CO_2 + 3H_2O + HNO_3 \tag{5.1.11}
\]

Hence each gram of carbon lost through respiration requires 3.73 grams of oxygen or

\[
\text{OUR} = 3.73 \left[ k_1 + (1-Y)U \right] M \tag{5.1.12}
\]

therefore,

\[
M = \frac{\text{OUR}}{3.73 \left[ k_1 + (1-Y)U \right]}
\]

Hence, our aerobic biological system involves four simultaneous, kinetically independent reactions, five components and seven constants. The constants involved are \( k_1, k_2, k_3, k_4, Y, a \) and \( \beta \).
5.2 Chemostat Experiments

The purpose of this series of experiments is to evaluate the functional dependence of the unit growth rate on the soluble degradable carbon concentration. A chemostat is essentially a biological reactor that acts as a continuous-flow, completely stirred tank reactor. The defining equations are easily derived from a mass balance around the reactor.

In Figure 5.2.1, $Q$ is the flow rate through the reactor and $V$ the volume of the reactor. The concentration of soluble degradable organic carbon in the feed is $C_o$ and that in the effluent is $C$. The concentration of microorganisms in the feed is assumed to be zero while that in the vessel or effluent is $M$ (as equivalent carbon).

Performing a mass balance on the soluble carbon, we have at steady-state,

$$0 = \frac{dC}{dt} = Q(C_o - C) - UMV \quad (5.2.1)$$

**FIGURE 5.2.1.** A Schematic Representation of a Chemostat, and Operating Variables.
where $U = \text{unit growth rate} \ (\text{see Section 5.1})$

Hence $U = f(c) = \frac{(C_0 - C)}{M t}$

where $t = \frac{V}{Q} = \text{residence time}$.

Also from definition, the yield factor

$$Y = \frac{M}{(C_0 - C)}$$

In our experiments, settled raw sewage was filtered through a two-inch thick layer of glass wool and used as the feed. This was stored in a constant head bottle and allowed to drip into an aerated 6 litre vessel (see Figure 5.2.2). Seeding was accomplished by the addition of about 100 ml of activated sludge to the reaction vessel. After two detention times, the effluent was sampled and analyzed regularly, until a steady-state was reached.

The results from seven runs are summarized in Appendix C. The average value of the yield factor $Y$ obtained is 0.57 with a standard deviation of 0.04. The functional dependence of $U$ is found to be linear with respect to the soluble degradable carbon concentration, in the range studies (25 - 50 mg/l). This is plotted in Figure 5.2.3. The correlation obtained is

$$U = 0.0010 \ C = k_4C$$

with a correlation coefficient of 0.85.
Figure 5.2.2. Experimental Set-Up for the Chemostat
Figure 5.2.3. Unit Growth Rate as a Function of Soluble Degradable Carbon Concentration
We have assumed that the solids in the feed is not
significantly solublized in the reactor.

To compare the results obtained we have to convert
Equation 5.1.2 to traditional units:

We have \[ \frac{dC}{dt} = \frac{d\text{BOD}_5}{dt} \times \frac{1}{1.9} \]

It is estimated that microorganisms account for
approximately 30% of the Mixed Liquor Suspended solids.
Hence \( M \times 2.1 = 0.3 \) (MLSS)

Therefore, Equation 5.1.2 becomes

\[ \frac{1}{1.9} \times \frac{d\text{BOD}_5}{dt} = -k_4 \times \frac{\text{BOD}_5}{1.9} \times \frac{0.3}{2.1} \text{(MLSS)} \]

or \[ \frac{d\text{BOD}_5}{dt} = -k_4 \times \frac{0.3}{2.1} \times \text{BOD}_5 \text{(MLSS)} \]

or \[ K_s = k_4 \times \frac{0.3}{2.1} \]

\[ = 0.00014 \text{ (hr)}^{-1} \text{ (mg/l)}^{-1} \]

Eckenfelder (2) reports a value of

\[ K_s = 0.00010 - 0.00013 \text{ (hr)}^{-1} \text{ (mg/l)}^{-1} \]
Keshavan et al (22) reports a value of

\[ K_S = 0.00016 \text{ (hr)}^{-1} \text{ (mg/l)}^{-1} \]

Hence, our results are approximately in agreement with the literature values.

5.3 Aeration Studies of Activated Sludge

As some of the rate proposed in Section 5.1 are expected to be slow, batch studies of aerated activated sludge have to be carried out over an extended period. Return activated sludge is a convenient "reaction mixture" to use, as it contains all the components in our reaction set.

Return activated sludge from the Drury Lane plant was used, and the aeration was carried out in a 6-litre vessel, for twenty five days. Samples were taken periodically, and the following analyses performed:

1. Biochemical Oxygen Demand of filtrate,
2. Dissolved Organic Carbon,
3. Suspended Solids, and
4. Oxygen Uptake rate.

Inorganic solids were determined both initially and at the end.

Two runs were made with different samples of return activated sludge from the Skyway Plant, Burlington. The results obtained are tabulated in Appendix D. The plots of \((P + M)\), OUR, SDOC and SNDOC versus time are shown
in Figures 5.3.1 - 5.3.6. The volatile suspended solids and the oxygen uptake rate were observed to drop with length of aeration. The soluble degradable organic carbon dropped slightly and then remained fairly constant. There was a marked increase in soluble non-degradable organic carbon with aeration in both cases.

To obtain an estimate of the variances in the measurements, a third run was started and allowed to run for a week. Then five samples were withdrawn simultaneously from the reaction vessel and analyzed immediately. The results are also tabulated in Appendix D, together with the variance-covariance matrix and its inverse matrix.

Before the parameter search was performed, an eight constant $Q_0$ was introduced and it is defined as the ratio of the initial concentration of microorganisms, $M_0$, to that of the total volatile solids, namely,

$$Q_0 = \frac{M_0}{(P + M)_0} \quad (5.3.1)$$

where the subscript $0$ refers to initial values. Otherwise, we have to calculate $M_0$ from the initial value of the oxygen uptake rate, and as $M_0$ is a critical value, an error in the oxygen uptake rate can have a marked effect on the search.

A fourth order Runge Kutta was used to calculate the values of the four components, $P$, $M$ SNDOC, and SDOC. The
Figure 5.3.1. Volatile Suspended Solids as a Function of Aeration Time
Figure 5.3.2. Oxygen Uptake Rate as a Function of Aeration Time

- RUN #D.1
- ■ observed values
- — predicted from model
Figure 5.3.3: SNDOC and SDOC versus Aeration Time

RUN #D.1
- observed SNDOC
- observed SDOC
- predicted from model

Soluble Non-degradable Carbon (mg/l)

Soluble Degradable Carbon (mg/l)

Aeration Time (days)
Figure 5.3.4. Volatile Suspended Solids as a Function of Aeration Time

RUN #D.2
- observed values
- predicted from model
Figure 5.3.5. Oxygen Uptake Rate as a Function of Aeration Time

RUN #D.2

- observed values
- predicted from model

Oxygen Uptake Rate (mgO₂/L/hr)

Aeration Time (days)
Figure 5.3.6. SNDOC and SDOC Versus Aeration Time

RUN #D.2

- observed SNDOC
- observed SDOC
- predicted from model

Soluble Non-degradable Carbon (mg/l)

Soluble Degradable Carbon (mg/l)

Aeration Time (days)
set of differential equations used were

\[
\frac{dP}{dt} = \left[ -k_3P + (1-\alpha-\beta)k_2 \right]M
\]
with an initial value of \((1-Q_0)(P+M)_0\) \hspace{1cm} (5.3.2)

\[
\frac{dM}{dt} = \left[ k_4(SDOC)Y - (k_1+k_2) \right]M
\]
with an initial value of \(Q_0(P+M)_0\) \hspace{1cm} (5.3.3)

\[
\frac{dSND\text{DOC}}{dt} = \beta k_2M
\]
with an initial value of \((SND\text{DOC})_0\) \hspace{1cm} (5.3.4)

and \[
\frac{dSD\text{OC}}{dt} = \left[ k_3P - k_4(SDOC) + k_2 \right]M
\]
with an initial value of \((SD\text{OC})_0\) \hspace{1cm} (5.3.5)

A SIMPLEX optimization routine was used and the objective function to be minimized is (18)

\[
\phi = \sum_{i=1}^{n} \sum_{r=1}^{4} \sum_{s=1}^{4} \sigma_{rs} (y_{ri} - \eta_{ri})(y_{si} - \eta_{si})
\]
\hspace{1cm} (5.3.6)

where \(\phi\) = objective function to be minimized

\(n\) = number of sets of observations made,

\(\sigma_{rs}\) = the \((r,s)\)th element of the inverse of the variance-covariance matrix,

\(y_{ri}\) = the \(i\)th observation of the \(r\)th response

and \(\eta_{ri}\) = the \(i\)th prediction of the \(r\)th response.
The four responses used are:

1. Volatile suspended solids (mgC/l), with the predicted value calculated from \( P + M \)

2. Oxygen uptake rate (mgO_2/l/hr), with the predicted value calculated from \( 3.7M k_1 + (L-Y)k_4 \) (SDOC)

3. Soluble non-degradable organic carbon, SNDOC, (mgC/l), and

4. Soluble degradable organic carbon, SDOC, (mgC/l)
A schematic representation of the parameter search is shown in Figure 5.3.7.

**FIGURE 5.3.7. Schematic Representation of Parameter Search**
The values of the constants obtained are shown in Table 5.3.1. The fitted curves are shown in Figures 5.3.1 to 5.3.6, together with the observed points.

<table>
<thead>
<tr>
<th>Run Number</th>
<th>( k_1 )</th>
<th>( k_2 )</th>
<th>( k_3 )</th>
<th>( k_4 )</th>
<th>( Y )</th>
<th>( \alpha )</th>
<th>( \beta )</th>
<th>( \theta_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-1</td>
<td>0.0029</td>
<td>0.0015</td>
<td>2.0x10^{-6}</td>
<td>6.0x10^{-4}</td>
<td>0.55</td>
<td>0.41</td>
<td>0.082</td>
<td>0.56</td>
</tr>
<tr>
<td>D-2</td>
<td>0.0029</td>
<td>0.0014</td>
<td>1.8x10^{-6}</td>
<td>5.6x10^{-4}</td>
<td>0.57</td>
<td>0.44</td>
<td>0.089</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Table 5.3.1. Parameters for the Aerobic Biological Sludge Process Model

The agreement in the values of the parameters in both runs are very good, considering the analytical errors involved. From the Chemostat experiments, the values of \( k_4 \) and \( Y \) obtained are \( 1.0 \times 10^{-3} \) and 0.57. The agreement in the yield factor is good, but the metabolism rate factor is much lower in the "endogenous phase" of the extended aeration studies. The results imply that the metabolism rate is retarded under conditions of prolonged starvation.

Sedivy (37) in his thesis on residual organics found \( \beta \) to be about 1-5%, using glucose as substrate. Our value is a bit high. The value of \( \theta_0 \) obtained suggests that only about half of the volatile suspended solids in the return sludge from the Skyway Plant, is actually "active mass".
No equivalent values for the other constants exist in the literature. Note that the basal metabolism rate constant \( k_d \) proposed by other workers is actually measured from the rate of decrease of volatile suspended solids and which in our case is a combination of \( k_1 \), \( k_2 \) and \( k_3 \). To illustrate that our reaction scheme fits the rate of decrease of volatile suspended solids better than the simple exponential decay, semi-log plots are shown in Figure 5.3.8 and 5.3.9, of the volatile solids versus time. In both runs, our model agrees with the exponential decay model up to about an aeration time of ten days. Beyond that the exponential decay model predicts much lower solids than is actually observed. Our model gives a much better fit beyond ten days, although it still predicts lower solids than is actually observed. This is probably because our model still lacks the ability to predict the concentration of particulate non-degradable organic carbon, which would build up with extended aeration.

As a matter of interest, the \( k_d \) value from our data, which is 0.055 day\(^{-1}\) (base e) agrees with Pipes and Meade (31) very well. Their data showed a range of \( k_d \) between 0.025 to 0.078 day\(^{-1}\) with an average value of 0.053 day\(^{-1}\). Eckenfelder (2) reports a value of 0.048 day\(^{-1}\).

As the statistical calculations are quite difficult, the estimation of confidence limits for the various constants
Figure 5.3.8. Log (Volatile Suspended Solids) Versus Time

Volatile Suspended Solids, P+M, (mgC/l)

RUN #D.1

- our model

- exponential decay model

\[ k_d = 0.0235 \text{ day}^{-1} \] (base 10)

Aeration Time (days)
Figure 5.3.9. Log (Volatile Suspended Solids) Versus Time

RUN #D.2
- our model
- exponential decay model

Volatile Suspended Solids, P+M, (mgC/l)

Aeration Time (days)
will not be attempted. Instead, the average sum of squares deviation from the regression line will be compared to the variance obtained in the replicate samples. This is presented in Table 5.3.2.

<table>
<thead>
<tr>
<th>Run</th>
<th>Number of Points or Samples</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Volatile Suspended Solids</td>
</tr>
<tr>
<td>D-1</td>
<td>16</td>
<td>8000</td>
</tr>
<tr>
<td>D-2</td>
<td>14</td>
<td>8400</td>
</tr>
<tr>
<td>Replicates</td>
<td>5</td>
<td>6450</td>
</tr>
</tbody>
</table>

Table 5.3.2. Comparison of Average Sum of Squares Deviation from Regression Line, with the Variance from Replicate Samples

The average sum of squares from the regression line compares quite well with the variance from the replicate analysis. This indicates that the model proposed is significant.

No measurements were made on the effect of temperature on the various rates. The above two runs were made at 23°C ± 2°C. A temperature correction factor of 1.047 will be used, as proposed by several authors (2, 47). Hence,

\[
k_1(T) = 0.0026 \times (1.047)^{T-23}
\]

\[
k_2(T) = 0.0015 \times (1.047)^{T-23}
\]
\[ k_3(T) = 2.0 \times 10^{-6} (1.047)^{T-23} \]
\[ k_4(T) = 0.0010 (1.047)^{T-23} \]

or \[ k_4(T) = 0.0006 (1.047)^{T-23} \] in food limiting conditions.

(5.3.7)

5.4 The Stripping Rate of Purgeable* Soluble Organics

Purgeable soluble organics tend to be stripped off in the aeration process. Hence their removal can occur both by biological action and by physical stripping due to the passage of air (16, 17).

According to mass transfer principles, the mass transfer will depend on the first order of the driving force, or concentration difference and also on the surface area of the air bubbles, namely,

\[ \frac{dSPOC}{dt} = -k_L \frac{A}{V} (SPOC - SPOC_B) \]  \hspace{1cm} (5.4.1)

where $SPOC =$ soluble purgeable organic carbon in solution

$SPOC_B =$ soluble purgeable organic carbon in bubble

$k_L =$ a mass transfer coefficient

$A =$ surface area of bubbles

and $V =$ volume of reactor

* Waste treatment terminology reserves the use of the word "volatile" for volatiles at 600°C. The term "purgeable" is then used here to define the soluble organics which can be physically removed by purging with a gas, at normal temperatures.
But \( \frac{A}{V} = a_v q \) \hspace{1cm} (5.4.2)

where \( a_v \) = surface area to volume ratio of air bubbles
and \( q \) = volumetric rate of air per unit volume of reactor.

Hence,

\[
\frac{d(SPOC)}{dt} = - k_L a_v q (SPOC) \hspace{1cm} (5.4.3)
\]

\[
= - k_5 q (SPOC) \hspace{1cm} (5.4.4)
\]

Solving,

\[
\ln \frac{(SPOC)}{(SPOC)_0} = - k_5 q t \hspace{1cm} (5.4.5)
\]

where \( (SPOC)_0 \) = initial value of SPOC.

To estimate the rate of stripping, settled raw sewage was filtered through a two-inch layer of glass wool and aerated at a fixed rate in a 2 litre vessel (no activated sludge was added). The soluble organic carbon was measured at regular intervals, until no further drop was observed. The remaining soluble organics is non-purgeable. The difference between the soluble organic carbon and the ultimate value (or the non-purgeable organic carbon) is the soluble purgeable organic carbon (SPOC).

Four air rates of 0.5, 1.0, 1.5 and 2.1 cu. ft. air/hr/cu. ft. reactor were used and the results are tabulated in
Figure 5.4.1. Semi-Log Plot of SPOC Versus Time

RUN #E.1
air rate = 2.1
cu.ft. air/hr/cu.ft. reactor

Purging Time (minutes)
Soluble Purgeable Organic Carbon
Figure 5.4.2. Semi-Log Plot of SPOC Versus Time

RUN # E2
air rate = 1.0
cu.ft. air/hr/cu.ft. reactor
Figure 5.4.3. Semi-Log Plot of SPOC Versus Time

RUN #E.3
air rate = 0.5 c
cu.ft./hr/cu.ft. reactor

Soluble Purgeable Organic Carbon (mgC/L)

Time (minutes)
Figure 5.4.4. Semi-Log Plot of SPOC Versus Time

RUN #E.4
air rate = 1.5
cu.ft./hr/cu.ft.
reactor
Appendix E. Semi-log plots of SPOC versus time are shown in Figures 5.4.1 to 5.4.4. The slopes of the lines will be \(-k_5q\). Table 5.4.1. shows the values of \(k_5\) obtained from the four runs. The average value of \(k_5\) is 2.06 with a standard deviation of 0.27.

<table>
<thead>
<tr>
<th>Run Number</th>
<th>E-1</th>
<th>E-2</th>
<th>E-3</th>
<th>E-4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>(q) cu.ft. air/hr cu.ft. reactor volume</td>
<td>2.1</td>
<td>1.0</td>
<td>0.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>slope = (k_5q) hr(^{-1})</td>
<td>2.18</td>
<td>0.80</td>
<td>0.40</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>(k_5) (base e)</td>
<td>2.40</td>
<td>1.85</td>
<td>1.85</td>
<td>2.15</td>
<td>2.06</td>
</tr>
</tbody>
</table>

5.5 Oxygen Transfer Efficiencies

The rate of oxygen transfer can be found by using the same equation as that for the stripping of purgeable organics, namely

\[
\frac{d [O_2]}{dt} = k_L \frac{A}{v} \left( [O_2]_\text{sat} - [O_2] \right) \tag{5.5.1}
\]

where \([O_2] = \text{concentration of oxygen in liquid}\)
\([O_2]_\text{sat} = \text{saturation concentration of oxygen in liquid}\)
\[ k_L' = \text{liquid film mass transfer coefficient} \]
\[ A = \text{surface area of air bubbles} \]

and \[ V = \text{volume of aeration tank} \]

The saturation concentration of oxygen in water at 1 atm can be calculated from the equation (9)

\[ O_2 \text{ sat.}, 1 \text{ atm.} = 14.16 - 0.3943T + 0.007714T^2 - 0.0000646T^3 \]  (5.5.2)

where \[ T = \text{temperature in °C} \]

\[ k_L' \] is a function of the aeration device, the air flow rate and of the depth of the aeration tank. The functional relationship is

\[ k_L' = N \cdot G^{(1-n)} \cdot H^{(1-m)} \]  (5.5.3)

where \[ N = \text{sometimes referred to as absorption number} \]
\[ G = \text{total air rate, scfm.} \]
\[ H = \text{depth, ft.} \]

and \[ n,m = \text{constant} \]

Table 5.5.1 shows the various values of the constants, for several aeration devices (9).

5.6 Nutrient Balance

The assumption made is that the nitrogen to carbon \((N/C)\) and phosphorus to carbon \((P/C)\) ratios in the raw waste is the same for both the particulate and soluble organic
Table 5.5.1. Oxygen Transfer Characteristics of Some Common Diffused Aeration Equipment.

<table>
<thead>
<tr>
<th>Unit</th>
<th>N</th>
<th>(1-n)</th>
<th>(1-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aloxite tubes</td>
<td>270</td>
<td>0.85</td>
<td>0.45</td>
</tr>
<tr>
<td>Sparjer</td>
<td>210</td>
<td>0.86</td>
<td>0.78</td>
</tr>
<tr>
<td>Seran tubes</td>
<td>275</td>
<td>0.8</td>
<td>(0.60)</td>
</tr>
<tr>
<td>Carborundum plates</td>
<td>65</td>
<td>0.8</td>
<td>(0.75)</td>
</tr>
</tbody>
</table>

Table 5.6.1. Average Nitrogen, Phosphorus and Carbon Concentrations in Raw Sewage from Drury Lane W.P.C.P. The Nitrogen and Phosphorus Values are Obtained from 29 Analyses by the O.W.R.C. The carbon concentrations are estimated from our analyses.

<table>
<thead>
<tr>
<th>Element Phase</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Carbon</th>
<th>N/C</th>
<th>P/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate</td>
<td>22</td>
<td>7</td>
<td>(90)</td>
<td>0.24</td>
<td>0.078</td>
</tr>
<tr>
<td>Soluble</td>
<td>23</td>
<td>6</td>
<td>(80)</td>
<td>0.29</td>
<td>0.075</td>
</tr>
</tbody>
</table>

components. This is supported by analyses made by the Ontario Water Resources Commission for the Drury Lane W.P.C.P. This is shown in the table below.
The composition of the bacterial cells is assumed to be $C_5H_7O_{2N}$ (54). This has a (N/C) ratio of 0.23. The (P/N) ratio in activated sludge is reported to be about 0.25 (9), hence (P/C) is approximately 0.06.

After the various effluent organic carbon components have been calculated, a mass balance over nitrogen and phosphorus is then performed. All excess nitrogen is assumed to be converted to ammonia and all excess phosphorus to inorganic phosphates.

Downing's data for the rate of nitrification will be used (7):

$$\frac{dNH_3}{dt} = - \frac{G \cdot NH_3 \cdot X}{Y \cdot (K + NH_3)} \quad (5.6.1)$$

and

$$\frac{dX}{dt} = -y \frac{dS}{dt} \quad (5.6.2)$$

where $NH_3$ = ammonia concentration (mgN/l)

$X$ = Nitrosomonas concentration (mg/l)

$G$ = 0.014 hr$^{-1}$

$K$ = 1.0 mg/l

and $Y = 0.05$ gms Nitrosomonas/gm $NH_3$-N

A slight modification will be made to Downing's equation. This is to account for a decrease in the rate due to an oxygen concentration of less than 1.0 mg/l. The retarding factor $f$ is defined where
\[ f = 1 \text{ for } [O_2] \geq 1.0 \text{ mg/l} \]
and \[ f = [O_2] \text{ for } 0.0 \leq [O_2] < 1.0 \text{ mg/l} \quad (5.6.3) \]
i.e.,
\[
\frac{dNH_3}{dt} = -\frac{fG \cdot NH_3 \cdot X}{Y \cdot (K + NH_3)} \quad (5.6.4)
\]

The mass of Nitrosomonas is found iteratively and stored in the EN vector as a fraction of the mixed liquor suspended solids mass.

The oxygen requirement during nitrification can be obtained from the equation
\[
NH_3 + 2O_2 \rightarrow HNO_3 + H_2O \quad (5.6.5)
\]
Hence, for each gram of NH\(_3\)-N converted to NO\(_3^-\), 4.57 grams of oxygen are required.

5.7 The Aerobic Biological Sludge Process Model - ACTSL1 and CSTR2

CSTR 2 is a continuous-flow, completely-stirred tank reactor model of the aerobic biological sludge process. ACTSL1 is a stirred tanks in series model which calls the basic CSTR2 program. ACTSL1 is the program that is actually used as the unit computation. Listings of the two programs are given in Appendix K. The equipment vector for ACTSL1 is reproduced below, of which EN(16) - EN(32) are actually used by the CSTR2 routine.
EN VECTOR

********
1.-15. STANDARD FORMAT
4. NUMBER OF REACTORS IN PARALLEL
5. TOTAL HEAD LOSS THROUGH ACT. SL. TANKS (FT OF WATER)
6. NUMBER OF INPUT STREAMS (= 2.0)
7. FIRST INPUT STREAM (= RETURN SLUDGE FLOW)
8. SECOND INPUT STREAM (= FEED STREAM)
11. NUMBER OF OUTPUT STREAMS (= 1.0)
12. OUTPUT STREAM NUMBER

NOTE: EN(16.-32.) ARE USED BY CSTR2
16. LENGTH OF REACTOR (FEET)
17. WIDTH OF REACTOR (FEET)
19. DEPTH OF REACTOR (FEET)
20. LYSIS RATE (K2 /HR)
21. BASAL METAB. RATE (K1 /HR)
22. RATE OF SOLUBILIZATION OF DEGRADABLE SOLIDS (K3 /HR)
23. STRIPPING RATE OF VOLATILE ORGANICS (K5 /HR)
24. MICROORGANISMS YIELD FACTOR (Y DIMENSIONLESS)
25. FRACTION OF LYSIS PRODUCTS TO SOLUBLE DEGRADABLE CARBON
26. FRACTION OF LYSIS PRODUCTS TO SOLUBLE NONDEGRADABLE CARBON
27. RATE OF AIR ADDITION TO EACH REACTOR (SCF/HR)
28. UNIT GROWTH RATE CONSTANT (K4 /HR)
29. FRACTION OF MLSS THAT IS NITRIFIERS
30. N/C RATIO IN RAW FEED
31. P/C RATIO IN RAW FEED
32. ABSORPTION NUMBER (FOR OXYGEN TRANSFER)

33. NOT PRESENTLY USED
34. NUMBER OF CSTR'S IN SERIES - EITHER AN RTD MODEL OR THE
ACTUAL NUMBER OF TANKS IN A STEP AERATION PROCESS
MAXIMUM OF TEN TANKS IN SERIES
35. FRACTION OF FEED STREAM TO FIRST TANK
36. FRACTION OF FEED STREAM TO SECOND TANK
37. - ETC
44. FRACTION OF FEED STREAM TO TENTH TANK (IF ANY)
45. NUMBER OF BLOWERS USED
46. CAPACITY OF EACH BLOWER SCF/HR

ACTSL1 may be used as the step aeration process model
or as a model for the activated sludge process and its
various modifications. For the contact stabilization process,
ACTSL1 will have to be used twice.

The computations carried out by the CSTR2 program
may be explained by the following steps:
(1) Stream variables are first converted to concentration units,

(2) The iteration then begins on the effluent concentrations of the reactive components. All inert components are passed through the model. The reaction rates used are:

(a) \[ \frac{\text{d}M}{\text{d}t} = (Yk_4 C - k_1 - k_2)M \]

where \( M = \text{SO}(1, 15) \)

\[ C = \text{SO}(1, 20) + \text{SO}(1, 21) = C' + C'' \]

\( k_4 = \text{EN}(28) \)

\( k_1 = \text{EN}(21) \)

and \( k_2 = \text{EN}(20) \)

(b) \[ \frac{\text{d}S'}{\text{d}t} = (- k_3 S' + k_2 (1 - \alpha - \beta))M \]

where \( S' = \text{SO}(1, 16) \)

\( \alpha = \text{EN}(25) \)

\( \beta = \text{EN}(26) \)

and \( k_3 = \text{EN}(22) \)

(c) \[ \frac{\text{d}S''}{\text{d}t} = - k_3 S''M \]

where \( S'' = \text{SO}(1, 18) \) as well as \( \text{SO}(1, 19) \)
(d) \[ \frac{dC'}{dt} = - (k_4 M + k_5 q) C' \]

where \( C' = SO(1, 20) \) and \( q = \text{volume air used/hr/volume of reactor.} \)

(e) \[ \frac{dC''}{dt} = (k_3 S + k_2 d - k_4 C'')M \]

where \( S = S' + S'' \) and \( C'' = SO(1, 21) \)

(f) \[ \frac{dSNDC}{dt} = k_2 \beta M \]

where \( SNDC = SO(1, 22) \)

The concentration of ammonia nitrogen released and the subsequent nitrification to nitrates are also calculated, within the iteration loop. The rate of change of dissolved oxygen is next given by

(g) \[ \frac{dO_2}{dt} = k_L a (O_S - O_2) - \frac{32}{12} \left\{ (1 - \gamma) k_4 C + k_1 \right\} M \]

\[ - 4.57 \left( \frac{dN}{dt} \right) \]

where \( O_2 = SO(1, 7) \)

\( O_S = \text{saturation oxygen concentration} \)
\( k_La \) = oxygen mass transfer coefficient

and \( \frac{dN}{dt} \) = nitrification rate.

(3) A balance is then made on phosphorus,

(4) The exit pH is next calculated assuming that the carbon-dioxide concentration is in equilibrium with air.
CHAPTER 6

6. SECONDARY SEDIMENTATION

In the activated sludge process the waste to be treated is mixed with a flocculent sludge containing microorganisms and other organic and inorganic solids, and aerated. The microorganisms are used to feed on the soluble portion of the waste and to convert them into more cell mass which may then be settled out. The level of suspended solids used in the activated sludge process range from 2000-4000 mg/l. As the treated water will constitute the plant effluent in most cases, it is important that the activated sludge is removed and the suspended solids concentration in the effluent be reduced to the level of about 20 mg/l. Secondary sedimentation performs such a purpose.

As the settled sludge will be recycled to the activated sludge tanks, and partially "wasted", it is equally important that we keep the solids content of the sludge high. The benefits resulting from a "thick" sludge are:

(a) It maintains a high level of mixed-liquor suspended solids in the activated sludge tanks,
(b) It reduces pumping costs,
(c) It improves digester operation on the waste sludge and hence requires smaller digester volumes,
(d) It increases the economy of sludge dewatering systems such as centrifuges, vacuum filters, etc., and
(e) It reduces the sludge volume for land or sea disposal.

6.1. Activated Sludge Characteristics

The clarification and thickening properties of an activated sludge have been related to its composition and character. A sludge with a relatively high content of inorganic solids (such as clay) will tend to be denser and hence more easily thickened. However, the character of the microorganisms in the sludge can determine whether a sludge will be flocculent and hence have good clarifying properties or whether the sludge will be compact and have good thickening properties.

The microbial population in activated sludge include the bacteria, fungi, protozoa and some rotifiers. The bacteria are the most predominant group, and as they are responsible for stabilizing the organic matter in the waste and in floc formation, they are the most important group as well. Numerous types of bacteria may be found in any sample of an activated sludge, but sometimes one or several genera may predominate, depending on the particular waste being treated.

A brief description of new operating conditions may affect the character of the microorganisms in the sludge
will be presented here. Assuming that oxygen is supplied in sufficient quantities, a high food to microorganism ratio will lead to a rapid rate of bacterial metabolism and reproduction. The bacterial cells are highly energetic and will tend to stay as discrete entities. Another reason for the bacterial cells to stay apart, is the high surface area that each cell will enjoy, aiding in the transfer of food and oxygen. This leads to the formation of a dispersed or diffused sludge with poor clarifying and thickening properties.

At a lower food to microorganism ratio, the bacterial cells have less energy and flocs begin to form when the cells are brought into contact with each other. The sludge also becomes more compact. The clarifying and thickening properties of the sludge improve.

At a very low food to microorganism ratio the bacterial cells are starved and many will die off. With less viable bacterial cells, the sludge will have a poorer flocculating ability, resulting in a poorer effluent. However, the sludge is still compact and will have good thickening characteristics. The above observations are illustrated in Figure 6.1.1.

In the case where the dissolved oxygen concentration in the activated sludge tanks is low, (0.5 mg/l) there is little oxygen penetration into the biological floc, resulting
Figure 6.1.1. Trends of Changes in SVI and XRSS with the Food to Microorganism Ratio.
in lowered bacterial growth. This encourages the growth of filamentous bacteria such as the Sphaerotilus, as they have a high surface area/volume ratio, and are more able to absorb the small amount of oxygen present. These filamentous growths render the sludge less compact and hence displays poor thickening properties. The effect of these filamentous growths on the flocculating and hence clarifying properties of the sludge is not too well know or reported.

Most fungi also have a filamentous structure and their growth tends to be stimulated by carbohydrate wastes, or conditions of low pH and nutrient deficiencies.

Prolonged periods of anaerobiosis in the secondary clarifier could lead to the production of gas, which when entrapped could cause the activated sludge flocs to rise, and escape over the effluent wiers. Denitrification could also contribute to the problem of a rising sludge.

6.2 Correlations for Activated Sludge Settling

From the above discussion, we realize that the twin functions of the secondary settling tanks, namely those of clarification and thickening, are very much related to the operating conditions in the activated sludge tanks. The level of clarification obtained can be described by the fraction of suspended solids escaping in the effluent, and the degree of compaction obtained, by the Sludge Volume Index.
The Sludge Volume Index is the volume in ml. occupied by 1 gm of the sludge after settling for half an hour.

Rex Chainbelt, Incorporated, has developed two correlations for this purpose (47):

\[ XRSS = \frac{382 (GSS)^{0.12} (FM)^{0.27}}{(MLSS)^{1.35} (TA)^{1.03}} \]  

and \[ SVI = 56.1 + 113 (1.05)^{T-20} (FM) \]

where \( XRSS \) = fraction of solids escaping in the effluent
\( GSS = \) overflow rate (usgpd/sq.ft.)
\( MLSS = \) mixed liquor suspended solids (mg/l)
\( FM = \) food to microorganism ratio (lbs BOD\(_5\)/lb MLVSS/day)
\( MLVSS = \) mixed liquor volatile suspended solids
\( TA = \) aeration time (hrs.)
\( SVI = \) sludge volume index (ml/gm)
and \( T = \) temperature (°C)

The above correlations are based on 41 observations and the correlation coefficient for the first equation is 0.63 whilst that of the second is 0.78.

The maximum concentration of the underflow solids can be estimated by the value \((10^6/SVI)\) mg/l. Although this represents the compaction obtained after half an hour of settling, it is a good estimate of the final compaction, as further changes in SVI are small, especially with mixed
liquor suspended solids of less than 3000 mg/l. It should be noted that there is a wide misconception that the SVI represents the settling rate of an activated sludge. The half an hour of settling required by the test is not meant to be a measure of the rate, but merely provides a reasonable time for which the sludge to achieve close to the ultimate compaction.

R. V. Villiers (51) performed laboratory scale settling column studies and arrived at the correlation

\[ XRSS = \frac{556 \cdot (GSS)^{0.494}}{(MLSS)^{1.82} \cdot (TA)^{0.439}} \]  \hspace{1cm} (6.2.3)

This correlation does not include the effect of the food to microorganism ratio, as does the previous correlation by Rex Chainbelt Inc. However, there is quite a significant difference in the exponents on the variables, between the two studies.

In a preliminary study, P. Leung from the Chemical Engineering Department, McMaster University, using laboratory scale experiments, arrived at the correlation

\[ XRSS = \frac{2560}{(MLSS)^{1.57} \cdot (TA)^{0.20}} \]  \hspace{1cm} (6.2.4)

This correlation does not include either the food to microorganism ratio or the overflow rate. However, the exponent that he obtained for the effect of the mixed liquor suspended
solids is intermediate between those of the earlier studies, but he found a very much smaller effect of aeration time than did the other two investigators. His results are tabulated in Appendix F.

The disparity between the three correlations could be explained if the nature of the raw wastes entering the plants from which the sludges were taken, were somehow significantly different. It would seem necessary to obtain a correlation based on a sludge actually produced by the plant.

In the absence of a good correlation for the sludge produced in the Burlington plants we have to choose either Equations 6.2.1 or 6.2.3. It should be noted that the above equations are developed from quiescent batch column studies and to apply them to real settling tanks, a correction factor of 1.5 is suggested by most authors. We will use the operating data for the Drury Lane Plant, in 1969, as a comparison:

\[
\begin{align*}
\text{OR} & = 960 \text{ usgpd/sq.ft.} \\
\text{MLSS} & = 2200 \text{ mg/l} \\
\text{TA} & = 9.6 \text{ hrs.} \\
\text{F/M} & = 0.3 \text{ lbs BOD}_5/\text{lb MLVSS/day}
\end{align*}
\]

and the obtained \( X_{RSS} = 0.090 \)
Using Equation 6.2.1:

\[
\begin{align*}
XRSS \text{ (calculated)} & = 0.019 \\
XRSS \text{ (corrected)} & = 0.019 \times 1.5 = 0.029
\end{align*}
\]

Using Equation 6.2.3:

\[
\begin{align*}
XRSS \text{ (calculated)} & = 0.054 \\
XRSS \text{ (corrected)} & = 0.054 \times 1.5 = 0.081
\end{align*}
\]

The Rex Chainbelt correlation gives too good an effluent, whilst the Villiers' equation gives a result which is closer to the actual operating condition. Hence, Equation 6.2.3. will be selected for use in our program.
6.3 The Secondary Clarifier Model - SECLAR 1

The listing for the program is given in Appendix K. The equipment vector for the model is reproduced below.

```
EN VECTOR
**********
1.-15. STANDARD FORMAT
4. NUMBER OF CLARIFIERS IN PARALLEL
5. HEAD LOSS THROUGH CLARIFIER (FEET OF WATER)
12. FIRST OUTPUT STREAM (EFFLUENT)
13. SECOND OUTPUT STREAM (UNDERFLOW)
14. THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
16. MODE OF OPERATION
   = 1.0 FOR FIXED FRACTION OF RECYCLE
   = 2.0 FOR MAXIMUM CONCENTRATION OF UNDERFLOW
17. FRACTION OF RECYCLE IF MODE=1
18. SURFACE AREA OF CLARIFIER (PER TANK) = SQ.FT.
19. SCUM FLOW CONCENTRATION (MG/L)
20. NUMBER OF UNDERFLOW SLUDGE PUMPS
21. CAPACITY OF PUMPS IGPHEACH
22. FRACTION OF CAPACITY USED
```

The computations carried out by the program can be explained in the following steps:

(1) The Sludge Volume Index of the activated sludge is first calculated, based on operating conditions in the aeration tanks. Equation 6.2.2. is used.

(2) The concentration of solids in the effluent, is then calculated from Equation 6.2.3.

(3) Secondary clarifiers can be operated with either a constant fraction of recycle of the underflow or with a constant depth of sludge blanket. In the second case, the underflow solids is at its maximum concentration, which can be estimated from the Sludge Volume Index. In the first case, the sludge blanket
depth is not constant but could drop when the underflow pumps are set too high or could rise and finally escape over the wiers when the underflow pumps are set too low. When there is no sludge blanket, the concentration of solids in the underflow is below the maximum value, as calculated from the SVI. EN(16) determines the policy used in the plant, and the underflow is calculated accordingly.

(4) The scum flow is then determined assuming 100% removal of all incoming scum. The scum solids concentration is determined by EN(19).

(5) Dissolved components are split according to the water flows.
CHAPTER 7

7. **ANAEROBIC DIGESTION**

The "Sewage Treatment Plant Design Manual" (38) adequately describes the purpose of anaerobic digestion as follows:

"...A primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge removed by sedimentation processes to a simpler, non-objectionable state. Digestion produces a sludge more amenable to dewatering without nuisance, and it renders the sludge fit for easy disposal by lagooning, dilution or similar means....Digestors also reduce the volume of sludge and in so doing produce gas which can be utilized for heating purposes."

The anaerobic digestion process has several disadvantages which may discourage their use in a wastewater treatment plant. Firstly, a high capital outlay is required, amounting to about 25-35% of the total capital cost. Secondly, digester upsets are frequent, thus requiring constant attention, and thirdly, there is always the hazard of a gas explosion.

7.1 **Theory**

There are two distinct processes occurring in an anaerobic digester - liquification and gasification. Liquefaction of the sludge solids is brought about by the extracellular
enzymes secreted by the bacteria, which hydrolyses the complex solids. Cellulose and carbohydrates are converted to simple sugars, alcohols and fatty acids. Proteins are converted to amino acids, while fats and grease are converted to glycerol and fatty acids. The formation of organic acids could result in a depression of the pH, if the alkalinity in the digesting sludge is not sufficient for neutralization. This liquefaction stage of digestion, is also called the acid phase, for obvious reasons, and the bacteria responsible are usually referred to as acid-formers.

In the gasification process, the end products of liquefaction are further broken down to gaseous end products. This could involve the activity of the same bacteria in the first phase, but with the exception that they are not capable of utilizing their own acid end products. This requires the work of a second group of bacteria which metabolize the fatty acids to give methane and carbon dioxide, and convert amino acids to ammonia. The ammonia released tends to neutralize a portion of the acids remaining and raise the pH. The gasification phase is also sometimes referred to as the methane phase, and the bacteria involved as methane-formers.

The digestion process can be schematically represented as:
Since the digester is operated under anaerobic conditions, the bacterial population has to be composed of either the facultative bacteria or the strict anaerobes. The acid-formers are predominantly facultative and many of them originate from the activated sludge fed to the digester. The methane formers are strict anaerobes, and are a small specialized group of bacteria. They are highly sensitive to pH changes and have an optimum pH range of 6.4 to 7.2. When a digester goes "sour" (or acidic) the methane-formers die off, and the gasification phase is seriously retarded.

A properly operating digester should have the liquefaction and gasification processes proceeding at about the same rate. An upset can be produced by an increase in the liquefaction rate, which could be prompted by a sudden increase in the solids fed to the digester.

To provide a reasonable description of the digestion process we need an expression to account for the rate of liquefaction of the organic solids. If a steady-state operation
is reached, the rate of gasification should equal the rate of liquefaction. We would also need an expression to determine the level of volatile organic acids maintained in the digester. This is necessary since the pH and the BOD of the digesting sludge would depend on the amount of volatile acids present.

A model for the anaerobic digester was first proposed by Fair and Moore (13) in 1932. They followed the digestion process in batch reactors and concluded that the rate of gas production is proportional to the amount of "gas" remaining in the digesting sludge:

\[
\frac{dy}{dt} = k (G-y) \quad (7.1.1)
\]

where \( y \) = amount of gas produced up to time \( t \)
\( G \) = total amount of gas produced

and \( k \) = rate constant.

They found \( k \) to be \( 0.168 \text{ day}^{-1} \), at \( 95^\circ \text{F} \). Since then, other workers have also obtained first order rates. Schulze (36) determined \( k \) to be \( 0.14 \text{ day}^{-1} \) at \( 92^\circ \text{F} \), and Simpson (42) arrived at a \( k \) value of \( 0.3 \text{ day}^{-1} \).

Since it would be useful to our modelling studies to know the rate of liquefaction of the digesting solids, we have to rearrange Equation 7.1.1. If gas production is a measure of volatile solids destruction, then \( (G-y) \) is proportional
to the amount of organic solids remaining.

i.e.,

\[(G-y) = a \cdot S\]  \hspace{1cm} (7.1.2)

where \( S \) = amount of organic solids remaining

and \( a \) = proportionality constant.

The proportionality constant is the volume of gas
produced per unit mass of organic solids. This has been
reported to be approximately 16-18 cu. ft./lb. solids destroyed,
for digesting sewage sludge.

Equation 7.1.1 then becomes

\[
\frac{dS}{dt} = -K \cdot S
\]  \hspace{1cm} (7.1.3)

Since most reactors are operated continuously or
semi-continuously, rather than batchwise, we will assume a
stirred tank model for the digester. The defining equation
for the digester then is:

\[
S = \frac{So}{1 + K\bar{t}}
\]  \hspace{1cm} (7.1.4)

where \( S \) = volatile solids remaining

\( So \) = feed volatile solids

and \( \bar{t} \) = detention time

or

\[
R = \frac{S}{So} = \frac{1}{1 + K\bar{t}}
\]  \hspace{1cm} (7.1.5)
where \( R = \) fraction of volatile solids remaining.

Or

\[
\frac{(1 - R)}{R} = K\bar{t} \tag{7.1.6}
\]

The relation here implies that the effluent volatile solids depend on both the influent volatile solids and the detention time, as contrasted to the theory of McCarty (see Chapter 2). This seems to be a more reasonable expression, and the importance of solids loading is supported by the observations of other workers (13, 19, 50).

Rankine (32) has presented data for the fraction of volatile solids destroyed as a function of the detention time in a conventional digester. His data is tabulated in Appendix G. A plot of \( (1 - R)/R \) versus \( \bar{t} \) is shown in Figure 7.1.2. \( K \) is found to be 0.025 day\(^{-1} \), and the correlation coefficient is 0.65. The range of solids loading employed as 0.033 - 0.135 lbs VM/cu.ft./day.

For the high-rate digestion process, the data of Torpey (50), Roy and Sawyer (34) and Estrada (12) are used. Their data is also tabulated in Appendix G, and the plot of \( (1 - R)/R \) versus \( \bar{t} \) is shown in Figure 7.1.3. The reaction rate constant \( K \) is found to be 0.085 day\(^{-1} \), and the correlation coefficient is 0.58. The range of solids loading employed here is 0.101 - 0.575 lbs/cu.ft./day.

Data on the dissolved biodegradable organic carbon in the supernatant is quite sparse. Hence, the equation
Figure 7.1.2. Conventional Digester Correlation

Conventional Digester

△ data of Rankine (1948)
Figure 7.1.3. High-Rate Digester Correlation

High-Rate Digester Studies
- ▲ data of Torpey (1955)
- ■ data of Roy & Sawyer (1955)
- ● data of Estrada (1960)
proposed by McCarty (see Chapter 2) will be used. He also estimated that the dissolved organic carbon is mainly composed of volatile acids.

The acidity due to the volatile acids is estimated by assuming that acetic acid is the major component, i.e.,

\[
\text{acidity (meq/1)} = \frac{\text{soluble organic carbon (mg/1)}}{24.0}
\]

(7.1.7)

The ammonia evolved tends to neutralize the volatile acids and raise the pH of the digester. Assuming that the nitrogen to carbon ratio in the feed sludge is approximately 0.23 (based on a sludge composition of C_5H_7O_2N), the ammonia nitrogen evolved is:

\[
\Delta N = 0.23 \Delta C
\]

(7.1.8)

where \( \Delta N \) = ammonia nitrogen evolved and \( \Delta C \) = organic carbon destroyed.

Hence, the alkalinity due to the ammonia is given by

\[
\text{alkalinity} = \frac{\Delta N}{14} = \frac{0.23 \Delta C}{14} \text{ meq/1}
\]

(7.1.9)

The effluent pH is then calculated by the module described in Section 9.2.

7.2 The Anaerobic Digestor Model - ANDIG1

A listing of the program is given in Appendix K. The equipment vector for the model is reproduced below:
### EN· VECTOR

**********

1. -15. STANDARD FORMAT

4. NUMBER OF DIGESTERS IN PARALLEL

5. HEAD LOSS IN DIGESTERS (FT OF WATER)

16. DIAMETER OF DIGESTER (FEET)

17. DEPTH OF DIGESTER (FEET)

18. = 1.0 FOR CONVENTIONAL DIGESTER OPERATION

 = 2.0 FOR HIGH RATE DIGESTER OPERATION

19. TEMPERATURE OF OPERATION

20. FRACTION OF WATER TO FIRST OUTPUT STREAM (SUPERNATANT)

 = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM

21. FRACTION OF SOLIDS TO FIRST OUTPUT STREAM (SUPERNATANT)

 (EXCLUDES SETTLEABLE INORGANIC SOLIDS)

 = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM

22. FRACTION OF SETTLEABLE INORGANIC SOLIDS TO SUPERNATE

 = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM

23. STORAGE SPACE FOR GAS PRODUCED

24. FRACTION OF VOLUME THAT IS EFFICIENTLY USED IN DIGESTION

The computations carried out by the program can be explained briefly by the following steps:

1. The fluid detention time is first calculated. EN(24) corrects for the fact that a fraction of the digester volume may be filled up with grit, etc., and hence is not available for digestion.

2. The fraction of volatile solids destroyed is calculated from Equation 7.1.5.

3. Based on a C:N:P ratio of 1.0:0.23:0.05, the amounts of nitrogen (as ammonia) and phosphorus released are then estimated.

4. The soluble organic carbon of effluent is then obtained from Equation 2.

5. The effluent pH is then calculated as discussed in Section 7.1.
(6) If the digester is used as the first stage of a two-stage digester, the contents are normally sent to the second stage, with little or no phase separation. This is maintained by constant stirring. Phase separation is used in the second stage to separate a clearer supernate from a concentrated solids underflow. There is no known correlation for the solids concentration of the supernate and hence the phase separations is specified by EN(20), EN(21), and EN(22). Soluble components are split according to the water flows.
CHAPTER 8

8. OTHER UNIT PROCESSES

Other unit processes commonly used in wastewater treatment include pretreatment, the use of biological filters (trickling filters) and chlorination. The primary purpose of pretreatment is to remove large and abrasive materials from the wastewater, to protect downstream equipment and pumps. It includes screening to remove the larger solid objects and grit removal.

Biological filters have been used as an alternative to the activated sludge process. In this process, the wastewater is passed over a biological growth, supported on a solid medium. The waste is absorbed by the biological growth and excess solids is sloughed off the "filter" and removed by sedimentation. The contact time is short, being of the order of a few minutes and the effluent is generally unsatisfactory.

Chlorination is practiced to prevent the transmission of pathogenic microorganisms to the receiving waters. It is generally applied to the secondary effluent and in cases where no secondary treatment is supplied, to the primary effluent. In the few cases where no treatment is practiced at all, the raw wastewater is chlorinated, prior to discharge.
The thickening of waste sludges is also practiced. This reduces the volume of sludge to be handled, either for disposal or for further solids processing within the plant. Other methods of dewatering include vacuum filtration, centrifugation and air flotation.

8.1 Pretreatment

Screening devices are usually classified as fine or coarse screens. In the category of fine screens there are perforated plates, wire-meshes and closely spaced bars. The openings are generally \( \frac{3}{16} \) in. or less. Coarse screens include comminuting devices, bar screens and coarse wire-meshes. The openings may be as large as 3 in.

The choice for the size of the openings is dictated by the size of the largest object which may be allowed to pass. In the majority of cases, a 1 in. opening is quite satisfactory.

The volume of screenings removed is difficult to estimate and depends not only on the screen size but also on the nature of the waste received, and the velocity of flow through the screens. The Rex Chainbelt Company (33) has developed a graph from which the average and maximum amount of screenings may be expected as a function of screen opening. This is reproduced in Figure 8.1.1. The average curve is approximately described by:
Figure 8.1.1. Screenings Volume as a Function of Bar Spacing
\[ V = 19 \times 10^{-0.8d} \]  
\[ (8.1.1) \]

where \( V \) = volume of screenings cu.ft./musg
and \( d \) = screen opening, inches

About 30 lbs. of dry solids may be expected per cu. ft. of screenings.

In grit removal, the object is to separate the non-putrescible solids from the waste flow with the minimum amount of entrained organic matter. This is achieved by differential sedimentation, which is made possible by the fact that the grit particles have subsiding velocities substantially greater than those of the organic solids. The flow-through velocities are also controlled to maintain the organic solids in suspension, by scouring the settled solids.

Velocity control can be maintained by the use of specially designed wiers, such as the Sutro Wier or the proportional wier. More recent developments in velocity-control devices include the use of compressed air to create a spiral current within the grit chamber. More details of the various types of grit chambers in use may be obtained from the "Sewage Treatment Plant Design Manual" (38).

As is the case with the quantity of screenings, the volume of grit to be expected at a plant cannot be confidently predicted. The quantities of grit received will depend on the area served by the sewers, the type of street and land
surfaces prevalent in the district and on the percentage of storm sewers feeding into the plant.

Due to the great variation in quantities of grit received, the model written for the grit chamber will require that we specify the volume of grit to be expected in cu.ft./mig. As a rough guide to use in Ontario, a survey of 28 plants having separate sewers gave an average grit volume of 2.4 cu.ft./mig, while 20 plants having partially combined sewers received on the average 3.3 cu.ft./mig.

8.2 Trickling Filters

The theory proposed for the rapid rate of organic removal in a trickling filter is that the waste is biosorped and incorporated into the biological growth, supported on the solid media. As the wastewater passes down through the filter, progressive removal is achieved until the clear effluent emerges. Howland (21) and Schulze (35) have shown that at low concentrations, the rate of removal is of the first order with respect to the concentration of soluble organics remaining:

\[ C = C_o e^{-kt} \]  \hspace{1cm} (8.2.1)

where \( C \) = effluent concentration of soluble organics

\( C_o \) = influent concentration of soluble organics
\[ k_1 = \text{reaction rate constant} \]

and \[ t = \text{mean contact time}. \]

Schulze (35) and Howland (21) have also shown that the mean contact time in a trickling filter is directly proportional to the depth and inversely proportional to the hydraulic loading to a power, \( n \), which depends on the solid media used.

i.e., \[ t = k_2 \frac{D}{Q^n} \] (8.2.2)

where \( t = \text{mean contact time (min.)} \)

\( D = \text{depth of filter (ft.)} \)

\( Q = \text{hydraulic loading (usgpm/sq.ft.)} \)

\( k_2 = \text{proportionality constant} \)

and \( n = \text{constant}. \)

Values of \( n \) range from 0.55 for spheres (55) to 0.66 for a screen filter (35). The \( n \) value for an increasingly popular media, the synthetic Dowpac Plastic Media, is 0.5.

It has also been shown that the reaction rate could decrease with depth. This could arise if the more easily removable portions of the waste are removed at the top of the filter, leaving a less readily degradable matter for the lower portion of the trickling filter. Another possibility exists whereby the microbial population in the filter is stratified with the more efficient bacteria and fungi at the top and progressing downwards to the predator microorganisms.
A general relationship can be developed by combining Equations 8.2.1 and 8.2.2, and with a modification for the effect of depth on the reaction rate:

\[ C = C_0 e^{-kd^m/Q^n} \]  

(8.2.3)

where \( k \) = rate coefficient or treatability factor

\( m \) = constant.

In the case where there is no effect of the depth on the reaction rate, \( m = 1 \). This has been found to be the case for domestic sewage by several investigators. Schulze (35) determined \( k \) to be 0.020 \( m \) to be 1.0 and \( n \) to be 0.66 for a screen treating settled sewage. McDermott (55) concurs similarly, but his rate coefficient is slightly lower, at 0.018. Germain (56) found \( m \) to be 1.0, \( n \) to be 0.48 and \( k \) to be much higher at 0.088, for the case of the Dowpac Filter Media. However, his data is based on only a few points.

8.3 Chlorination

The purpose of the model will be merely to calculate the chlorine requirements in a wastewater treatment plant. Since the effluent will not be directly used as a drinking water supply, but is discharged to a water-course, the criteria for chlorination is not so strict.
The chlorine dosage required depends on the degree of treatment the effluent has gone through. Raw sewage will require a higher chlorine dosage than the effluent from a secondary clarifier. The "Sewage Treatment Plant Design Manual" (38) gives the range of chlorine dosages commonly used, and this is reproduced in Table 8.3.1.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Chlorine Dosage mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw sewage</td>
<td>6 - 12</td>
</tr>
<tr>
<td>Raw sewage (septic)</td>
<td>12 - 25</td>
</tr>
<tr>
<td>Settled sewage</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Settled sewage (septic)</td>
<td>12 - 40</td>
</tr>
<tr>
<td>Chemical Precipitation effluent</td>
<td>3 - 10</td>
</tr>
<tr>
<td>Trickling filter effluent</td>
<td>3 - 10</td>
</tr>
<tr>
<td>Activated sludge effluent</td>
<td>2 - 8</td>
</tr>
<tr>
<td>Sand filter effluent</td>
<td>1 - 5</td>
</tr>
</tbody>
</table>

Table 8.3.1. Range of Chlorine Dosages Required for Disinfection.

8.4 Sludge Thickening and Dewatering

Sludge thickening performance is not very well correlated. Hence, only a simple mass balance model will
be used. This is a slight modification of the SEPAOl model available from the GEMCS library of routines. The fractions of water (and water soluble components) and solids to the supernatant is supplied as inputs to the program.

Other dewatering devices are also approximately described by the same model.
CHAPTER 9

9. MODULES FOR HANDLING STREAM VARIABLES

There are certain calculations which occur frequently in some or most of the simulation models used in this study. As mentioned in Section 3, the stream elements 13-22 form the basic components of a waste flow. The simulation models directly use these variables in their internal calculations. However, in wastewater treatment practice, the more commonly used variable are those of stream elements 8-12, which include the BOD, SS, VSS, TOC and DOC. Hence it is necessary to convert from the "working" variables to the commonly reported variables.

Another area where calculations are frequently needed is in the pH - alkalinity relationship. Also in the activated sludge model, it is more convenient to use concentration variables (i.e., mg/l) than it is to use flow variables such as lbs./hr. Hence a module is also available to convert component flows into component concentrations.

9.1 Inter-relationship of Stream Variables

A series of experiments were performed to determine the relationships between the stream elements 8-12 and those of 13-22. Section 3.2 gives the relevant defining equations.
The Total Organic Carbon (TOC), which includes both the particulate and dissolved organic carbon forms, was first determined. To ensure that the injection needle would not "filter" out any solids, the sample was subjected to ultra-frequency sonication for five minutes.

The Total Five-day Biochemical Demand (TBOD$_5$), which includes the BOD$_5$ of both the particulate and soluble components, was then determined using the original sample.

The sample was then filtered on two Whatman's #40 filter papers (ashless). One filter paper was then ashed in a muffle furnace at 600°C and the other was dried at 103°C. This will yield the volatile suspended solids (VSS) of the sample. The filtrate was then used to determine the Dissolved Organic Carbon (SOC) and the Dissolved Five-day Biochemical Oxygen Demand (DBOD$_5$). All the above mentioned analyses were performed according to "Standard Methods" (48).

The results are summarized in Appendix G. The average values obtained for the conversion factors are:

(a) $FAC1 = \frac{DBOD_5}{SOC} = 1.91$

with a standard deviation of 0.17

(b) $FAC2 = \frac{BOD_5 \text{ (particulate)}}{OC \text{ (particulate)}} = \frac{TBOD_5 - DBOD_5}{TOC - SOC} = 1.24$

with a standard deviation of 0.12
Eckenfelder (8) derived the value of 1.85 for FAC1. Smith (46) used the value 1.87 for FAC1. These two values agreed with our data. Smith reported a value of 0.80 for FAC2, whilst our value of 1.24 is much higher. The value of 2.13 is used by Smith for FAC3, which is close to our value of 2.09.

9.2 pH - Alkalinity Relationships

The major contributors to the alkalinity of municipal wastewaters are the species in the carbonate buffer system and ammonia. To a lesser extent, the phosphates and borates could contribute to the alkalinity.

The equilibrium conditions existing in solution can be described by (49):

For the carbonate system

\[ \text{H}_2\text{CO}_3^* \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \]  \hspace{1cm} (9.2.1)

\[ \text{HCO}_3^- \rightleftharpoons \text{H}^+ + \text{CO}_3^- \]  \hspace{1cm} (9.2.2)

where \([\text{H}_2\text{CO}_3^*] = [\text{CO}_2 \text{dissolved}] + [\text{H}_2\text{CO}_3^-]\)  \hspace{1cm} (9.2.3)

For the ammonium system

\[ \text{NH}_4^+ \rightleftharpoons \text{NH}_3 + \text{H}^+ \]  \hspace{1cm} (9.2.4)
Self-ionization of water

\[ H_2O \rightleftharpoons H^+ + OH^- \quad (9.2.5) \]

The equilibrium constants for the above equations are:

\[ k_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3^*]} = 10^{-6.3} \quad (9.2.6) \]

\[ k_2 = \frac{[H^+][CO_3^{3-}]}{[HCO_3^-]} = 10^{+10.3} \quad (9.2.7) \]

\[ k_n = \frac{[H^+][NH_3]}{[NH_4^+]} = 10^{-9.3} \quad (9.2.8) \]

and \[ k_w = [H^+] [OH^-] = 10^{-14.0} \quad (9.2.9) \]

The definition for alkalinity can then be expressed as

\[ [ALK] = [H_3W^-] + 2 [CO_3^{2-}] + [NH_3] + [OH^-] - [H^+] \quad (9.2.10) \]

where \([ALK]\) = alkalinity equivalents/litre

\([HCO_3^-]\) = bicarbonate ion concentration moles/litre

\([CO_3^{2-}]\) = carbonate ion concentration moles/litre

\([NH_3]\) = free ammonia concentration moles/litre

\([OH^-]\) = hydroxyl ion concentration moles/litre

and \([H^+]\) = hydrogen ion concentration moles/litre
Due to the conservation of mass, we note that

\[
[H_2CO_3^*] + [HCO_3^-] + [CO_3^{2-}] = \text{constant} = [C_T] \quad (9.2.11)
\]

and \([NH_3] + [NH_4^+] = \text{constant} = [C_N] \quad (9.2.12)\)

Hence, from Equations 9.2.6 and 9.2.7, as well as from 9.2.11

\[
[C_T] = \left\{ \frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]} \right\} [HCO_3^-] \quad \text{(9.2.13)}
\]

or \([HCO_3^-] = [C_T] \left\{ \frac{1}{[H^+] + 1 + \frac{k_2}{[H^+]}} \right\} \quad \text{(9.2.13)}\)

Similarly

\[
[CO_3^{2-}] = [C_T] \left\{ \frac{k_2}{[H^+]} \right\} \left\{ \frac{1}{[H^+] + 1 + \frac{k_2}{[H^+]}} \right\} \quad \text{(9.2.14)}
\]

and \([NH_3] = [C_N] \left\{ \frac{1}{1 + \frac{[H^+]}{K_n}} \right\} \quad \text{(9.2.15)}\)

Therefore

\[
[ALK] = [C_T] \left\{ 1 + \frac{2k_2}{[H^+]} \right\} \left\{ \frac{1}{[H^+] + 1 + \frac{k_2}{[H^+]}} \right\} \quad \text{(9.2.14)}
\]

\[
[ALK] = [C_T] \left\{ \frac{1}{[H^+] + 1 + \frac{k_2}{[H^+]}} \right\} \quad \text{(9.2.15)}
\]
This is the defining equation used to relate the four variables \([\text{ALK}], [C_T], [CN]\) and pH. Given three of the variables, the fourth may be calculated. Note also that if streams are mixed, and assuming a closed system, there must be conservation of \([\text{ALK}], [C_T]\) and \([CN]\).

On expanding Equation 9.2.16, we obtain a polynomial of the fifth order in \(H^+\):

\[
[H^+]^5 + [H^+]^4 \left\{ \text{ALK} + k_1 + k_N \right\}
+ [H^+]^3 \left\{ \text{ALK} \left( k_1 + k_N \right) + k_1 k_N + k_1 k_2 - k_w - k_1 [C_T] - k_N [CN] \right\}
+ [H^+]^2 \left\{ k_1 [\text{ALK}] \left( k_2 + k_N \right) + k_1 k_2 k_N - k_1 k_N k_w - k_1 k_N \left[ C_T \right] \right. \\
\left. - k_1 k_w - 2 k_1 k_2 \left[ C_T \right] - k_1 k_N \left[ CN \right] \right\}
+ [H^+] \left\{ k_1 k_2 k_N \text{ALK} - k_1 k_N k_w - 2 k_1 k_2 k_N \left[ C_T \right] \right. \\
\left. - k_1 k_2 k_w - k_1 k_2 k_N \left[ CN \right] \right\}
- k_1 k_2 k_N k_w = 0
\] (9.2.17)

We could simplify the above equation by making some order of magnitude simplifications. Roughly, \([\text{ALK}] \approx [CN] \approx [C_T] \approx 10^{-3}\).
This means that in the pH range of 5-9, the terms $[\text{OH}^-] - [\text{H}^+] \ll [\text{ALK}]$ in Equation 9.2.16. Hence we can drop out these two terms resulting in:

$$
\left[\text{C}_T\right] \left\{ \frac{1}{[\text{H}^+] + 1 + \frac{k_2}{k_1}} \right\} = \left[\text{ALK}\right] - \left[\text{C}_N\right] \left\{ \frac{1}{1 + \frac{[\text{H}^+]}{K_N}} \right\}
$$

On expansion, a third order polynomial in $[\text{H}^+]$ results:

$$
[\text{H}^+]^3 [\text{ALK}] + [\text{H}^+]^2 k_N \left( [\text{ALK}] - [\text{C}_N] \right) + k_1 \left( [\text{ALK}] - [\text{C}_T] \right)
$$

$$
+ [\text{H}^+] \left\{ k_1 k_N \left( [\text{ALK}] - [\text{C}_N] - [\text{C}_T] \right) + k_1 k_2 \left( [\text{ALK}] - 2 [\text{C}_T] \right) \right\}
$$

$$
+ k_1 k_2 k_N \left\{ [\text{ALK}] - [\text{C}_N] - 2 [\text{C}_T] \right\} = 0
$$

Equation 9.2.19 has been found for the several cases tried to give only one real root and two imaginary roots. This is very fortunate and helps simplify the solution of the cubic equation, for which a simple interval bisection technique is used. The bisection subroutine uses the geometric mean of the left and right estimates of the solution, in its convergence.
9.3 Inter-conversion Between Mass Flow and Concentration

Although the units used for the stream variables are for mass flow, it is frequently useful to convert them into concentration units. The model for the aerobic biological processes has its rate equations all in terms of component concentrations. The summary report generated has all the values expressed in concentrations, which is more meaningful than mass flows.

Due to the analytical procedures used in wastewater treatment, soluble components are usually expressed as milligrams per litre of water, while solid components are expressed in milligrams per litre of sample. In the case where the concentrations involved are less than 1000 mg/l (0.1%) the difference between the two is negligible. However, since sludges of up to 80,000 mg/l (8%) are handled in our system, the distinction should be made.

For soluble components we then use

\[ C_i = \frac{F_i}{W} \times 10^{-6} \]  

(9.3.1)

where \( C_i \) = concentration of soluble component \( i \) (mg/l)
\( F_i \) = mass flow of soluble component \( i \) (lbs/hr)
and \( W \) = mass flow of water (lbs/hr)
For particulate components we use

$$C_i = \frac{F_i}{Q} \times 10^{-5}$$  \hspace{1cm} (9.3.2)

where $C_i =$ concentration of particulate component $i$ (mg/l)
$F_i =$ mass flow of particulate component $i$ (lbs/hr)
and $Q =$ total volumetric flow of stream (gal/hr)
10. WASTEWATER TREATMENT COSTS

Besides the technical aspects of wastewater treatment, we have to concern ourselves with the costs that such a program would entail. In the expectation of increased activity in the area of pollution abatement, it is becoming more essential that we have accurate cost estimates to base our designs on. A large part of current practice has been to use "rules of thumb" which have fairly large safety factors built into them. An optimal design for a treatment plant, subject to the requirements of the regulatory bodies, can be arrived at by combining the technical section of our simulation with the corresponding cost estimates.

For each unit process in wastewater treatment, capital costs as well as operating and maintenance costs are available as a function of the most prominent capacity factor. For example, the capital cost of the activated sludge tanks is derived as a function of its volume. Most of the correlations are based on the same idea as the six-tenths capacity factor used in Chemical Engineering.

The bulk of the correlations come from the work of Russell and Swanson as reported in Smith's paper in 1969 (46), and from Eckenfelder and Barnard (2). Industrial waste treatment costs are also given in the latter report.
The capital costs are all updated to 1969 costs by the use of the Engineering News Record Index of 1120. This index, being based on changes in the price of steel, cement, lumber and common labour, is most appropriate for wastewater treatment process equipment. The capital cost correlations used are summarized in Table 10.1.

The total cost of the unit processes (installed) is then the sum of the separate costs. It is assumed that the duplication of a unit merely doubles the cost for the unit. This does not take into account that there may be savings due to shared pipings or channels or other factors.

The Physical Plant Cost can then be found by adding the cost of the control house and site improvements on to the total unit processes cost. The Engineering Costs added to the Physical Plant Cost will give the Direct Plant Cost. The Engineering Cost factor is obtained as a fraction of the Physical Plant Cost. As given in Smith (46)

\[
\text{CENG} = 8.0 \left( \frac{1,000,000}{\text{Physical Plant Cost}} \right)^{0.146} \tag{10.1}
\]

where \( \text{CENG} = \) Engineering Cost factor.

The Fixed Capital Cost can then be computed by adding the Contractor's fee (10% of Direct Plant Cost) and the contingency costs (15% of Direct Plant Cost) to the Direct Plant Cost. These figures are suggested by Smith (46) and
<table>
<thead>
<tr>
<th>Unit</th>
<th>Capacity Variable</th>
<th>Capital Cost $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretreatment</td>
<td>Design flow, Q, migd</td>
<td>21800 (A)0.63</td>
</tr>
<tr>
<td>Primary Sedimentation</td>
<td>Surface Area, SA, thousand sq. ft.</td>
<td>17300 (SA) + 6700 (SA)0.1</td>
</tr>
<tr>
<td>Activated Sludge Tanks</td>
<td>Volume, V, mig</td>
<td>27000 (V) + 67000</td>
</tr>
<tr>
<td>Air Blowers</td>
<td>Blower capacity, C, thousand cfm</td>
<td>13600 + 7600 (C)</td>
</tr>
<tr>
<td>Final Sedimentation</td>
<td>Surface area, SA, thousand sq. ft.</td>
<td>16200 (SA) + 6900/(SA)0.13</td>
</tr>
<tr>
<td>Return Sludge Pumps</td>
<td>Pump capacity, PC, migh</td>
<td>4700 + 1700 (PC)</td>
</tr>
<tr>
<td>Anaerobic Digester</td>
<td>Volume, DV, thousand cu. ft.</td>
<td>1340 (DV) + 1.800 (V)0.13</td>
</tr>
<tr>
<td>Chlorinator</td>
<td>Design flow, Q, migd</td>
<td>12600 (Q)0.47</td>
</tr>
<tr>
<td>Vacum Filter</td>
<td>Filter area, FA, hundred sq. ft.</td>
<td>16500 + 48000 (FA)</td>
</tr>
<tr>
<td>Sludge Incinerator</td>
<td>Sludge handing capacity, S, lbs/day</td>
<td>7.1 (S) + 0.3 (S)1.61</td>
</tr>
<tr>
<td>Sludge Drying Beds</td>
<td>Surface area, A, sq. ft.</td>
<td>2.23 (A)</td>
</tr>
<tr>
<td>Sludge Thickener</td>
<td>Surface area, SA, thousand sq. ft.</td>
<td>(SA)(24200 + 11700/exp(SA/13.3))</td>
</tr>
<tr>
<td>Trickling Filter (Dowpac)</td>
<td>Volume, FV, thousand cu. ft.</td>
<td>66000 (FV)0.6</td>
</tr>
</tbody>
</table>

Table 10.1. Capital Cost Correlations
### Fixed Capital Estimate

**DRURY LANE SEWAGE TREATMENT PLANT - BURLINGTON. CAPITAL COST IN 1962**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretreatment</td>
<td>$28,567.21</td>
</tr>
<tr>
<td>Primary Settling Tanks</td>
<td>$32,399.94</td>
</tr>
<tr>
<td>Activated Sludge Tanks</td>
<td>$115,112.80</td>
</tr>
<tr>
<td>Air Blowers</td>
<td>$36,785.71</td>
</tr>
<tr>
<td>Secondary Settling Tanks</td>
<td>$56,952.29</td>
</tr>
<tr>
<td>Sludge Return Pumps</td>
<td>$6,658.21</td>
</tr>
<tr>
<td>Anaerobic Digesters</td>
<td>$118,303.96</td>
</tr>
<tr>
<td>Chlorinator</td>
<td>$9,270.00</td>
</tr>
<tr>
<td><strong>Total Unit Processes (Installed)</strong></td>
<td><strong>$404,050.13</strong></td>
</tr>
<tr>
<td>Control House</td>
<td>$81,677.54</td>
</tr>
<tr>
<td>Plant Site</td>
<td>$7,579.74</td>
</tr>
<tr>
<td><strong>Physical Plant Cost</strong></td>
<td><strong>$493,507.41</strong></td>
</tr>
<tr>
<td>Engineering</td>
<td>$43,768.61</td>
</tr>
<tr>
<td><strong>Direct Plant Cost</strong></td>
<td><strong>$537,276.02</strong></td>
</tr>
<tr>
<td>Contractor's Fee (0.1 DPC)</td>
<td>$53,727.60</td>
</tr>
<tr>
<td>Contingency (0.15 DPC)</td>
<td>$80,591.40</td>
</tr>
<tr>
<td><strong>Fixed Capital Cost</strong></td>
<td><strong>$671,595.03</strong></td>
</tr>
</tbody>
</table>

**Table 10.2. Capital Cost for Drury Lane Plant**
are about average in the Chemical Process Industry. The derivation of the Fixed Capital Cost is summarized in Table 10.2, for the case of the Drury Lane, Burlington Water Pollution Control Plant. The actual plant cost in 1962 was $676,033.78, while the estimated cost was $671,595.03. The difference is less than 1%.

The operating and maintenance costs of the unit processes are normally reported in the literature together as one cost. Smith (46) and Eckenfelder and Barnard (2) have reported them in terms of annual costs (utilities excluded). This necessitates the use of a "Labour Index" to bring these costs up to date. However, we can avoid this by converting the annual costs to man-hours required per year, by dividing by the labour cost $/man-hours for the year in which the correlations were obtained. This was calculated from the average wage of $110/week or approximately $3.00/man-hour in 1966 (26). The annual cost is then computed by multiplying the man-hours required by the current labour cost. Table 10.3 summarizes the operating and maintenance man-hours used in the program.

Again we have assumed that the duplication of a unit will double the number of man-hours required to operate and maintain the units.

The sum of the Operating and Maintenance Costs for the unit processes will give the total labour cost. This,
together with supervision, utilities, sludge haulage, chemical
and plant supplies, will give the Direct Operating and Maintenance
Cost. Supervision is assumed to be 10% of the Total Labour
Cost. Chemical and plant supplies are assumed to be 6% and
5% of the Total Labour Cost, respectively. These estimates
are obtained from the Ontario Water Resources Commission
annual reports on their plant operations. The estimates
of power consumption provided by Michel (26) can be correlated
to give the following annual power consumption \( P \) in kwh:

For Primary Plant \( P = 101000 Q^{0.65} \)
For Trickling Filter Plant \( P = 162000 Q^{0.65} \)
For Activated Sludge Plant \( P = 378000 Q^{0.65} \)

where \( Q \) is the plant flow in mgd.

Sludge haulage fees in Ontario vary and from the
annual reports of the Ontario Water Resources Commission,
an approximate correlation is obtained as:

\[
\text{Sludge haulage costs} = 8000 (Q)^{0.5} \text{ \$/yr.}
\]

where \( Q \) = sludge volume hauled, mgd/yr.

Indirect costs are generally not significant, the
most important of which is for laboratory analyses. The bigger
plants usually conduct their own analyses, while the smaller
ones tend to send them away to be done. The Net Operating
and Maintenance cost will then be the sum of the Direct and
Indirect costs.
To obtain the true annual cost, we have to take into account the cost of the Fixed Capital Investment. In the case of owned capital, we have to include depreciation and opportunity costs. The capital recovery factor to use is:

\[
CRF = \frac{S(1 + S)^n}{(1 + S)^n - 1}
\]

(10.2)

where \( CRF \) = Capital Recovery Factor

\( S \) = interest rate that owned capital can obtain elsewhere

and \( n \) = expected life of plant.

The cost of the Fixed Capital Investment to the municipality of company, annually, is then

\[
R = CRF (I_O - I_S)
\]

where \( R \) = amortization

\( I_O \) = Fixed Capital Investment

and \( I_S \) = scrap value of project at the end of \( n \) years.

In the case of borrowed capital, which is the usual case with most municipalities, we have to add debt retirement plus accrued interest to the Net Operating and Maintenance Cost to obtain the true Annual Cost. The factor can be calculated from the same equation, but the interest rate on the loan \( s \) and the debt retirement period \( n \) may be different.

The derivation of Total Annual Cost is shown in Table 10.4, again, for the case of the Drury Lane, Burlington Water Pollution
Control Plant. The actual operating cost in 1969 was $103,520.52, while the projected cost was $109,116.34, which is about 5% higher.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Capacity Variable</th>
<th>Annual Operation &amp; Maintenance man/hr. Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretreatment</td>
<td>Plant flow, Q, migd</td>
<td>133(Q) + 510(Q)(^{0.37})</td>
</tr>
<tr>
<td>Primary Sedimentation</td>
<td>Surface area, SA, thousand sq. ft.</td>
<td>222(SA) + 555(SA)(^{0.5})</td>
</tr>
<tr>
<td>Activated Sludge</td>
<td>Aerator volume, V, migd and plant flow, Q, migd</td>
<td>720(Q) + 590(Q)/(\sqrt{v})(^{0.67})</td>
</tr>
<tr>
<td>including blower and final</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sedimentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaerobic Digester</td>
<td>Digester volume, DV, thousand cu. ft.</td>
<td>13(DV) + 144(DV)(^{0.5})</td>
</tr>
<tr>
<td>Chlorinator</td>
<td>Plant flow, Q, migd</td>
<td>30(Q) + 170(Q)(^{0.37})</td>
</tr>
<tr>
<td>Vacuum Filter</td>
<td>Plant flow, Q, migd</td>
<td>0.27(Q) + 154(Q)(^{0.37})</td>
</tr>
<tr>
<td>Sludge Incinerator</td>
<td>Plant flow, Q, migd</td>
<td>400(Q) + 1600(Q)(^{0.37})</td>
</tr>
<tr>
<td>Sludge Drying Beds</td>
<td>Surface area, A, sq. ft.</td>
<td>0.014(A) + 20(A)(^{0.37})</td>
</tr>
<tr>
<td>Trickling Filter</td>
<td>Volume, FV, thousand cu. ft.</td>
<td>10(FV) + 210(FV)(^{0.5})</td>
</tr>
</tbody>
</table>

Table 10.3. Annual Operating and Maintenance Man-Hour Requirements
### ANNUAL OPERATING COST

**DRURY LANE SEWAGE TREATMENT PLANT - BURLINGTON. TOTAL ANNUAL COST IN 1969**

<table>
<thead>
<tr>
<th>Unit Processes</th>
<th>Man-Hours</th>
<th>Cost $/YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretreatment</td>
<td>819.67</td>
<td>2868.84</td>
</tr>
<tr>
<td>Primary Sedimentation</td>
<td>1442.33</td>
<td>5048.16</td>
</tr>
<tr>
<td>Activated Sludge</td>
<td>2850.95</td>
<td>9978.31</td>
</tr>
<tr>
<td>Anaerobic Digestion</td>
<td>1028.51</td>
<td>3599.78</td>
</tr>
<tr>
<td>Chlorination</td>
<td>250.29</td>
<td>876.01</td>
</tr>
<tr>
<td>Sludge-Hauling</td>
<td></td>
<td>7332.12</td>
</tr>
</tbody>
</table>

| Total Unit Processes O and M        | 6391.74   | 29703.22  |
| Supervision (0.1 L)                |           | 2970.32   |
| Utilities                           |           | 10261.24  |
| Chemicals (0.06 L)                 |           | 1782.19   |
| Plant Supplies (0.05 L)            |           | 1485.16   |

| Direct O and M Cost                | $46202.14 |
| Laboratory                         | 0.00      |

| Net O and M Cost                   | $46202.14 |
| Annuity Payments                   | 62914.20  |

| Total Annual Cost                  | $109116.34|

*Table 10.4. Operating Costs for Drury Lane Plant*
CHAPTER 11

11. INTER-ACTIVE VERSION

An inter-active version of the simulation was written to enable the user to set up a dialogue with the computer. This can be used in the following ways:

(1) As a teaching tool to train operators and other students,

(2) To enable plant personnel to predict plant performance due to changes in feed flows and/or operating conditions, and

(3) As a quick and accurate aid to plant designers.

An important feature of the inter-active version is that it requires only a very minimum knowledge of the GEMCS system for its use. This is achieved through a series of questions and answers posed by the computer. Of course, a user with a good knowledge of GEMCS, can manipulate and use the inter-active version with greater flexibility.

The inter-active version consists of four subroutines and a slightly modified version of the main program of GEMCS. The four subroutines are FLWCHT, CASET, ICLOAD and ENSET. Their functions will be described below.

FLWCHT enables the user to set up his own plant layout, together with the physical dimensions of the various units. It has an enlarged process flow diagram covering most of the common unit processes encountered in wastewater treatment
plants. This is shown in Figure 11.1. The units are selected or by-passed by the use of the mixer-splitter module. The majority of the data set is read in by DLOAD1, to minimize the use of the teletype to input such information. Module numbers, module types, input and output stream numbers and so on are predetermined for all the units in the process flow diagram and hence can be read in by DLOAD1. The calculation order and the physical dimensions of the various units are determined by a dialogue with the user.

CASET is used to generate a random case study. It generates a random feed by multiplying the average value of each component flow by a random factor ranging between 0.5 and 2.0. It also generates a failure in one of the plant units. The purpose of the subroutine is to teach operators what to do in the event that such a flow or plant failure occurs, as well as to locate the cause of such a failure.

ICLOAD is the analytical laboratory of the simulation. All information regarding stream flows and component concentrations are supplied through ICLOAD. A charge is levied for each analysis performed, the object of the game being to locate and correct a plant failure with the minimum number of analyses. A surcharge is also placed on any unsatisfactory effluent. Five cents is levied on each pound of suspended solids and Biochemical Oxygen Demand, above the regulatory level of 20 mg/l for both. This provides the incentive to correct a plant failure with the minimum delay.
ENSET enables the user to change any operating conditions by changing the appropriate values of the EN vectors. The process flow diagram however, cannot be changed. This must be done through FLWCHT.

In addition to the above four subroutines, slight changes are made to the other modules, primarily to suppress excessive printing.
Figure 11.1. Process Flow Diagram for the Interactive Version
### Key to Figure 11.1.

<table>
<thead>
<tr>
<th>Module Number</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>SCREEN1 - Screens</td>
</tr>
<tr>
<td>3</td>
<td>GRIT1 - Grit chambers</td>
</tr>
<tr>
<td>4</td>
<td>MIXER1</td>
</tr>
<tr>
<td>5</td>
<td>PRISET1 - Primary clarifiers</td>
</tr>
<tr>
<td>6</td>
<td>MIXER1</td>
</tr>
<tr>
<td>7</td>
<td>ACTSIL1 - Activated sludge tanks</td>
</tr>
<tr>
<td>8</td>
<td>SECLAR1 - Secondary clarifiers</td>
</tr>
<tr>
<td>9</td>
<td>SETSPI</td>
</tr>
<tr>
<td>10</td>
<td>MIXER1 - Control sludge wasting</td>
</tr>
<tr>
<td>11</td>
<td>MIXER1</td>
</tr>
<tr>
<td>12</td>
<td>SEPA01 - (Thickener)</td>
</tr>
<tr>
<td>13</td>
<td>MIXER1</td>
</tr>
<tr>
<td>14</td>
<td>ANDIG1 - First stage digestion</td>
</tr>
<tr>
<td>15</td>
<td>ANDIG1 - Second stage digestion</td>
</tr>
<tr>
<td>16</td>
<td>SETSPI</td>
</tr>
<tr>
<td>17</td>
<td>MIXER1</td>
</tr>
<tr>
<td>18</td>
<td>CHLOR1 - Chlorinator</td>
</tr>
<tr>
<td>19</td>
<td>MIXER1</td>
</tr>
<tr>
<td>20</td>
<td>MIXER1</td>
</tr>
<tr>
<td>22</td>
<td>COUNT1</td>
</tr>
<tr>
<td>23</td>
<td>COUNT1</td>
</tr>
<tr>
<td>24</td>
<td>REPTOL - Report generator</td>
</tr>
<tr>
<td>25</td>
<td>CASET - Case generator</td>
</tr>
</tbody>
</table>
CHAPTER 12

12. TEST RUNS

The two plants selected for simulation are the Drury Lane and the Skyway Sewage Treatment plants. The former is a conventional activated sludge process, whilst the latter employs the extended aeration modification. In addition to testing the various models developed, the two simulations should show that the same kinetics can be used for the activated sludge process, regardless of the process modification.

The base cases used will be the average flow and operating conditions for 1969, obtained from plant data and also from the Ontario Water Resources Commission’s Annual Summaries. The 1969 data were chosen, as the operating and flow conditions were fairly constant throughout the year. Due to the diurnal variation in the feed flows, the steady-state models can, at best, predict the average performance of the various units. It is for this reason that no attempt was made to collect base case data on any particular day, as this would require at least a twenty four hour sampling schedule, for a week.

12.1 Simulation of the Drury Lane, Burlington Sewage Treatment Plant

The process flow diagram for the plant is shown in Figure 12.1.1, and the design data is summarized in Appendix I.
Figure 12.1.1. Process Flow Diagram of the Drury Lane Plant
## Key to Figure 12.1.1.

<table>
<thead>
<tr>
<th>Module Number</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PRISET1 - Primary clarifiers</td>
</tr>
<tr>
<td>2</td>
<td>MIXER1</td>
</tr>
<tr>
<td>3</td>
<td>ACTSL1 - Activated sludge tanks</td>
</tr>
<tr>
<td>4</td>
<td>SECLAR1 - Secondary clarifiers</td>
</tr>
<tr>
<td>5</td>
<td>CØNT02 - Controls sludge wasting</td>
</tr>
<tr>
<td>6</td>
<td>SETSP1</td>
</tr>
<tr>
<td>7</td>
<td>CØNTL1</td>
</tr>
<tr>
<td>10</td>
<td>GRIT1 - Grit chambers</td>
</tr>
<tr>
<td>11</td>
<td>CHLØRL - Chlorinator</td>
</tr>
<tr>
<td>12</td>
<td>MIXER1</td>
</tr>
<tr>
<td>13</td>
<td>ANDIG1 - First stage digestion</td>
</tr>
<tr>
<td>14</td>
<td>ANDIG1 - Second stage digestion</td>
</tr>
<tr>
<td>15</td>
<td>CØNTL1</td>
</tr>
<tr>
<td>16</td>
<td>MIXER1</td>
</tr>
<tr>
<td>17</td>
<td>SETSP1</td>
</tr>
<tr>
<td>18</td>
<td>MIXER1</td>
</tr>
<tr>
<td>24</td>
<td>REPTOL1 - Report generator</td>
</tr>
</tbody>
</table>
It was originally designed for a flow of 2.5 migd. However, due to the expansion of the Skyway plant, part of the flow was diverted to the latter plant, and the actual flow received was 1.6 migd, in 1969. The average BOD and TSS for the raw sewage is 215 mg/l and 299 mg/l, respectively.

The pretreatment section consists of 1-inch bar screens and grit channels with a detention time of approximately one minute. Primary treatment consists of two tanks with dimensions 29.3 ft. x 18 ft. x 12.25 ft. Secondary treatment is provided by two triple-pass activated sludge tanks, each with a total length of 321.5 ft., width of 18 ft. and depth of 10.7 ft. Total air blower capacity is 3000 scfm. Two circular secondary clarifiers are employed, each with a radius of 25 ft. and depth of 10.6 ft. A two-stage digestion system is used to handle the waste sludge generated. The first stage consists of two 40 ft. diameter tanks with a depth of 20 ft., and the second stage consists of one 40 ft. diameter tank with a depth of 18 ft. A summary of the operating conditions and the parameters used for the simulation is shown in Table 12.1.1.

The data set used for the simulation is shown in Appendix I. The computer printout for the case is also included in Appendix I. A summary of the results from the simulation, together with the plant data is shown in Table 12.1.2.

The removal of Total Suspended Solids by the primary clarifier was predicted to be 49% while the observed removal
was 48%. The BOD removal predicted was 30% compared to the actual removal of 33%. Both removals were predicted very well by the primary clarifier model.

The Total Suspended Solids in the final effluent is identical with the value observed, which was 20 mg/l. The BOD of the final effluent was predicted to be 22 mg/l, while the observed value was lower at 15 mg/l. The agreement is quite good.

The predicted Total Suspended Solids of the return activated sludge was 11,700 mg/l with a volatile content of 57%. The observed values were 12,000 mg/l and 60% respectively.

The simulation predicted that a greater volume of sludge should be sent to the digester than was actually observed. A raw sludge flow of 7600 igpd was calculated, while the reported flow was much lower at 5300 igpd. This is reasonable since a considerable amount of solids is lost during a rain, but which is not accounted for. The figures imply that about 30% of the solids which should go to the digester was lost over the weirs of the secondary clarifiers, either during a storm or due to a plant upset.

The simulation predicted a digested sludge flow of 3000 igpd at a Total Suspended content of 5.8% as compared to the volumes of 2300 igpd hauled away for disposal. The anaerobic digester model predicted a much higher volatile solids
destruction than was observed. This is reflected in the lower volatile solids concentration predicted for the digested sludge.

RAW SEWAGE:

average flow = 1.6 mgd
average TSS = 299 mg/l
average VSS = 195 mg/l
percent of volatile solids settleable = (77%)
percent of inorganic solids settleable = (46%)
average BOD = 215 mg/l
average DOC = (61) mg/l

PRIMARY SETTLING TANKS: (using nomenclature of Chapter 4)

\[ W_r = \phi \exp (-kt^d \cdot n^b) \]

where  
\[ k = 0.23 \]
\[ \alpha = 0.5 \]
\[ \beta = 0.25 \]
and  
\[ \phi = 0.85 \]

average underflow solids concentration = 60,000 mg/l

ACTIVATED SLUDGE TANKS: (using nomenclature of Chapter 5)

\[ k_1 = 0.0028 \text{ hr}^{-1} \]
\[ k_2 = 0.0014 \text{ hr}^{-1} \]
\[ k_3 = 0.000002 \text{ hr}^{-1} \]
\[ k_4 = 0.0010 \text{ hr}^{-1} \]
\[ k_5 = 2.2 \text{ hr}^{-1}/(\text{cu.ft.air/cu.ft.reactor}) \]
\[ y = 0.54 \]

\[ MLSS = 2200 \text{ mg/l} \]

RTD model: 3 CSTR's in series.

SECONDARY SETTLING TANKS: (using nomenclature of Chapter 6)

\[ XRSS = \frac{556 \cdot (GSS 0.494) \times 1.5}{(MLSS 1.82)(TM 1.5)} \]

\[ SVI = 56.1 + 113 \text{ (FM) } (1.05T^{-20}) \]

fraction of time return sludge pumps used = 0.3

ANAEROBIC DIGESTER: (using nomenclature of Chapter 7)

1st stage at high-rate, \( k = 0.082 \)

2nd stage at conventional rate, \( k = 0.026 \text{ day}^{-1} \)

fraction of flow to supernate = 0.6

Figure 12.1.1. Operating Conditions and Parameters Used In the Simulation of the Drury Lane Plant
<table>
<thead>
<tr>
<th>Stream</th>
<th>Flow (migd)</th>
<th>BOD (mg/l)</th>
<th>TSS (mg/l)</th>
<th>VSS (mg/l)</th>
<th>DOC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant Data</td>
<td>Predicted</td>
<td>Plant Data</td>
<td>Predicted</td>
<td>Plant Data</td>
</tr>
<tr>
<td>Raw Feed</td>
<td>1.6</td>
<td>-</td>
<td>215</td>
<td>-</td>
<td>191</td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>1.6</td>
<td>1.6</td>
<td>145</td>
<td>151</td>
<td>153</td>
</tr>
<tr>
<td>Primary Clarifier</td>
<td>-</td>
<td>0.0069</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Underflow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>1.6</td>
<td>1.59</td>
<td>15</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>Return Activated Sludge</td>
<td>(0.32)</td>
<td>0.30</td>
<td>-</td>
<td>-</td>
<td>12000</td>
</tr>
<tr>
<td>Raw Sludge to Digester</td>
<td>0.0053</td>
<td>0.0076</td>
<td>-</td>
<td>-</td>
<td>58000</td>
</tr>
<tr>
<td>Digester Supernate</td>
<td>0.0028</td>
<td>0.0044</td>
<td>-</td>
<td>-</td>
<td>8000</td>
</tr>
<tr>
<td>Digested Sludge</td>
<td>0.0023</td>
<td>0.0030</td>
<td>-</td>
<td>-</td>
<td>57000</td>
</tr>
</tbody>
</table>

Table 12.1.2. Simulation of the Drury Lane, Burlington, Water Pollution Control Plant
12.2 Simulation of the Skyway, Burlington, Sewage Treatment Plant

The process flow diagram for the plant is shown in Figure 12.2.1, and the design data is summarized in Appendix J. The average flow in 1969 was 3.3 mgd, but due to an expansion completed in 1970, it is now receiving about 6.0 mgd.

Pretreatment consists of a 2½ inch coarse screen followed by a 1 inch screen, both mechanically cleaned. Grit removal is achieved by an aerated grit chamber with a detention time of approximately 20 minutes. There are no primary tanks in the Skyway Plant. The activated sludge process employed is that of the extended aeration modification, and consists of six single-pass tanks with dimensions of 270 ft. x 27 ft. x 15 ft. The total blower capacity is 18000 scfm. Secondary clarification is provided by four settling tanks, 60 ft. square and 12 ft. deep. Waste sludge is thickened in a circular tank, 20 ft. in diameter and 9 ft. deep. A summary of the operating conditions and the parameters used in the simulation is shown in Table 12.2.1.

The data set for the simulation is shown in Appendix J, together with the computer printout for the case. A summary of the results from the simulation together with the plant data is shown in Table 12.2.2.
Figure 12.2.1. Process Flow Diagram of the Skyway Plant
### Key to Figure 12.2.1.

<table>
<thead>
<tr>
<th>Module Number</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MIXER1</td>
</tr>
<tr>
<td>2</td>
<td>SCREEN1 - Screens</td>
</tr>
<tr>
<td>3</td>
<td>GRIT1 - Grit chambers</td>
</tr>
<tr>
<td>4</td>
<td>ACTSL1 - Activated sludge tanks</td>
</tr>
<tr>
<td>5</td>
<td>SECLAR1 - Secondary clarifiers</td>
</tr>
<tr>
<td>6</td>
<td>SETSP1</td>
</tr>
<tr>
<td>7</td>
<td>CRNT02 - Controls sludge wasting</td>
</tr>
<tr>
<td>8</td>
<td>SEPA01 - (Thickener)</td>
</tr>
<tr>
<td>9</td>
<td>MIXER1</td>
</tr>
<tr>
<td>10</td>
<td>CHLØR1 - Chlorinator</td>
</tr>
<tr>
<td>11</td>
<td>CRNT11</td>
</tr>
<tr>
<td>12</td>
<td>CRNT11</td>
</tr>
<tr>
<td>24</td>
<td>REPT01 - Report generator</td>
</tr>
</tbody>
</table>
The simulation predicted a slightly better final effluent than was observed. The BOD and TSS predicted were 8 mg/l and 10 mg/l respectively, while the observed values were 12 mg/l and 12 mg/l respectively.

From plant data, the average suspended solids concentration in the return sludge was 10,000 mg/l, while the simulation predicted a value of 9,500 mg/l. The agreement is very good. However, the average volatile content of the sludge observed was 60% while the simulation gave a value of 42%.

A greater discrepancy occurred here than was with the case of the Drury Lane Plant, in the volume of sludge hauled away. The simulation predicted that a volume of 22,000 igpd at a solids content of 2.1% should be hauled away, but actual plant figures indicated that only 4000 igpd at 2.0% solids were hauled away. Although upsets are frequent in a plant this size, the almost five-fold difference in the thickened sludge for disposal is unexpected. From a rough balance on the solids over the entire plant, the volume of sludge produced should be approximately

\[
\frac{3.3 \times 10^6 \times (185 - 12)}{20,000}
\]

\[
= 28,000 \text{ igpd, at 20\% solids}
\]

This figure is in better agreement with the predicted value. Continuous sampling of the final effluent will probably show up the difference.
RAW SEWAGE:

average flow = 3.3 mgd
average TSS = 185 mg/l
average VSS = 85 mg/l
average BOD = 155 mg/l
average DOC = 62 mg/l

ACTIVATED SLUDGE Tanks: (using nomenclature of Chapter 5)

\[ k_1 = 0.0028 \text{ hr}^{-1} \]
\[ k_2 = 0.0014 \text{ hr}^{-1} \]
\[ k_3 = 0.000002 \text{ hr}^{-1} \]
\[ k_4 = 0.0010 \text{ hr}^{-1} \]
\[ k_5 = 2.2 \text{ hr}^{-1} \]
\[ Y = 0.54 \]

MLSS = 4000 mg/l

RTD model: 3 CSTR's in series

SECONDARY SETTLING DATA: (using nomenclature of Chapter 6)

\[ XRSS = \frac{556 (GSS 0.494) \times 1.5}{(MLSS 1.82) (TM 1.5)} \]

SVI = 56.1 + 113 (FM) (1.05 T-20)

Fraction of time return sludge pumps used = 0.4

THICKENER: Fraction of liquid to overflow = 0.6
Fraction of solids to overflow = 0.1

Table 12.2.1. Operating Conditions and Parameters Used in the Simulation of the Skyway Plant
<table>
<thead>
<tr>
<th>Stream</th>
<th>Flow (migd)</th>
<th>BOD (mg/l)</th>
<th>TSS (mg/l)</th>
<th>VSS (mg/l)</th>
<th>DOC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant Data</td>
<td>Predicted</td>
<td>Plant Data</td>
<td>Predicted</td>
<td>Plant Data</td>
</tr>
<tr>
<td>Raw Feed</td>
<td>3.3</td>
<td>-</td>
<td>155</td>
<td>-</td>
<td>185</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>3.3</td>
<td>3.3</td>
<td>12</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Return Activated Sludge</td>
<td>2.1</td>
<td>2.35</td>
<td>-</td>
<td>-</td>
<td>10000</td>
</tr>
<tr>
<td>Thickened Sludge</td>
<td>0.004</td>
<td>0.022</td>
<td>-</td>
<td>-</td>
<td>20000</td>
</tr>
</tbody>
</table>

Table 12.2.2. Simulation of the Skyway, Burlington, Water Pollution Control Plant
CHAPTER 13

13. DISCUSSION OF RESULTS

13.1 Discussion of Experimental Data

13.1.1 Primary Settling Data

Our settling curve analysis is based on the settleable solids present in the raw waste. The same analysis when applied to the total suspended solids gave less consistent results between the runs, as can be seen from Table 13.1.1.

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Source</th>
<th>k</th>
<th>α</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>Dundas (1971)</td>
<td>0.164</td>
<td>0.372</td>
<td>0.216</td>
</tr>
<tr>
<td>A-2</td>
<td>Drury Lane (1971)</td>
<td>0.202</td>
<td>0.403</td>
<td>0.285</td>
</tr>
<tr>
<td>A-3</td>
<td>Dundas (1970)</td>
<td>0.211</td>
<td>0.410</td>
<td>0.311</td>
</tr>
<tr>
<td>A-4</td>
<td>Dundas (1969)</td>
<td>0.150</td>
<td>0.397</td>
<td>0.252</td>
</tr>
</tbody>
</table>

Table 13.1.1. Correlations for the Batch Settling Data, Based on Total Solids

An assumption made in our model is that the removal obtained is the same for all classes of settleable solids. The validity of the assumption, although not tested, can be checked by taking volatile suspended solids measurements, together with the usual suspended solids readings.

159
A shortcoming of our data is the fact that our batch settling column is only 8 ft. tall. This means that an effective liquid depth of only 6 ft. may be used. Most primary settling tanks have liquid depths between 8 ft. and 12 ft., thereby necessitating the extrapolation of our data, to predict their performance.

13.1.2 Tracer Studies of Primary Sedimentation Tanks

In an attempt to evaluate the level of turbulence existing in the primary settling tanks, tracer studies were performed. The results were discouraging. Tracer recoveries were of the order of 80% and consequently the detention times estimated from the exit age distributions were much lower than the hydraulic detention times. The loss of the tail end of the exit age distribution also affects whatever model we try to fit to the flow pattern. Another tracer system should have been used where the recovery obtained is much higher.

The use of a pulse input is also a poor choice as it generates a tail end in the exit age distribution, which is very important but where the accuracy of measurement is poor. Time Series Analysis, using a series of random pulse inputs would largely remove this source of error.
We had to revert to a simplified treatment to correct for the effects of turbulence by defining the efficiency factor. The fact that a fairly constant efficiency factor exists for the primary tanks in both the Dundas and Drury Lane plants seem to suggest that a correlation is possible, relating the efficiency factor with a parameter that represents the level of turbulence in the tanks.

13.1.3 Data From the Chemostat Experiments

Our Chemostat set-up is rather simple and lacks a good control over the operating conditions. A closer control should have been kept on the temperature in the reactor. With proper temperature control, the experiments could be repeated at other temperature levels. The flow rate from the constant head tank was found to vary and had to be adjusted about twice a day.

We have assumed in our calculations that the original solids in the feed are not significantly solubilized during the experiment, and that the increase in solids in the effluent is mainly due to synthesis of microbial cells. There will be a slight solubilization of the feed solids, and hence our calculated value for $M$, the synthesized microbial cell mass, will be low. This problems can be corrected by filtering the raw waste
through a filter press or by using a "synthetic" raw sewage, having only the soluble components.

Another assumption made was that the effluent soluble organic carbon was entirely degradable. This was not checked by taking the Biochemical Oxygen Demands of the filtered effluent. However, the least squares fit of the data points gave a correlation $\nu = 1.04 \times 10^{-3} (C + 0.55)$. The intercept on the horizontal axis is not significantly different from zero (but is in fact even negative). A significant positive intercept of say 5 mg/l or greater will indicate that not all of the effluent soluble carbon is degradable.

13.1.4 Data on the Aeration Studies of Activated Sludge

Since some of the biological rates in the kinetic scheme proposed in Chapter 5 are expected to be very slow, we had to aerate the return activated sludge for at least two weeks. No raw sewage was added to the return sludge. The reason is that the soluble degradable carbon in the raw sewage will have a very rapid rate of assimilation and hence creating a "stiff" condition in the solution of the differential equation describing its rate of reaction.

Several assumptions were made in the analysis of the results. The conversion factors obtained in Section 9.2,
were used in calculating the soluble degradable carbon and in calculating the carbon equivalent of the volatile solids. Equation 5.1.12, relating the oxygen uptake rate to the rate of carbon loss due to respiration, and hence to the concentration of microorganisms, was assumed to hold. The above assumptions can be tested by integrating the area under the oxygen uptake rate curve (which is the total oxygen consumption), and comparing with the amount of carbon loss. For Run No. D-1,
\[ \frac{\Delta O_2}{\Delta C} = \frac{6200}{1700} = 3.65 \]
and for Run No. D-2,
\[ \frac{\Delta O_2}{\Delta C} = \frac{5800}{1500} = 3.86 \]
Both values are close to the factor of 3.73 obtained in Section 5.1.

A comparison of the results from the chemostat experiments and the extended aeration studies showed that the unit growth rate factor, \( k_4 \), was much lower in the latter case. The value of \( k_4 \) obtained in the chemostat experiments was 0.0010 hr\(^{-1}\) (mg/l)\(^{-1}\) whilst that obtained from the extended aeration studies was 0.0006 hr\(^{-1}\) (mg/l)\(^{-1}\). The former experiments were
run under conditions where the substrate concentrations were high, whilst the latter experiments were made under food-deficient conditions. This suggests that an extended food-deficient condition could lead to decreased microbial activity, in what is commonly known as a "lag-phase". This implies then that \( k_4 \) is not actually a constant but could depend on the length of substrate privation. However, in activated sludge processes, the former condition normally occurs. The food-deficient condition would occur if we use the aerobic biological reaction in a solids digestion process.

Only a few readings were taken of the soluble degradable organic carbon throughout the duration of the runs. This was because the BOD measurements required a fairly large volume of sample. A larger reactor should have been used.

13.2 Discussion of Plant Simulations

13.2.1 Simulation of Drury Lane, Burlington, Sewage Treatment Plant

The agreement between the predicted and observed values for the primary and final effluents were very good. The results show that primary sedimentation tanks can be modelled quite successfully if a sufficiently accurate
and detailed breakdown of the feed solids are provided. But normally a complete solids analysis, as required by our stream list is never performed, and the simulation may require the use of a less detailed model.

The activated sludge process was also modelled very successfully. The kinetic rates, measured experimentally, predicted the final effluent very well. An examination of the converged values for the return sludge stream showed that 42% of the volatile solids is composed of microorganisms. This is in agreement with the value of approximately 50% obtained in Section 5.3, for the return sludge from the Skyway Plant.

Several other case studies were made under different operating and flow conditions. Table 13.2.1 shows the individual effects of increasing capacities in the primary clarifiers, aeration tanks, secondary clarifiers and of just increasing the mixed liquor suspended solids in the aeration tanks to 3000 mg/l.

The effect of adding an extra primary clarifier was merely to improve the primary effluent to a BOD of 146 mg/l and a TSS of 141 mg/l. There was no significant improvement in the final effluent.

The effect of adding an extra aeration tank improved the final effluent to a BOD of 15 mg/l and a TSS of 17 mg/l. No improvements were expected to occur in the primary effluent.
<table>
<thead>
<tr>
<th>Stream</th>
<th>BOD</th>
<th>TSS</th>
<th>DOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Sewage</td>
<td>215</td>
<td>299</td>
<td>61</td>
</tr>
<tr>
<td>CASE STUDY WITH NORMAL OPERATING CONDITIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>151</td>
<td>153</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>22</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>CASE STUDY WITH A THIRD PRIMARY CLARIFIER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>146</td>
<td>141</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>21</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>CASE STUDY WITH A THIRD AERATION TANK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>150</td>
<td>153</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>15</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>CASE STUDY WITH A THIRD SECONDARY CLARIFIER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>150</td>
<td>153</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>21</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>CASE STUDY WITH MLSS INCREASED TO 3000 mg/l</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>151</td>
<td>153</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>16</td>
<td>16</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 13.2.1. Effect of Plant Alterations, at the Same Flow.
The extra secondary clarifier reduced the TSS in the final effluent to 17 mg/l, with not much improvement in the BOD.

The results of merely increasing the mixed liquor suspended solids in the aeration tanks to 3000 mg/l were quite surprising. The final effluent improved to a BOD of 16 mg/l and a TSS of 16 mg/l. This is just like having an extra aeration tank! This is quite logical since about 50% more solids will be carried in the aeration tanks at 3000 mg/l as compared to the operating value of 2200 mg/l.

Table 13.2.2 shows the effect of increasing the raw waste flow to 2.0 and 2.4 mgd., with the same influent BOD and TSS, and with no change in equipment capacity. It should be noted that the plant was originally designed for a flow of 2.5 mgd with an influent BOD of 200 and an influent TSS of 180 mg/l. However, both the influent BOD and TSS have increased over the years. The reported influent BOD and TSS in 1969 were, as mentioned before, 215 mg/l and 299 mg/l respectively.

At the operating conditions of 1969, with a feed flow of 1.6 mgd, the final effluent BOD and TSS were predicted to be 22 mg/l and 20 mg/l respectively. This is just bordering on the limits set by the Ontario Water
Resources Commission. At a feed flow of 2.0 mgd, the primary effluent deteriorated slightly to a BOD of 153 mg/l and a TSS of 160 mg/l, while the final effluent BOD and TSS rose to 28 mg/l and 25 mg/l respectively. At a feed flow of 2.4 mgd, the primary effluent deteriorated further to a BOD of 156 mg/l and a TSS of 166 mg/l while the final effluent BOD and TSS predicted were 34 mg/l and 30 mg/l respectively, which is completely unsatisfactory.

The limiting equipment was found to be in the aeration tanks. If expansion is to be contemplated at the Drury Lane Plant to handle a higher flow, top priority should be given to expand the aeration tank capacity. The problem can be alleviated by maintaining a higher mixed liquor suspended solids in the activated sludge process.
<table>
<thead>
<tr>
<th>Stream</th>
<th>BOD</th>
<th>TSS</th>
<th>DOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Sewage</td>
<td>215</td>
<td>299</td>
<td>61</td>
</tr>
<tr>
<td><strong>CASE STUDY WITH 1.6 migd FEED FLOW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>151</td>
<td>153</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>22</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td><strong>CASE STUDY WITH 2.0 migd FEED FLOW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>153</td>
<td>160</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>28</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td><strong>CASE STUDY WITH 2.4 migd FEED FLOW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>156</td>
<td>166</td>
<td>61</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>34</td>
<td>30</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 13.2.2. Effect of Increased Plant Flows, with no Change in Present Equipment Capacities
13.2.2 Simulation of the Skyway, Burlington, Plant

In this case the activated sludge process model predicted a slightly better final effluent than was observed. However, the results show that the extended aeration process is not something special, but is merely the same activated sludge process, under a different name. The results also suggest that the 18 hour detention time required by the Ontario Water Resources Commission and other public agencies for a treatment plant without a primary clarifier is not necessary.

To show the effects of decreased detention time, or increased feed flow, on the final effluent, case studies were made at 6, 8 and 10 mgd using the same feed composition. The two new final clarifiers, which are now completed, are added to the process flow diagram, together with the new (third) sludge return pump. The resulting detention times are 16, 12, and 10 hours respectively, all excluding sludge recycle.

The results are shown in Table 13.2.3. The final effluent at 10 mgd feed flow, is predicted to have a BOD of 15 mg/l and a TSS of 20 mg/l, which is still acceptable. It should be pointed out that the feed to the plant (based on 1969 values) which has a BOD
of 155 mg/l and a TSS of 185 mg/l is approximately equivalent to the primary effluent of many conventional activated sludge plants, and hence a detention time of 8-12 hours, which is sufficient for a conventional activated sludge plant, should also be sufficient for the "extended aeration" modification. The only justification for requiring more aeration time in a "extended aeration" plant is when the influent BOD and TSS are both higher than say 200 mg/l.
<table>
<thead>
<tr>
<th>Stream</th>
<th>BOD</th>
<th>TSS</th>
<th>DOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Sewage</td>
<td>155</td>
<td>185</td>
<td>62</td>
</tr>
<tr>
<td><strong>CASE STUDY WITH 6.0 migd FEED FLOW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Effluent</td>
<td>11</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td><strong>CASE STUDY WITH 8.0 migd FEED FLOW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Effluent</td>
<td>13</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td><strong>CASE STUDY WITH 10.0 migd FEED FLOW</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Effluent</td>
<td>15</td>
<td>20</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 13.2.3. Effect of Increased Feed Flows, at the Skyway Plant.
CHAPTER 14

14. CONCLUSION

Simulation models for primary sedimentation, the activated sludge process, secondary sedimentation, anaerobic digestion and several other unit processes have been developed. The models were based on known and developed theories, supported by laboratory and plant data.

The primary clarifier was modelled on correlations obtained from batch column settling studies. It was found that if settleable suspended solids were used rather than the total suspended solids, better correlations resulted. This is to be expected as the total suspended solids include the non-settleable solids as well.

For the modelling of the activated sludge process, a new reaction scheme, based on the physiological activities of the bacterial and the bacterial cell mass, was proposed. Batch aeration studies of activated sludge were used to obtain estimates of the parameters used in the reaction scheme. This is an improvement over the use of mixed liquor suspended solids, as the fraction of "active mass" in the sludge is dependent on feed compositions and operating conditions in the plant.

For the secondary clarifier model, use was made of correlations developed by Villiers and the Rex Chainbelt
Company, for the fraction of solids escaping over the wiers and the Sludge Volume Index of the sludge produced, respectively. The anaerobic digester model assumed a first order rate for the liquefaction of organic solids, the rate constants being obtained from experimental data published in the literature.

Two plants were used in the simulation studies. The first is a conventional activated sludge plant, while the second is an extended aeration plant. The results from the simulation studies were in very good agreement with plant data for the liquid streams. The actual sludge volumes produced from both plants were lower than those predicted by the simulation. The loss of solids over the wiers of the secondary clarifiers, during plant upsets or storm flows, probably accounted for the lower production of sludge from both plants.

An inter-active version of the computer simulation was also developed and tested under varying conditions. This can be used as an effective teaching aid for operators and students in the wastewater treatment area.
REFERENCES


6. DOBBINS, W.E., "Effect of Turbulence on Sedimentation", Transactions American Society of Civil Engineers, 109, 629 (1944)


174
12. ESTRADA, A., "Design and Cost Considerations in High-Rate Sludge Digestion", Journal Sanitary Engineering Division, American Society of Civil Engineers, 86, SA3, 111 (1960)


17. GAUDY, A.F., TURNER, B.G. and PUSZTASZERI, S., "Biological Treatment of Volatile Waste Components", Journal Water Pollution Control Federation, 65, 75 (1963)


28. O'ROURKE, J.T. and McCARTY, P.L., "Anaerobic Treatment at Reduced Temperatures", presented at the Water Pollution Control Federation Annual Meeting (October 1967)


30. OWRC Annual Reports for the Drury Lane and the Skyway Plants, Burlington (1969)


32. RANKINE, R.S., "Digester Capacity Requirements", Sewage Works Journal, 20, 478 (1948)

33. REX CHAINBELT CO., Product Manual No. 315-2.307 (1955)

34. ROY, H.K. and SAWYER, C.N., "A Laboratory Evaluation of High-Rate Sludge Digestion", Sewage and Industrial Wastes, 27, 1356 (1955)

35. SCHULZE, K.L., "Load and Efficiency of Trickling Filters", Journal Water Pollution Control Federation, 32, 245 (1960)


41. SILVESTON, P.L., "Simulation of the Mean Performance of Municipal Waste Treatment Plants", 21st Conference Canadian Society of Chemical Engineers, Montreal (October 1971)

42. SIMPSON, J., "Waste Treatment", (Ed. by Isaac, P.), Pergamon Press, London (1960)

43. SINGH, D.P., BRYSON, A.W. and SILVESTON, P.L., "A Stochastic Model for Primary Settlers", 5th Annual Symposium on Water Pollution Research, University of Waterloo (February 1970)


45. SMITH, R., "Cost of Conventional and Advanced Treatment of Wastewaters", U.S. Department of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio (July 1968)

46. SMITH, R., "Preliminary Design of Wastewater Treatment Systems", Journal Sanitary Engineering Division, American Society of Civil Engineers, 95, 117 (1969)


50. TORPEY, W.N. "High-Rate Digestion of Concentrated Primary and Activated Sludge", Sewage and Industrial Wastes, 26, 479 (1954)


54. HOOVER, S.R. and PORGES, N., Sewage and Industrial Wastes, 24, 306 (1952)

55. McDERMOTT, J.H., "Influence of Media Surface Area upon the Performance of an Experimental Trickling Filter", Thesis, Purdue University (1957)

56. GERMAIN, J.E., "Economical Treatment of Domestic Waste by Plastic Medium Trickling Filters", Journal Water Pollution Control Federation, 38, 192 (1966)
APPENDIX A

PRIMARY SETTLING DATA ON BATCH COLUMN

RUN #A.1  Raw Sewage from Dundas W.P.C.P.
RUN #A.2  Raw Sewage from Drury Lane,   
           Burlington W.P.C.P.
RUN #A.3  Raw Sewage from Dundas W.P.C.P.,   
           1970 Data.
RUN #A.4  Raw Sewage from Dundas W.P.C.P.,   
           1969 Data.
RUN A.1.

Raw Sewage from Dundas W.P.C.P.

Settling Data: Original suspended solids - average of duplicates.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>252</td>
<td>106</td>
<td>156</td>
<td>132</td>
<td>124</td>
<td>116</td>
<td>82</td>
</tr>
<tr>
<td>2.5</td>
<td>247</td>
<td>210</td>
<td>164</td>
<td>146</td>
<td>129</td>
<td>122</td>
<td>82</td>
</tr>
<tr>
<td>3.5</td>
<td>253</td>
<td>210</td>
<td>179</td>
<td>152</td>
<td>137</td>
<td>129</td>
<td>83</td>
</tr>
<tr>
<td>4.5</td>
<td>248</td>
<td>209</td>
<td>180</td>
<td>156</td>
<td>147</td>
<td>151</td>
<td>82</td>
</tr>
<tr>
<td>5.5</td>
<td>248</td>
<td>220</td>
<td>188</td>
<td>159</td>
<td>152</td>
<td>151</td>
<td>84</td>
</tr>
<tr>
<td>Depth Correction (ft)</td>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

Average of initial solids = 250 mg/l (rounded up)
Average of final non-settleable solids = 82 mg/l (rounded up)
Hence total settleable solids = 168 mg/l
% of settleable solids = 100 (SS - 82)/168
Weight % settleable solids as a function of time and depth:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Depth (ft)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>100</td>
<td>62</td>
<td>44</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>100</td>
<td>77</td>
<td>49</td>
<td>38</td>
<td>28</td>
<td>24</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>100</td>
<td>77</td>
<td>58</td>
<td>42</td>
<td>33</td>
<td>28</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>100</td>
<td>77</td>
<td>58</td>
<td>44</td>
<td>39</td>
<td>35</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>100</td>
<td>82</td>
<td>63</td>
<td>46</td>
<td>42</td>
<td>35</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>Correction</td>
<td>ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fraction of settleable solids removed, as a function of time and depth, using
Equation 4.1.6:

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Time (min)</th>
<th>Fraction Settleable Solids Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>16</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.73</td>
</tr>
<tr>
<td>3.0</td>
<td>20</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>62</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>84</td>
<td>0.74</td>
</tr>
<tr>
<td>4.0</td>
<td>23</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>41</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>74</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>0.74</td>
</tr>
</tbody>
</table>

(Con't.)
<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Time (min)</th>
<th>Fraction Settleable Solids Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>25</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>116</td>
<td>0.73</td>
</tr>
<tr>
<td>6.0</td>
<td>26</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>0.74</td>
</tr>
</tbody>
</table>
RUN #A.2.

Raw Sewage from Drury Lane, Burlington W.P.C.P.

Settling Data: Original suspended solids -
average of duplicates

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Depth (ft)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>2.0</td>
<td>282</td>
<td>208</td>
<td>178</td>
<td>157</td>
<td>142</td>
<td>135</td>
<td>131</td>
<td>128</td>
<td>120</td>
<td>88</td>
</tr>
<tr>
<td>3.0</td>
<td>3.0</td>
<td>272</td>
<td>225</td>
<td>181</td>
<td>167</td>
<td>161</td>
<td>154</td>
<td>144</td>
<td>128</td>
<td>124</td>
<td>88</td>
</tr>
<tr>
<td>4.0</td>
<td>4.0</td>
<td>276</td>
<td>244</td>
<td>204</td>
<td>176</td>
<td>169</td>
<td>152</td>
<td>137</td>
<td>138</td>
<td>133</td>
<td>86</td>
</tr>
<tr>
<td>5.0</td>
<td>5.0</td>
<td>278</td>
<td>251</td>
<td>203</td>
<td>176</td>
<td>168</td>
<td>154</td>
<td>140</td>
<td>135</td>
<td>132</td>
<td>89</td>
</tr>
<tr>
<td>6.0</td>
<td>6.0</td>
<td>273</td>
<td>238</td>
<td>208</td>
<td>189</td>
<td>175</td>
<td>169</td>
<td>156</td>
<td>146</td>
<td>132</td>
<td>88</td>
</tr>
</tbody>
</table>

Depth Correction (ft)

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
</tr>
</thead>
</table>

Average total initial suspended solids = 275 mg/l
Average final suspended solids = 88 mg/l
Total settleable solids = 187 mg/l
Weight % settleable solids = 100 (SS - 88)/187
Temperature = 20°C
Weight % settleable solids as a function of time and depth:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (ft)</td>
<td>0</td>
<td>0.1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>2.0</td>
<td>100</td>
<td>66</td>
<td>48</td>
<td>37</td>
<td>29</td>
<td>25</td>
<td>23</td>
<td>21</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>3.0</td>
<td>100</td>
<td>73</td>
<td>50</td>
<td>42</td>
<td>39</td>
<td>35</td>
<td>30</td>
<td>21</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>4.0</td>
<td>100</td>
<td>83</td>
<td>62</td>
<td>47</td>
<td>43</td>
<td>34</td>
<td>26</td>
<td>26</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>5.0</td>
<td>100</td>
<td>88</td>
<td>62</td>
<td>47</td>
<td>42</td>
<td>35</td>
<td>28</td>
<td>25</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>6.0</td>
<td>100</td>
<td>81</td>
<td>64</td>
<td>54</td>
<td>47</td>
<td>43</td>
<td>37</td>
<td>31</td>
<td>23</td>
<td>0</td>
</tr>
</tbody>
</table>

Depth Correction (ft)

| 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 |
Weight fraction of settleable solids removed, as a function of time and depth, using Equation 4.1.6:

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Time (min)</th>
<th>Weight Fraction Settleable Solids Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>8</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.78</td>
</tr>
<tr>
<td>3.0</td>
<td>12</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>54</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>68</td>
<td>0.78</td>
</tr>
<tr>
<td>4.0</td>
<td>15</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.72</td>
</tr>
</tbody>
</table>

(Con't.)
<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Time (min)</th>
<th>Weight Fraction Settleable Solids Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0</td>
<td>68</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>0.78</td>
</tr>
<tr>
<td>5.0</td>
<td>17</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>62</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.78</td>
</tr>
<tr>
<td>6.0</td>
<td>19</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>92</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>114</td>
<td>0.78</td>
</tr>
</tbody>
</table>
RUN #A.3.


Settling Data: Original suspended solids - average of duplicates.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (ft)</td>
<td>2.1</td>
<td>234</td>
<td>164</td>
<td>138</td>
<td>130</td>
<td>123</td>
<td>115</td>
<td>111</td>
<td>110</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>3.1</td>
<td>243</td>
<td>186</td>
<td>151</td>
<td>140</td>
<td>132</td>
<td>126</td>
<td>120</td>
<td>116</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>4.1</td>
<td>246</td>
<td>193</td>
<td>162</td>
<td>147</td>
<td>139</td>
<td>133</td>
<td>127</td>
<td>122</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>5.1</td>
<td>262</td>
<td>198</td>
<td>172</td>
<td>153</td>
<td>143</td>
<td>138</td>
<td>133</td>
<td>129</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>6.1</td>
<td>264</td>
<td>200</td>
<td>175</td>
<td>158</td>
<td>143</td>
<td>141</td>
<td>136</td>
<td>132</td>
<td>128</td>
</tr>
</tbody>
</table>

| Depth Correction (ft) | 0 | 0.1 | 0.2 | 0.3 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |

Average total initial suspended solids = 250 mg/l
Average final suspended solids = 73 mg/l
Total settleable solids = 177 mg/l
Weight % settleable solids = 100 (SS - 72)/177
Weight % settleable solids as a function of time and depth:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Depth (ft)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>100</td>
<td>50</td>
<td>37</td>
<td>32</td>
<td>28</td>
<td>24</td>
<td>21</td>
<td>21</td>
<td>18</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>100</td>
<td>64</td>
<td>44</td>
<td>38</td>
<td>33</td>
<td>30</td>
<td>27</td>
<td>24</td>
<td>21</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>100</td>
<td>68</td>
<td>50</td>
<td>42</td>
<td>37</td>
<td>34</td>
<td>30</td>
<td>28</td>
<td>25</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>100</td>
<td>71</td>
<td>56</td>
<td>45</td>
<td>40</td>
<td>37</td>
<td>34</td>
<td>32</td>
<td>28</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>100</td>
<td>72</td>
<td>58</td>
<td>48</td>
<td>40</td>
<td>38</td>
<td>35</td>
<td>33</td>
<td>30</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Depth Correction (ft)</td>
<td></td>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>
Weight fraction of settleable solids removed, as a function of time and depth, using Equation 4.1.6:

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Time (min)</th>
<th>Weight Fraction Settleable Solids Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>9</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>0.74</td>
</tr>
<tr>
<td>3.0</td>
<td>13</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.74</td>
</tr>
<tr>
<td>4.0</td>
<td>16</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.75</td>
</tr>
<tr>
<td>Depth (ft)</td>
<td>Time (min)</td>
<td>Weight Fraction settleable Solids Removed</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>5.0</td>
<td>18</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td>0.75</td>
</tr>
<tr>
<td>6.0</td>
<td>21</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.75</td>
</tr>
</tbody>
</table>
RUN #A.4.

Raw Sewage from Dundas W.P.C.P.

Settling Data: Original suspended solids - average of duplicates - data of Hudspith et al, 1969

<table>
<thead>
<tr>
<th>Time(min)</th>
<th>Depth(ft)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>192</td>
<td>158</td>
<td>145</td>
<td>133</td>
<td>152</td>
<td>160</td>
<td>144</td>
<td>140</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0</td>
<td>187</td>
<td>166</td>
<td>165</td>
<td>167</td>
<td>160</td>
<td>146</td>
<td>150</td>
<td>145</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0</td>
<td>248</td>
<td>204</td>
<td>178</td>
<td>163</td>
<td>156</td>
<td>158</td>
<td>188</td>
<td>145</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0</td>
<td>244</td>
<td>208</td>
<td>176</td>
<td>174</td>
<td>162</td>
<td>162</td>
<td>138</td>
<td>168</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0</td>
<td>246</td>
<td>202</td>
<td>176</td>
<td>172</td>
<td>164</td>
<td>164</td>
<td>144</td>
<td>156</td>
<td>158</td>
</tr>
</tbody>
</table>

Average of initial solids = 246 mg/l
Average of final non-settleable solids = 92 mg/l
Hence total settleable solids = 154 mg/l
% settleable solids = 100 (SS - 92)/154

*Insufficient mixing?
Weight % settleable solids as a function of time and depth:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Depth (ft)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
<th>24 Hrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>100</td>
<td>66</td>
<td>43</td>
<td>34</td>
<td>27</td>
<td>39</td>
<td>44</td>
<td>34</td>
<td>31</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3.2</td>
<td>100</td>
<td>62</td>
<td>48</td>
<td>47</td>
<td>49</td>
<td>44</td>
<td>37</td>
<td>38</td>
<td>34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.2</td>
<td>100</td>
<td>73</td>
<td>56</td>
<td>47</td>
<td>42</td>
<td>43</td>
<td>42</td>
<td>62</td>
<td>34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5.2</td>
<td>100</td>
<td>72</td>
<td>55</td>
<td>53</td>
<td>45</td>
<td>45</td>
<td>30</td>
<td>49</td>
<td>42</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6.2</td>
<td>100</td>
<td>71</td>
<td>55</td>
<td>52</td>
<td>47</td>
<td>47</td>
<td>34</td>
<td>42</td>
<td>43</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Depth Correction (ft) | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
Weight fraction of settleable solids removed as a function of time and depth, using Equation 4.1.6:

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Time (min)</th>
<th>Weight Fraction settleable Solids Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>10</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.74</td>
</tr>
<tr>
<td>3.0</td>
<td>13</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>0.73</td>
</tr>
<tr>
<td>4.0</td>
<td>16</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>97</td>
<td>0.72</td>
</tr>
<tr>
<td>Depth (ft)</td>
<td>Time (min)</td>
<td>Fraction Settleable Solids Removed</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>5.0</td>
<td>18</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>76</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>111</td>
<td>0.74</td>
</tr>
<tr>
<td>6.0</td>
<td>20</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>123</td>
<td>0.75</td>
</tr>
</tbody>
</table>
APPENDIX B

Exit Age Distributions of Primary Tanks

RUN #B.1-3 Dundas Plant
RUN #B.4-6 Drury Lane Plant

SETTLEABLE SOLIDS REMOVAL DATA
## Table B.1. Settleable Solids Removal Data

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Raw Flow (migd)</th>
<th>Settleable Suspended Solids</th>
<th>% Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Influent</td>
<td>Effluent</td>
</tr>
<tr>
<td>B.1</td>
<td>2.1</td>
<td>285</td>
<td>171</td>
</tr>
<tr>
<td>B.2</td>
<td>2.3</td>
<td>240</td>
<td>155</td>
</tr>
<tr>
<td>B.3</td>
<td>1.8</td>
<td>252</td>
<td>159</td>
</tr>
<tr>
<td>B.4</td>
<td>2.2</td>
<td>244</td>
<td>100</td>
</tr>
<tr>
<td>B.5</td>
<td>2.0</td>
<td>207</td>
<td>75</td>
</tr>
<tr>
<td>B.6</td>
<td>1.6</td>
<td>210</td>
<td>71</td>
</tr>
</tbody>
</table>
APPENDIX C

DATA FROM THE CHEMOSTAT EXPERIMENTS

RUN #C.1. Detention Time = 40 hours
RUN #C.2. Detention Time = 45 hours
RUN #C.3. Detention Time = 60 hours
RUN #C.4. Detention Time = 30 hours
RUN #C.5. Detention Time = 45 hours
RUN #C.6. Detention Time = 70 hours
RUN #C.7. Detention Time = 50 hours

204
<table>
<thead>
<tr>
<th>Run. Number</th>
<th>Detention Time (Hrs.)</th>
<th>FEED</th>
<th>EFFLUENT</th>
<th>$M = \frac{\Delta SS}{2.1}$ (mg/l)</th>
<th>$U = k_4 C$ (mg/l/hr)$^{-1}$</th>
<th>$Y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>69</td>
<td>26</td>
<td>45</td>
<td>14</td>
<td>4.9x10$^{-2}$</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>70</td>
<td>22</td>
<td>43</td>
<td>17</td>
<td>3.6x10$^{-2}$</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>65</td>
<td>25</td>
<td>35</td>
<td>16</td>
<td>3.2x10$^{-2}$</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>65</td>
<td>28</td>
<td>50</td>
<td>9</td>
<td>5.5x10$^{-2}$</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
<td>62</td>
<td>30</td>
<td>35</td>
<td>16</td>
<td>3.8x10$^{-2}$</td>
</tr>
<tr>
<td>6</td>
<td>70</td>
<td>60</td>
<td>24</td>
<td>25</td>
<td>19</td>
<td>2.6x10$^{-2}$</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>72</td>
<td>25</td>
<td>30</td>
<td>23</td>
<td>3.6x10$^{-2}$</td>
</tr>
</tbody>
</table>

Average value of $Y = 0.57$

Standard deviation = 0.037

Temperature = $25^\circ C \pm 3^\circ C$

Source: Filtered raw sewage from Skyway, Burlington

(Note: $M$ is obtained from the increase in suspended solids by the conversion factor of 2.1. Both $C$ and $M$ are expressed in terms of carbon).
APPENDIX D

EXTENDED AERATION STUDIES ON ACTIVATED SLUDGE

(a) Two runs using return sludge from the Skyway, Burlington W.P.C.P.
(b) Replicates analyses using five simultaneously-drawn samples.
RUN #D.1

Aeration of return activated sludge from the Skyway, Burlington W.P.C.P.

Original Data:

<table>
<thead>
<tr>
<th>Aeration Time (days)</th>
<th>Suspended Solids (mg/l)</th>
<th>Oxygen Uptake Rate (mgO_2/l/hr)</th>
<th>Soluble Organic Carbon (mgC/l)</th>
<th>BOD_5 (filtrate) (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6970</td>
<td>30.0</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>1</td>
<td>6710</td>
<td>21.6</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6260</td>
<td>18.6</td>
<td>29</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>6040</td>
<td>16.2</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5550</td>
<td>15.0</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5200</td>
<td>10.2</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>4710</td>
<td>12.0</td>
<td>52</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>4880</td>
<td>10.8</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>4560</td>
<td>9.6</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>4670</td>
<td>9.0</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3960</td>
<td>6.6</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>4250</td>
<td>6.0</td>
<td>53</td>
<td>8</td>
</tr>
<tr>
<td>17</td>
<td>3940</td>
<td>6.6</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>3840</td>
<td>3.6</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>3520</td>
<td>3.0</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>3660</td>
<td>2.4</td>
<td>67</td>
<td>14</td>
</tr>
</tbody>
</table>

Temperature = 23 ± 2°C  

pH = 7.5 ± 0.3  

Air Rate = 1.0 litre/hr/litre reactor volume  

Ash content of sludge:

- initial = 1650 mg/l  
- final = 1480 mg/l  
- average = 1520 mg/l
**Converted Data:**

<table>
<thead>
<tr>
<th>Aeration Time (days)</th>
<th>VSS (mgC/l)</th>
<th>OUR (mgO₂/l/hr)</th>
<th>SNDODC (mgC/l)</th>
<th>SDOC (mgC/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2600</td>
<td>20.0</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>2470</td>
<td>21.6</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2260</td>
<td>18.6</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>2150</td>
<td>16.2</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1920</td>
<td>15.0</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1750</td>
<td>10.2</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1520</td>
<td>12.0</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>1600</td>
<td>10.8</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1450</td>
<td>9.6</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1500</td>
<td>9.0</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1160</td>
<td>6.6</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1300</td>
<td>6.0</td>
<td>49</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>1150</td>
<td>6.6</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>1120</td>
<td>3.6</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>950</td>
<td>3.0</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1020</td>
<td>2.4</td>
<td>60</td>
<td>7</td>
</tr>
</tbody>
</table>

VSS = Volatile suspended solids (mg/l) (see Section 9.1)

= (Total Suspended Solids - 1520)/2.1

SDOC = Soluble degradable organic carbon (mgC/l)

= BOD₅ (filtrate)/1.9

SNDOC = Soluble non-degradable organic carbon (mgC/l)

= soluble organic carbon - SDOC
Aeration of return activated sludge from the Skyway, Burlington W.P.C.P.

Original Data:

<table>
<thead>
<tr>
<th>Aeration Time (days)</th>
<th>Suspended Solids (mg/l)</th>
<th>Oxygen Uptake Rate (mgO₂/l/hr)</th>
<th>Soluble Organic Carbon (mgC/l)</th>
<th>BOD₅ (filtrate) (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7900</td>
<td>30.6</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>1</td>
<td>7370</td>
<td>25.2</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7260</td>
<td>21.6</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7100</td>
<td>21.6</td>
<td>33</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>6530</td>
<td>18.6</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5800</td>
<td>15.0</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5900</td>
<td>15.6</td>
<td>48</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>5290</td>
<td>13.8</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5380</td>
<td>11.4</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>5290</td>
<td>10.8</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>4700</td>
<td>7.8</td>
<td>59</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>4950</td>
<td>6.6</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>4850</td>
<td>6.6</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>4910</td>
<td>5.4</td>
<td>61</td>
<td>12</td>
</tr>
</tbody>
</table>

Temperature = 23 ± 2°C  

pH = 7.4 ± 0.4  

Air Rate = 1.0 litre air/hr/litre reactor volume  

Ash content of sludge:  
initial = 1700 mg/l  
final = 1890 mg/l  
average = 1800 mg/l
### Converted Data:

<table>
<thead>
<tr>
<th>Aeration Time (days)</th>
<th>VSS (mgC/l)</th>
<th>OUR (mgO₂/l/hr)</th>
<th>SNDOC (mgC/l)</th>
<th>SDOC (mgC/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2900</td>
<td>30.6</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>2650</td>
<td>25.2</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2600</td>
<td>21.6</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2520</td>
<td>21.6</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>2250</td>
<td>18.6</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1900</td>
<td>15.0</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1950</td>
<td>15.6</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>1660</td>
<td>13.8</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1700</td>
<td>11.4</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1660</td>
<td>10.8</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1380</td>
<td>7.8</td>
<td>53</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>1500</td>
<td>6.6</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1450</td>
<td>6.6</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1480</td>
<td>5.4</td>
<td>55</td>
<td>6</td>
</tr>
</tbody>
</table>

VSS = volatile suspended solids (mgC/l) (see Section 9.1)

SDOC = soluble degradable organic carbon (mgC/l) = BOD₅ (filtrate)/1.9

SNDOC = soluble non-degradable organic carbon (mgC/l) = soluble organic carbon - SDOC
(b) Replicate Analyses on Five Simultaneously-drawn Samples:

Original Data:

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Volatile Suspended Solids (mg/l)</th>
<th>Oxygen Uptake Rate (mgO_2/l/hr)</th>
<th>Soluble Organic Carbon (mgC/l)</th>
<th>BOD_5 (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3820</td>
<td>12.6</td>
<td>47</td>
<td>10.4</td>
</tr>
<tr>
<td>2</td>
<td>3550</td>
<td>9.6</td>
<td>51</td>
<td>7.6</td>
</tr>
<tr>
<td>3</td>
<td>3890</td>
<td>9.6</td>
<td>45</td>
<td>8.4</td>
</tr>
<tr>
<td>4</td>
<td>3920</td>
<td>10.2</td>
<td>44</td>
<td>11.6</td>
</tr>
<tr>
<td>5</td>
<td>3610</td>
<td>12.0</td>
<td>51</td>
<td>6.4</td>
</tr>
</tbody>
</table>

NOTE: (a) 10 ml samples were used for VSS
(b) dilution for BOD_5 is 25%. Filtrate is close to saturation. Hence no need for O_2 correction.

The above data is converted to the similar values used in the four responses for the objective function:

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>P+M (mgC/l)</th>
<th>OUR (mgO_2/l/hr)</th>
<th>SNDOC (mgC/l)</th>
<th>SDOC (mgC/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1820</td>
<td>12.6</td>
<td>41</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>1690</td>
<td>9.6</td>
<td>47</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>1850</td>
<td>9.6</td>
<td>41</td>
<td>4.4</td>
</tr>
<tr>
<td>4</td>
<td>1870</td>
<td>10.2</td>
<td>38</td>
<td>6.0</td>
</tr>
<tr>
<td>5</td>
<td>1720</td>
<td>12.0</td>
<td>48</td>
<td>3.3</td>
</tr>
</tbody>
</table>

NOTE: (a) P+M = volatile suspended solids/2.1
(b) SDOC = BOD_5/1.9
(c) SNDOC = soluble organic carbon - SDOC
Variance - Covariance Matrix (18)

Component 1 = volatile suspended solids (mgC/l)
Component 2 = oxygen uptake rate (mgO₂/hr/l)
Component 3 = soluble non-degradable carbon (mgC/l)
Component 4 = soluble degradable carbon (mgC/l)

\[
\begin{bmatrix}
6450.0 & 7.5 & -332.5 & 69.5 \\
-7.5 & 1.98 & 0.75 & 0.045 \\
-332.5 & 0.75 & 18.5 & -4.325 \\
69.5 & 0.045 & -4.325 & 1.213
\end{bmatrix}
\]

Inverse of Variance - Covariance Matrix

\[
\begin{bmatrix}
0.139 & -1.22 & 4.19 & 7.00 \\
-1.22 & 11.2 & -36.8 & -61.9 \\
4.19 & -36.8 & 126.3 & 212.0 \\
7.00 & -61.9 & 212.0 & 358.0
\end{bmatrix}
\]
APPENDIX E

DATA FOR THE STRIPPING RATE OF PURGEABLE SOLUBLE ORGANIC CARBON BY AERATION WITH AIR

RUN #E.1  Air Rate = 2.1 cu.ft.air/hr/cu.ft. reactor
RUN #E.2  Air Rate = 1.0 cu.ft.air/hr/cu.ft. reactor
RUN #E.3  Air Rate = 0.5 cu.ft.air/hr/cu.ft. reactor
RUN #E.4  Air Rate = 1.5 cu.ft.air/hr/cu.ft. reactor
RUN #E.1.

Air Rate = 2.1 cu.ft.air/hr/cu.ft. reactor

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>SOC (mg/l)</th>
<th>SPOC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>123</td>
<td>24</td>
</tr>
<tr>
<td>1</td>
<td>118</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>116</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>115</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>110</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>113</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>106</td>
<td>7</td>
</tr>
<tr>
<td>17</td>
<td>106</td>
<td>7</td>
</tr>
<tr>
<td>20</td>
<td>103</td>
<td>4</td>
</tr>
<tr>
<td>25</td>
<td>102</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>101</td>
<td>2</td>
</tr>
<tr>
<td>40</td>
<td>99</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>99</td>
<td>0</td>
</tr>
</tbody>
</table>

Soluble non-purgeable organic carbon assumed to be = 99 mg/l
SOC = total soluble organic carbon
SPOC = soluble purgeable organic carbon
SPOC = SOC - 99
**RUN #E.2.**

Air Rate = 1.0 cu.ft.air/hr/cu.ft. reactor

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>SOC (mg/l)</th>
<th>SPOC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>126</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>124</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>121</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>124</td>
<td>18</td>
</tr>
<tr>
<td>15</td>
<td>118</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>116</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>118</td>
<td>12</td>
</tr>
<tr>
<td>30</td>
<td>114</td>
<td>8</td>
</tr>
<tr>
<td>40</td>
<td>112</td>
<td>6</td>
</tr>
<tr>
<td>50</td>
<td>110</td>
<td>4</td>
</tr>
<tr>
<td>60</td>
<td>109</td>
<td>3</td>
</tr>
<tr>
<td>70</td>
<td>108</td>
<td>2</td>
</tr>
<tr>
<td>80</td>
<td>106</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>106</td>
<td>0</td>
</tr>
</tbody>
</table>

Soluble non-purgeable organic carbon assumed to be = 106 mg/l

SOC = total soluble organic carbon
SPOC = soluble purgeable organic carbon
SPOC = SOC - 106
RUN #E.3.

Air Rate = 0.5 cu.ft.air/hr/cu.ft. reactor

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>SOC (mg/l)</th>
<th>SPOC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>131</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>129</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>128</td>
<td>17</td>
</tr>
<tr>
<td>15</td>
<td>127</td>
<td>16</td>
</tr>
<tr>
<td>20</td>
<td>126</td>
<td>15</td>
</tr>
<tr>
<td>30</td>
<td>124</td>
<td>13</td>
</tr>
<tr>
<td>40</td>
<td>122</td>
<td>11</td>
</tr>
<tr>
<td>50</td>
<td>120</td>
<td>9</td>
</tr>
<tr>
<td>60</td>
<td>119</td>
<td>8</td>
</tr>
<tr>
<td>80</td>
<td>117</td>
<td>6</td>
</tr>
<tr>
<td>100</td>
<td>115</td>
<td>4</td>
</tr>
<tr>
<td>120</td>
<td>111</td>
<td>0</td>
</tr>
<tr>
<td>140</td>
<td>111</td>
<td>0</td>
</tr>
</tbody>
</table>

Soluble non-purgeable organic carbon assumed to be = 111 mg/l
SOC = total soluble organic carbon
SPOC = soluble purgeable organic carbon
SPOC = SOC - 111
RUN #E.4.

Air Rate = 1.5 cu.ft.air/hr/cu.ft. reactor

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>SOC (mg/l)</th>
<th>SPOC (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>130</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>126</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>121</td>
<td>23</td>
</tr>
<tr>
<td>10</td>
<td>116</td>
<td>18</td>
</tr>
<tr>
<td>15</td>
<td>113</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>109</td>
<td>11</td>
</tr>
<tr>
<td>25</td>
<td>106</td>
<td>8</td>
</tr>
<tr>
<td>30</td>
<td>105</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>102</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>98</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>98</td>
<td>0</td>
</tr>
</tbody>
</table>

Soluble non-purgeable carbon assumed to be = 98 mg/l
SOC = total soluble organic carbon
SPOC = soluble purgeable organic carbon
SPOC = SOC - 98
APPENDIX F

DATA OF ACTIVATED SLUDGE

SETTLING FROM P. LEUNG

218
<table>
<thead>
<tr>
<th>Aeration Time (Hrs.)</th>
<th>MLSS (mg/l)</th>
<th>Effluent SS (mg/l)</th>
<th>SVI</th>
<th>Prediction Effluent SS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2100</td>
<td>35</td>
<td>101.3</td>
<td>38</td>
</tr>
<tr>
<td>1.0</td>
<td>600</td>
<td>74</td>
<td>83.0</td>
<td>68</td>
</tr>
<tr>
<td>1.0</td>
<td>3800</td>
<td>20</td>
<td>156</td>
<td>23</td>
</tr>
<tr>
<td>3.0</td>
<td>220</td>
<td>93</td>
<td>91.3</td>
<td>96</td>
</tr>
<tr>
<td>3.0</td>
<td>2100</td>
<td>34</td>
<td>97.9</td>
<td>26</td>
</tr>
<tr>
<td>3.0</td>
<td>4000</td>
<td>9.5</td>
<td>171</td>
<td>18</td>
</tr>
<tr>
<td>5.0</td>
<td>600</td>
<td>50</td>
<td>82.7</td>
<td>49</td>
</tr>
<tr>
<td>5.0</td>
<td>3800</td>
<td>14.5</td>
<td>153</td>
<td>17</td>
</tr>
<tr>
<td>5.5</td>
<td>2100</td>
<td>30</td>
<td>99.4</td>
<td>23</td>
</tr>
</tbody>
</table>

Data of Peter Leung

The predicted effluent $S_{Se}$ was found to be

$$S_{Se} = \frac{2560}{(MLSS)^{0.57} (TA)^{0.20}}$$

or

$$XRSS = S_{Se} = \frac{2560}{(MLSS)^{1.57} (TA)^{0.20}}$$

The SVI was not found to correlate well.
Figure F.1. Comparison of Observed Effluent Solids with Correlation
(Data of P. Leung)

Using Correlation

\[ SS = \frac{2560}{(MLSS)^{0.57}(TA)^{0.20}} \]
APPENDIX G

ANAEROBIC DIGESTION DATA

(a) Conventional Digester -
Data of Rankine (32).

(b) High Rate Digester -
Data of Torpey (50), Roy and
Sawyer (34) and Estrada (12).
(a) **Conventional Digester**

Data of Rankine (32).

<table>
<thead>
<tr>
<th>Detention Time (days)</th>
<th>Fraction Reduction of Volatile Solids = (1-R)</th>
<th>(1-R)/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>0.42</td>
<td>0.71</td>
</tr>
<tr>
<td>26</td>
<td>0.39</td>
<td>0.64</td>
</tr>
<tr>
<td>27</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>29</td>
<td>0.37</td>
<td>0.59</td>
</tr>
<tr>
<td>35</td>
<td>0.45</td>
<td>0.82</td>
</tr>
<tr>
<td>35</td>
<td>0.63</td>
<td>1.70</td>
</tr>
<tr>
<td>37</td>
<td>0.44</td>
<td>0.78</td>
</tr>
<tr>
<td>39</td>
<td>0.52</td>
<td>1.09</td>
</tr>
<tr>
<td>50</td>
<td>0.52</td>
<td>1.09</td>
</tr>
<tr>
<td>53</td>
<td>0.55</td>
<td>1.22</td>
</tr>
<tr>
<td>55</td>
<td>0.56</td>
<td>1.27</td>
</tr>
<tr>
<td>65</td>
<td>0.64</td>
<td>1.77</td>
</tr>
<tr>
<td>67</td>
<td>0.70</td>
<td>2.33</td>
</tr>
<tr>
<td>75</td>
<td>0.57</td>
<td>1.33</td>
</tr>
<tr>
<td>62</td>
<td>0.53</td>
<td>1.13</td>
</tr>
</tbody>
</table>
(b) **High Rate Digester**

<table>
<thead>
<tr>
<th>Source</th>
<th>Detention Time (days)</th>
<th>Fraction Reduction of Volatile Solids = (1-R)/R</th>
<th>(1-R)/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torpey (50)</td>
<td>14.0</td>
<td>0.56</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>10.3</td>
<td>0.45</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>8.3</td>
<td>0.47</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>0.45</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>3.7</td>
<td>0.37</td>
<td>0.59</td>
</tr>
<tr>
<td>Roy (34)</td>
<td>20.0</td>
<td>0.58</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
<td>0.57</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>0.56</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>0.54</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>0.52</td>
<td>1.09</td>
</tr>
<tr>
<td>Estrada (12)</td>
<td>22.5</td>
<td>0.61</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td>22.0</td>
<td>0.54</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>19.8</td>
<td>0.64</td>
<td>1.77</td>
</tr>
<tr>
<td></td>
<td>18.8</td>
<td>0.61</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td>18.0</td>
<td>0.63</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td>15.9</td>
<td>0.68</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>15.7</td>
<td>0.57</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>14.8</td>
<td>0.48</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>13.9</td>
<td>0.40</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>13.3</td>
<td>0.52</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>12.0</td>
<td>0.66</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>10.1</td>
<td>0.42</td>
<td>0.71</td>
</tr>
</tbody>
</table>
APPENDIX H

INTER-RELATIONSHIPS BETWEEN ORGANIC CARBON,
BIOCHEMICAL OXYGEN DEMAND AND VOLATILE SUSPENDED SOLIDS
<table>
<thead>
<tr>
<th>Sample</th>
<th>Raw Sewage</th>
<th>VSS</th>
<th>Filtrate</th>
<th>DBOD</th>
<th>TBOD-DBOD</th>
<th>VSS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TBOD</td>
<td>TOC</td>
<td></td>
<td>DBOD</td>
<td>SOC</td>
<td>TOC</td>
</tr>
<tr>
<td>1</td>
<td>220</td>
<td>160</td>
<td>230</td>
<td>114</td>
<td>60</td>
<td>1.90</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>226</td>
<td>320</td>
<td>110</td>
<td>58</td>
<td>1.96</td>
</tr>
<tr>
<td>3</td>
<td>260</td>
<td>177</td>
<td>224</td>
<td>110</td>
<td>68</td>
<td>1.62</td>
</tr>
<tr>
<td>4</td>
<td>289</td>
<td>192</td>
<td>236</td>
<td>145</td>
<td>72</td>
<td>2.02</td>
</tr>
<tr>
<td>5</td>
<td>315</td>
<td>218</td>
<td>286</td>
<td>149</td>
<td>85</td>
<td>1.75</td>
</tr>
<tr>
<td>6</td>
<td>310</td>
<td>187</td>
<td>244</td>
<td>149</td>
<td>74</td>
<td>2.01</td>
</tr>
<tr>
<td>7</td>
<td>308</td>
<td>196</td>
<td>272</td>
<td>151</td>
<td>70</td>
<td>2.15</td>
</tr>
</tbody>
</table>

**Average** = 1.91 | 1.24 | 2.09

**Standard Deviation** = 0.17 | 0.12 | 0.11

**TBOD** = total BOD₅ (mg/l)

**DBOD** = BOD₅ of soluble organics (mg/l)

**TOC** = total organic carbon (mg/l)

**SOC** = soluble organic carbon (mg/l)
APPENDIX I

SIMULATION DATA AND RESULTS FOR THE DRURY LANE,

BURLINGTON, SEWAGE TREATMENT PLANT
BURLINGTON DRURY LANE
WATER POLLUTION CONTROL PLANT

INFLUENT

GIRIT
REMOVAl
CHANNELS

SUPERNATANT

D I G E S T E R S

SECONDARY BYPASS

PRIMARY SEDIMENTATION TANKS

RAW SLUDGE

Digested Sludge To Tank Truck

SECONDARY SEDIMENTATION TANKS

RETURN AND WASTE ACTIVATED SLUDGE

AERATION TANK

AERATION TANK

CHLORINE CONTACT CHAMBER

EFFLUENT TO LAKE ONTARIO
DESIGN DATA

<table>
<thead>
<tr>
<th>PROJECT NO.</th>
<th>2-0051-60</th>
<th>TREATMENT</th>
<th>Activated Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN FLOW</td>
<td>2.5 mgd</td>
<td>DESIGN POPULATION</td>
<td>30,000</td>
</tr>
<tr>
<td>BOD - Raw Sewage</td>
<td>200 mg/l</td>
<td>SS - Raw Sewage</td>
<td>180 mg/l</td>
</tr>
<tr>
<td>- Removal</td>
<td>90%</td>
<td>- Removal</td>
<td>90%</td>
</tr>
</tbody>
</table>

PRIMARY TREATMENT

Screening

1" bar screens

Grit Removal

Type: Grit channels
Retention: 0.8 min

Primary Sedimentation

Type: Walker Process
Size: Two 49.3' x 18' x 12.25' (135,700 gal)
Retention: 1.3 hr
Loading: Surface, 1400 gal/ft²/day
Weir, 17,100 gal/ft/day

SECONDARY TREATMENT

Aeration Tanks

Type: Diffused air; triple-pass
Size: Two tanks, each with
2 passes 118' x 18' x 10.7'
1 pass 85.5' x 18' x 10.7'
(833,000 gal. total)
Retention: 8.0 hours

Air Supply

One Sutorbilt - 1500 cfm
Two Roots-Connerville - 750 cfm

Diffusers - (each tank)

1) 132 Schumacher Brandel tubes in first two passes

2) 41 Spargers on 2' centres in third pass

Secondary Sedimentation

Type: Rex Uniflow Tow-Bro
Size: Two 50' dia x 10.6' swd (260,000 gal)
Retention: 2.5 hr
Loading: Surface, 1000 gal/ft²/day
Weir, 8500 gal/ft/day

CHLORINATION

Type: Kent

Chlorine Contact Chamber
- in outfall

OUTFALL

- to Lake Ontario

SLUDGE HANDLING

Digestion System

Type: Two-stage

Primary --
Size: Two 40' dia tanks (313,000 gal total), depth = 20'
Loading: 2.7 lb/ft³/mo

Secondary --
Size: One 40' dia tank (143,000 gal)
Loading Total: 1.9 lb/ft³/mo

depth = 18'
### DATA SET FOR THE SIMULATION OF THE DRURY-LANE PLANT

<table>
<thead>
<tr>
<th>DRURY LANE, BURLINGTON, STP</th>
<th>1.0</th>
<th>1.0</th>
<th>1.0</th>
<th>0.0</th>
<th>0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>18.0</td>
<td>25.0</td>
<td>1.0</td>
<td>2.0</td>
<td>5.0</td>
<td>12.0</td>
</tr>
<tr>
<td>16.0</td>
<td>10.0</td>
<td>1.0</td>
<td>5.0</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>4.0</td>
<td>6.0</td>
<td>15.0</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>17.0</td>
<td>13.0</td>
<td>14.0</td>
<td>15.0</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>18.0</td>
<td>11.0</td>
<td>24.0</td>
<td>15.0</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>28.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>7.0</td>
<td>25.0</td>
<td>5.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>660000.0</td>
<td>4.0</td>
<td>0.0</td>
<td>56.0</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>23.0</td>
<td>0.5</td>
<td>6.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>16.0</td>
<td>2751.5</td>
<td>1.0</td>
<td>6.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>1865.97</td>
<td>131.2</td>
<td>0.0</td>
<td>28.4</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>451.5</td>
<td>131.2</td>
<td>0.0</td>
<td>28.4</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>54.1</td>
<td>4499.4</td>
<td>0.0</td>
<td>979.1</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>149860.6</td>
<td>8.74</td>
<td>15060.6</td>
<td>25.04</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>1236.4</td>
<td>186.7</td>
<td>40.0</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>5086.3</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1845.8</td>
<td>144.2</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49.3</td>
<td>9111.98</td>
<td>25.04</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>5086.3</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1845.8</td>
<td>144.2</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>12.75</td>
<td>5086.3</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>6.0</td>
<td>25.0</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>13.0</td>
<td>16.0</td>
<td>7.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>2.0</td>
<td>9.0</td>
<td>10.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>12.25</td>
<td>12.25</td>
<td>60000.0</td>
<td>80000.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>5086.3</td>
<td>6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>16.0</td>
<td>700.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>3.0</td>
<td>10.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>3.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>7.0</td>
<td>46.0</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>8.0</td>
<td>3.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>4.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>13.0</td>
<td>18.0</td>
<td>0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>2.2</td>
<td>0.54</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>2.2</td>
<td>0.00010</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>3.0</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60000.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>22.0</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>6.0</td>
<td>11.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>982.0</td>
<td>80000.0</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25000.0</td>
<td>0.3</td>
<td>15.0</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>4.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>6.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>6.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>5.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:0</td>
<td>5:0</td>
<td>16:0</td>
<td>0.001</td>
<td>101:0</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>------</td>
<td>--------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>10:0</td>
<td>12:0</td>
<td>15:0</td>
<td>0.0077</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>11:0</td>
<td>13:0</td>
<td>15:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>11:0</td>
<td>25:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>12:0</td>
<td>1:0</td>
<td>16:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>3:0</td>
<td>9:0</td>
<td>10:0</td>
<td>11:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>1:0</td>
<td>14:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>13:0</td>
<td>12:0</td>
<td>24:0</td>
<td>2:0</td>
<td>2:0</td>
<td></td>
</tr>
<tr>
<td>11:0</td>
<td>15:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>20:0</td>
<td>2:0</td>
<td>40:0</td>
<td>1:0</td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>1:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>12:0</td>
<td>24:0</td>
<td>1:0</td>
<td>2:0</td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>15:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>15:0</td>
<td>16:0</td>
<td>17:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>40:0</td>
<td>0.08</td>
<td>0:0</td>
<td>40:0</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>15:0</td>
<td>2:0</td>
<td>50:0</td>
<td>101:0</td>
<td>5:0</td>
<td></td>
</tr>
<tr>
<td>14:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>11:0</td>
<td>10:0</td>
<td>4:0</td>
<td>0.001</td>
<td>1:0</td>
<td></td>
</tr>
<tr>
<td>16:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>16:0</td>
<td>1:0</td>
<td>18:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>18:0</td>
<td>18:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>19:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>17:0</td>
<td>4:0</td>
<td>15:0</td>
<td>0:0</td>
<td>9:0</td>
<td></td>
</tr>
<tr>
<td>1:0</td>
<td>14:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>1:0</td>
<td>14:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>11:0</td>
<td>16:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>24:0</td>
<td>16:0</td>
<td>35:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>35:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>18:0</td>
<td>13:0</td>
<td>2:0</td>
<td>9:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>24:0</td>
<td>0:0</td>
<td>5:0</td>
<td>6:0</td>
<td>8:0</td>
<td></td>
</tr>
<tr>
<td>7:0</td>
<td>14:0</td>
<td>16:0</td>
<td>17:0</td>
<td>0:0</td>
<td></td>
</tr>
<tr>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td>0:0</td>
<td></td>
</tr>
</tbody>
</table>

RUN WITH AVERAGE FLOW CONDITIONS -1969
RUN WITH AVERAGE FLOW CONDITIONS - 1969

<table>
<thead>
<tr>
<th>Value</th>
<th>FRAc</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.40</td>
<td>0.0034</td>
</tr>
<tr>
<td>25.04</td>
<td>0.0000</td>
</tr>
<tr>
<td>2.50</td>
<td>0.0000</td>
</tr>
<tr>
<td>80.86</td>
<td>0.0034</td>
</tr>
<tr>
<td>3.79</td>
<td>0.0075</td>
</tr>
<tr>
<td>48.11</td>
<td>0.0015</td>
</tr>
<tr>
<td>7.87</td>
<td>0.0037</td>
</tr>
<tr>
<td>351.11</td>
<td>0.00526</td>
</tr>
<tr>
<td>1779.03</td>
<td>0.00034</td>
</tr>
<tr>
<td>1006.39</td>
<td>0.00151</td>
</tr>
<tr>
<td>772.64</td>
<td>0.00120</td>
</tr>
<tr>
<td>198.70</td>
<td>0.000375</td>
</tr>
<tr>
<td>279.32</td>
<td>0.000327</td>
</tr>
<tr>
<td>1.21</td>
<td>0.00003</td>
</tr>
<tr>
<td>7.61</td>
<td>0.000566</td>
</tr>
<tr>
<td>117.30</td>
<td>0.0003345</td>
</tr>
<tr>
<td>10.32</td>
<td>0.007073</td>
</tr>
<tr>
<td>25.65</td>
<td>0.001444</td>
</tr>
<tr>
<td>6.47</td>
<td>0.003722</td>
</tr>
</tbody>
</table>

END OF LOOP 6  
***CONVERGED

END OF LOOP 101  
END OF LOOP 1  
***CONVERGED

END OF LOOP 102  
***CONVERGED

$\$$ $\$$ $\$$ FINAL OUTPUT STREAMS FOR MODULE 18 - MIXER1 $\$$ $\$$

<table>
<thead>
<tr>
<th>Value</th>
<th>FRAc</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.000</td>
<td>6.746</td>
</tr>
<tr>
<td>658757.355</td>
<td>658757.308</td>
</tr>
<tr>
<td>13.547</td>
<td>0.000</td>
</tr>
<tr>
<td>2.127</td>
<td>10.050</td>
</tr>
<tr>
<td>6.194</td>
<td>6.406</td>
</tr>
<tr>
<td>0.000</td>
<td>5.894</td>
</tr>
<tr>
<td>211</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$\$$ $\$$ $\$$ FINAL OUTPUT STREAMS FOR MODULE 11 - CHLOR1 $\$$ $\$$

<table>
<thead>
<tr>
<th>Value</th>
<th>FRAc</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.000</td>
<td>6.746</td>
</tr>
<tr>
<td>658757.355</td>
<td>658757.308</td>
</tr>
<tr>
<td>25.042</td>
<td>1.500</td>
</tr>
<tr>
<td>658757.355</td>
<td>0.000</td>
</tr>
<tr>
<td>13.504</td>
<td>7.653</td>
</tr>
<tr>
<td>2.127</td>
<td>0.000</td>
</tr>
<tr>
<td>6.194</td>
<td>8.211</td>
</tr>
<tr>
<td>0.000</td>
<td>8.401</td>
</tr>
</tbody>
</table>

$$ $$ FINAL OUTPUT STREAMS FOR MODULE 16 - MIXER1 $$ $$
| 12.000 | 7.000 | 66008.582 | 25.000 | 5.000 |
| 0.000 | 10.264 | 101.640 | 40.260 | 14.230 |
| 197.538 | 128.898 | 34.680 | 30.960 | 6.600 |
| 40.920 | 0.000 | 11.880 | 1.980 | 3.660 |
| 36.300 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.000 | 15.180 | 0.330 | 3.960 | 0.000 |

$$ $$ FINAL OUTPUT STREAMS FOR MODULE 10 - GRIT1 $$ $$
| 13.000 | 7.000 | 66008.582 | 25.000 | 4.500 |
| 66000.000 | 2.640 | 101.640 | 40.260 | 14.230 |
| 194.176 | 128.898 | 23.318 | 36.960 | 6.600 |
| 40.920 | 0.000 | 11.880 | 1.980 | 3.660 |
| 36.300 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.000 | 15.180 | 0.330 | 3.960 | 0.000 |

$$ $$ FINAL OUTPUT STREAMS FOR MODULE 1 - PRISET1 $$ $$
| 2.000 | 8.992 | 66790.415 | 25.042 | 3.500 |
| 667861.462 | 0.000 | 64.035 | 40.318 | 10.662 |
| 102.424 | 49.009 | 95.619 | 36.810 | 3.660 |
| 16.872 | 0.000 | 96.833 | 1.971 | 3.660 |
| 36.319 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.000 | 23.570 | 0.617 | 5.830 | 0.000 |
| 9.000 | 8.992 | 287.929 | 25.042 | 3.500 |
| 280.400 | 0.000 | 97.039 | 36.810 | 3.660 |
| 153.813 | 119.376 | 67.283 | 194.942 | 0.017 |
| 41.644 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.152 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.000 | 0.950 | 0.000 | 0.000 | 0.000 |
| 0.000 | 0.010 | 0.000 | 0.000 | 0.000 |
## FINAL OUTPUT STREAMS FOR MODULE 2 - M1CER1

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
<th>Temperature</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.00</td>
<td>8.988</td>
<td>66790.415</td>
<td>25.042</td>
<td>3.500</td>
</tr>
<tr>
<td>2</td>
<td>102.242</td>
<td>64.035</td>
<td>40.316</td>
<td>10.662</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16.672</td>
<td>15.815</td>
<td>36.818</td>
<td>3.663</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>36.315</td>
<td>96.833</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.000</td>
<td>23.570</td>
<td>5.813</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

## FINAL OUTPUT STREAMS FOR MODULE 3 - AC1SL1

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
<th>Temperature</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.000</td>
<td>8.474</td>
<td>14184.710</td>
<td>25.042</td>
<td>4.500</td>
</tr>
<tr>
<td>2</td>
<td>140787.010</td>
<td>9.000</td>
<td>446.583</td>
<td>1.336</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1956.203</td>
<td>720.423</td>
<td>185.444</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.324</td>
<td>20.413</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7.000</td>
<td>28.801</td>
<td>20476.0</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>9073.252</td>
<td>40.474</td>
<td>11.552</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1066.741</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>16.771</td>
<td>1.316</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>3.085</td>
<td>0.073</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

## FINAL OUTPUT STREAMS FOR MODULE 4 - SECLAR1

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
<th>Temperature</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.000</td>
<td>8.474</td>
<td>80940.066</td>
<td>25.042</td>
<td>2.500</td>
</tr>
<tr>
<td>2</td>
<td>80864.472</td>
<td>3.790</td>
<td>486.895</td>
<td>7.861</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.779</td>
<td>1005.570</td>
<td>198.626</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>278.858</td>
<td>1.120</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7.600</td>
<td>117.246</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.000</td>
<td>25.564</td>
<td>6.468</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

## FINAL OUTPUT STREAMS FOR MODULE 5 - CCNT02

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
<th>Temperature</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.000</td>
<td>8.476</td>
<td>65876.306</td>
<td>25.042</td>
<td>1.500</td>
</tr>
<tr>
<td>2</td>
<td>568757.316</td>
<td>0.000</td>
<td>10.048</td>
<td>6.404</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13.547</td>
<td>5.896</td>
<td>0.000</td>
<td>1.517</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.191</td>
<td>95.913</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.000</td>
<td>20.892</td>
<td>5.269</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6.000</td>
<td>15060.581</td>
<td>1.500</td>
<td>334.754</td>
<td></td>
</tr>
</tbody>
</table>

## FINAL OUTPUT STREAMS FOR MODULE 6 - SETSP1

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
<th>Temperature</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.000</td>
<td>8.476</td>
<td>15060.581</td>
<td>25.042</td>
<td>4.500</td>
</tr>
<tr>
<td>2</td>
<td>149860.604</td>
<td>0.000</td>
<td>475.640</td>
<td>1.457</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1762.944</td>
<td>767.160</td>
<td>197.452</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>276.731</td>
<td>21.728</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.408</td>
<td>21.911</td>
<td>1.195</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>11.000</td>
<td>3.179</td>
<td>1.500</td>
<td>334.754</td>
<td></td>
</tr>
</tbody>
</table>

## FINAL OUTPUT STREAMS FOR MODULE 7 - MERT01

<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate</th>
<th>Temperature</th>
<th>Voltage</th>
<th>Current</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.000</td>
<td>8.476</td>
<td>15060.581</td>
<td>25.042</td>
<td>4.500</td>
</tr>
<tr>
<td>2</td>
<td>149860.604</td>
<td>0.000</td>
<td>475.640</td>
<td>1.457</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1762.944</td>
<td>767.160</td>
<td>197.452</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>276.731</td>
<td>21.728</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.408</td>
<td>21.911</td>
<td>1.195</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>11.000</td>
<td>3.179</td>
<td>1.500</td>
<td>334.754</td>
<td></td>
</tr>
</tbody>
</table>
### FINAL OUTPUT STREAMS FOR MODULE 5 - CCNT02

<table>
<thead>
<tr>
<th></th>
<th>8.000</th>
<th>140787</th>
<th>720.711</th>
<th>0.000</th>
<th>197.452</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1656.20</td>
<td>935.493</td>
<td>456.841</td>
<td>0.000</td>
<td>316.498</td>
</tr>
<tr>
<td></td>
<td>259.976</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>1.323</td>
<td>0.045</td>
<td>20.413</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>1.796</td>
<td>4.465</td>
<td>1.126</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### FINAL OUTPUT STREAMS FOR MODULE 12 - MIXER1

<table>
<thead>
<tr>
<th></th>
<th>14.000</th>
<th>319.816</th>
<th>69.160</th>
<th>0.000</th>
<th>64.888</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>209.305</td>
<td>144.846</td>
<td>64.290</td>
<td>0.000</td>
<td>15.196</td>
</tr>
<tr>
<td></td>
<td>41.651</td>
<td>0.000</td>
<td>12.119</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.168</td>
<td>0.000</td>
<td>45.00</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.109</td>
<td>0.004</td>
<td>0.027</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### FINAL OUTPUT STREAMS FOR MODULE 17 - SETSP1

<table>
<thead>
<tr>
<th></th>
<th>15.000</th>
<th>314.448</th>
<th>69.160</th>
<th>0.000</th>
<th>8.500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>316.613</td>
<td>0.000</td>
<td>64.290</td>
<td>0.000</td>
<td>15.196</td>
</tr>
<tr>
<td></td>
<td>209.305</td>
<td>144.846</td>
<td>64.290</td>
<td>0.000</td>
<td>15.196</td>
</tr>
<tr>
<td></td>
<td>41.651</td>
<td>0.000</td>
<td>12.119</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.168</td>
<td>0.000</td>
<td>45.00</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.109</td>
<td>0.004</td>
<td>0.027</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### FINAL OUTPUT STREAMS FOR MODULE 13 - ANDIG1

<table>
<thead>
<tr>
<th></th>
<th>16.000</th>
<th>186.728</th>
<th>0.000</th>
<th>40.000</th>
<th>6.500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1863.988</td>
<td>0.000</td>
<td>1.540</td>
<td>0.000</td>
<td>1.595</td>
</tr>
<tr>
<td></td>
<td>8.095</td>
<td>2.925</td>
<td>5.143</td>
<td>0.000</td>
<td>1.597</td>
</tr>
<tr>
<td></td>
<td>0.841</td>
<td>0.000</td>
<td>2.445</td>
<td>0.000</td>
<td>0.539</td>
</tr>
<tr>
<td></td>
<td>0.101</td>
<td>0.000</td>
<td>29.962</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>8.383</td>
<td>0.002</td>
<td>1.824</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### FINAL OUTPUT STREAMS FOR MODULE 14 - ANDIG1

<table>
<thead>
<tr>
<th></th>
<th>17.000</th>
<th>127.218</th>
<th>40.000</th>
<th>6.500</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1242.645</td>
<td>0.000</td>
<td>7.415</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>74.645</td>
<td>15.356</td>
<td>59.146</td>
<td>0.142</td>
</tr>
<tr>
<td></td>
<td>4.416</td>
<td>0.000</td>
<td>1.285</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>0.067</td>
<td>0.000</td>
<td>19.975</td>
<td>0.0000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>5.588</td>
<td>0.002</td>
<td>1.216</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$\text{FINAL OUTPUT STREAMS FOR MODULE 18 - MIXER1}$ $\text{FINAL OUTPUT STREAMS FOR MODULE 11 - CHLOR1}$
<table>
<thead>
<tr>
<th>STREAM</th>
<th>NUMBER</th>
<th>FLOW</th>
<th>DO</th>
<th>TOC</th>
<th>DOC</th>
<th>BOD</th>
<th>SS</th>
<th>VSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAW FEED</td>
<td>18</td>
<td>66008.58</td>
<td>4.00</td>
<td>153.98</td>
<td>61.00</td>
<td>215.47</td>
<td>299.26</td>
<td>195.27</td>
</tr>
<tr>
<td>INPUT TO PRI. CLAR.</td>
<td>13</td>
<td>66008.58</td>
<td>4.00</td>
<td>153.98</td>
<td>61.00</td>
<td>215.47</td>
<td>294.17</td>
<td>195.27</td>
</tr>
<tr>
<td>EFF. OF PRI. CLAR.</td>
<td>2</td>
<td>66790.41</td>
<td>0.00</td>
<td>95.87</td>
<td>60.37</td>
<td>150.71</td>
<td>153.08</td>
<td>74.58</td>
</tr>
<tr>
<td>UNCFLOW PRI CLAR</td>
<td>9</td>
<td>287.89</td>
<td>0.00</td>
<td>198.04</td>
<td>14</td>
<td>60.37</td>
<td>17472.90</td>
<td>63847.75</td>
</tr>
<tr>
<td>OUTPUT OF AER TANKS</td>
<td>4</td>
<td>80940.07</td>
<td>4.69</td>
<td>601.55</td>
<td>9.72</td>
<td>433.06</td>
<td>2197.95</td>
<td>1242.86</td>
</tr>
<tr>
<td>EFF. OF SEC. CLAR.</td>
<td>5</td>
<td>65876.31</td>
<td>0.00</td>
<td>15.25</td>
<td>15.72</td>
<td>21.74</td>
<td>24.56</td>
<td>11.62</td>
</tr>
<tr>
<td>UNCFLOW SEC CLAR</td>
<td>6</td>
<td>15060.58</td>
<td>0.00</td>
<td>3158.18</td>
<td>9.72</td>
<td>2222.72</td>
<td>11705.68</td>
<td>6611.85</td>
</tr>
<tr>
<td>RETURN ACT. SLUDGE</td>
<td>8</td>
<td>14148.72</td>
<td>0.00</td>
<td>3158.18</td>
<td>9.72</td>
<td>2222.72</td>
<td>11705.68</td>
<td>6611.85</td>
</tr>
<tr>
<td>WASTE ACT. SLUDGE</td>
<td>7</td>
<td>911.86</td>
<td>0.00</td>
<td>3158.18</td>
<td>9.72</td>
<td>2222.72</td>
<td>11705.68</td>
<td>6611.85</td>
</tr>
<tr>
<td>INPUT TO DIGESTER</td>
<td>14</td>
<td>319.82</td>
<td>0.00</td>
<td>21624.99</td>
<td>59.87</td>
<td>20289.09</td>
<td>65445.39</td>
<td>45290.35</td>
</tr>
<tr>
<td>DIGESTER SUPERNATE</td>
<td>16</td>
<td>186.73</td>
<td>0.00</td>
<td>828.20</td>
<td>82.43</td>
<td>854.23</td>
<td>4335.31</td>
<td>1566.42</td>
</tr>
<tr>
<td>DIGESTED SLUDGE</td>
<td>17</td>
<td>127.22</td>
<td>0.00</td>
<td>5828.41</td>
<td>82.43</td>
<td>5530.88</td>
<td>58674.73</td>
<td>12070.57</td>
</tr>
</tbody>
</table>
APPENDIX J

SIMULATION DATA AND RESULTS FOR THE SKYWAY,

BURLINGTON, SEWAGE TREATMENT PLANT
### DESIGN DATA

<table>
<thead>
<tr>
<th>PROJECT NO.</th>
<th>2-0105-62</th>
<th>DESIGN FLOW</th>
<th>6 mgd</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD - Raw Sewage</td>
<td>200 mg/l</td>
<td>SS - Raw Sewage</td>
<td>200 mg/l</td>
</tr>
</tbody>
</table>

#### PRETREATMENT

**Coarse Screening**
- Type: Link Belt, mechanically-cleaned
- Size: 2 1/4" space

**Lift Station Pumps (at 30' tdh)**
- 2 @ 6 mgd each; 2 @ 5 mgd each

**Screening**
- Type: Link Belt, mechanically-cleaned
- Size: 1" space

**Grit Removal**
- Type: Air degritter
- Size: One 20.3' x 25' x 14.2'
- Retention: 20.8 min

#### SECONDARY TREATMENT

**Aeration Tanks**
- Type: Diffused air, single pass
- Size: Six 270' x 27' x 15'
  - (660,300 ft., or 4.12 mil gal)
- Retention: 16.5 hr
- Loading: 9.5 lb BOD/1000 ft³

**Air Supply**
- Type: Hoffman multi-stage

**centrifugal blowers**
- Size: 3 - 4000 cfm (max); 1-6000 cfm (max)

**Diffusers**
- Type: Saran-covered flexofusers
- Spacing: 250 tubes per tank

**Secondary Sedimentation**
- Type: Eimco
- Size: Four 60' x 60' x 12' swd
  - (538,000 gal) (only two completed)
- Retention: 4.1 hours
- Loading: Surface, 434 gal/ft²/day
- Weir, 7,100 gal/ft/day

#### CHLORINATION

**Type:** Fischer & Porter

**Size:** Two 2000 lb/day

**Chlorine Contact Chamber**
- nil
- chlorination in outfall

#### OUTFALL

- to Hamilton Harbour

#### SLUDGE HANDLING

**Type:** Thickening tank, decanted

**Size:** One 20' dia x 9' depth
- (2830 ft³ or 1760 gal)
DATA SET FOR THE SIMULATION OF THE SKYWAY PLANT
240

BURLINGTON SKYWAY STP

1.0
o.o
14.0
1.0
5.0
12·0
-25.0
1.0
leO
r.o
leO
1.0
3e0
1.0
1400000e0
OeO
l8e0
55.0
o.o
7.0
998359e7
o.o
1214.9
3e47
o.o
10.0
13704.9
o.o
zo.o
4.0
o.o
13.0
1.0
2.0
z.o
1.0
z.o
1.0
1.0
3.0
1.0
reo
4e0
2e0
leO
270.0
Oe0028
o.os
0.07
o.o
o.o
240000.0
5.0
·1.0
3e0
1.0
125000.0
6e0
leO
leO
7•0
1.0
2·0
8.0
r.o
2·£
9 ..
2·0
r.o
leO
1000
1·

1.0
o.o
25.0
2.0
6.0
9.0

1.0
o.o
1.0
3.0
7.0
10.0

1.0
o.o

o.o
o.o

7.0
8.0
24.0

4.0
11.0

1.0
1·0
r.o
leO
leO

1.0
1eO
1.0
t.o
1.0
140000.0
OeO
40.0
5e0
100.0
1.0
100227.0
OeO
5602.0
o.o
99.84
34.54
1371.4
OeO
900e0
o.o
1 .o
6 .o

1.0
1.0
1.0
leO
leO

1.0
1.0
1e0

25e0
OeO
60.0
8.0
OeO
6e0
25.0
OeO
o.o
o.o
o.o
6e15
25.0
o.o
o.o
o.o
o.o
10.0

5e0
OeO
9e0
7e0
OeO
o.o
5.5
OeO
654.7
OeO
o.o
OeO
5e5
o.o
12.0
o.o
o.o
o.o

17.0
10e0
12.0

o.o
o.o
OeO

o.o
o.o
o.o

15e0
o.o
o.o
15.0
o.o
OeO
46e0
4.0
OeO
15.2
2e2
oeoo1o
o.o
o.o
o.o

3.0
o.o
o.o
1.6
o.o
OeO
6e0
OeO
o.o
3.0
0.54
Oe005
3.0
OeO
OeO

Oe5
o.o
-o.o
Oe5
o.o
OeO
1.5
o.o
o.o
Oe0014
0.45
0.23
1.0
o.o
3e0

7.4
4.0
o.o
o.o
o.o
20.0
8.585
OeO
OeO
OeO
0.92
0.054
8.585
o .. o
o.o
o.o
o·o
.o
1.0
1.0
2.0
o.o
r5.0
2.0
3.0
11.0
3.0
4.0
7e0
8e0
5·0
27.0
o.ooooo2
120000e0
250.0
o.o
o.o

0

1~0

1.0

9.0
s.o
6e0
Oe3
0.4
4.0
7.0
7e0
17.0
7.0
s.o
s.o
9.0
10.0
1.0
6.0
25.0

22e0
o.o
7e0
3600.0

2e0
o.o
13e0
8oooo.o

1.0
OeO
OeO
2.0

15.0
o.o
OeO
15.0
o.o
9.0
15.0
o.o
11.0
16.0
12·0
o.o

OeO
o.o
o.o
4.0
o.o
o.o
0.6
o.o
o.o
o.o
o.o
o.o

4e0
OeO
o.o
4000o0
o.o
o.o
0.10
o.o
o.o
o.o
o.o
o.o

13·8
25.

1500
o.

5.0
o.o

o.o
o.o


| 11.0 | 25.0 | 50.0 | 0.0 | 101.0 | 10.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9.0 | 10.0 | 5.0 | 0.001 | 10.0 | 0.0 |
| 1.0 | 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 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12.0 | 2.0 | 50.0 | 101.0 | 5.0 | 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 |
| 10.0 | 10.0 | 10.0 | 0.001 | 101.0 | 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 | 0.0 | 0.0 |
| 24.0 | 16.0 | 36.0 | 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 |
| 5.0 | 0.0 | 6.0 | 7.0 | 8.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11.0 | 0.0 | 0.0 | 12.0 | 0.0 | 0.0 |

RUN WITH AVERAGE FLOW CONDITIONS IN 1969
RUN WITH AVERAGE FLOW CONDITIONS IN 1969

END OF LOOP 1
END OF LOOP 2
END OF LOOP 3
END OF LOOP 4
END OF LOOP 5
*** CONVERGED
END OF LOOP 101
END OF LOOP 1
END OF LOOP 2
*** CONVERGED
END OF LOOP 102
END OF LOOP 1
END OF LOOP 2
*** CONVERGED
END OF LOOP 103
END OF LOOP 1
END OF LOOP 2
*** CONVERGED
END OF LOOP 104
*** CONVERGED

<table>
<thead>
<tr>
<th>Module</th>
<th>Final Output Streams</th>
<th>Mixer1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>25.000</td>
<td>8.582</td>
</tr>
<tr>
<td></td>
<td>139.0759.785</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>14.364</td>
<td>5.890</td>
</tr>
<tr>
<td></td>
<td>1.822</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>4.845</td>
<td>1.271</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>139.076</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.922</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.474</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.000</td>
</tr>
</tbody>
</table>

|        |                     | 11.394 | 0.001 | 0.000 |
|        |                     | 0.000  | 0.000  | 0.000 |
|        |                     | 0.000  | 0.000  | 0.000 |

|        |                     | 8.550  | 0.000  | 0.000 |

|        |                     | 25.000 | 1.500  | 1.500 |
|        |                     | 139.076 | 11.394 | 0.000 |
|        |                     | 8.922  | 0.000  | 0.000 |
|        |                     | 8.474  | 0.000  | 0.000 |
|        |                     | 0.000  | 0.000  | 0.000 |
|        |                     | 0.000  | 0.000  | 0.000 |
|        |                     | 8.550  | 0.000  | 0.000 |

|        |                     | 25.000 | 1.500  | 1.500 |

<p>|        |                     | 139.076 | 11.394 | 0.000 |
|        |                     | 8.922  | 0.000  | 0.000 |
|        |                     | 8.474  | 0.000  | 0.000 |
|        |                     | 0.000  | 0.000  | 0.000 |
|        |                     | 0.000  | 0.000  | 0.000 |
|        |                     | 8.550  | 0.000  | 0.000 |</p>
<table>
<thead>
<tr>
<th>Module</th>
<th>Output Streams</th>
<th>Time (sec)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>SCREEN1</td>
<td>25.000</td>
<td>5.000</td>
</tr>
<tr>
<td>3</td>
<td>GRIT1</td>
<td>25.000</td>
<td>4.000</td>
</tr>
<tr>
<td>4</td>
<td>ACTSL1</td>
<td>25.000</td>
<td>5.500</td>
</tr>
<tr>
<td>5</td>
<td>SECLR1</td>
<td>25.000</td>
<td>1.500</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>25.000</td>
<td>1.500</td>
</tr>
<tr>
<td>7</td>
<td>CCNT02</td>
<td>25.000</td>
<td>6.000</td>
</tr>
</tbody>
</table>

**Final Output Streams**

- **SCREEN1**
  - Time: 25.000 sec
  - Value: 5.000

- **GRIT1**
  - Time: 25.000 sec
  - Value: 4.000

- **CCNT02**
  - Time: 25.000 sec
  - Value: 6.000

- **SECLR1**
  - Time: 25.000 sec
  - Value: 1.500

- **AC1SL1**
  - Time: 25.000 sec
  - Value: 2.500

- **SECLR1**
  - Time: 25.000 sec
  - Value: 1.500

- **SECLR1**
  - Time: 25.000 sec
  - Value: 1.500
<table>
<thead>
<tr>
<th>14.364</th>
<th>5.889</th>
<th>8.475</th>
<th>0.000</th>
<th>0.583</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.682</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.601</td>
</tr>
<tr>
<td>4.845</td>
<td>1.271</td>
<td>13.000</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>46.067</td>
<td>0.949</td>
<td>0.000</td>
</tr>
<tr>
<td>7.000</td>
<td>8.585</td>
<td>100227.123</td>
<td>25.000</td>
<td>1.500</td>
</tr>
<tr>
<td>998360.390</td>
<td>0.000</td>
<td>1664.610</td>
<td>4.391</td>
<td>14562.560</td>
</tr>
<tr>
<td>9528.279</td>
<td>3906.250</td>
<td>56220.300</td>
<td>0.000</td>
<td>65128.28</td>
</tr>
<tr>
<td>1208.291</td>
<td>3.478</td>
<td>99.836</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>34.509</td>
<td>0.137</td>
<td>0.000</td>
</tr>
<tr>
<td>13.000</td>
<td>8.585</td>
<td>18.263</td>
<td>25.000</td>
<td>1.500</td>
</tr>
<tr>
<td>175.418</td>
<td>0.000</td>
<td>6.928</td>
<td>0.001</td>
<td>8.322</td>
</tr>
<tr>
<td>14.562</td>
<td>14.561</td>
<td>4.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>6.934</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$\$\$\$\$ FINAL OUTPUT STREAMS FOR MODULE 6 - SETSP1 $\$\$\$\$

| 8.000 | 8.585 | 973682.264 | 25.000 | 5.500 |
| 975610.112 | 0.000 | 18219.231 | 4.391 | 14562.560 |
| 9310.685 | 3817.044 | 5493.641 | 0.000 | 63628.28 |
| 1180.698 | 0.000 | 0.000 | 0.000 | 0.001 |
| 3.399 | 0.901 | 97.556 | 0.000 | 0.000 |
| 0.000 | 0.053 | 33.717 | 5.957 | 0.000 |
| 9.000 | 8.585 | 2288.859 | 25.000 | 5.500 |
| 2279.278 | 0.000 | 42.579 | 0.100 | 33.263 |
| 217.595 | 89.206 | 128.389 | 0.000 | 14.886 |
| 217.593 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.073 | 0.021 | 2.280 | 0.000 | 0.000 |
| 0.000 | 0.001 | 0.788 | 0.140 | 0.000 |

$\$\$\$\$ FINAL OUTPUT STREAMS FOR MODULE 7 - CCNTO2 $\$\$\$\$

<p>| 10.000 | 8.585 | 1374.208 | 25.000 | 5.500 |
| 13733.153 | 0.000 | 4.308 | 0.606 | 34.668 |
| 21.875 | 8.921 | 113.759 | 0.000 | 1.485 |
| 2.759 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.048 | 0.013 | 1.373 | 0.000 | 0.000 |
| 0.000 | 0.001 | 0.475 | 0.84 | 0.000 |
| 11.000 | 8.585 | 914.650 | 25.000 | 5.500 |
| 9066.125 | 0.000 | 38.271 | 0.040 | 29.861 |
| 195.835 | 80.285 | 115.550 | 0.000 | 13.397 |
| 24.834 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.032 | 0.000 | 0.907 | 0.000 | 0.000 |
| 0.000 | 0.000 | 0.313 | 0.056 | 0.000 |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25.000</td>
<td>8.582</td>
<td>139076.643</td>
<td>25.000</td>
<td>1.000</td>
</tr>
<tr>
<td>1390760.532</td>
<td>0.000</td>
<td>8.922</td>
<td>6.117</td>
<td>11.395</td>
</tr>
<tr>
<td>14.364</td>
<td>5.899</td>
<td>8.475</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>4.845</td>
<td>1.271</td>
<td>139.076</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.075</td>
<td>48.067</td>
<td>8.549</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$$$ FINAL OUTPUT STREAMS FOR MODULE 10 - CLOR1 $$$

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25.000</td>
<td>8.582</td>
<td>139076.643</td>
<td>25.000</td>
<td>1.000</td>
</tr>
<tr>
<td>1390760.532</td>
<td>0.000</td>
<td>8.922</td>
<td>6.117</td>
<td>11.395</td>
</tr>
<tr>
<td>14.364</td>
<td>5.899</td>
<td>8.475</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>4.845</td>
<td>1.271</td>
<td>139.076</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.000</td>
<td>0.075</td>
<td>48.067</td>
<td>8.549</td>
<td>0.000</td>
</tr>
</tbody>
</table>
### Summary Report CN Plant Operations - Case 1

<table>
<thead>
<tr>
<th>Stream</th>
<th>Number</th>
<th>Flow</th>
<th>DO</th>
<th>TOC</th>
<th>DOC</th>
<th>EOC</th>
<th>SS</th>
<th>VSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAW FEED</td>
<td>1</td>
<td>140010.72</td>
<td>4.00</td>
<td>101.99</td>
<td>62.00</td>
<td>154.99</td>
<td>183.99</td>
<td>83.99</td>
</tr>
<tr>
<td>OUTPUT OF AER TANKS</td>
<td>5</td>
<td>239322.03</td>
<td>7.16</td>
<td>785.71</td>
<td>4.40</td>
<td>616.86</td>
<td>3993.45</td>
<td>1640.76</td>
</tr>
<tr>
<td>EFF. OF SEC. CLAR.</td>
<td>6</td>
<td>139076.64</td>
<td>0.00</td>
<td>6.41</td>
<td>4.40</td>
<td>8.19</td>
<td>10.33</td>
<td>4.23</td>
</tr>
<tr>
<td>UNDERFLOW SEC CLAR</td>
<td>7</td>
<td>100227.12</td>
<td>0.00</td>
<td>1860.29</td>
<td>4.40</td>
<td>1453.26</td>
<td>5906.69</td>
<td>3897.40</td>
</tr>
<tr>
<td>RETURN ACT. SLUDGE</td>
<td>8</td>
<td>97938.26</td>
<td>0.00</td>
<td>1860.29</td>
<td>4.40</td>
<td>1453.26</td>
<td>9506.69</td>
<td>3897.40</td>
</tr>
<tr>
<td>WASTE ACT. SLUDGE</td>
<td>9</td>
<td>2288.86</td>
<td>0.06</td>
<td>1860.29</td>
<td>4.40</td>
<td>1453.26</td>
<td>9506.69</td>
<td>3897.40</td>
</tr>
<tr>
<td>THICKENED SLUDGE</td>
<td>11</td>
<td>914.65</td>
<td>0.00</td>
<td>4184.22</td>
<td>4.40</td>
<td>3264.73</td>
<td>21410.93</td>
<td>8777.71</td>
</tr>
<tr>
<td>PLANT BYPASS</td>
<td>12</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
APPENDIX K

Computer Listings
LISTING OF THE GEMCS EXECUTIVE

PROGRAM TST (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)

GEMCS/6400

***** PRINTING CONTROL CHARACTERS *****

KPRNT(1)=1 CAUSES PRINTING OF NCONT, LLST, NS
KPRNT(1)=0 SUPPRESSES ABOVE PRINTING
KPRNT(2)=1 CAUSES PRINTING OF INITIAL STREAMS
KPRNT(2)=0 SUPPRESSES ABOVE PRINTING
KPRNT(3)=1 CAUSES PRINTING OF MODULES SETS
KPRNT(3)=0 SUPPRESSES ABOVE PRINTING
KPRNT(4)=1 CAUSES PRINTING OF NPOINT
KPRNT(4)=0 SUPPRESSES ABOVE PRINTING
KPRNT(5)=1 CAUSES PRINTING OF SN TABLE ON ENTERING LOOP
KPRNT(5)=0 SUPPRESSES ABOVE PRINTING
ISP =1 PRINTS BOTH THE INPUT STREAMS AND OUTPUT STREAMS LEAVING
A MODULE - CAN BE SET BY HAVING MSN NEGATIVE IN DATA SET
ISP=U SUPPRESSES ABOVE PRINTING - DONE AUTOMATICALLY BY GEMCS
AFTER TWO LOOPS

***** COMMON DECLARATIONS - JUNE 8 *****

COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
COMMON MODE,NPLNT,LOOPC
COMMON SN(25,30),ENEN(60G),NPOINT(25,2)

DIMENSION NAME(20)
NAME(1)=8H MIXER1
NAME(2)=8H CONT1
NAME(3)=8H SETST1
NAME(4)=8H SETSP1
NAME(5)=8H SEPA1
NAME(6)=8H PRISET1
NAME(7)=8H ACIS1
NAME(8)=8H DPT1
NAME(9)=8H SEA1
NAME(10)=8H TRICK1
NAME(11)=8H GRIT1
NAME(12)=8H ANDIG1
NAME(13)=8H CHLOR1
NAME(14)=8H COST1
NAME(15)=8H SCREEN1
NAME(16)=8H DEPT1
NAME(17)=8H CONT2
NAME(18)=8H CONV1
NAME(19)=8H CASE1
NAME(20)=8H THICK1

III=25
CALL DLOAD1
LOOPC=1
WRITE(6,196) LOOPC
READ(5,198) TITLE
WRITE(6,200) TITLE

CALCULATING EQUIPMENT IN CALCULATION ORDER LIST

IK IS USED AS AN INDICATOR
IK=1 FOR A STRAIGHT THROUGH CALCULATION
IK=0 FOR A RECYCLE OPERATION
IK=0
IF(LOOP.EQ.999) IK=1

CONTINUE
NC=1
MODE=0
KTEST=0
LOOP=1
IF(IK.EQ.0) GO TO 98
MODE=1
KTEST=1
LOOP=999

READ EN VECTOR

IF (KPRNT(5)) 108,108,104
104 CONTINUE
WRITE (6,182) LOOP
DO 106 IKE=1,III
IF (SN(IKE,1) .LE. 0.0) GO TO 106
WRITE (6,194) (SN(IKE,J),J=1,JJ)
106 CONTINUE

NE=LLST(NC)
MM=NE
CALL DISKIO (1,MM)
NN=EN(3)+.001
NIN=EN(6)+.001
NOUT=EN(11)+.001
NTYPE=ABS(EN(2))+.001
KSW=0
IF (EN(2) .LE. 0.0) KSW=1
IF (LOOP .LE. 2) ISP=0
IF (LOOP .GT. 2) ISP=1

FINDING INPUT STREAMS
IF (NIN.EQ.U) GO TO 128
DO 12 2 J=NIN
CALL STREAM (S)
IF (IS=III) 114,114,110
110 CONTINUE
SI(I,1)=S
DO 112 J=2,JJ
SI(I,J)=0.
112 CONTINUE
GO TO 122
114 DO 116 J=1,JJ
SI(I,J)=SN(IS,J)
116 CONTINUE
IF (INT(S+.001)) 122,122,118
118 CONTINUE
M=S+.001
IF (NS(M)-6) 122,122,120
120 CONTINUE
SN(IS,1)=0.
122 CONTINUE
IF (ISP) 128,128,124
WRITE (6,184) NE,NAME(NTYPE)
DO 126 IKE=1,NIN
WRITE (6,194) (SI(IKE,J),J=1,JJ)
126 CONTINUE
128 CONTINUE

CALL MODULE (NTYPE)

STORING OUTPUT STREAMS AND PRINTING
IF(NOUT) 166,166,136
136 CONTINUE
DO 150 I=1,NOUT
S=EN(I+1)
SO(I,1)=S
M=S+.001
IF (NS(M)-6) 140,150,140
CALL STREAM (-S)
IF (IS=III) 146,146,142
CALL STREAM (0.)
IF (IS=III) 146,146,144
144 WRITE (6,190)  
146 GO TO 150  
148 SN(IS,J)=SO(I,J)  
150 CONTINUE  
C  
154 IF (ISP) 158,158,154  
156 WRITE (6,186) NE, NAMENTYPE)  
158 CONTINUE  
C  
164 NE=NAMEINTYPE  
166 DO 156 IK=1,NOUT  
170 WRITE(I6,194) (SO(IKE,J),J=1,JJ)  
172 IF (KTEST) 174,174,176  
174 KTEST=1  
176 LOOPC=LOOPC+1  
180 WRITE (6,192)  
182 FORMAT (1H0,32H$$$$$ SN TABLE ON ENTERING LOOP 15,7H $$$$ )  
184 FORMAT (1H0,31H$$$$$ INPUT STREAMS FOR MODULE ,I5,4H - ,  
186 FORMAT (1H0,32H$$$$$ OUTPUT STREAMS FOR MODULE ,I5,4H - ,A8,  
188 FORMAT (1H0,38H$$$$$ FINAL OUTPUT STREAMS FOR MODULE ,I5,4H - ,  
190 FORMAT (1H0,25H$$$$$ ERROR IN SN ***** )  
192 FORMAT (1H0,38H******** END OF EXECUTION ********* )  
194 FORMAT (1H1,16F12.3)  
196 FORMAT(1H1,28H$$$$$ CASE ,14,24H $$$$$$$$$$$$$$  
198 FORMAT(10A8)  
200 FORMAT(1H0,10A8)  
202 CD TOT 0212
SUBROUTINE STREAM (S)

COMMON LLST(50), NS(100), EN(100), SI(4*30), SO(4*30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

DO 2 IS=1, III
IF (ABS(SN(15,1)) - ABS(S(1)) - .001) 4, 2, 2
CONTINUE
IS=IS+1
4 RETURN
END

SUBROUTINE DISKIO (IPNT, MM)

COMMON LLST(50), NS(100), EN(100), SI(4*30), SO(4*30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

C THIS SUBROUTINE SIMULATES DISKIO ON 360/30
C IF IPNT=1. READS FROM MODULE SETS TABLE
C IF IPN=2, WRITES ONTO MODULE SETS TABLE
MQ=NPOINT(KM,1)
ML=NPOINT(MM,2)
IF (IPNT=1) 6, 2, 6
DO 4 I=1, ML
EN(I)=EEN(MQ+I)
4 CONTINUE
GO TO 14
6 IF (IPNT=2) 12, 8, 12
DO 10 I=1, ML
EEN(MQ+I)=EEN(I)
10 CONTINUE
GO TO 14
12 WRITE (6,16) IPNT, MM
14 RETURN
C
16 FORMAT (1H0, 22H DISKIO ERROR-IPNT, MM=, 15, 1X, 15)
END

SUBROUTINE DLOAD1

COMMON LLST(50), NS(100), EN(100), SI(4*30), SO(4*30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)
DIMENSION TITLE(10)
DIMENSION AKPRNT(10), ALLST(10)
DIMENSION ANS(100)

DO 2 I=1, 100
EN(I)=0.
2 CONTINUE
DO 6 J=1, 30
DO 4 I=1, 4
SI(J+1)=0.
SO(J+1)=0.
4 CONTINUE
DO 6 IK=1, III
SN(IK+1)=0.
6 CONTINUE
DO 7 J=1, 25
NPOINT(J+1)=0.
7 NPOINT(J+1)=0.
NCOUNT=0
C
WRITE(6, 79)
WRITE(6,81)
READ (5,80) TITLE
WRITE(6,82) TITLE
WRITE(6,81)
READ (5,100) AKPRNT
DO B I=1,10
KPRNT(I)=AKPRNT(I)
CONTINUE

REPORT ON PRINTING EXPECTED
CONTINUE

IF (KPRNT(1)-1) 12,10,12
WRITE (6,84)
IF (KPRNT(2)-1) 16,14,16
WRITE (6,86)
IF (KPRNT(3)-1) 20,18,20
WRITE (6,88)
CONTINUE

READ NO. OF MODULES IN CALCULATION ORDER, AND NO. OF COMPONENTS

READ (5,100) ANCALC,ANOCOM,ANPLNT
NCALC=ANCALC
NOCOMP=ANOCOM
NPLNT=ANPLNT
IF (NPLNT.GT.0) WRITE (6,108) NPLNT
IF (KPRNT(I)-1) 24,22,24
WRITE (6,95) NOCOMP
WRITE (6,92) NCALC
CONTINUE
IF (-NCALC) 28,26,26
NCALC=-NCALC
LOOP=999
GO TO 30

READ CALCULATION ORDER
READ (5,100) (ALLST(I),I=1,NCALC)
DO 32 I=1,NCALC
LLST(I)=ALLST(I)
CONTINUE
IF (KPRNT(I)-1) 36,34,36
WRITE (6,93)
WRITE (6,94) (LLST(I),I=1,NCALC)
CONTINUE

READ STREAM CODES, MSN IS THE MAXIMUM STREAM NUMBER, IF NEGATIVE OUTPUT STREAMS WILL BE PRINTED DURING EXECUTION
READ (5,100) AMSN
MSN=AMSN
IF (-MSN) 40,38,38
MSN=-MSN
ISP=1
IF (KPRNT(I)-1) 44,42,44
WRITE (6,96) MSN
READ (5,100) (ANS(I),I=1,MSN)
DO 46 I=1,MSN
NS(I)=ANS(I)
CONTINUE
IF (KPRNT(I)-1) 50,48,50
WRITE (6,94) (NS(I),I=1,MSN)
JJ=NOCOMP+5
READ (5,100) ANSR
NSR=ANSR
IF (KPRNT(2)-1) 54,52,54
WRITE (6,98) NSR
DO 60 I=1,NSR
READ (5,100) (SN(I,J),J=1,1,JJ)
CALL CONVERT(2,1,1,1,1)
CALL BALANCE(1,1)
IF (KPRNT(2)-1) 58,56,58
WRITE (6,102) (SN(I,J),J=1,1,JJ)
WRITE (6,102)
CONTINUE
CONTINUE

READING MODULE SETS, NOE IN NUMBER

READ (5, 1UU) ANOE
NOE = ANOE
IF (KPRNT(3) - 1) 64, 62, 64
WRITE (6, 1UU4) NOE
DO 72 I = 1, NOE
DO 66 IZ = 1, 1UU
EN(12) = 0.
CONTINUE
READ (5, 1UU) (EN(N), N = 1, 5)
NN = EN(3)
NCOUNT = NCOUNT + NN
READ (5, 1UU) (EN(N), N = 6, NN)
IF (KPRNT(3) - 1) 70, 68, 70
WRITE (6, 1UU2) (EN(N), N = 1, NN)
WRITE (6, 102)
MM = EN(I) + .01
NPOINT(MM, 1) = NCOUNT - NN
NPOINT(MM, 2) = NN
CALL DISKIO (2*MM)
CONTINUE
IF (KPRNT(4) * GT.0) GO TO 74
GO TO 78
WRITE (6, 106)
DO 76 I = 1, 25
WRITE (6, 90) I, NPOINT(I, 1), NPOINT(I, 2)
CONTINUE
CONTINUE
FORMAT STATEMENTS FOR DLOAD
RETURN

FORMAT (1H1)
FORMAT (10A8)
FORMAT (1HU, 12UH$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$5)
FORMAT (1HU, 1H5, 19X, 19A8, 19X, 1H5)
FORMAT (1HU, 22HPRINTING NCONT, LIST, NS)
FORMAT (1HU, 24HPRINTING INITIAL STREAMS)
FORMAT (1HU, 20HPRINTING MODULE SETS)
FORMAT (1X, 9I6)
FORMAT (1HU, 41H NUMBER OF MODULES IN CALCULATION ORDER = , 15)
FORMAT (1HU, 27H CALCULATION ORDER LIST IS =
FORMAT (1X, 2015)
FORMAT (1HU, 23H NUMBER OF COMPONENTS = , 15)
FORMAT (1HU, 30H NUMBER OF STREAM CODES READ = , 15)
FORMAT (1HU, 33H NUMBER OF INITIAL STREAMS READ = , 15)
FORMAT (5F12.2)
FORMAT (1X, 1LF12.4)
FORMAT (1HU, 29H NUMBER OF MODULE SETS READ = , 15)
FORMAT (1HU, 77H, 20H MODULE NEN LENGTH , 15)
FORMAT (1HU, 25H NUMBER OF PLANT CASES = , 15)
END
SUBROUTINE MODULE(NT)

C
GO TO (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20), NT

C
1 CALL MIXER1
 GO TO 50
2 CALL CONTL1
 GO TO 50
3 CALL SETST1
 GO TO 50
4 CALL SETSP1
 GO TO 50
5 CALL SEPA01
 GO TO 50
6 CALL PRIST1
 GO TO 50
7 CALL ACTSL1
 GO TO 50
8 CALL DPTR1
 GO TO 50
9 CALL S CLR1
 GO TO 50
10 CALL TRICK1
 GO TO 50
11 CALL GRT1
 GO TO 50
12 CALL ANDIG1
 GO TO 50
13 CALL CHLOR1
 GO TO 50
14 CALL COST1
 GO TO 50
15 CALL SCREEN1
 GO TO 50
16 CALL REPT01
 GO TO 50
17 CALL CONT02
 GO TO 50
18 CALL CONVO1
 GO TO 50
19 CALL CASET
 GO TO 50
20 CALL THICK1

C
50 RETURN
END
SUBROUTINE DLOAD3

WRITTEN BY P. TAN 1971

MODULE TO RUN NEW CASES
READS IN NEW STREAMS AND MODULE SETS

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOOT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOPPC
COMMON SN(25,30), SEN(600), NPOINT(25,2)
DIMENSION TITLE(10)

READ(5,100) TITLE
WRITE(6,101) TITLE

READ NUMBER OF STREAM CHANGES
READ(5,112) ANSR
NSR=ANSR+0.001
IF(NSR.LE.0) GO TO 300
WRITE(6,111) NSR
FORMAT(1H14,15,25HINITIAL STREAMS ARE READ )

READ STREAMS
DO 530 I=1,NSR
BORROWS VECTOR FROM SO(4,J), J=1, JJ
READ(5,112) (SO(4,J), J=1, JJ)
CALL CONVERT(2,2,4,2)
CALL BALANCE(2,4)
WRITE(6,113)
WRITE(6,113) (SO(4,J), J=1, JJ)
S=SO(4,1)
IF(III-IS) 400,401,401
CALL STREAMS(S)
400 CALL STREAM(0,0)
IF(III-IS) 403,401,401
DO 402 J=1, JJ
402 SN(IS,J)=SO(4,J).
530 CONTINUE

READ NUMBER OF MODULE CHANGES
READ(5,112) ANOE
NOE=ANOE+0.001
IF(NOE.LE.0) GO TO 301
WRITE(6,114) NOE
FORMAT(1H14,15,21HMODULE SETS ARE READ )

READ MODULES
DO 540 I=1, NOE
DO 541 12=1, 100
541 EN(12)=0.0
READ(5,112) (EN(N), N=1, 5)
NN=EN(3)+0.001
MM=EN(1)+0.001
READ(5,112) (EN(N), N=6, NN)
WRITE(6,113)
WRITE(6,113) (EN(N), N=1, NN)
CALL DISKIO(2, MM)
540 CONTINUE
301 CONTINUE
RETURN

403 WRITE(6,405)
405 FORMAT(1H1405* ERROR IN SN - VECTOR SPACE INSUFFICIENT *///)
RETURN
END
SUBROUTINE SETST1

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, IINC, NCALC, NOCOMP, NSR
COMMON MOD, OPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

ALTERS THE TEMPERATURE IN ANY STREAM
EN(4) = CHANGE IN TEMP (+VE FOR INCREASE AND -VE FOR DROP)
WRITTEN BY P. TAN
FOR WWTP SIMULATION

DO 1 I=2, JJ
  10 SI(1,1) = SI(1,1) + EN(4)

RETURN
END

SUBROUTINE SETSP1

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, IINC, NCALC, NOCOMP, NSR
COMMON MOD, OPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

WRITTEN BY P. TAN
FOR WWTP SIMULATION
ALTERS THE HEAD IN ANY STREAM
EN(5) = CHANGE IN HEAD (+VE FOR GAIN, -VE FOR LOSS)

DO 1 I=2, JJ
  10 SI(1,1) = SI(1,1) + EN(5)

RETURN
END

SUBROUTINE CONT1

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, IINC, NCALC, NOCOMP, NSR
COMMON MOD, OPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

WRITTEN BY A. I. JOHNSON AND T. TOONG MAY 1968

EN LIST
1. EQUIPMENT NUMBER
2. EQUIPMENT TYPE
3. LENGTH OF EN LIST = 21
4. LARGEST LOOP IDENTIFICATION NUMBER IN PROCESS FLOW DIAGRAM
5. PRINTING CONTROL - NUMBER OF LOOPS BETWEEN PRINTING OF THE STREAM UNDER TEST (ONLY NON ZERO COMPONENTS* AND THEIR FRACTIONAL CHANGES
6.-15. TEN ZEROS
16. NO. OF MODULES IN CALC ORDER LIST CONTROLLED BY CONT1
17. MAXIMUM NO. OF LOOPS
18. STREAM NUMBER OF STREAM TESTED
19. FRACTIONAL TOLERANCE
20. LOOP IDENTIFICATION NO.
21. LOOP IDENTIFICATION NO.
22. -(19+JJ) = 0.0
C
C
13300 IF(999-LOOP) 13030,13030,13300
13000 NN=EN(3)+.001
LOOP=EN(2)+.001
ML=EN(20)+.001
LL=LOOP-ML+1
WRITE(6,13001) LOOP
13001 FORMAT(1HC,71) END OF LOOP,I5)
D=FLOAT(LL)/EN(5)
C=FLOAT(INT(D))-D
E=EN(18)
IF(INT(E+.001)) 13011,13015,13011
13011 CALL STREAM (E)
IF(LL-2) 13015,13150,13150
13150 LL=LL+1
DO 13150 J=3,JJ
S=SN(J5,JJ)
IF(INT(S+.001)) 13016,13U13,13016
13016 TEST=(S-EN(J+19))/S
IF(ABS(TEST)-EN(19)) 13017,13017,13170
13170 LL=LL+1
13017 IF(J-3) 13024,13019,13024
13019 WRITE(6,13004) E,TEST
IF(C) 13023,13130,13130
13130 WRITE(6,13077)
13077 FORMAT(1X3H.....J.........VALUE.........FRAC)
13024 IF(ABS(C)-.001) 13135,13135,13013
13135 WRITE(6,13005) J,S,TEST
13005 FORMAT(1X13,F12.2,F12.6)
13004 FORMAT(1HC,36HFRATIONAL CHANGE IN TOTAL OF STREAM,F5.0,F10.8)
1)
13013 CONTINUE
IF(L) 13022,13022,13022
13020 WRITE(6,13001)
13001 FORMAT(1HC,12H**CONVERGED)
EN(21)=EN(2U)
IF(FLOAT(LOOP).GE.EN(4)) LOOP=999
GO TO 13023
13022 IF(LL-INT(EN(17)+.001)) 13015,13025,13015
13025 WRITE(6,13030)
13002 FORMAT(1HC,16H**NOT CONVERGED)
EN(21)=EN(2U)
IF(FLOAT(LOOP).GE.EN(4)) LOOP=999
GO TO 13023
13015 EN(21)=LOOP+1
LOOP=LOOP+1
NC=NC-INT(EN(16))-1
IF(INT(E+.001)) 13023,13030,13023
13023 DO13021 J=3,JJ
13021 EN(J+19)=SN(IS,J)
MM=NE
CALL DISKIO(2,MM)
13000 CONTINUE
C
13030 RETURN
END
SUBROUTINE CONV01

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

WRITTEN BY P. TAN 25/6/71
FOR WWTP SIMULATION

CONVERGENCE PROMOTION ON A STREAM

EN VECTOR
************
1. = MODULE NUMBER
2. = MODULE TYPE (18)
3. = MODULE LENGTH ( 16 + (JJ-2)*2 )
4. = LOOP AT WHICH MODULE IS EFFECTIVE
5. = STREAM NUMBER OF STREAM TO BE CONVERGENCE-PROMOTED
6. = STREAM NUMBER OF STREAM TO BE CONVERGENCE-PROMOTED
7. = STORAGE SPACE FOR STREAM

NLOOP = EN(4)+0.01
IF (LOOP.LT.NLOOP) RETURN
KOUNT=EN(16)+0.01
KOUNT=KOUNT+1
S=EN(5)
CALL STREAM(S)
GO TO (1,2,3), KOUNT

1. DO 600 J=3, JJ
EN(14+J)=SN(IS,J)
EN(16)=KOUNT
RETURN

2. DO 610 J=3, JJ
EN(12+JJ+J)=SN(IS,J)
EN(16)=KOUNT
RETURN

3. DO 630 J=13, JJ
DENOM=2.0*EN(12+JJ+J)-EN(14+J)-SN(IS,J)
IF (DENOM.EQ. 0.0) GO TO 630
SN(IS,J)=EN(12+JJ+J)*EN(12+JJ+J)-SN(IS,J)*EN(14+J))/DENOM
CONTINUE
EN(16)=1.0
I=S+0.01
CALL BALANCE(1, I)

RETURN
END
LISTING OF THE PRIMARY SETTLING TANK MODEL

SUBROUTINE PRIST1

COMMON LLST(50), NS(100), EN(100), SI(4, 30), SO(4, 30), KPRNT(10)
COMMON IS, JFJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25, 30), EEN(600), NPON(25, 2)

SIMULATES A PRIMARY SETTLING TANK
WRITTEN BY P. TAN
FOR WWTP SIMULATION
FOR REVISED STREAM LIST 2/9/71

EN VECTOR
**********
1. -15. STANDARD FORMAT
4. NUMBER OF TANKS IN PARALLEL
5. HEAD LOSS THROUGH TANKS (FT OF WATER)
7. FIRST INPUT STREAM (RAW WASTE STREAM)
8. SECOND INPUT STREAM (SUPERNATE FROM THE DIGESTERS - IF ANY)
9. THIRD INPUT STREAM (WASTE ACTIVATED SLUDGE - IF ANY)
10. FIRST OUTPUT STREAM (EFFLUENT)
11. SECOND OUTPUT STREAM (UNDERFLOW)
12. THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
13. LENGTH OF TANK (FEET)
14. WIDTH OF TANK (FEET)
15. DEPTH OF TANK (FEET)
16. SOLIDS CONCENTRATION OF SCUM FLOW (MG/L)
17. EFFICIENCY FACTOR FOR TANKS
18. FRACTION OF FLOCCULATED SOLIDS FROM WASTE ACTIVATED
   SLUDGE AND DIGESTER SUPERNATE THAT IS RESUSPENDED
20. NUMBER OF UNDERFLOW SLUDGE PUMPS
21. CAPACITY OF PUMPS 1GPH EACH
22. FRACTION OF CAPACITY AT WHICH PUMPS ARE RUN

CALL ALKMIX(PH)

DO 700 J=2, 500
   SO(I, J)=0.0
700 IF(NIN.EQ.0) GO TO 40

INPUT STREAMS 2 AND 3 ARE SLUDGE STREAMS - HENCE SETTLE MUCH
FASTER THAN SOLIDS IN RAW WASTE. DISP IS THE FRACTION OF SOLIDS
FROM INPUT STREAMS 2 AND 3 WHICH ARE RESUSPENDED.

DISP=EN(22)
DISP1=1.0-DISP

DO 620 J=13, 19
   SO(I, J)=SO(I, J)+SI(I, J)*DISP1
620 DO 610 J=1, 500
   SI(I, J)=SI(I, J)+SI(I, J)*DISP
610 IF(SI(I, 5).LT.SJ(I, 5)) SI(I, 5)=SI(I, 5)/SI(I, 3)
CONTINUE

CALCULATE EXIT HEAD
SO(1,5) = SI(1,5) - EN(5)
SO(2,5) = SI(1,5) - EN(5)
SO(3,5) = SI(1,5) - EN(5)

SO(1,2) = PH
SO(2,2) = PH
SO(3,2) = PH
SO(1,4) = SI(1,4)
SO(2,4) = SI(1,4)
SO(3,4) = SI(1,4)

CALCULATE SURFACE AREA
IF (EN(16) .LE. 0.0) GO TO 730
AREA = EN(16) * EN(17) * EN(4)
GO TO 720
730 AREA = 3.142 * EN(17) * EN(16) * EN(4) / 4.0
720 CONTINUE

CALCULATING RESIDENCE TIME TBAR (MINUTES)
TBAR = AREA / EN(18) / SI(1,3) * 374.4

CALCULATING OVERFLOW RATE OR (IGPD/SQ.FT.)
OR = SI(1,3) * 24.0 / AREA

CALCULATE THE THEORETICAL REMOVAL FROM BATCH TEST DATA
REMOVAL = 1.0 - EXP(-0.23 * TBAR ** 0.5 / EN(18) ** 0.25)

ACCOUNT FOR THE DECREASE IN EFFICIENCY DUE TO TURBULENCE
REMOVAL = REMOVAL * EN(21)

MATERIAL BALANCE
SO(2,13) = SO(2,13) + SI(1,13) * REMOVAL
SO(2,15) = SO(2,15) + SI(1,15) * REMOVAL
SO(2,16) = SO(2,16) + SI(1,16) * REMOVAL
SO(2,17) = SO(2,17) + SI(1,17) * REMOVAL
REML = 1.0 - REMOVAL
SI(1,13) = SI(1,13) + SI(1,13) * REM1
SI(1,15) = SI(1,15) + SI(1,15) * REM1
SI(1,16) = SI(1,16) + SI(1,16) * REM1
SI(1,17) = SI(1,17) + SI(1,17) * REM1

CALCULATE UNDERFLOW FLOW
SO(2,6) = EN(25) * EN(23) * EN(24) * 10.0
SO(2,13) = SO(2,13) + SO(2,16) + SO(2,17) / SO(2,6)
ASSUME THAT THE MAXIMUM UNDERFLOW CONCENTRATION IS 60000 MG/L
IF (SSF .LE. 0.06) GO TO 19
INSUFFICIENT WITHDRAWAL OF UNDERFLOW LEADS TO CARRY-OVER OF SOLIDS
SO(1,13) = SO(1,13) + SI(1,13) * (1.0 - 0.06 / SSF)
SO(1,15) = SO(1,15) + SI(1,15) * (1.0 - 0.06 / SSF)
SO(1,16) = SO(1,16) + SI(1,16) * (1.0 - 0.06 / SSF)
SO(1,17) = SO(1,17) + SI(1,17) * (1.0 - 0.06 / SSF)
SO(2,13) = SO(2,13) * 0.06 / SSF
SO(2,15) = SO(2,15) * 0.06 / SSF
SO(2,16) = SO(2,16) * 0.06 / SSF
SO(2,17) = SO(2,17) * 0.06 / SSF
19 CONTINUE

SET SCUM FLOW
SI(3,18) = SI(1,18) * 0.9
SI(1,18) = SI(1,18) + SI(1,18) - SO(3,18)
SO(2,18) = 0.0
SO(1,6) = SO(3,18) * (1.0 - EN(20) * 1.0E-6) / EN(20) * 2.2E6

EFFLUENT FLOW
SO(1,6) = SI(1,6) - SO(2,6) - SO(3,6)

SET SCUM VARIABLES (OTHER THAN SCUM) SIMILAR TO EFFLUENT F = SO(3,6) / (SO(1,6) + SO(3,6))
SO(3,13) = SO(3,13) * F
SO(1,12) = SO(1,12) - SO(3,13)
SO(3,15) = SO(1,15) * F
SO(1,15) = SO(1,15) - SO(3,15)
\begin{verbatim}
S0(3,16) = S0(1,16) * F
S0(1,16) = S0(1,16) - S0(3,16)
S0(3,17) = S0(1,17) * F
S0(1,17) = S0(1,17) - S0(3,17)

COMPONENTS IN SOLUTION SPLIT ACCORDING TO FLOW

DO 600 I = 20, JJ
  S0(1,I) = SI(1,I) * S0(1,6) / SI(1,6)
  S0(2,I) = SI(1,I) * S0(2,6) / SI(1,6)
  S0(3,I) = SI(1,I) - S0(1,I) - S0(2,I)

600 CONTINUE

S0(1,14) = SI(1,14) * S0(1,6) / SI(1,6) + S0(1,14)
S0(2,14) = SI(1,14) * S0(2,6) / SI(1,6) + S0(2,14)
S0(3,14) = SI(1,14) * S0(3,6) / SI(1,6) + S0(3,14)
S0(1,19) = SI(1,19) * S0(1,6) / SI(1,6) + S0(1,19)
S0(2,19) = SI(1,19) * S0(2,6) / SI(1,6) + S0(2,19)
S0(3,19) = SI(1,19) * S0(3,6) / SI(1,6) + S0(3,19)

SET ALL EXIT OXYGEN CONCENTRATIONS TO ZERO

S0(1,7) = 0.0
S0(2,7) = 0.0
S0(3,7) = 0.0

CALL BALANCE(2,1)
CALL BALANCE(2,2)
CALL BALANCE(2,3)

IF(ISPL) 1,1,2
   CONTINUE

WRITE(6,300) REMOVAL
   FORMAT(1X,17H SOLIDS REMOVAL = ,F10.3)
WRITE(6,400) OR
   FORMAT(1X,17H OVERFLOW RATE = ,F10.3,12H IGPD/SQFT)
WRITE(6,410) TBAR
   FORMAT(1X,17H DETENTION TIME = ,F10.3,10H MINUTES)

RETURN
END
\end{verbatim}
SUBROUTINE ACTSL1

COMMON LS(100),EN(100),SI(4,20),SN(4,20),KPRNT(10)
COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
COMMON SN(25,30),EN(600),NPOINT(25,2)
COMMON /A/ TAER,TM,FM,DELS

SIMULATES THE ACTIVATED SLUDGE PROCESS
CAN ALSO BE USED TO SIMULATE THE STEP AERATION PROCESS
CALLS THE BASIC CSTR PROGRAM FOR AEROBIC BIOLOGICAL REACTIONS

EN VECTOR

1. -15. STANDARD FORMAT
4. NUMBER OF REACTORS IN PARALLEL
5. TOTAL HEAD LOSS THROUGH ACT. SL. TANKS (FT OF WATER)
6. NUMBER OF INPUT STREAMS (= 2.0)
7. FIRST INPUT STREAM (= RETURN SLUDGE FLOW)
8. SECOND INPUT STREAM (= FEED STREAM)
11. NUMBER OF OUTPUT STREAMS (= 1.0)
12. OUTPUT STREAM NUMBER

NOTE EN(16.-32.) ARE USED BY CSTR2

16. LENGTH OF REACTOR (FEET)
17. WIDTH OF REACTOR (FEET)
18. DEPTH OF REACTOR (FEET)
19. = 1.0 IF NOT USING A RESIDENCE TIME DISTRIBUTION MODEL
   = EN(34) IF USING A RTD MODEL
20. LYSIS RATE (K2 /HR)
21. BASAL METAB. RATE (K1 /HR)
22. RATE OF SOLUBILIZATION OF DEGRADABLE SOLIDS (K3 /HR)
23. STRIPPING RATE OF VOLATILE ORGANICS (K5 /HR)
24. MICROORGANISMS YIELD FACTOR (DIMENSIONLESS)
25. FRACTION OF LYSIS PRODUCTS TO SOLUBLE DEGRADABLE CARBON
26. FRACTION OF LYSIS PRODUCTS TO SOLUBLE NONDEGRADABLE CARBON
27. RATE OF AIR ADDITION TO EACH REACTOR (SCF/HR)
28. UNIT GROWTH RATE CONSTANT (K4 /HR)
29. FRACTION OF MLSS THAT IS NITRIFIERS
30. N/C RATIO IN RAW FEED
31. P/C RATIO IN RAW FEED
32. ABSORPTION NUMBER (FOR OXYGEN TRANSFER)
33. NOT PRESENTLY USED
34. NUMBER OF CSTR'S IN SERIES - EITHER AN RTD MODEL OR THE
   ACTUAL NUMBER OF TANKS IN A STEP AERATION PROCESS
   MAXIMUM OF TEN TANKS IN SERIES
35. FRACTION OF FEED STREAM TO FIRST TANK
36. FRACTION OF FEED STREAM TO SECOND TANK
   ETC
44. FRACTION OF FEED STREAM TO FNTH TANK (IF ANY)
45. NUMBER OF BLOWERS USED
46. CAPACITY OF EACH FLOWER SCF/HR

EN(27)=EN(45)EN(46)/EN(4)/EN(34)

SIN=SI(1,1)+SI(2,1)

DO 600 J=2,JJ
SI(4,J)=SI(2,J)
600

CALCULATING THE VARIABLES FOR USE BY THE SECONDARY CLARIFIER
FM IS THE FOOD TO MICROORGANISM RATIO AND TAER IS, THE AERATION TIME
TANKS=EN(34)
IF(EN(19).GT.1.0) TANKS=1.0
TAER=EN(16)*EN(17)*EN(19)*TANKS*6.24/(SI(1,3)+SI(2,3))*EN(4)
TM=TAER/EN(34)
FM=SI(1,2)/SI(1,12)/TAER*24.0
SUBROUTINE CSTR2

COMMON LLST(5), NS(100), EN(100), SI(4, 30), SO(4, 30), KPRNT(10)
COMMON NE, JJ, LOOP, NIN, ROUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25, 30), EEN(600), NPOINT(25, 2)
COMMON /A/ TAER, TM, FM, DELS

THIS IS THE BASIC CSTR ROUTINE TO DESCRIBE THE AEROBIC
BIOLOGICAL PROCESSES AND IS CALLED BY ACTSL
WRITTEN BY P. TAN

EN VECTOR

**********
NOTE - CSTR2 USES ONLY EN(16, -32).
EN(1, -15) AND EN(33, - ) ARE USED BY ACTSL1
NOTE - CSTR2 HAS ONLY ONE INPUT STREAM, THE MIXED LIQUOR FLOW
16. LENGTH OF REACTOR (FEET)
17. WIDTH OF REACTOR (FEET)
18. DEPTH OF REACTOR (FEET)
19. = 1.0 IF NOT USING A RESIDENCE TIME DISTRIBUTION MODEL
   = EN(34) IF USING A RTD MODEL
20. LYSIS RATE (K2 /HR)
21. BASAL METAB. RATE (K1 /HR)
22. RATE OF SOLUBILIZATION OF DEGRADABLE SOLIDS (K3 /HR)
23. STRIPPING RATE OF VOLATILE ORGANICS (K5 /HR)
24. MICROORGANISMS YIELD FACTOR ( DIMENSIONLESS)
25. FRACTION OF LYSIS PRODUCTS TO SOLUBLE DEGRADABLE CARBON
26. FRACTION OF LYSIS PRODUCTS TO SOLUBLE NONDEGRADABLE CARBON
27. RATE OF AIR ADDITION TO EACH REACTOR (SCF /HR)
28. UNIT RATE GROWTH CONSTANT (K4 /HR)
29. FRACTION OF MLSS THAT IS NITRIFIERS
30. N/C RATIO IN RAW FEED
31. P/C RATIO IN RAW FEED
32. ABSORPTION NUMBER (FOR OXYGEN TRANSFER)
CALL CONVERT(1,3,1,3,1)

DO 600 J=2,JJ
600 SO(I,J)=SI(I,J)

SI15=SI(1,15)
SI1619=SI(1,16)+SI(1,17)+SI(1,18)+SI(1,19)

CALCULATING OXYGEN SATURATION AT INLET TEMPERATURE
CS=14.16-SI(1,14)*(0.3943-SI(1,4)*(0.007714-5.0000646*SI(1,4))

CALCULATING VOLUME OF REACTOR
V=EN(16)*EN(17)*EN(18)/EN(19)

CALCULATING OXYGEN TRANSFER COEFFICIENT KLA
AKL=EN(12)*((EN(27)/60.0)**0.85)*(EN(18)**0.7)/V

BACT IS THE CONCENTRATION OF NITROSOMONAS
BACT=EN(12)*SI(1,11)
BACTIN=BACT

KOUNT=1

INITIAL GUESS OF DEGRADABLE CARBON IS HALF FEED VALUE
INITIAL GUESS OF OTHER VARIABLES ARE FEED VALUES
SO(1,20)=0.5*SO(1,20)
SO(1,21)=0.5*SO(1,21)

BEGIN ITERATION FOR EFFLUENT CONCENTRATIONS OF CSTR

CONTINUE

CALCULATING RATE OF SOLUBLE CARBON REMOVAL
CC=SO(1,20)+SO(1,21)
RFC=EN(21)*CC

SO(1,20)=SI(1,20)/((1.0+TM*(RFC*SO(1,15)/CC+EN(23)*EN(27)/V))
SO(1,21)=((SI(1,21)+TM*SO(1,15)*(EN(20)+EN(25)+EN(22)*SO(1,16)+
1*SO(1,18)+SO(1,19))/1.0+TM*RFC*SO(1,15)/CC)

SO(1,22)=SI(1,22)+TM*EN(20)*EN(26)*SO(1,15)

CALCULATING EXIT SOLIDS
SO(1,15)=SI(1,15)/((1.0+TM*(EN(24)+RFC-EN(20)-EN(21)))
SO(1,16)=SI(1,16)/((1.0+TM*SO(1,15)*(EN(22)-EN(20)*(1.0-EN(25)-
EN(26))/SO(1,16)))
SO(1,18)=SI(1,18)/((1.0+TM*EN(22)*SO(1,15))
SO(1,19)=SI(1,19)/((1.0+TM*EN(22)*SO(1,15))

BALANCE ON NITROGEN
AVNIT IS THE AVAILABLE AMMONIACAL NITROGEN
AVNIT=SI(1,27)+(SI(1,15)-SO(1,15))*0.23+(SI(1,8)-SI(1,15)-
1*SO(1,16)-SO(1,17)-SO(1,18)-SO(1,19)-SO(1,20)-SO(1,21)-SO(1,22))

CALCULATE CONVERSION OF AMMONIA TO NITRATES
EFF=SO(1,7)
IF(SO(1,7)<0.9) EFF=1.0

SO(1,27)=AVNIT/(1.0+0.275*BACT*TM*EFF/(1.0+SO(1,27)))
IF(SO(1,27)<0.5) GO TO 40

CONTINUE
SO(1,27)=0.9
WRITE(6,410)

410 CONTINUE
SO(1,28)=SI(1,28)+(AVNIT-SO(1,27))
BACT=BACTIN+(AVNIT-SO(1,27))*0.05

CALCULATING EXIT OXYGEN CONCENTRATION
SO(1,7)=(SI(1,7)-TM*((RFC*EN(24)+EN(21))*SO(1,15)*2.66
1+(AVNIT-SO(1,27))*4.57*AKL*CS)/1.0+TM*AKL)
IF(SO(1,7)<0.5) SO(1,7)=0.0
KOUNT = KOUNT + 1
IF (KOUNT GT 20) GO TO 20
IF (ABS((CC-SO(1,20)-SO(1,21))/CC) GT 0.005) GO TO 10
GO TO 30

20 CONTINUE
WRITE (6, 400)
400 FORMAT (1HU, 2UHCSTR2 NOT CONVERGED )

30 CONTINUE

PHOSPHORUS BALANCE
SO(1,29) = SI(1,29) + (SI15-SO(1,15)) * 0.05 + (SI1619-SO(1,16)-SO(1,17))
1-SO(1,18)-SO(1,19)) * EN(31)
IF (SO(1,29) * L1.0.0) GO TO 50
GO TO 51

50 CONTINUE
SO(1,29) = 0.0
WRITE (6, 420)
420 FORMAT (1HU, 3UHDEFICIENCY IN FEED PHOSPHORUS )

51 CONTINUE

DUE TO THE HIGH DEGREE OF FLOCCULATION IN THE AERATION TANKS
COLLOIDAL COMPONENTS ARE CONVERTED TO SETTLEABLE
SO(1,13) = SO(1,13) + SO(1,14)
SO(1,14) = 0.0
SO(1,16) = SO(1,16) + SO(1,19)
SO(1,19) = 0.0

CALCULATING THE FRACTION OF NITRIFIERS IN THE EXIT SOLIDS
EN(29) = BACT/SO(1,11)

CALCULATING EXIT PH
ASSUME CARBON DIOXIDE CONCENTRATION IS IN EQUILIBRIUM WITH AIR
SO(1,2) = -ALOG10(2.6E-7/SI(1,23))

CALL CONVERT(2,2,1,2,1)
CALL BALANCE(2,1)

RETURN
END
LISTING OF THE SECONDARY SETTLING TANK MODEL

SUBROUTINE SECLAR1

COMMON LLST(50), NS(100), EN(100), SI(4, 30), SO(4, 30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOP
COMMON SN(25, 30), SE(IEN(600)), NPOINT(25, 2)
COMMON /A/ TAER, TM, FM, DELS

WRITTEN BY P. TAN
FOR WWTP SIMULATION
FOR REVISED STREAM LIST 2/9/71

SIMULATES A SECONDARY CLARIFIER

EN VECTOR

**********
1. -15. STANDARD FORMAT
4. NUMBER OF CLARIFIERS IN PARALLEL
5. HEAD LOSS THROUGH CLARIFIER (FEET OF WATER)
12. FIRST OUTPUT STREAM (EFFLUENT)
13. SECOND OUTPUT STREAM (UNDERFLOW)
14. THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
16. MODE OF OPERATION
   = 1.0 FOR FIXED FRACTION OF RECYCLE
   = 2.0 FOR MAXIMUM CONCENTRATION OF UNDERFLOW
17. FRACTION OF RECYCLE IF MODE=1
18. SURFACE AREA OF CLARIFIER (PER TANK) - SQ.FT.
19. SCUM FLOW CONCENTRATION (MG/L)
20. NUMBER OF UNDERFLOW SLUDGE PUMPS
21. CAPACITY OF PUMPS (GPH EACH)
22. FRACTION OF CAPACITY USED

EN(17) = EN(20) * EN(21) * EN(22) / SI(1, 3)
SO(1, 2) = SI(1, 2)
SO(2, 2) = SI(1, 2)
SO(3, 2) = SI(1, 2)
SO(4, 2) = SI(1, 4)
SO(2, 4) = SI(1, 4)
SO(3, 4) = SI(1, 4)

CALCULATE EXIT HEADS
SO(1, 5) = SI(1, 5) - EN(5)
SO(2, 5) = SI(1, 5) - EN(5)
SO(3, 5) = SI(1, 5) - EN(5)

CALCULATING THE SLUDGE VOLUME INDEX
SVI = 56.1 + 113.J*FM*(1.55**SI(1, 4) - 2.0)

CALCULATING THE MAXIMUM UNDERFLOW CONCENTRATION
CU = 1.0E+06/SVI

CALCULATING THE MIXED LIQUOR SUSPENDED SOLIDS XMLSS
XMLSS = SI(1, 11) / SI(1, 6) * 1.0E6

METHOD = EN(16) + 0.001
GO TO (1, 2)* METHOD

CONTINUE FOR FIXED FRACTION OF RECYCLE
SO(2, 6) = SI(1, 6) * EN(17)
SO(1, 6) = SI(1, 6) - SO(2, 6)

CALCULATING THE OVERFLOW RATE GSS (USGPD/SQFT)
GSS = SO(1, 6) * 2.879 / EN(18) / EN(4)

APPLY CORRELATION
THE FACTOR 1.5 IS SUGGESTED BY RICH TO ACCOUNT FOR
THE EXTRAPOLATION OF BATCH SETTLING TESTS TO ACTUAL TANKS
XRSS = 556.1 * (GSS**0.494) / (XMLSS**1.82) / (TAER**0.439) * 1.5

MATERIAL BALANCE
SO(1, 11) = SI(1, 11) * XRSS
C UNDERFLOW CONCENTRATION CANNOT BE GREATER THAN CU
IF (SO(2, 11) / SO(2, 6) * 1.0E6 .LT. CU) GO TO 10
SO(2, 11) = CU * 1.0E-6 * SO(2, 6)
SO(1, 11) = SI(1, 11) - SO(2, 11)
GO TO 10
C CONTINUE
C FOR MAXIMUM CONCENTRATION OF UNDERFLOW
C ROUGH ESTIMATE OF UNDERFLOW FLOW
SO(2, 6) = SI(1, 11) * 1.0E6 / CU
SO(1, 6) = SI(1, 6) - SO(2, 6)
C CALCULATING THE OVERFLOW RATE GSS (USGPD/SQFT)
GSS = SO(1, 6) * 2.879/EN(118)/EN(4)
C APPLY CORRELATION
XRSS = 556 * S0(2, 6)**0.494 / (XMLSS**1.82) / (TAER**0.439)*1.5
SO(1, 11) = SI(1, 11) * XRSS
SO(2, 11) = SI(1, 11) - SO(1, 11)
C CALCULATING CORRECTED UNDERFLOW FLOW
SO(2, 6) = SO(2, 11) * 1.0E6 / CU
SO(1, 6) = SI(1, 6) - SO(2, 6)
C CONTINUE
C ASSUME THAT THE FLOCS ARE UNIFORM IN COMPOSITION
C ALSO ASSUME THAT THE OVERFLOW AND UNDERFLOW SOLIDS HAVE THE
C SAME COMPOSITION AS THE INCOMING FLOCS
P1 = SO(1, 11) / SI(1, 11)
DO 600 I = 13, 19
SO(J, 1) = P1 * SI(J, 1)
SO(2, 1) = SI(1, 1) - SO(1, 1)
CONTINUE
C SPLIT OVERFLOW INTO EFFLUENT AND SCUM FLOW
SO(3, 18) = SI(1, 18)
SO(1, 18) = 0.0
SO(2, 18) = 0.0
SO(3, 6) = SO(3, 18) * (1.0 - EN(19) * 1.0E-6) / EN(19) * 2.2E6
SO(1, 6) = SO(1, 6) - SO(3, 6)
P1 = SO(3, 6) / (SO(1, 6) + SO(3, 6))
DO 610 I = 13, 17
SO(J, 1) = P1 * SI(J, 1)
SO(1, 1) = SI(1, 1) - SO(1, 1)
CONTINUE
SO(3, 19) = SO(1, 19) * P1
SO(1, 19) = SI(1, 19) - SO(3, 19)
C SPLIT SOLUBLE COMPONENTS ACCORDING TO FLOW
P1 = SO(1, 6) / SI(1, 6)
P2 = SO(2, 6) / SI(1, 6)
DO 620 I = 20, JJ
SO(J, 1) = SI(J, 1) * P1
SO(2, 1) = SI(1, 1) * P2
SO(3, 1) = SI(1, 1) - SO(1, 1) - SO(2, 1)
CONTINUE
C SET ALL EXIT OXYGEN CONCENTRATIONS AT ZERO
SO(1, 7) = 0.0
SO(2, 7) = 0.0
SO(3, 7) = 0.0
C CALL BALANCE(2, 1)
CALL BALANCE(2, 2)
CALL BALANCE(2, 3)
C IF(ISP) 30, 30, 31
30 WRITE(6, 300) TAER
300 FORMAT(1H4, 22HAERATION TIME = ,F10.3, 7H HOURS)
301 FORMAT(1X, 22HF00D TO MICRO RATIO = ,F10.3)
WRITE(6, 302) GSS
LISTING OF THE ANAEROBIC DIGESTER MODEL

SUBROUTINE ANDIG1

COMMON LLST(50), NS(140), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LUOP, NTN, NOUT, MSN, ISP, NC, I11, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EN(600), NPOINT(25,2)

SIMULATES AN ANAEROBIC DIGESTER
WRITTEN BY P. TAN  AUG/71

EN VECTOR
*************
1.-15. STANDARD FORMAT
4. NUMBER OF DIGESTERS IN PARALLEL
5. HEAD LOSS IN DIGESTERS (FT OF WATER)
16. DIAMETER OF DIGESTER (FEET)
17. DEPTH OF DIGESTER (FEET)
18. = 1.0 FOR CONVENTIONAL DIGESTER OPERATION
   = 2.0 FOR HIGH RATE DIGESTER OPERATION
19. TEMPERATURE OF OPERATION
20. FRACTION OF WATER TO FIRST OUTPUT STREAM (SUPERNATANT)
   = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
21. FRACTION OF SOLIDS TO FIRST OUTPUT STREAM (SUPERNATANT)
   (EXCLUDES SETTLEABLE INORGANIC SOLIDS)
   = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
22. FRACTION OF SETTLEABLE INORGANIC SOLIDS TO SUPERNATE
    = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
23. STORAGE SPACE FOR GAS PRODUCED
24. FRACTION OF VOLUME THAT IS EFFICIENTLY USED IN DIGESTION

USING SO(4,JJ) AS TEMPORARY STORAGE OF INTERMEDIATE RESULTS

DO 600 IK=2, JJ
   SO(4,IK)=SI(1,IK)
600  CONTINUE

C CALCULATING VOLUME OF DIGESTER (CU FT)
   VOL=3.142*EN(16)*EN(16)*EN(17)/4.0*EN(4)
   VOL=VOL*EN(24)

C CALCULATING DIGESTER RESIDENCE TIME (DAYS)
   RESTIME=VOL*6.24/SI(1,3)/24.0

C CALCULATING VOLATILE SOLIDS LOADING ON DIGESTER LB/CF/DAY
   SSLOAD=SI(1,12)*24.0/VOL

C ALKALINITY CALCULATIONS
   ALK=20.0*SI(1,23)/SI(1,6)
\[ \text{CN}=71.43 \times \text{SI}(1,27)/\text{SI}(1,6) \]

\[ \text{PH}=\text{SI}(1,2) \]

\[ \text{CALL ALKPH}(1, \text{ALK}, \text{ACT}, \text{CN}, \text{PH}) \]

\[ \text{CT} = \text{ACT} \]

\[ \text{SET REACTION CONSTANT FOR HIGH RATE OR CONVENTIONAL OPERATION} \]

\[ \text{NCOR}=\text{EN}(18)+0.01 \]

\[ \text{GO TO } (1,2) \times \text{NCOR} \]

\[ \text{AK1}=0.026 \times 1.04^{-\text{EN}(19)-35.0} \]

\[ \text{GO TO } 10 \]

\[ \text{AK1}=0.080 \times 1.04^{-\text{EN}(19)-35.0} \]

\[ \text{CONTINUE} \]

\[ \text{CALCULATE FRACTION OF VOLATILE SOLIDS DESTROYED} \]

\[ \text{FRAC}=1.0-1.0/(1.0+\text{AK1} \times \text{RESTIME}) \]

\[ \text{STORE RESULTING LIQUOR IN S0(4,J) - PRIOR TO SEPARATION} \]

\[ \text{DO 610 IK}=15,19 \]

\[ \text{S0}(4,1K)=\text{SI}(1,IK) \times (1.0-\text{FRAC}) \]

\[ \text{CALCULATE VOLUME OF GAS LIBERATED} \]

\[ \text{GAS}=17.0 \times \text{SI}(1,12) \times \text{FRAC} \]

\[ \text{EN}(23) = \text{GAS} \]

\[ \text{CALCULATE VOLATILE ACID CARBON IN EFFLUENT} \]

\[ \text{AKMAX}=0.28 \times \exp(-0.036 \times (35.0-\text{EN}(19))) \]

\[ \text{VAC}=200.0 \times \exp(0.12 \times (35.0-\text{EN}(19)))/(1.0+\text{AKMAX} \times \text{RESTIME}) \]

\[ \text{S0}(4,20)=\text{SI}(1,20) \times \text{SI}(1,6) \times \text{VAC} \times 1.0 \times E-6 \]

\[ \text{NUTRIENT BALANCE} \]

\[ \text{S0}(4,27)=\text{SI}(1,27) + \text{SI}(1,12)/2.1 \times \text{FRAC} \times 0.23 \]

\[ \text{S0}(4,29)=\text{SI}(1,29) + \text{SI}(1,12)/2.1 \times \text{FRAC} \times 0.05 \]

\[ \text{CALL BALNCE}(2,4) \]

\[ \text{CALCULATE EFFLUENT PH} \]

\[ \text{ACID}=(\text{VAC}-\text{SI}(1,20))/\text{SI}(1,6) \times 1.0 \times E6)/24.0/1000.0 \]

\[ \text{CNNEW}=71.43 \times \text{S0}(4,27)/\text{S0}(4,6) \]

\[ \text{ALK}=\text{ALK}+(\text{CNNEW}-\text{CN}) \times \text{ACID} \]

\[ \text{CALL ALKPH}(2, \text{ALK}, \text{CT}, \text{CNNEW}, \text{APH}) \]

\[ \text{S0}(4,2)=\text{APH} \]

\[ \text{S0}(1,2)=\text{APH} \]

\[ \text{S0}(2,2)=\text{APH} \]

\[ \text{S0}(4,23)=\text{ALK} \times \text{S0}(4,6)/20.0 \]

\[ \text{CALCULATING EFFLUENT AND UNDERFLOW FLOWS} \]

\[ \text{IF( EN}(20) \times GE. 1.0 ) \text{ GO TO } 31 \]

\[ \text{SETTING THE SUPERNATANT FLOW} \]

\[ \text{S0}(1,6)=\text{S0}(4,6) \times \text{EN}(20) \]

\[ \text{DO 620 IK}=20, JJ \]

\[ \text{S0}(1,IK)=\text{S0}(4,IK) \times \text{EN}(20) \]

\[ \text{CONTINUE} \]

\[ \text{S0}(1,13)=\text{S0}(4,13) \times \text{EN}(22) \]

\[ \text{DO 640 IK}=14, 19 \]

\[ \text{S0}(1,IK)=\text{S0}(4,IK) \times \text{EN}(21) \]

\[ \text{CONTINUE} \]

\[ \text{CALL BALNCE}(2,1) \]

\[ \text{CALCULATE DIGESTED SLUDGE FLOW BY MATERIAL BALANCE} \]

\[ \text{DO 650 IK}=6, JJ \]

\[ \text{S0}(2,IK)=\text{S0}(4,IK)-\text{S0}(1,IK) \]

\[ \text{CONTINUE} \]

\[ \text{S0}(2,3)=\text{S0}(4,3)-\text{S0}(1,3) \]

\[ \text{GO TO } 32 \]

\[ \text{CONTINUE} \]

\[ \text{ONLY ONE STREAM DRAWN OFF - THE FIRST OUTPUT STREAM} \]

\[ \text{DO 660 IK}=2, JJ \]

\[ \text{S0}(1,IK)=\text{S0}(4,IK) \]

\[ \text{S0}(2,IK)=0.0 \]

\[ \text{CONTINUE} \]

\[ \text{CONTINUE} \]
C SET ALL EXIT OXYGEN CONCENTRATIONS TO ZERO
SO(1,7)=0.0
SO(2,7)=0.0
C
C IF(ISP) 20,20,21
20 CONTINUE
WRITE(6,400) RESTIME
400 FORMAT(1HU,25HDETENTION TIME = F12.3,6H DAYS )
WRITE(6,410) SSLOAD
410 FORMAT(1X,25HSOLIDS LOADING = F12.3,15H LBS/CUFT/DAY )
GAS=GAS*24.0
WRITE(6,430) GAS
430 FORMAT(1X,25HGAS PRODUCED = F12.3,11H CUFT/DAY )
WRITE(6,420) FRAC
420 FORMAT(1X,25HFRACTION VSS DESTROYED = F12.3)
20 CONTINUE
C
RETURN
END
SUBROUTINE TRICK1

COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
COMMON MODE,NPLNT,LOOP
COMMON SN(25,30),EN(600),NPOINT(25,2)

SIMULATES A TRICKLING FILTER
UTILIZES THE EQUATION PROPOSED BY ECKENFELDER
WRITTEN BY P. TAN SEPT/71

EN VECTOR
***********
1. -15. STANDARD FORMAT
4. NUMBER OF TRICKLING FILTERS IN PARALLEL
5. HEAD LOSS IN FILTER (FT OF WATER - GREATER THAN HEIGHT)
16. DEPTH OF FILTER (FEET)
17. DIAMETER OF FILTER (FEET)
18. REACTION CONSTANT
19. EXPONENT ON DEPTH
20. EXPONENT ON LIQUID LOADING RATE

DO 600 J=2,JJ
SO(1,J)=SI(1,J)
SO(1,5)=SI(1,5)-EN(5)

CALCULATE SURFACE AREA
AREA=3.142*EN(17)*EN(17)/4.0*EN(4)

CALCULATE THE LIQUID LOADING RATE (USGPD/SQFT)
Q=SI(1,3)*28.79/AREA

CALCULATE REMOVAL OF BOD ACCORDING TO EQUATION
REM = FRACTION OF DEGRADABLE CARBON REMAINING
REM=EXP(-EN(18)*EN(16)**EN(19)/Q**EN(20))

ASSUME THAT THE REMOVAL APPLIES TO ALL DEGRADABLE COMPONENTS
SO(1,16)=SI(1,16)*REM
DO 610 J=18,22
SO(1,J)=SI(1,J)*REM

ASSUME MICROORGANISM YIELD FACTOR IS 0.54
SO(1,15)=0.54*(SI(1,16)+SI(1,18)+SI(1,19)+SI(1,20)+SI(1,21)
+SI(1,22))*1.0-REM)

CALL BALNCE(2,1)

RETURN

END
LISTING OF THE SCREEN MODEL

SUBROUTINE SCREEN

COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
COMMON IT,NE,JJ,LOOP,NIN,NGUT,MSN,ISP,NC,II,NCALC,NCOMP,NSR
COMMON MODE,NPLNT,LOOPC
COMMON SN(25,3U),EEN(600),NPOINT(25,2)

END VECTOR

********** 1.-15. STANDARD FORMAT

1. SCREENINGS, IF KNOWN FROM PLANT OPERATIONS (CUFT/MIG)
   = 0.0 IF USING BARMINUTER
   = ANY NEGATIVE NUMBER IF WANT TO USE INTERNAL SCREENINGS

4. ESTIMATE

5. HEAD LOSS ACROSS SCREEN (FT OF WATER)

16. SCREEN SIZE, IF USING INTERNAL ESTIMATE OF SCREENINGS (IN)

DO 600 J=2,JJSO(I,J)=SI(I,J)
   SO(1,5)=SI(1,5)-EN(5)

CALCULATE VOLUME OF SCREENINGS PER DAY

IF(EN(4))1,2,3
   SCR=19.0*10.0**(-0.8*EN(16))
   GO TO 4
RETURN
   SCR=EN(4)

VOL=SI(1,3)*SCR*24.0*1.0E-6

ESTIMATED DRY WEIGHT OF SCREENINGS IS 30 LBS/CUFT
CALCULATING MASS OF SCREENINGS PER HOUR

WRAGS=30.0*VOL/24.0

CONVERT TO EQUIV CARBON

WRAGS=WRAGS/2.1
   SO(1,16)=SI(1,16)-WRAGS

CALL BALANCE(2,1)

IF(ISP) 10,10,11
   WRITE(6,400) VOL

WRITE(6,400) VOL

400 FORMAT(11H0,13HSCREENINGS=,F8.2,10H CUFT/DAY )

10 CONTINUE

RETURN

END
LISTING OF THE GRIT REMOVAL MODEL

SUBROUTINE GRIT1

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOOT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

WRITTEN BY P. TAN 27/8/71
DEGRITTER FOR SEWAGE TREATMENT
SIMPLE MODEL USING THE AVERAGE AMOUNT OF GRIT COLLECTED /MIG

EN VECTOR
*********
1. - 15. STANDARD FORMAT
4. - CU.FT. OF GRIT PER MILLION GALLONS OF RAW FEED
5. - HEAD LOSS THROUGH CHAMBER (FT OF WATER)

DO 600 J=2, JJ
50(1, J) = SI(1, J)
SO(1, 5) = SI(1, 5) - EN(5)
CUFT = SI(1, 3) * EN(4) * 1.0E-6
GRIT = CUFT * 0.40 * 62.4 * 2.65
SO(1, 11) = SI(1, 11) - GRIT
SO(1, 13) = SI(1, 13) - GRIT
IF (ISP) 1, 2
2 CUFT = CUFT * 24.0
WRITE(6, 400) CUFT
400 FORMAT (1H', 'VOLUME OF GRIT REMOVED = ', F8.2, 11H CU FT/DAY )
CONTINUE
RETURN
END
LISTING OF THE CHLORINATOR MODEL

SUBROUTINE CHLOR1

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NOUT, KSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)
DIMENSION CLC61

EN VECTOR

1.-15. STANDARD FORMAT
4. DISPOSITION OF WASTE
   = 1.0 FOR RAW SEWAGE
   = 2.0 FOR SEPTIC RAW SEWAGE
   = 3.0 FOR SETTLED RAW SEWAGE
   = 4.0 FOR SEPTIC SETTLED RAW SEWAGE
   = 5.0 FOR BIOLOGICAL TREATMENT EFFLUENT
   = 6.0 FOR SAND FILTER EFFLUENT
5. USED FOR STORING AMOUNT OF CHLORINE USED PER DAY

CL(1)=10.0
CL(2)=20.0
CL(3)=8.0
CL(4)=16.0
CL(5)=6.0
CL(6)=3.0

DO 600 J=2, JJSOC1, Jl=SC1, Jl
   I=EN(4)+0.01
   CL2=SI(1,3)*24.0*10.0*CL(1)*1.0E-6
   EN(5)=CL2

   IF(ISP) 10,10,11
   WRITE(6,40U) CL2
10 CONTINUE

RETURN

END
LISTING OF THE MIXER-SPLITTER MODEL

SUBROUTINE MIXER1

COMMON LLIST(5), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, NII, NCALC, NCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)

EN VECTOR
1. -15. STANDARD FORMAT
16. FRACTION OF FLOW TO FIRST OUTPUT STREAM
17. ETC

IF(NIN.GT.1) GO TO 30
DO 650 J=2, NIN
650  
1  
CONTINUE
CALL ALKMIX(1)
SUM OF INPUT STREAMS IS TEMPORARILY STORED IN SO(NOUT,J)

IF(NOUT.EQ.1) RETURN
DO 620 I=1, NOUT
620  
DO 620 J=6, NOUT
600  
CONTINUE
IF(SI(I,5).LT.SO(NOUT,5)) SO(NOUT,5)=SI(I,5)
CONTINUE
SO(NOUT,4)=SO(NOUT,4)/SO(NOUT,3)

CONTINUE
RETURN
END
LISTING OF THE SIMPLE PHASE SEPARATOR MODEL

SUBROUTINE SEPA01

COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
COMMON MODE,NPLNT,LOOPC
COMMON SN(25,30),EEN(600),NPOINT(25,2)

EN VECTOR
*******
1.-15. STANDARD FORMAT
4. FRACTION OF FLOW TO FIRST OUTPUT STREAM (SUPERNATE)
5. FRACTION OF SOLIDS TO FIRST OUTPUT STREAM (SUPERNATE)

C

SO(1,2)=SI(1,2)
SO(2,2)=SI(1,2)
SO(1,4)=SI(1,4)
SO(2,4)=SI(1,4)
SO(1,5)=SI(1,5)
SO(2,5)=SI(1,5)

IF(SI(1,6).GT.0.0) GO TO 10
DO 650 J=6,JJ
SO(2,J)=0.0
650 CONTINUE
SO(1,3)=0.0
SO(2,3)=0.0
RETURN

10 CONTINUE

SO(1,6)=EN(4)*SI(1,3)*10.0
SO(2,6)=SI(1,6)-SO(1,6)

SEPARATE SOLIDS
DO 600 J=13,19
SO(1,J)=SI(1,J)*EN(5)
SO(2,J)=SI(1,J)-SO(1,J)
600 CONTINUE

SOLUBLE COMPONENTS ARE SPLIT ACCORDING TO FLOW
P1=SO(1,6)/SI(1,6)
DO 610 J=20,JJ
SO(1,J)=SI(1,J)*P1
SO(2,J)=SI(1,J)-SO(1,J)
610 CONTINUE

CALL BALNCE(2,1)
CALL BALNCE(2,2)

RETURN

END
LISTING OF THE PROGRAM TO CONTROL THE MLSS IN THE AERATION TANKS

SUBROUTINE CONT02

COMMON LST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EN(600), NPOINT(25,2)
COMMON /A, TAER, TM, FM, DELS
DATA DELS/0.0/

WRITTEN BY P. TAN
FOR WWTP SIMULATION

CONTROLS THE MLSS IN THE AERATION TANKS

EN VECTOR

1.-15. STANDARD FORMAT
4. FEED STREAM TO AERATION TANKS (EXCLUDING RECYCLE FLOW)
5. MLSS REQUIRED IN AERATION TANKS
12. FIRST OUTPUT STREAM (RECYCLE STREAM)
13. SECOND RECYCLE STREAM (WASTE SLUDGE FLOW)

S=EN(4)
CALL STREAM(S)

CALCULATE FRACTION OF INCOMING FLOW TO RECYCLE - A
A=(EN(5)*1.0E-6*SN(15,6)-SN(15,11)-DELS)/(SI(1,11)-EN(5)*SI(1,6)*1.0E-6)

IF(A.LT.0.0) A=0.0
IF(A.GT.1.0) A=1.0
DO 600 I=3, JJ
   S0(1,I)=SI(1,I)*A
   S0(2,I)=SI(1,I)-S0(1,I)

S0(1,2)=SI(1,2)
S0(2,2)=SI(1,2)
S0(1,4)=SI(1,4)
S0(2,4)=SI(1,4)
S0(1,5)=SI(1,5)
S0(2,5)=SI(1,5)
S0(1,7)=0.0
S0(2,7)=0.0

RETURN
END
SUBROUTINE BALNCE(NVECT, I)

COMMON LLST(5), NS(100), EN(100), SI(4, 30), SO(4, 30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, NI, NC, I1, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25, 30), EEN(600), NPOINT(25, 2)

WRITTEN BY P. TAN
FOR WASTE-WATER SIMULATION
BALANCES THE STREAM VARIABLES IN A STREAM (ELEMENTS 8-12)

NVECT=1 FOR SN VECTORS
NVECT=2 FOR SO VECTOR
C1 = RATIO OF BOD5 TO SOLUBLE DEGRAD ORGANICS (EQUIV CARBON)
C2 = RATIO OF BOD5 TO PARTICULATE DEGRAD ORGANICS (EQUIV CARBON)
C3 = RATIO OF VSS TO PARTICULATE ORGANICS (EQUIV CARBON)

C1=1.9
C2=1.2
C3=2.1

GO TO (1, 2), NVECT

CONTINUE
PC=SN(I, 15)+SN(I, 16)+SN(I, 17)+SN(I, 18)+SN(I, 19)
SN(I, 12)=C3*PC
SN(I, 11)=SN(I, 12)+SN(I, 13)+SN(I, 14)
SN(I, 9)=SN(I, 20)+SN(I, 21)+SN(I, 22)
SN(I, 8)=SN(I, 9)+PC
SN(I, 6)=C1*(SN(I, 20)+SN(I, 21))+C2*(SN(I, 16)+SN(I, 18)+SN(I, 19))
SN(I, 3)=0.978*(SN(I, 13)+SN(I, 14))+ 0.096*(SN(I, 15)+SN(I, 16))
+SN(I, 17)+SN(I, 19))+ 0.104*SN(I, 18)+ 0.1*SN(I, 6)
RETURN

CONTINUE
PC=SO(I, 15)+SO(I, 16)+SO(I, 17)+SO(I, 18)+SO(I, 19)
SO(I, 12)=C3*PC
SO(I, 11)=SO(I, 12)+SO(I, 13)+SO(I, 14)
SO(I, 9)=SO(I, 20)+SO(I, 21)+SO(I, 22)
SO(I, 8)=SO(I, 9)+PC
SO(I, 6)=C1*(SO(I, 20)+SO(I, 21))+C2*(SO(I, 16)+SO(I, 18)+SO(I, 19))
SO(I, 3)=0.978*(SO(I, 13)+SO(I, 14))+ 0.096*(SO(I, 15)+SO(I, 16))
+SO(I, 17)+SO(I, 19))+ 0.104*SO(I, 18)+ 0.1*SO(I, 6)
RETURN

END
SUBROUTINE CONVERT(M, KIN, JIN, KOUT, JOUT)

COMMON LS(160), NS(160), SN(160), SI(4, 30), SO(4, 30), KPRINT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, II, INCALC, NOCOMP, NNR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25, 30), EEN(600), NPOINT(25, 2)
DIMENSION V(30)

CONVERTS STREAM VARIABLES FROM POUNDS PER HOUR TO PPM
OR VICE VERSA

INPUT VARIABLES
M = 1 FOR CONVERTING LBS/HR TO PPM
M = 2 FOR CONVERTING PPM TO LBS/HR
KIN = VECTOR TO BE READ FROM
JIN = ROW NUMBER OF INPUT VECTOR
KOUT = VECTOR TO BE WRITTEN ON TO
JOUT = ROW NUMBER OF OUTPUT VECTOR

VARIABLES 2. TO 6. ARE NOT CHANGED

READ FROM INPUT VECTOR
GO TO (1, 2, 3), KIN

DO 600 J=2, JJ
600 V(J) = SN(JIN, J)
GO TO 10

DO 610 J=2, JJ
610 V(J) = SN(JIN, J)
GO TO 10

DO 620 J=2, JJ
620 V(J) = SI(JIN, J)
GO TO 10

CONTINUE

IF(V(6), GT, 0.0 ) GO TO 40
V(3) = 0.0
DO 700 J = 6, JJ
700 V(J) = 0.0
GO TO 11

CONTINUE

CONVERSION
GO TO (4, 5), M

CONTINUE

CONVERTING FROM LBS/HR TO PPM
SOLUBLE COMPONENTS
V(7) = V(7)/V(6)*1.0E6
V(9) = V(9)/V(6)*1.0E6
DO 630 J = 20, JJ
630 V(J) = V(J)/V(6)*1.0E6

PARTICULATE COMPONENTS
V(8) = V(8)/V(3)*1.0E5
DO 640 J = 10, 19
640 V(J) = V(J)/V(3)*1.0E5
GO TO 11

CONTINUE

CONVERTING FROM PPM TO LBS/HR
SOLUBLE COMPONENTS
V(7) = V(7)*V(6)*1.0E-6
V(9) = V(9)*V(6)*1.0E-6
DO 650 J = 20, JJ
650
V(J) = V(J) * V(6) * 1.0E-6

C PARTICULATE COMPONENTS
V(8) = V(8) * V(3) * 1.0E-5
DO 660 J = 10, 19
V(J) = V(J) * V(3) * 1.0E-5
CONTINUE
C WRITING ON TO OUTPUT VECTOR
C GO TO (6, 7, 8), KOUT
C
DO 670 J = 2, JJ
SN(JOUT, J) = V(J)
GO TO 12
DO 680 J = 2, JJ
SO(JOUT, J) = V(J)
GO TO 12
DO 690 J = 2, JJ
SI(JOUT, J) = V(J)
CONTINUE
C
RETURN
END
LISTING OF THE PROGRAM RELATING PH AND ALKALINITY

SUBROUTINE ALKMIX(PH)
COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
COMMON IS,IE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
COMMON MODE,NSPLNT,LOOPC
COMMON SN(25,30),EEN(600),NPOINT(25,2)

SUBROUTINE TO CALCULATE THE RESULTING PH WHEN STREAMS ARE MIXED

SUMALK=0.0
SUMCN=0.0
SUMCT=0.0
DO 600 I=1,NIN
IF(SI(1,6) LE 0.0) GO TO 600
IF(SI(1,2) LE 0.0) SI(1,2)=7.0
ALK=2U.0*SI(I+23)/SI(I+6)
CN=71.43*SI(I+27)/SI(I+6)
PH=SI(I+2)
CALL ALKPH(1,ALK,CT,CN,PH)
SUMALK=SUMALK+ALK
SUMCT=SUMCT+CT
SUMCN=SUMCN+CN
CONTINUE

CALL ALKPH(2,SUMALK,SUMCT,SUMCN,APH)
PH=APH
RETURN
END

SUBROUTINE ALKPH(NZ,ALK,CT,CN,PH)
DIMENSION XCOF(4)

SUBROUTINE TO CALCULATE CT OR PH GIVEN THE OTHER THREE VARIABLES

PK1=6.3
PK2=10.3
PKN=9.3
GO TO (1,2), NZ

CALCULATE CT
CONTINUE
CT=(ALK-CN/(1.0+10.0**(PKN-PH)))*(1.0+10.0**(PK1-PH)+1.0+10.0**
1(PH-PK2))/(1.0+10.0**(PH-PK2)*2.0)
RETURN

CALCULATE PH
CONTINUE
A1=ALK-CN
A2=ALK-CT
A3=ALK-CN-CT
A4=ALK-2.0*CT
A5=ALK-CN-2.0*CT
XCOF(1)=10.0**(-PK1-PK2-PKN)*A5
XCOF(2)=(A3*10.0**(-PK1-PKN)+A4*10.0**(-PK1-PK2))
XCOF(3)=(A1*10.0**(-PKN)+A2*10.0**(-PK1))
XCOF(4)=ALK

CALL BISECT(XCOF,H)
PH=-ALOG10(H)
RETURN
END
SUBROUTINE BISECT(XCOF,H)

DIMENSION XCOF(4)

F(XCOF,H) = XCOF(1) + H*(XCOF(2) + H*(XCOF(3) + H*XCOF(4)))

HL = 1.0E-5
HR = 1.0E-9

IF(F(XCOF,HL)*F(XCOF,HR)) 10,20,30
H = SQRT(HL*HR)
IF(F(XCOF,HL)*F(XCOF,H) LT 0.0) GO TO 2
HL = H
GO TO 4
HR = H

2 IF(ABS((HL-HR)/HL) GT 0.01) GO TO 10
H = HL
RETURN

4 IF(ABS(F(XCOF,HL)) EQ 0.0) H = HL
RETURN

10 H = HR
IF(ABS(F(XCOF,HL)) LT ABS(F(XCOF,HR))) H = HL
RETURN

END
LISTING OF THE REPORT GENERATOR

SUBROUTINE REPTUL

COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,ILL,NCALC,NOCOMP,NSR
COMMON MODE,NPLNT,LOOCC
COMMON SN(25,30),EEN(600),NPOINT(25,2)

WRITTEN BY P. TAN
FOR WATP SIMULATION

REPORTS ON THE VARIOUS STREAMS IN THE PLANT

EN VECTOR
***********
EN VECTOR LENGTH = 35

1. - 3. STD FORMAT
4. - 15. = 0.0
EN(16) = RAW FEED TO PLANT (STREAM NUMBER)
EN(17) = INPUT TO PRIMARY CLARIFIER
EN(18) = EFFLUENT OF PRIMARY CLARIFIER
EN(19) = UNDERFLOW OF PRIMARY CLARIFIER
EN(20) = INPUT TO AERATION TANKS
EN(21) = OUTPUT OF AERATION TANKS
EN(22) = INPUT TO SECONDARY CLARIFIER
EN(23) = EFFLUENT OF SECONDARY CLARIFIER
EN(24) = UNDERFLOW OF SECONDARY CLARIFIER
EN(25) = RETURN ACTIVATED SLUDGE
EN(26) = WASTE ACTIVATED SLUDGE
EN(27) = INPUT TO DIGESTERS
EN(28) = DIGESTER SUPERNATANT
EN(29) = DIGESTED SLUDGE
EN(30) = INPUT TO THICKENER
EN(31) = THICKENED SLUDGE
EN(32) = INPUT TO TRICKLING FILTER
EN(33) = OUTPUT OF TRICKLING FILTER
EN(34) = PLANT BYPASS
EN(35) =

SET STREAM NUMBER TO 0.0 IF DO NOT WISH TO REPORT ON STREAM

IF (MODE.EQ. 0) RETURN

WRITE(6,79)
WRITE(6,80)
WRITE(6,82) LOOCC
WRITE(6,89)
WRITE(6,85)

DO 50 I=1,20
S=EN(I+15)
IF (S.LE.0.0) GO TO 50
CALL STREAM(S)
IT=IS
CALL CONVERT(1,1,IT,3,1)
SI(I,1)=S
IW=29+I

WRITE(6,IW) SI(1,1),SI(1,3),(SI(1,J),J=7,12)

50 CONTINUE
WRITE(6,79)
MODE=0

FORMAT(1HO,2OH RAW FEED, F5.0,7F10.2)
FORMAT(1HO,2OH INPUT TO PRI. CLAR, F5.0,7F10.2)
FORMAT(1HO,2OH EFFL. OF PRI. CLAR, F5.0,7F10.2)
FORMAT(1HO,2OH UNDERFLOW PRI. CLAR, F5.0,7F10.2)
FORMAT(1HO,2OH OUTPUT TO AER TANKS, F5.0,7F10.2)
FORMAT(1HO,2OH WASTE ACTIVATED SLUDGE, F5.0,7F10.2)
FORMAT(1HO,2OH RETURN ACTIVATED SLUDGE, F5.0,7F10.2)
FORMAT(1HO,2OH DIGESTED SLUDGE, F5.0,7F10.2)
FORMAT(1HO,2OH DIGESTER SUPERNATANT, F5.0,7F10.2)
FORMAT(1HO,2OH DIGESTER SUPERNATANT, F5.0,7F10.2)
FORMAT(1HO,2OH THICKENER, F5.0,7F10.2)
FORMAT(1HO,2OH THICKENED SLUDGE, F5.0,7F10.2)
FORMAT(1HO,2OH TRICKLING FILTER, F5.0,7F10.2)
FORMAT(1HO,2OH PLANT BYPASS, F5.0,7F10.2)
<table>
<thead>
<tr>
<th>FORMAT</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1H,2H)</td>
<td>INPUT TO SEC. CLAR.</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>HEFF. OF SEC. CLAR.</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>UNDERFLOW SEC. CLAR.</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>RETURN ACT. SLUDGE</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>WASTE ACT. SLUDGE</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>INPUT TO DIGESTER</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>DIGESTER SUPERNATE</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>DIGESTED SLUDGE</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>INPUT TO THICKENER</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>THICKENED SLUDGE</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>TRICK. FILT. INPUT</td>
<td>F5.0</td>
</tr>
<tr>
<td>(1H,2H)</td>
<td>PLANT BYPASS</td>
<td>F5.0</td>
</tr>
</tbody>
</table>

SUMMARY REPORT ON PLANT OPERATIONS - CASE

<table>
<thead>
<tr>
<th>STREAM</th>
<th>NUMBER</th>
<th>FLOW</th>
<th>DO</th>
<th>DOC</th>
<th>BOD</th>
<th>SS</th>
<th>VSS</th>
</tr>
</thead>
</table>

RETURN END
LISTING OF THE COST ESTIMATION PROGRAM

SUBROUTINE COSTl

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, SJ, LOOP, NIN, NOUT, MS, IS, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EN(1600), NPOINT(25,2)
DIMENSION, TITLE(10), ELECT(3)

CALCULATES THE FIXED CAPITAL INVESTMENT, THE OPERATING AND
MAINTENANCE COSTS OF A WASTEWATER TREATMENT PLANT.
PLACES A SURTAX ON EFFLUENT IF THE EFFLUENT QUALITY IS POOR.
COSTS TAKEN FROM ECKENFELDER AND BARNHARDT, AND FROM SMITH.

EN VECTOR
***********
1. MODULE NUMBER
2. MODULE TYPE
3. MODULE LENGTH
4.-15. = TWELVE ZEROES

UNIT PROCESS

16. PRETREATMENT
17. NO. OF PRETREATMENT UNITS
18. PRIMARY SEDIMENTATION
19. NO. OF PRI. SETTLING TANKS
20. ACTIVATED SLUDGE TANKS
21. NO. OF AERATION TANKS
22. AIR BLOWERS
23. NO. OF AIR BLOWERS
24. FINAL SEDIMENTATION
25. NO. OF FINAL TANKS
26. SLUDGE RETURN PUMPS
27. NO. OF SLUDGE RETURN PUMPS
28. ANAEROBIC DIGESTION
29. NO. OF ANAEROBIC DIGESTERS
30. CHLORINATION
31. NO. OF CHLORINATION UNITS
32. VACUUM FILTRATION
33. NO. OF VACUUM FILTERS
34. SLUDGE INCINERATION
35. NO. OF SLUDGE INCINERATORS
36. SLUDGE DRYING BEDS
37. NO. OF DRYING BEDS
38. SLUDGE THICKENING
39. NO. OF THICKENERS
40. SLUDGE HAULAGE
41. 0.0
42. TRICKLING FILTERS
43. NO. OF TRICKLING FILTERS
44. AERATED LAGOONS
45. NO. OF LAGOONS
46. TYPE OF PLANT
   (FOR UTILITIES COST)

47. NOT PRESENTLY USED
48. NOT PRESENTLY USED
50. DESIGNED FLOW MIGPD
51. LABOUR COST $/MAN-HOUR
52. ENR INDEX FOR YEAR
53. LABORATORY COST $/YR
54. STREAM NUMBER OF EFFLUENT (FOR SURCHARGE PURPOSES)
55. ACTUAL PLANT FLOW MIGPD

A=11H*
B=1H-
ELECT(1)=101000.0
ELECT(2)=1012600.0
ELECT(3)=10378000.0

*******************************************************************************
C CAPITAL COST ESTIMATE

WRITE(6,400)
WRITE(6,401) (A,I=1,22)
READ(5,200) TITLE
WRITE(6,550) TITLE

C CALCULATE THE CAPITAL COSTS OF THE VARIOUS UNIT PROCESSES
Q=EN(50)
ENRFAC=EN(52)/1120.*UPC
UPC=0.0
DO 600 I=1,15
IF(EN(14+2*I).LE.0.0) GO TO 600
GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15),I

1 COST=21800.0*(Q/EN(17))**0.63*ENRFAC*EN(17)
WRITE(6,451) COST
GO TO 610

2 COST=(1730.0*EN(18)+6700.0*EN(18)**0.1)*ENRFAC*EN(19)
WRITE(6,452) COST
GO TO 610

3 COST=(2700.0*EN(20)+6700.0)*ENRFAC*EN(21)
WRITE(6,453) COST
GO TO 610

4 COST=(1360.0+7600.0*EN(22))*ENRFAC*EN(23)
WRITE(6,454) COST
GO TO 610

5 COST=(1620.0*EN(24)+6900.0*EN(24)**0.13)*ENRFAC*EN(25)
WRITE(6,455) COST
GO TO 610

6 COST=(4700.0+1740.0*Q/EN(27))*ENRFAC*EN(27)
WRITE(6,456) COST
GO TO 610

7 COST=(1340.0*EN(28)+13800.0*EN(28)**0.13)*ENRFAC*EN(29)
WRITE(6,457) COST
GO TO 610

8 COST=(1260.0*Q/EN(30)**0.47)*ENRFAC*EN(31)
WRITE(6,458) COST
GO TO 610

9 COST=(1650.0+480.0*EN(32))*ENRFAC*EN(33)
WRITE(6,459) COST
GO TO 610

10 COST=(7.1*EN(34)/EN(35)+0.3*(EN(34)/EN(35))**1.61)*ENRFAC*EN(35)
WRITE(6,460) COST
GO TO 610

11 COST=2.23*EN(36)*EN(37)
WRITE(6,461) COST
GO TO 610

12 COST=EN(38)*((24200.0+11700.0)/EXP(EN(38)/13.3))*ENRFAC*EN(39)
WRITE(6,462) COST
GO TO 610

13 COST=6600.0*EN(42)**0.6*ENRFAC*EN(43)
WRITE(6,464) COST
GO TO 610

15 COST=2.5*EN(44)*EN(45)*ENRFAC
WRITE(6,465) COST

610 UPC=UPC+COST
600 CONTINUE

C WRITE(6,402) (B,I=1,14)
WRITE(6,403) UPC

C CALCULATE THE CAPITAL COST OF THE CONTROL HOUSE
COST=58600.0*Q**0.7*ENRFAC
WRITE(6,466) COST

PPC=UPC+COST

C CALCULATING THE CAPITAL COST OF THE PLANT SITE + IMPROVEMENTS
COST=4600.0*Q**0.88*ENRFAC
WRITE(6,467) COST
PPC=PPC+COST

C WRITE(6,402) (B,I=1,14)
C CALCULATE THE ENGINEERING COST FACTOR
CENG=U.08*(1.0E6/PPC)**0.146
C CALCULATE THE ENGINEERING COSTS
COST=CENG*PPC
WRITE(6,405) COST
DPC=PPC+COST
C WRITE(6,402) (B=1,14)
WRITE(6,406) DPC
C CALCULATING THE CONTRACTOR'S FEE
COST=DPC*0.1
WRITE(6,407) COST
FCI=DPC+COST
C CALCULATING THE CONTINGENCY COSTS
COST=DPC*0.15
WRITE(6,408) COST
FCI=FCI+COST
C WRITE(6,402) (B=1,14)
WRITE(6,409) FCI
WRITE(6,410) FCI
WRITE(6,411)
C******************************************************************
COPERATING AND MAINTENANCE COST ESTIMATE
CWRITE(6,412)
WRITE(6,413)
READ(5,2U6) TITLE
WRITE(6,550) TITLE
WRITE(6,414)
C∑HRS=U.0
UPOM=U.0
Q=EN(55)
CDO 620 I=1,15
IF(EN(14+2*I),LE,0.0) GO TO 620
GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,21
HOUR=133.0*Q+510.0*Q**0.37
COST=HOUR*EN(51)
WRITE(6,501) HOUR,COST
GO TO 630
22 HOUR=(222.0*Q*EN(18)+555.0*Q*EN(18)**0.5)*EN(19)
COST=HOUR*EN(51)
WRITE(6,502) HOUR,COST
GO TO 630
23 HOUR=(720.0*Q+590.0*Q/EN(20)**0.67)
COST=HOUR*EN(51)
WRITE(6,503) HOUR,COST
GO TO 630
24 GO TO 620
25 GO TO 620
26 GO TO 620
27 HOUR=(13.0*EN(28)+144.0*EN(28)**0.5)
COST=HOUR*EN(51)
WRITE(6,507) HOUR,COST
GO TO 630
28 HOUR=(30.0*Q+170.0*Q**C.37)
COST=HOUR*EN(51)
WRITE(6,508) HOUR,COST
GO TO 630
29 HOUR=(0.27*Q+154.0*Q**0.37)
COST=HOUR*EN(51)
WRITE(6,509) HOUR,COST
GO TO 630
30 HOUR=(400.0*Q+1600.0*Q**0.37)
COST=HOUR*EN(51)
WRITE(6,510) HOUR,COST
GO TO 630
31 HOUR=(0.014*EN(36)+20.0*EN(36)**0.37)
COST=HOUR*EN(51)
WRITE(6,511) HOUR,COST
GO TO 630
GO TO 620
GO TO 620
HOUR=(10.0*EN(42)+12.0*EN(42)**0.5)
COST=HOUR*EN(51)
WRITE(6,514) HOUR,COST
GO TO 630
HOUR=(50.0*EN(44)+100.0*EN(44)**0.5)
COST=HOUR*EN(51)
WRITE(6,515) HOUR,COST
C
CONTINUE
SUMHRS=SUMHRS+HOUR
UPOM=UPOM+COST
CONTINUE
C
WRITE(6,415) (B,I=1,128)
WRITE(6,413) SUMHRS,UPOM
C
CALCULATE THE SUPERVISION COST
COST=U.1*UPOM
WRITE(6,414) COST
DOM=UPOM+COST
CALCULATE THE UTILITIES COST
KI=EN(46)+6.0
COST=ELECT(KI)**0.65*EN(47)
WRITE(6,416) COST
DOM=DOM+COST
C
CALCULATE SLUDGE HAULAGE COSTS
COST=800.0*EN(44)**0.5
WRITE(6,513) COST
DOM=DOM+COST
C
CALCULATE THE CHEMICALS COST
COST=0.06*UPOM
WRITE(6,417) COST
DOM=DOM+COST
C
CALCULATE PLANT SUPPLIES
COST=0.05*UPOM
WRITE(6,418) COST
DOM=DOM+COST
WRITE(6,419) (B,I=1,14)
WRITE(6,420) DOM
C
CALCULATING LABORATORY COSTS
COST=EN(53)
WRITE(6,421) COST
OMNET=DOM+COST
C
CALCULATING SURCHARGE ON EFFLUENT (IF EFFLUENT QUALITY IS POOR)
IF(EN(54).LE.0.0) GO TO 50
S= EN(54)
CALL STREAM(S)
LBS=SN(IS,3)*3.5*E-4
IF(SN(IS,10).LT.LBS) GO TO 51
SURBOD=(SN(IS,11)-LBS)*0.05
GO TO 52
SURBOD=0.0
51 IF(SN(IS,11).LT.LBS) GO TO 53
SURSS=(SN(IS,11)-LBS)*0.05
GO TO 54
SURSS=0.0
53 TOTSUR=SURBOD+SURSS
WRITE(6,422) TOTSUR
OMNE=OMNET+TOTSUR
C
C
WRITE(6,419) (B,I=1,14)
WRITE(6,423) OMNET
C
CALCULATING THE COST OF THE FIXED CAPITAL INVESTMENT
BASED ON AN INTEREST RATE OF 8.5 PERCENT AND A PLANT LIFE OF 25 YEARS. NOTE THAT THE ANNUITY PAYMENTS REPRESENT DEBT RETIREMENT
AND INTEREST CHARGED IN THE CASE OF BORROWED CAPITAL OR
DEPRECIATION AND OPPORTUNITY COST IN THE CASE OF OWNED CAPITAL

CAPITAL RECOVERY FACTOR = S*(1+S)**N/((1+S)**N-1)

WHERE S IS THE INTEREST RATE AND N THE LIFE OF THE PLANT

CF=(1+U+0.08)*25.0

COST = FC*I/(0.8*CF/(CF-1.0))

WRITE(6,424) COST

WRITE (6,419) (B*I=1.14)

TAC=OMNET+COST

WRITE (6,428) TAC

WRITE (6,419) (B*I=1.14)

WRITE (6,430)

200 FORMAT (10A8)

400 FORMAT (1H1,3GX,22HFIXED CAPITAL ESTIMATE )

401 FORMAT (1H0,3GX,22A1)

402 FORMAT (1H0,5UX,14A1)

403 FORMAT (1H0,1UX,4HTOTAL UNIT PROCESSES (INSTALLED) $ ,F14.2)

404 FORMAT (1H0,1UX,4HPHYSICAL PLANT COST $ ,F14.2)

405 FORMAT (1H0,1UX,4HTOTAL PLANT COST $ ,F14.2)

406 FORMAT (1H0,1UX,4HCONTRACTOR'S FEE (0.1 DPC) $ ,F14.2)

407 FORMAT (1H0,1UX,4HCONTINGENCY (0.15 DPC) $ ,F14.2)

408 FORMAT (1H0,1UX,4HDIRECT PLANT CAPITAL COST $ ,F14.2)

409 FORMAT (1H0,1UX,4HANNUAL OPERATING COST $ ,F14.2)

410 FORMAT (1H0,5UX,22HANNUAL OPERATING COST )

411 FORMAT (1H0,15X,15HUNIT PROCESSES +15X,9HMAN-HOURS,10X,9HCOST $/YR)

413 FORMAT (1H0,UX,3HUNIT PROCESSES O AND M $ ,F14.2,4X,1HS,

1F14.2)

414 FORMAT (1H0,UX,3HSUPERVISION (0.1 L) 19X,F14.2)

415 FORMAT (1H0,UX,14A1,5X,14A1)

416 FORMAT (1H0,UX,3HUUTILITIES $ ,F14.2)

417 FORMAT (1H0,UX,3HCHEMICALS (0.06 L) $ ,F14.2)

418 FORMAT (1H0,UX,3HPLANT SUPPLIES (0.05 L) $ ,F14.2)

419 FORMAT (1H0,UX,59X,14A1)

420 FORMAT (1H0,UX,3HDIRECT O AND M COST $ ,F14.2,4X,1HS,

1F14.2)

421 FORMAT (1H0,UX,3HLABORATORY $ ,F14.2)

422 FORMAT (1H0,UX,3HSURCHARGE ON EFFLUENT $ ,F14.2)

423 FORMAT (1H0,UX,3HNET O AND M COST $ ,F14.2)

424 FORMAT (1H0,UX,3HHANNUAL PAYMENTS $ ,F14.2)

425 FORMAT (1H0,UX,3HANNUAL COST $ ,F14.2)

430 FORMAT (1H1,UX,3HNET 0 AND M COST $ ,F14.2)

452 FORMAT (1H1,UX,4HPRIMARY SETTLING TANKS $ ,F14.2)

453 FORMAT (1H1,UX,4HACTIVATED SLUDGE TANKS $ ,F14.2)

454 FORMAT (1H1,UX,4HHAIR BLOWERS $ ,F14.2)

455 FORMAT (1H1,UX,4HSECON DARY SETTLING TANKS $ ,F14.2)

456 FORMAT (1H1,UX,4HSLUDGE RETURN PUMPS $ ,F14.2)

457 FORMAT (1H1,UX,4HANAEROBIC DIGESTERS $ ,F14.2)

458 FORMAT (1H1,UX,4HCLORINATOR $ ,F14.2)

459 FORMAT (1H1,UX,4HVACUUM FILTERS $ ,F14.2)

460 FORMAT (1H1,UX,4HINCINERATORS $ ,F14.2)

461 FORMAT (1H1,UX,4HSLUDGE DRYING BEDS $ ,F14.2)

462 FORMAT (1H1,UX,4HSLUDGE THICKENERS $ ,F14.2)

463 FORMAT (1H1,UX,4HSLUDGE DRYING BEDS $ ,F14.2)

464 FORMAT (1H1,UX,4HLTRICKLING FILTERS $ ,F14.2)

465 FORMAT (1H1,UX,4HCHLORINATION $ ,F14.2)

466 FORMAT (1H1,UX,4HCONTROL HOUSE $ ,F14.2)

467 FORMAT (1H1,UX,3HPLANT SITE $ ,F14.2)

501 FORMAT (1H1,UX,3HSTREET ADMISSION $ ,F14.2,5X,F14.2)

502 FORMAT (1H1,UX,3H PRIMARY SEDIMENTATION $ ,F14.2,5X,F14.2)

503 FORMAT (1H1,UX,3H ACTIVATED SLUDGE $ ,F14.2,5X,F14.2)

504 FORMAT (1H1,UX,3HANAEROBIC DIGESTION $ ,F14.2,5X,F14.2)

505 FORMAT (1H1,UX,3HCHLORINATION $ ,F14.2,5X,F14.2)

506 FORMAT (1H1,UX,3HVACUUM FILTERATION $ ,F14.2,5X,F14.2)

510 FORMAT (1H1,UX,3HINCINERATION $ ,F14.2,5X,F14.2)

511 FORMAT (1H1,UX,3HSLUDGE DRYING BEDS $ ,F14.2,5X,F14.2)

512 FORMAT (1H1,UX,3HSLUDGE HAULING $ ,F14.2,5X,F14.2)

513 FORMAT (1H1,UX,3HTRICKLING FILTERS $ ,F14.2,5X,F14.2)

514 FORMAT (1H1,UX,3HCHLORINATION $ ,F14.2,5X,F14.2)

515 FORMAT (1H1,UX,3HACTIVATED LAGOONS $ ,F14.2,5X,F14.2)

516 FORMAT (1H1,UX,10A8,///)

RETURN.

END
LISTING OF THE INTER-ACTIVE VERSION OF GEMCS

PROGRAM WWTPI (INPUT, OUTPUT, WWRUN, TAPE2=INPUT, TAPE6=OUTPUT, 1TAPE5=WWRUN)

COMMON LLST*(50), NS(100), EN(100), S1(4, 30), SO(4, 30), KPRNT(10)
COMMON IS, N, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, I11, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOP
COMMON SNT(25, 30), EEN(60, 0), NPOINT(25, 2)
DIMENSION TITLE(10)
DIMENSION NAME(20)

GEMCS/INTERCOM

***** PRINTING CONTROL CHARACTERS *****

KPRNT(1) = 1 CAUSES PRINTING OF LLST, NS
KPRNT(1) = 0 SUPPRESSES ABOVE PRINTING
KPRNT(2) = 1 CAUSES PRINTING OF INITIAL STREAMS
KPRNT(2) = U SUPPRESSES ABOVE PRINTING
KPRNT(3) = 1 CAUSES PRINTING OF MODULES SETS
KPRNT(3) = U SUPPRESSES ABOVE PRINTING
KPRNT(4) = 1 CAUSES PRINTING OF NPOINT
KPRNT(4) = U SUPPRESSES ABOVE PRINTING
KPRNT(5) = 1 CAUSES PRINTING OF SN TABLE ON ENTERING LOOP
KPRNT(5) = U SUPPRESSES ABOVE PRINTING
KPRNT(6) = 1 PRINTING OF FINAL OUTPUT STREAMS
KPRNT(6) = U SUPPRESSES ABOVE PRINTING

REWORKS

NAME(1) = 8H MIXER
NAME(2) = 8H CONT1
NAME(3) = 8H SETST1
NAME(4) = 8H SETSP1
NAME(5) = 8H SEPA01
NAME(6) = 8H PRISET1
NAME(7) = 8H ACISL1
NAME(8) = 8H DPTR1
NAME(9) = 8H SECLR1
NAME(10) = 8H TRICK1
NAME(11) = 8H GRIT1
NAME(12) = 8H ANDIG1
NAME(13) = 8H CHLOR1
NAME(14) = 8H COST1
NAME(15) = 8H SCREEN1
NAME(16) = 8H REPT01
NAME(17) = 8H CONTU2
NAME(18) = 8H CONVO1
NAME(19) = 8H CASET
NAME(20) = 8H THICK1

WRITE(6, 234)
FORMAT(1HU, 5UH) TO ANSWER QUESTIONS BELOW TYPE 1.0/YES OR 0.0/NO

III=25
CALL DLOAD1

IK IS AN INDICATOR AS TO WHETHER A STRAIGHT THROUGH CALCULATION
IS USED (IK=1) OR WHETHER A RECYCLE IS PRESENT (IK=0)

IF(LOOP.EQ.999) IK=1
WRITE(6,240)
FORMAT(1X*30UH
WHERE I WANT TO SET UP A NEW PLANT -
READ(2,221) FLAG
IF(FLAG.LE.0.) GO TO 92
CONTINUE
CALL FLWCHT
92 CONTINUE
CONTINUE
96 WRITE(6,238)
FORMAT(1X*45UH
WHERE I WANT TO SET A RANDOM FLOW AND CASE STUDY -
READ(2,221) FLAG
IF(FLAG.LE.0.) GO TO 93
CONTINUE
C Sets a case run around input feed
C Case must have equipment number 25 and should not be included in the calculation order.
CALL DISKIO(1,25)
CALL CASET
GO TO 1000
C CONTINUE
C CALL STREAM(1.0)
IN=IS
CALL STREAM(2.0)
IF(IN.LE.100) GO TO 94
CALL STREAM(0.0)
SN(IN,1)=2.0
94 CONTINUE
DO 600 J=2,JJ
SN(IN,J)=SN(IN,J-1)
600 CONTINUE
DO 1000 LOOPC=1
WRITE (6,196) LOOPC
1000 CONTINUE
C Calculating equipment in calculation order list
NC=1
MODE=0
KTEST=0
LOOP=1
IF(IKE.EQ.0) GO TO 98
MODE=1
KTEST=1
LOOP=999
CONTINUE
READ EN VECTOR
IF (KPRNT(5)) 108,108,104
104 CONTINUE
WRITE (6,182) LOOP
DO 106 IKE=1,I,III
IF (SN(IKE,1)*LE.0.0) GO TO 106
WRITE (6,194) (SN(IKE,J),J=1,JJ)
106 CONTINUE
NE=LLST(IN)
MM=NE
CALL DISKIO (1,MM)
EN=EN(3)+.001
NIN=EN(6)+.001
NOUT=EN(11)+.001
NTYPE=ABS(EN(2))+.001
KSW=0
IF EN(2)*LE.0.0) KSW=1
ISP=0 Suppresses all printing of input and output streams
ISP=0
FINISH INPUT STREAMS
IF(NIN.EQ.0) GO TO 128
DO 122 I=1,NIN
S=EN(I+6)
CALL STREAM (S)
IF (IS=III) 114,114,110
110 CONTINUE
SI(I,1)=S
DO 112 J=2,JSI(I,J)=0.
112 CONTINUE
GO TO 122
114 DO 116 J=1,JSI(I,J)=SN(IS,J)
116 CONTINUE
IF (INT(S+00)) 122,122,118
118 CONTINUE
M=S+.001
IF (NS(M)-6) 122,120,120
120 CONTINUE
SN(IS,1)=0.
122 CONTINUE
IF (ISP) 128,128,124
WRITE (6,184) NE ,NAME(NTYPE)
DO 126 IKE=1,NIN
WRITE(6,194) (SI(IKE,J),J=1,JJ)
126 CONTINUE
C 128 CONTINUE
C
CALL MODULE (NTYPE)
C
STORING OUTPUT STREAMS AND PRINTING
C
IF(NOUT) 166,166,136
136 CONTINUE
DO 150 I=1,NOUT
IF(SO(I,3).LE.0.0) GO TO 150
S=EN(I+11)
SO(I,1)=S
M=S+.001
IF(NS(M)-6) 140,150,140
140 CALL STREAM(S)
IF (IS=III) 146,146,142
142 CALL STREAM (0.)
IF (IS=III) 146,146,144
144 WRITE (6,194)
GO TO 150
146 DO 148 J=1,JSN(IS,J)=SO(I,J)
148 CONTINUE
150 CONTINUE
C
IF (ISP) 158,158,154
WRITE (6,186) NE , NAME(NTYPE)
DO 156 IKE=1,NOUT
WRITE(6,194) (SO(IKE,J),J=1,JJ)
156 CONTINUE
C 158 IF (LOOP-999) 166,160,160
160 IF (KSN.NE.0) GO TO 166
IF(XPRINT(6).LT.1) GO TO 166
WRITE(6,188) NE , NAME(NTYPE)
DO 164 IKE=1,NOUT
WRITE(6,194)
WRITE(6,195) (SO(IKE,J),J=1,JJ)
164 CONTINUE
C
166 NC=NC+1
IF (NC-NCALC) 192,102,168
CONTINUE
IF (LOOP=999) 170,172,172
CONTINUE
NC=0
GO TO 166
IF (KTEST) 174,174,176
NC=0
KTEST=1
MODE=1
GO TO 166
CONTINUE
CALL ICLOAD
WRITE (*,220) 220 FORMAT (1X,35H WANT TO MAKE ANY PLANT CHANGES -
READ (2,221) FLAG
IF (FLAG.LE.0.0) GO TO 230
CALL ENSET
LOOPC=LOOPC+1
WRITE (*,196) LOOPC
GO TO 100
230 CONTINUE
WRITE (*,238)
FORMAT (1X,45H WANT TO GENERATE A NEW RANDOM CASE STUDY -
READ (2,221) FLAG
IF (FLAG.LE.0.0) GO TO 95
GO TO 236
95 CONTINUE
WRITE (*,240)
FORMAT (1H,32H $$$ SN TABLE ON ENTERING LOOP , 15, 7H $$$
182 FORMAT (1H,32H $$ INPUT STREAMS FOR MODULE , 15,4H - ,
1A8,7H $$
184 FORMAT (1H,32H $$ OUTPUT STREAMS FOR MODULE , 15,4H - , 8A ,
2A7H $$
186 FORMAT (1H,32H $$ FINAL OUTPUT STREAMS FOR MODULE , 15,4H - ,
3A8,7H $$
188 FORMAT (1H,25H ERROR IN SN ****
190 FORMAT (1H,38H END OF EXECUTION **********
192 FORMAT (1H,10F12.3)
194 FORMAT (1H,2UH********************************************,10H
RUN, 14,26H
196 FORMAT (10A8)
198 FORMAT (10A8)
200 FORMAT (1H,10A8)
221 FORMAT (F12.3)
C
END
COMMON LLST(50), SN(100), EN(100), SI(4*30), SQ(4*30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NCSE, NSR
COMMON LLST, NLPLNT, LOOPC
COMMON SN(25,30), EN(600), NPPOINT(25,2)

SETS THE CALCULATION ORDER OF A GIVEN PLANT AND
SETS THE VARIOUS EQUIPMENT PARAMETERS

LP1=0
LP2=0
LLST(1)=2
LLST(2)=3
LLST(3)=4
NCALC=3

WRITE(6,400)
FORMAT(1H40,22HANY PRIMARY TANKS = )
READ(2,200) F

NCALC=NCALC+1
WRITE(6,500)
FORMAT(1X,20HPRIMARY CLARIFIER)
WRITE(6,510)
FORMAT(1X,30HNUMBER OF TANKS IN PARALLEL = )
READ(2,200) F
EEN(MQ+4)=F
WRITE(6,520)
FORMAT(1X,26HLENGTH OF TANK (IN FT) = )
READ(2,200) F
EEN(MQ+16)=F
WRITE(6,530)
FORMAT(1X,25HWIDTH OF TANK (IN FT) = )
READ(2,200) F
EEN(MQ+17)=F
WRITE(6,540)
FORMAT(1X,25HDEPTH OF TANK (IN FT) = )
READ(2,200) F
EEN(MQ+18)=F
WRITE(6,550)
FORMAT(1X,26HNUMBER OF SLUDGE PUMPS = )
READ(2,200) F
EEN(MQ+23)=F
WRITE(6,560)
FORMAT(1X,35HCAPACITY OF SLUDGE PUMPS (GPH) = )
READ(2,200) F
EEN(MQ+24)=F
WRITE(6,570)
FORMAT(1X,4HFRACNTION OF CAPACITY PUMPS ARE USED = )
READ(2,200) F
EEN(MQ+25)=F

NCALC=NCALC+1
LLST(NCALC)=6

WRITE(6,410)
FORMAT(1H40,22HANY ACTIVATED TANKS = )
READ(2,200) F

SETTING THE SPLITTER BEFORE THE ACTIVATED SLUDGE TANKS
MQ=NPPOINT(6,1)
ASKING FOR DETAILS ON THE ACTIVATED SLUDGE TANKS

NCALC = NCALC + 1
LLST (NCALC) = 7
MQ = NPPOINT (7 * 1)
WRITE (6, 580)

FORMAT (1X, 25H ACTIVATED SLUDGE TANKS )
WRITE (6, 510)
READ (2, 20U) F
EEN (MQ+14) = F
WRITE (6, 520)
READ (2, 20U) F
EEN (MQ+16) = F
WRITE (6, 530)
READ (2, 20U) F
EEN (MQ+17) = F
WRITE (6, 540)
READ (2, 20U) F
EEN (MQ+18) = F
WRITE (6, 545)

FORMAT (5X, 37H NUMBER OF STIRRED TANKS IN SERIES = )
READ (2, 20U) F
EEN (MQ+34) = F
WRITE (6, 555)

FORMAT (5X, 30H ARE YOU USING STEP AERATION )
READ (2, 20U) F
EEN (MQ+19) = 1.0
IF (F .LE. 0.0) THEN
  EEN (MQ+19) = EEN (MQ+34)
END IF
IF (F .LE. 0.0) GO TO 35
SUM = SUM + F
DO 600 KM = 1, 10
  WRITE (6, 565) KM
  WRITE (6, 565) KM
FORMAT (1X, 25H FRAGMENT OF FEED TO TANK 13.4H = )
READ (2, 20U) F
EEN (MQ+34 + KM) = F
SUM = SUM + F
IF (SUM .GE. 1.0) GO TO 35
600 CONTINUE
35 WRITE (6, 575)

FORMAT (5X, 25H NUMBER OF AIR BLOWERS = )
READ (2, 20U) F
EEN (MQ+45) = F
WRITE (6, 585)

FORMAT (5X, 32H CAPACITY OF BLOWERS (SCF/HR) = )
READ (2, 20U) F
EEN (MQ+46) = F

NCALC = NCALC + 1
LLST (NCALC) = 8

ASKING FOR DETAILS OF THE SECONDARY CLARIFIERS
MQ = NPPOINT (8 * 1)
WRITE (6, 590)

FORMAT (1HU, 2USH SECONDARY CLARIFIER )
WRITE (6, 510)
READ (2, 20U) F
EEN (MQ+4) = F
WRITE (6, 505)

FORMAT (5X, 25H SURFACE AREA (SQ FT) = )
READ (2, 20U) F
EEN (MQ+18) = F
WRITE (6, 550)
READ (2, 20U) F
EEN (MQ+20) = F
WRITE (6, 560)
READ (2, 20U) F
EEN (MQ+21) = F
WRITE (6, 570)
READ (2, 20U) F
EEN (MQ+22) = F
c
NCALC=NCALC+1
LLST(1NCALC)=9
NCALC=NCALC+1
LLST(1NCALC)=10
c
ASKING FOR DETAILS OF THE WASTE SLUDGE POLICY
MQ=NPOINT(lU, 1)
WRITE(6,535)
535 FORMAT(lX,3U1FRACTION OF SLUDGE WASTED = )
READ(2,200) F
EEN(MQ+17)=F
EEN(MQ+16)=1.0-F
NCALC=NCALC+1
LLST(1NCALC)=11
c
WRITE(6,420)
420 FORMAT(lX,2U1WASTE ACT SL TO /,5X,2CHPRI CLAR -TYPE 1.0
1-,5X,31HDIRECTLY TO DIGESTER -TYPE 2.0 ,/5X,21HTHICKENER -TYPE
23.0 )
READ(2,200) F
JF=F+0.01
MQ=NPOINT(l1, 1)
EEN(MQ+16)=0.0
EEN(MQ+17)=0.0
EEN(MQ+18)=0.0
EEN(MQ+15+JF)=1.0
IF(F.LT.3.0) GO TO 40
NCALC=NCALC+1
LLST(1NCALC)=12
NCALC=NCALC+1
LLST(1NCALC)=19
WRITE(6,430)
430 FORMAT(lX,2U1HIS THICKENED SLUDGE SENT TO DIGESTER - )
READ(2,200) F
MQ=NPOINT(19, 1)
EEN(MQ+17)=F
EEN(MQ+16)=1.0-F
c
40 NCALC=NCALC+1
LLST(1NCALC)=20
c
WRITE(6,440)
440 FORMAT(lH18HANY DIGESTERS - )
READ(2,200) F
IF(F.LT.1.0) GO TO 50
LP2=1
NCALC=NCALC+1
LLST(1NCALC)=13
c
ASKING FOR DETAILS OF THE DIGESTERS
WRITE(6,450)
450 FORMAT(lX,3U1ONE OR TWO STAGE DIGESTION - )
READ(2,200) F
MQ=NPOINT(12, 1)
EEN(MQ+16)=F-1.0-EEN(MQ+16)
IF(F.LT.2.0) GO TO 60
NCALC=NCALC+1
LLST(1NCALC)=14
MQ=NPOINT(14, 1)
WRITE(6,460)
460 FORMAT(lX,22HFIRST STAGE DIGESTER
WRITE(6,510)
510 READ(2,200) F
EEN(MQ+4)=F
WRITE(6,515)
515 FORMAT(5X,3VDIAMETER OF TANK (IN FT) = )
READ(2,200) F
EEN(MQ+16)=F
WRITE(6,540)
READ(2,200) F
EEN(MQ+17)=F
WRITE(6,525)
TEMPERATURE OF DIGESTION DEG C = 

\[
\text{READ}(2,200) F 
\]
\[
\text{EEN(MQ+19)}=F 
\]
\[
\text{C} 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=15 
\]
\[
\text{WRITE}(6,47U) 
\]
\[
\text{FORMAT}(1X,23HSECOND STAGE DIGESTER} 
\]
\[
\text{GO TO 65} 
\]
\[
\text{C} 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=15 
\]
\[
\text{WRITE}(6,48U) 
\]
\[
\text{FORMAT}(1X,23HANAEROBIC DIGESTER} 
\]
\[
\text{CONTINUE} 
\]
\[
\text{MQ=NPOINT(15,1)} 
\]
\[
\text{WRITE}(6,510) 
\]
\[
\text{READ}(2,200) F 
\]
\[
\text{EEN(MQ+4)}=F 
\]
\[
\text{WRITE}(6,515) 
\]
\[
\text{READ}(2,200) F 
\]
\[
\text{EEN(MQ+16)}=F 
\]
\[
\text{WRITE}(6,540) 
\]
\[
\text{READ}(2,200) F 
\]
\[
\text{EEN(MQ+17)}=F 
\]
\[
\text{WRITE}(6,525) 
\]
\[
\text{READ}(2,200) F 
\]
\[
\text{EEN(MQ+19)}=F 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=16 
\]
\[
\text{C} 
\]
\[
\text{IF(LP1.NE.1)} \text{GO TO 70} 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=22 
\]
\[
\text{MQ=NPOINT(22,1)} 
\]
\[
\text{EEN(MQ+4)}=(\text{FLOAT(LP1+LP2-1)})*100.0 +1.0 
\]
\[
\text{EEN(MQ+20)}=1.0 
\]
\[
\text{EEN(MQ+21)}=1.0 
\]
\[
\text{EEN(MQ+17)}=10.0 
\]
\[
\text{IF(LP2.NE.1)} \text{EEN(MQ+17)}=20.0 
\]
\[
\text{IF(LP2.NE.1)} \text{GO TO 80} 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=23 
\]
\[
\text{MQ=NPOINT(23,1)} 
\]
\[
\text{EEN(MQ+4)}=(\text{FLOAT(LP1+LP2-1)})*100.0 +1.0 
\]
\[
\text{EEN(MQ+20)}=\text{EEN(MQ+4)} 
\]
\[
\text{EEN(MQ+21)}=\text{EEN(MQ+4)} 
\]
\[
\text{EEN(MQ+17)}=5.0 
\]
\[
\text{IF(LP1.NE.1)} \text{EEN(MQ+17)}=20.0 
\]
\[
\text{C} 
\]
\[
\text{CONTINUE} 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=17 
\]
\[
\text{NCALC}=NCALC+1 
\]
\[
\text{LLST}(NCALC)=18 
\]
\[
\text{C} 
\]
\[
\text{ASKING FOR AVERAGE FEED CONDITIONS} 
\]
\[
\text{WRITE}(6,750) 
\]
\[
\text{FORMAT(1H0,3U) WANT TO SET UP FEED STREAM} 
\]
\[
\text{READ}(2,200) F 
\]
\[
\text{IF(F.LE.0.0)} \text{RETURN} 
\]
\[
\text{CALL_STREAM(1.0)} 
\]
\[
\text{WRITE}(6,700) 
\]
\[
\text{FORMAT(1H0,4U) AVERAGE FLOW TO YOUR PLANT (MIGD) = } 
\]
\[
\text{READ}(2,200) F 
\]
\[
\text{FLOW=F*1.0E6/24.0} 
\]
\[
\text{FRAC=FLOW/\text{SN(IS,3)} 
\]
\[
\text{DO 610 J=6,7J} 
\]
\[
\text{SN(IS+J)=SN(IS,J)*FRAC} 
\]
\[
\text{SN(IS+3)=FLOW} 
\]
\[
\text{WRITE}(16,760) 
\]
\[
\text{FORMAT(1X,5U) NOTE THAT BOD APPROX GREATER THAN TWICE DOC} 
\]
WRITE(6,710)
FORMAT(1X,31) AVERAGE BOD5 TO YOUR PLANT =  
READ(2,200) F
SN(IS,10)=FLOW*10.0*F*1.0E-6
WRITE(6,720)
FORMAT(1X,43) AVERAGE SUSPENDED SOLIDS TO YOUR PLANT = 
READ(2,200) F
SN(IS,11)=FLOW*10.0*F*1.0E-6
WRITE(6,730)
FORMAT(1X,36) AVERAGE DISSOLVED ORGANIC CARBON = 
READ(2,200) F
SN(IS,9)=FLOW*10.0*F*1.0E-6
SN(IS,22)=0.0
SN(IS,20)=0.2*SN(IS,9)
SN(IS,21)=SN(IS,9)-SN(IS,20)-SN(IS,22)
BODSOL=1.0*(SN(IS,20)+SN(IS,21))
BODP=SN(IS,11)-BODSOL
VSS=SN(IS,15)
SN(IS,16)=0.5*VSS
SN(IS,17)=0.4*VSS
SN(IS,18)=0.3*VSS
SN(IS,19)=0.3*VSS
SN(IS,12)=2.1*(VSS+SN(IS,15))
SN(IS,13)=0.6*(SN(IS,11)-SN(IS,12))
SN(IS,14)=0.4*(SN(IS,11)-SN(IS,12))
SN(IS,8)=SN(IS,9)+VSS+SN(IS,15)
IV=IS
CALL STREAM(2.0)
520 DO 620 J=2,JJ
520 SNC(IS,J)=SN(IS,J)**FRAC
CONTINUE
SN(IS,3)=SN(IS,3)**FRAC
C PURGE SN FILE
DO 630 I=1,II
IS=SN(I,1)+0.01
IF((IS.EQ.1) .OR. (IS.EQ.16) .OR. (IS.EQ.2)) GO TO 630
SN(I,1)=0.0
CONTINUE
RETURN
END
SUBROUTINE CASET

COMMON LIST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, JJ, LOOP, NIN, NOUT, MSN, ISP, NC, III, NCALC, NCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)
COMMON /C/ IND

GENERATES A CASE STUDY AROUND THE AVERAGE RAW FLOW

EN VECTOR

***********
1. - 15. STANDARD FORMAT
6. = 1.0
7. STREAM NUMBER OF USUAL RAW WASTE FLOW (= 1.0)
8. = 1.0
9. STREAM NUMBER OF GENERATED INPUT STREAM (= 2.0)
16. EQUIPMENT NUMBER OF PRIMARY SETTLER (= 5.0)
17. EQUIPMENT NUMBER OF THE ACTIVATED SLUDGE TANKS (= 7.0)
18. EQUIPMENT NUMBER OF THE SECONDARY CLARIFIERS (= 8.0)
20. ANY NUMBER BETWEEN 1.0E6 TO 1.0E8 - USED AS THE STARTER

IN THE RANDOM NUMBER GENERATOR

IF(EN(20), GE, 1.0E6) GO TO 9

WRITE(6,470)

FORMAT(6,470)

TYPE ANY NUMBER BETWEEN 1 MILLION TO 100 MILLION
READ(2,200) F

200 FORMAT(F12.3)

MO = NPOINT(25,1)
EEN(MO+20) = F
EN(20) = F
IND = EN(20)
IND = IND+2+1
CONTINUE

WRITE(6,500)

FORMAT(6,500)

1X, 2CHREADY TO PLAY GAMES  */,, 20H  CLUES.. ...

S = EN(7)
CALL STREAM(S)
IN = IS
S = EN(12)
CALL STREAM(S)
IF(IS, LE, III) GO TO 22
CALL STREAM(U, 0)
CONTINUE

IO = IS
SN(IO + 1) = EN(12)

GENERATING A RAW WASTE FLOW

CONTINUE

CALL RANDOM(Z)
IF(Z, LT, 0.25) GO TO 10
SN(IO + 6) = SN(IN, 6) * Z**2.0

CONTINUE

CALL TOXIC COMPONENT FLOW

DO 600 J = 13, JJ
CONTINUE

CALL RANDOM(Z)
IF(Z, LT, 0.25) GO TO 20
SN(IO + J) = SN(IN, J) * Z**2.0

CONTINUE

SET TOXIC COMPONENT FLOW

CALL BALANCE(1, IO)
GENERATING EQUIPMENT FAILURES

CALL RANDOM(Z)
KO=Z*11.0+1.0
GO TO (1,1,2,2,3,3,4,4,4,4,5,5),KO
MM=EN(16)+U*0.01
DO 610 I=1,NCALC
610 IF(LLST(I),EQ,MM) GO TO 620
GO TO 24

CONTINUE
MQ=NPOINT(MM,1)
IF(KO,EQ,2) GO TO 11
EEN(MQ+4)=EEN(MQ+4)-1.0
WRITE(6,410)
410 FORMAT(1X,5S'ONE OF THE PRIMARY SLUDGE PUMPS IS NOT WORKING')
GO TO 5

MM=EN(17)+U*0.01
DO 650 I=1,NCALC
650 IF(LLST(I),EQ,MM) GO TO 660
GO TO 24

CONTINUE
MQ=NPOINT(MM,1)
IF(KO,EQ,4) GO TO 12
EEN(MQ+4)=EEN(MQ+4)-1.0
WRITE(6,430)
430 FORMAT(1X,4S'ONE OF THE AIR BLOWERS IS DOWN')
GO TO 5

MM=EN(18)+U*0.01
DO 670 I=1,NCALC
670 IF(LLST(I),EQ,MM) GO TO 680
GO TO 24

CONTINUE
MQ=NPOINT(MM,1)
IF(KO,EQ,6) GO TO 13
EEN(MQ+4)=EEN(MQ+4)-1.0
WRITE(6,450)
450 FORMAT(1X,45S'ONE OF THE SECONDARY CLARIFIERS IS DOWN')
GO TO 5

MM=EN(19)+U*0.01
DO 690 I=1,NCALC
690 IF(LLST(I),EQ,MM) GO TO 700
GO TO 24

CONTINUE
KO=KO-6
GO TO (14,15,16,17),KO
14 IF(EEN(MQ+4),LT,240) GO TO 24
EEN(MQ+4)=EEN(MQ+4)-1.0
WRITE(6,460)
460 FORMAT(1X,25S'DIGESTER IS DOWN')
GO TO 5

CONTINUE
GO TO 5

CALL RANDOM(Z)
EEN(MQ+24)=Z
GO TO 5

EEN(MQ+19)=25.0
CONTINUE
SUBROUTINE RANDOM(Z)

GENERATES RANDOM NUMBERS HAVING A UNIFORM DISTRIBUTION BETWEEN 0-1
USES THE MIXED MULTIPLICATIVE CONGRUENTIAL METHOD

COMMON /C/ IND
DATA IL/1/

IF(IL.EQ.0) GO TO 1
IL=0
M=2**30
FM=M
N=2**15+3
IX=IND

CONTINUE
IX=MOD(N*IX,M)
FX=IX
Z=FX/FM

RETURN
SUBROUTINE ICLOAD

COMMON LLST(50), NS(100), EN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON IS, NE, J, LOOP, NOUT, NSN, ISP, NC, III, NCALC, NOCOMP, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOIN(25,2)
DIMENSION COST(15)

C COST(1) = 0.0
C COST(2) = 8.0
C COST(3) = 20.0
C COST(4) = 2.0
C COST(5) = 0.0
C COST(6) = 20.0
C COST(7) = 8.0
C COST(8) = 8.0
C COST(9) = 8.0
C COST(10) = 10.0
C COST(11) = 8.0
C COST(12) = 15.0
C COST(13) = 20.0
C COST(14) = 20.0
C COST(15) = 20.0
TCOST = 0.0

ALLOWS PLAYER TO MAKE DECISIONS AS TO PLANT OPERATIONS AND TO MAKE ANALYSES OF ANY STREAM COMPONENT.
COSTS ARE CALCULATED FOR ANY ANALYSIS AND A SURCHARGE IS APPLIED TO ANY PLANT DISCHARGING AN UNSATISFACTORY EFFLUENT.

THE FINAL EFFLUENT MUST BE STREAM 35.0

CALL STREAM(35.0)
FLOW = SN(IS, 3) * 24.0 * 1.0E-6
WRITE(6, 400) FLOW

FORMAT(1X, 15HEFFLUENT FLOW = *12.6, 6H MIGD )
BOD = SN(IS, 1)*1.0E5/SN(IS, 3)
WRITE(6, 410) BOD

FORMAT(1X, 15HEFFLUENT BOD = , F8.1)
TCOST = TCOST + COST(10)
SS = SN(IS, 11)*1.0E5/SN(IS, 3)
WRITE(6, 420) SS

FORMAT(1X, 15HEFFLUENT SS = , F8.1)
TCOST = TCOST + COST(11)

APPLY SURCHARGE ON EFFLUENT
BODCH = SN(IS, 1)*30.0*SN(IS, 3)*1.0E-5
IF(BODCH LE 0.0) BODCH = 0.0
SSCH = SN(IS, 11)*30.0*SN(IS, 3)*1.0E-5
IF(SSCH LE 0.0) SSCH = 0.0
SURCH = 2.0*(BODCH + SSCH)
WRITE(6, 480) SURCH

FORMAT(1H0, 35H, = SURCHARGE ON EFFLUENT = $ , F8.2 * 6H /DAY )

ASKING FOR ANALYSES
WRITE(6, 430)

FORMAT(1H0, 25H WANT ANY ANALYSES DONE )
READ(2, 200) AN
IF(AN LE 0.0) GO TO 100
CONTINUE

WRITE(6, 440)

FORMAT(1X, 20H TYPE STREAM NUMBER )
READ(2, 200) S

FORMAT(F12.3)

200 CALL STREAM(S)

210 CALL CONVERT(1, 1, IS, 3, 1)

CONTINUE

WRITE(6, 450)

FORMAT(1X, 20H TYPE ELEMENT NUMBER )
READ(2, 200) SJ
IF(SJ LE 0.0) GO TO 110
IJ = SJ + 0.01
WRITE(6, 460) SJ(1:1)

460 FORMAT(1X, 20H ANALYSIS GIVES )
IF(IJ LE 0.30) IJ = 15
TCOST=TCOST+COST(IJ)
GO TO 120

C 100 CONTINUE
WRITE(6,470) TCOST
470 FORMAT(1HU,3UH TOTAL ANALYTICAL COST = $ ,F8.2)
C WRITE(6,520)
520 FORMAT(1HU,45H WANT TO SEE THE SUMMARY REPORT ON STREAMS - )
READ(2,200) AN
IF(AN.LT.1.0) GO TO 190
CALL DISK10(1,24)
CALL REPT01
190 CONTINUE
C RETURN
END

SUBROUTINE ENSET

C COMMON LIST(50), NS(100), FN(100), SI(4,30), SO(4,30), KPRNT(10)
COMMON NE, JJ, LOOP, NOUT, NS, ISP, NC, III, NCALC, NOCRM, NSR
COMMON MODE, NPLNT, LOOPC
COMMON SN(25,30), EEN(600), NPOINT(25,2)
C ALLOWS PLAYER TO MAKE PLANT ADJUSTMENTS
C 140 CONTINUE
WRITE(6,500)
500 FORMAT(1X,22H EQUIPMENT NUMBER )
READ(2,200) S
200 FORMAT(F12.3)
IF(S.LE.0.0) GO TO 130
MM=S+0.01
M0=NPOINT(MM,1)
150 CONTINUE
WRITE(6,510)
510 FORMAT(1X,4H ELEM. NUMBER AND VALUE CHANGED TO )
READ(2,210) SJ, EL
210 FORMAT(2F12.3)
IF(SJ.LE.0.0) GO TO 140
IJ=SI+6.01
EEN(MQ+IJ)=EL
GO TO 150
C 130 CONTINUE
C RETURN
END
### Data set for the interactive version

<table>
<thead>
<tr>
<th>McMaster Wastewater Treatment Plant Simulation</th>
<th>Interactive Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>19.0</td>
<td>25.0</td>
</tr>
<tr>
<td>7.0</td>
<td>8.0</td>
</tr>
<tr>
<td>13.0</td>
<td>14.0</td>
</tr>
<tr>
<td>22.0</td>
<td>23.0</td>
</tr>
<tr>
<td>30.0</td>
<td>31.0</td>
</tr>
<tr>
<td>36.0</td>
<td>37.0</td>
</tr>
<tr>
<td>42.0</td>
<td>43.0</td>
</tr>
<tr>
<td>48.0</td>
<td>49.0</td>
</tr>
<tr>
<td>54.0</td>
<td>55.0</td>
</tr>
<tr>
<td>60.0</td>
<td>61.0</td>
</tr>
<tr>
<td>66.0</td>
<td>67.0</td>
</tr>
<tr>
<td>72.0</td>
<td>73.0</td>
</tr>
<tr>
<td>78.0</td>
<td>79.0</td>
</tr>
<tr>
<td>84.0</td>
<td>85.0</td>
</tr>
<tr>
<td>90.0</td>
<td>91.0</td>
</tr>
<tr>
<td>96.0</td>
<td>97.0</td>
</tr>
<tr>
<td>102.0</td>
<td>103.0</td>
</tr>
<tr>
<td>108.0</td>
<td>109.0</td>
</tr>
<tr>
<td>114.0</td>
<td>115.0</td>
</tr>
<tr>
<td>120.0</td>
<td>121.0</td>
</tr>
<tr>
<td>126.0</td>
<td>127.0</td>
</tr>
<tr>
<td>132.0</td>
<td>133.0</td>
</tr>
<tr>
<td>138.0</td>
<td>139.0</td>
</tr>
<tr>
<td>144.0</td>
<td>145.0</td>
</tr>
<tr>
<td>150.0</td>
<td>151.0</td>
</tr>
<tr>
<td>156.0</td>
<td>157.0</td>
</tr>
<tr>
<td>162.0</td>
<td>163.0</td>
</tr>
<tr>
<td>168.0</td>
<td>169.0</td>
</tr>
<tr>
<td>174.0</td>
<td>175.0</td>
</tr>
<tr>
<td>180.0</td>
<td>181.0</td>
</tr>
<tr>
<td>186.0</td>
<td>187.0</td>
</tr>
<tr>
<td>192.0</td>
<td>193.0</td>
</tr>
<tr>
<td>198.0</td>
<td>199.0</td>
</tr>
<tr>
<td>204.0</td>
<td>205.0</td>
</tr>
<tr>
<td>210.0</td>
<td>211.0</td>
</tr>
<tr>
<td>216.0</td>
<td>217.0</td>
</tr>
<tr>
<td>222.0</td>
<td>223.0</td>
</tr>
<tr>
<td>228.0</td>
<td>229.0</td>
</tr>
<tr>
<td>234.0</td>
<td>235.0</td>
</tr>
<tr>
<td>240.0</td>
<td>241.0</td>
</tr>
<tr>
<td>246.0</td>
<td>247.0</td>
</tr>
<tr>
<td>252.0</td>
<td>253.0</td>
</tr>
<tr>
<td>258.0</td>
<td>259.0</td>
</tr>
<tr>
<td>264.0</td>
<td>265.0</td>
</tr>
<tr>
<td>270.0</td>
<td>271.0</td>
</tr>
<tr>
<td>276.0</td>
<td>277.0</td>
</tr>
<tr>
<td>282.0</td>
<td>283.0</td>
</tr>
<tr>
<td>288.0</td>
<td>289.0</td>
</tr>
<tr>
<td>294.0</td>
<td>295.0</td>
</tr>
<tr>
<td>300.0</td>
<td>301.0</td>
</tr>
<tr>
<td>12.0</td>
<td>5.0</td>
</tr>
<tr>
<td>1.0</td>
<td>20.0</td>
</tr>
<tr>
<td>2.0</td>
<td>22.0</td>
</tr>
<tr>
<td>1.0</td>
<td>9.0</td>
</tr>
<tr>
<td>4.0</td>
<td>26.0</td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.0</td>
<td>12.0</td>
</tr>
<tr>
<td>1.0</td>
<td>26.0</td>
</tr>
<tr>
<td>1.0</td>
<td>27.0</td>
</tr>
<tr>
<td>4.0</td>
<td>20.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.0</td>
<td>12.0</td>
</tr>
<tr>
<td>1.0</td>
<td>29.0</td>
</tr>
<tr>
<td>2.0</td>
<td>18.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.08</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.0</td>
<td>29.0</td>
</tr>
<tr>
<td>1.0</td>
<td>30.0</td>
</tr>
<tr>
<td>1.0</td>
<td>13.0</td>
</tr>
<tr>
<td>1.0</td>
<td>33.0</td>
</tr>
<tr>
<td>1.0</td>
<td>18.0</td>
</tr>
<tr>
<td>1.0</td>
<td>33.0</td>
</tr>
<tr>
<td>1.0</td>
<td>35.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2.0</td>
<td>21.0</td>
</tr>
<tr>
<td>2.0</td>
<td>24.0</td>
</tr>
<tr>
<td>1.0</td>
<td>16.0</td>
</tr>
<tr>
<td>2.0</td>
<td>19.0</td>
</tr>
<tr>
<td>1.0</td>
<td>25.0</td>
</tr>
<tr>
<td>22.0</td>
<td>2.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.0</td>
<td>10.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>23.0</td>
<td>20.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>24.0</td>
<td>16.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td>12.0</td>
<td>0.0</td>
</tr>
<tr>
<td>12.0</td>
<td>0.0</td>
</tr>
<tr>
<td>25.0</td>
<td>19.0</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>5.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>