DOCUMENTATION FOR OUTFALL

A COMPUTER PROGRAM FOR THE CALCULATION OF OUTFALL LENGTHS BASED UPON DILUTION REQUIREMENTS

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OCEAN OUTFALL ANALYSIS

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PREFACE

This report has been prepared to illustrate the use of oceanographic data and a digital computer program developed by the San Juan Field Office of the U.S. Environmental Protection Agency to aid in the location and analysis of ocean outfalls. The report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. This approval does not signify concurrence or approval of any procedures or results contained herein.

ACKNOWLEDGEMENTS

The art work contained in this report was illustrated by Robert Rauenbuhler of the Environmental Protection Agency in Edison, New Jersey.

The initial concept for the OUTFALL Program was advanced by Dr. Donald R. Washington, former director of the Region II San Juan Field Office. Much appreciation is extended to him for his cooperative work and assistance with the theoretical aspects of the program. Thanks is also given to Mr. Donald J. Baumgartner and Mr. Calloway, of the National Environmental Research Center in Corvallis, Oregon.

Thanks must be extended to Ethan T. Smith, Chief, Data Systems Branch for his encouragement and support of this effort and to Steve Chapra of that same section for his many hours of assistance in debugging the computer program.

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David L. Guthrie

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INTRODUCTION

After wastewater is treated, a method may be used to convey it to offshore waters, where natural processes break it down further. A common mechnanism is the ocean outfall.

Basically, the philosophy of the disposal of wastewater through a submarine outfall is to maximize the initial dilution of discharged wastewaters so to minimize any adverse impact(s) on the receiving waters. Beneficial uses of receiving waters vary greatly from water supply to aesthetic beauty, but usually the most important reference point is the maintenance of the water quality standards which have been defined for the applicable water usage.

The chemical biological and hydrodynamic characteristics of the receiving waters are critical considerations in determining the actual outfall routine and the ultimate disposal site.

OUTFALL is a computer program which can be used to evaluate a coastal system under consideration as a disposal site. It is designed to evaluate and/or predict the length of outfall needed to adequately dilute a proposed discharge in order to provide compliance with coastal water quality standards.

Any coastal system is extremely complex, and as such requires many considerations in its investigation. Some of the most important factors which can be evaluated in OUTFALL include the effects of onshore currents, tides, density and salinity gradients, ambient surface and hypolimnetic velocities, the initial jet velocity, the quantity of discharge, the slope of the ocean bottom, and coliform die-off rates in the vicinity of outfall locations.

Analytical expressions are used to calculate the factors of dilution, diffusion, and die-off in order to compute the total dilution, taking into account the aforementioned variables. This value is then compared to a dilution value needed to meet water quality standards and iterated until an outfall length is reached where the calculated dilution value meets that which is required to meet the applicable water quality standards both at the maximum point of plume rise above the diffuser and the more stringent nearshore standards at a specified distance offshore.

This documentation consists of a description of the program as well as its input. A listing of OUTFALL, which is compatible with the IBM 370/155 system, a case study, and a sample output from the program are included in the appendices.

THE SYSTEM: DEFINITION OF TERMS

- INITIAL DILUTION occurs when a wastewater is discharged through a diffuser into a receiving water of greater density; it is diluted by turbulent jet mixing. Due to its buoyancy, the plume rises toward the surface, and a turbulence and mixing action is caused by the velocity gradient between the edge of the plume and the surrounding water.

- DISPERSION takes place after initial dilution, when a rather homogenous mixture forms above the diffuser section, and the sewage field begins to move according to prevailing ocean currents.

- DECAY is the apparent die-off of bacteria in the sewage including flocculation and sedimentation of the microorganisms as well as mortality.

- TOTAL DILUTION is the product of the initial dilution, the dispersion, and decay factors.

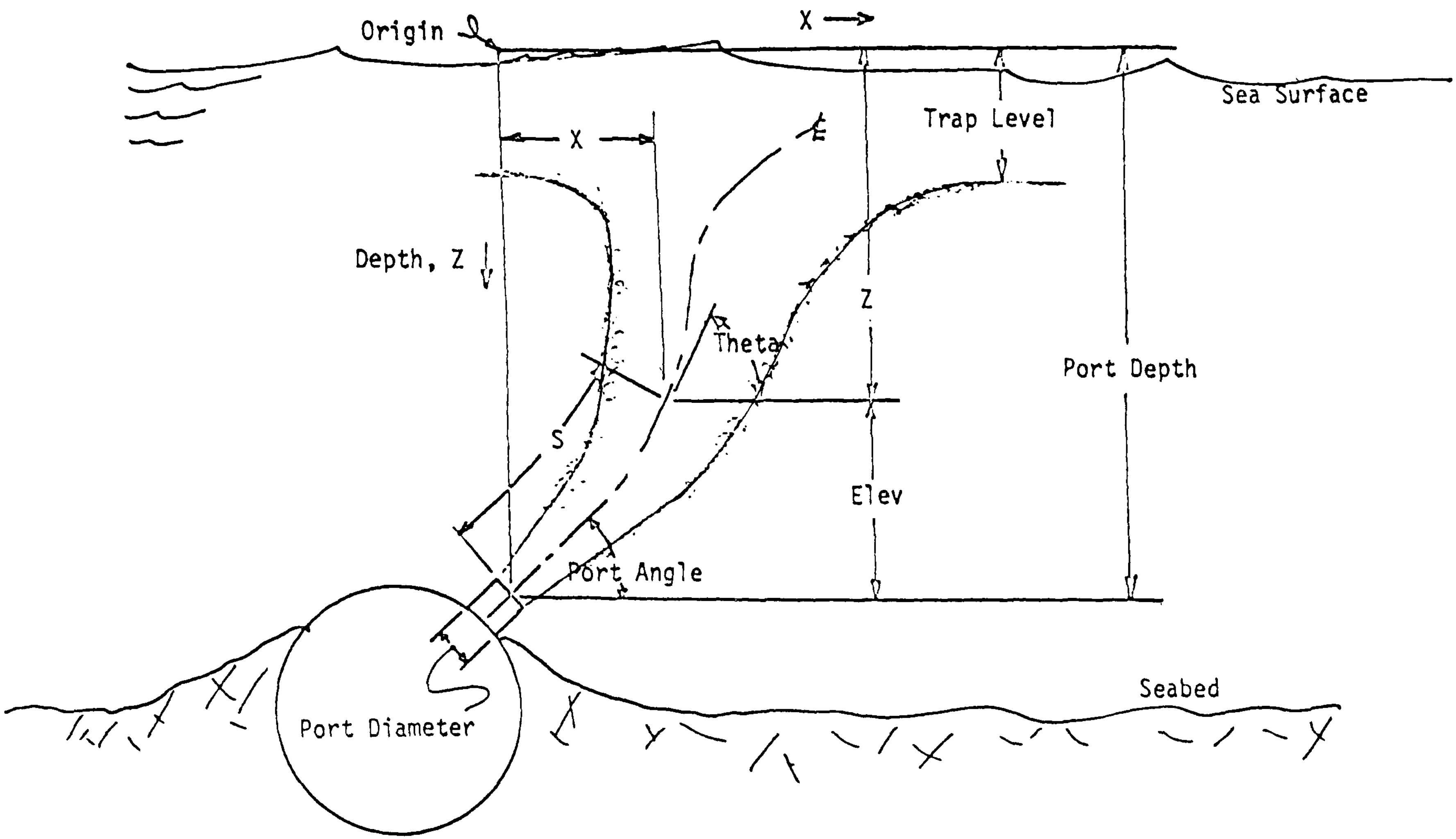


FIGURE 1. Definition Sketch for Input Specification and Output Interpretation.

THEORY

In the calculation of optimum outfall length, X, a development of total dilution D_T, which is composed of initial dilution, D_1, dispersion, D_2 , and die-off or decay, D_3, is necessary. These factors are multiplicative because as an initial concentration, C_o, is multiplied by an initial dilution, D_1 , a secondary concentration, C_1, results which is then multiplied by a secondary dilution factor, dispersion, D_2, resulting in a new concentration, C_2, and so forth until the final concentration, C_3, is obtained. Mathematically, the expressions are: $C_1 = D_1 C_o$, $C_2 = D_2 C_1$, and $C_3 = D_3 C_2$, Substituting and rearranging by the associative law, $C_3 = D_3 (D_2 (D_1 C_o))$ or $C_3 = D_1 D_2 D_3 C_o$. Hence, it follows that

$$D_T = D_1 \times D_2 \times D_3 \qquad (1)$$

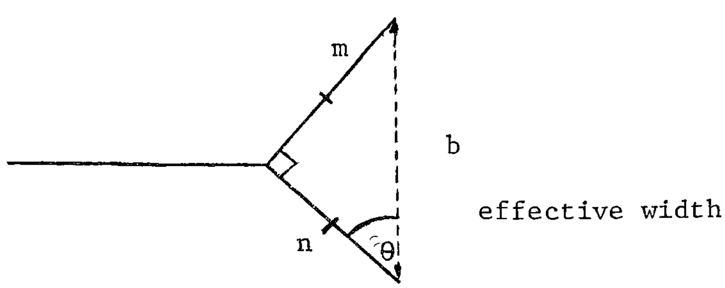
which has also been mentioned by Burchett, et. al.

When moderately strong currents are encountered, the initial dilution may be estimated from a continuity relation between the sewage flowrate and the flowrate of fresh seawater over the outfall diffuser as proposed by Pearson and mentioned by Metcalf and Eddy:

$$D_1 = (V_1 \, bd) \; / \; Q \qquad (2)$$

It should be noted that the initial dilution value, D_1, as presented in equation (2) is subject to much controversy. As in most cases, density gradients exist in the surrounding seawater, and the turbulence caused by the velocity gradient between the edge of the plume and the surrounding seawater must be incorporated. Also, the continuity equation requires that the combining of the wastewater flow and the seawater flow is the perfect mixing of the two flows at some distance above the diffuser section. However, this approach is fairly simplified and neither takes density stratification nor quiescent media into account. Therefore, a different approach developed by Baumgartner, Trent, and Byram[7] entitled "PLUME" was used to find D_1 in the OUTFALL program. This method is based on similarity prinicipals as presented by Baumgartner and Trent[8]. Solution is carried out by a fourth-order Runga-Kutta technique, and calculation of the potential core length is based on Abraham's method[9] and is an integral part of the results.

The effective diffuser system length is an important term in outfall design. In this publication, it will be developed according to the design value of 14 ft. diffuser/mgd wastewater[5]. The outfall is represented diagramatically as having two legs as follows:



Because it is an isoceles triangle, m=n and m+n=14 ft/mgd xQ_w, where b is the effective width of the diffuser. Therefore, the effective width can be determined by the following:

$$\cos\ \theta = \frac{adj}{hyp} = \frac{m}{b} \qquad (3)$$

$$\cos\ \theta = \frac{.5\ (14\ ft/mgd)\ Q_w}{b} \qquad (4)$$

$$b = \frac{.5\ (14\ ft/mgd)\ Q_w}{.707} \qquad (5)$$

Hence,

$$b = 9.9\ ft/mgd\ ,\ Q_w = 6.4\ ft/cfs\ ,\ Q_w \qquad (6)$$

$$D_1 = (.03281\ ft/cm)\ V_1\ bd/Q \qquad (7)$$

and substituting equation (6) for b, the following expression for D_1 results in:

$$D_1 = \frac{.03281\ (6.4\ Q_w)\ V_1 d}{Q_w} = (.210)\ V_1 d \qquad (8)$$

The theory of dispersion of the sewage field after it is initially diluted has been developed by Brooks[2] and has resulted in the following equation, derived on the basis of the "4/3-law", in which the coefficient of eddy diffusion, E, is a function of the diffuser length raised to the four-thirds power. Thus, the following equations result; from Brooks[2]:

$$D_2 = 1/\mathrm{erf}\left(\sqrt{1.5\ /\ ((1 + 2/3\ B\ X\ /b)^3\ \ -1)}\right) \qquad (9)$$

and

$$E = 0.001\ (b)^{4/3} \qquad (10)$$

It has also been determined by Brooks[2] that:

$$B = 12E/V_2 b \qquad (11)$$

This term was developed to take into account the horizontal diffusivity of the spreading plume, as entrainment of the wastewater becomes important in the dispersion mechanism.

In order to find (2/3) BX/b in equation (9), equation (10) is substituted in equation (11) to obtain B:

$$B = \frac{(12)\ (0.001)\ (b)^{4/3}}{V_2 b} = \frac{(1.2 \times 10^{-2}) b^{1/3}}{V_2} \qquad (12)$$

Therefore,

$$(2/3)\ BX/b = \frac{(1.2 \times 10^{-2})\ b^{1/3}}{V_2} \frac{(2X)}{(3b)} = \frac{8 \times 10^{-3}\ b^{-2/3}\ X}{(.03281\ ft/cm) V_2} \qquad (13)$$

$$= \frac{(2.438 \times 10^{-1}) b^{-2/3}\ X}{V_2} \qquad (14)$$

But equation (14) can be simplified even further, by substituting equation (6):

$$(2/3)\ BX/b = \frac{(2.438 \times 10^{-1})\ (6.4\ Q_w)^{-2/3}\ X}{V_2} \qquad (15)$$

$$= \frac{(2.438 \times 10^{-1})\ (.290)\ Q_w^{-2/3}\ X}{V_2}$$

$$= \frac{(7.071 \times 10^{-2})\ Q_w^{-2/3}\ X}{V_2} \qquad (16)$$

Hence, the final expression for dispersion is obtained:

$$D_2 = 1/\mathrm{erf}\left(\sqrt{1.5/\ ((1 + \frac{(7.071 \times 10^{-2}) Q_w^{-2/3} X)^3 - 1)}{V_2}} \right) \qquad (17)$$

Bacterial decay, the third significant factor in waste dilution, is patterned after a first - order relationship as follows:

$$D_3 = e^{kt} = \exp\ (K\ (\frac{X}{V_2})) \qquad (18)$$

This equation results from an expression defining reduction in bacterial concentration from initial dilution to time t as follows:

$$D_3 = \frac{C_o}{C_t} \qquad (19)$$

In the relationship in equation (18), K is actually a logarithmic conversion to relate T_{90}, the time required in hours for a 90 percent reduction in bacterial concentration, to a time constant as follows:

$$K = 2.3/\ (3600\ \text{sec/hr})T_{90} = 6.39 \times 10^{-4}\ /T_{90} \qquad (20)$$

Therefore, expanding the decay term,

$$D_3 = \exp\ (K\ (X/V_2)) = \exp\ (KX/V_2\ (.03281\ \text{ft/cm})) \qquad (21)$$

and substituting equation (20) for K:

$$D_3 = \exp\ ((6.39 \times 10^{-4})\ X/\ (.03281)\ T_{90}V_2)$$

$$= \exp\ ((1.95 \times 10^{-2})\ X/T_{90}V_2) \qquad (22)$$

For convenience, constant values can be assigned as:

$$\theta_1 = 2.10 \times 10^{-1}$$

$$\theta_2 = 7.071 \times 10^{-2}$$

$$\theta_3 = 1.95 \times 10^{-2}$$

Therefore, equations (8), (17), and (22) become:

$$D_1 = \theta_1\ V_1\ d \qquad (23)$$

$$D_2 = 1/\text{erf}\left(\sqrt{1.5 \Big/ \left[\left(1 + \frac{\theta_2 Q_w^{2/3}\ X}{V_2}\right)^3 - 1\right]}\right) \qquad (24)$$

$$D_3 = \exp\ (\theta_3 X/T_{90}V_2) \qquad (25)$$

Substituting (8), (17), and (22) into equation (1) yields the final expression for total dilution, utilizing the continuity expression for D_1:

$$D_T = \frac{\theta_1\ V_1\ d e^{\theta_3\ X/T_{90}\ V_2}}{\text{erf}\left(\sqrt{1.5 \Big/ \left[\left(\frac{1 + \theta_2 Q_w^{-2/3} X}{V_2}\right)^3 - 1\right]}\right)} \qquad (26)$$

In the model, the expression $\theta_1\ V_1$ d, or D_2, is replaced by program "PLUME" as a subroutine. However, the expression given here can yield a rapid estimation of D_1 and thus D_T, without conducting complex iterative techniques. For a more concise discussion of these primary equations and ocean outfall design criteria, see Beckman[1], Brooks[2], Burchett[3], Frankel[4], and Metcalf and Eddy[5].

VARIABLE	EXPLANATION
D_T	Total dilution
D_1	Initial dilution
D_2	Dispersion
D_3	Decay
V_1	Ocean current velocity
b	Effective width of the diffuser system
d	Average depth of the sewage field
Q_w	Sewage flowrate
B	Interim variable
X	Distance along the plume centerline
E	Coefficient of eddy diffusion
V_2	Ocean current velocity
K	Bacterial decay constant
T_{90}	Time required for a 90 percent reduction in bacterial concentration.

The Computer Program*

The program begins by reading the "city data", "physical data", and the "plume data". Then the "density data" is read in and subroutine SIGMAT is called to find the density. At this point, the number of ports (FN) is found by the following formula:

$$FN = 14 \frac{ft.}{mgd} * .646 \frac{mgd}{cfs} * Q_w(cfs) * \frac{1}{10 \text{ ft diffuser spacing}} \quad (27)$$

where 14 ft/mgd and 10 ft diffuser spacing are design criteria.[5] The values of 14 ft/mgd and 10 ft. diffuser spacing were those chosen by the author. If new values are desired, these must be changed in the program itself. The "plume data" are then written. Having read the initial values, a range of effluent coliform concentrations are assigned by a test of NN, which is initially assigned to be equal to 0. The class is then assigned by a test of NCLASS, and the "city data" is written. The first T_{90} value is assigned to be equal to 1 hour, and JJ, the counter for the different respective treatment levels, is initialized at 0. The first part of the program then ends with the computation of the total dilution (D_T) necessary to meet a given water quality standard by the following formula:

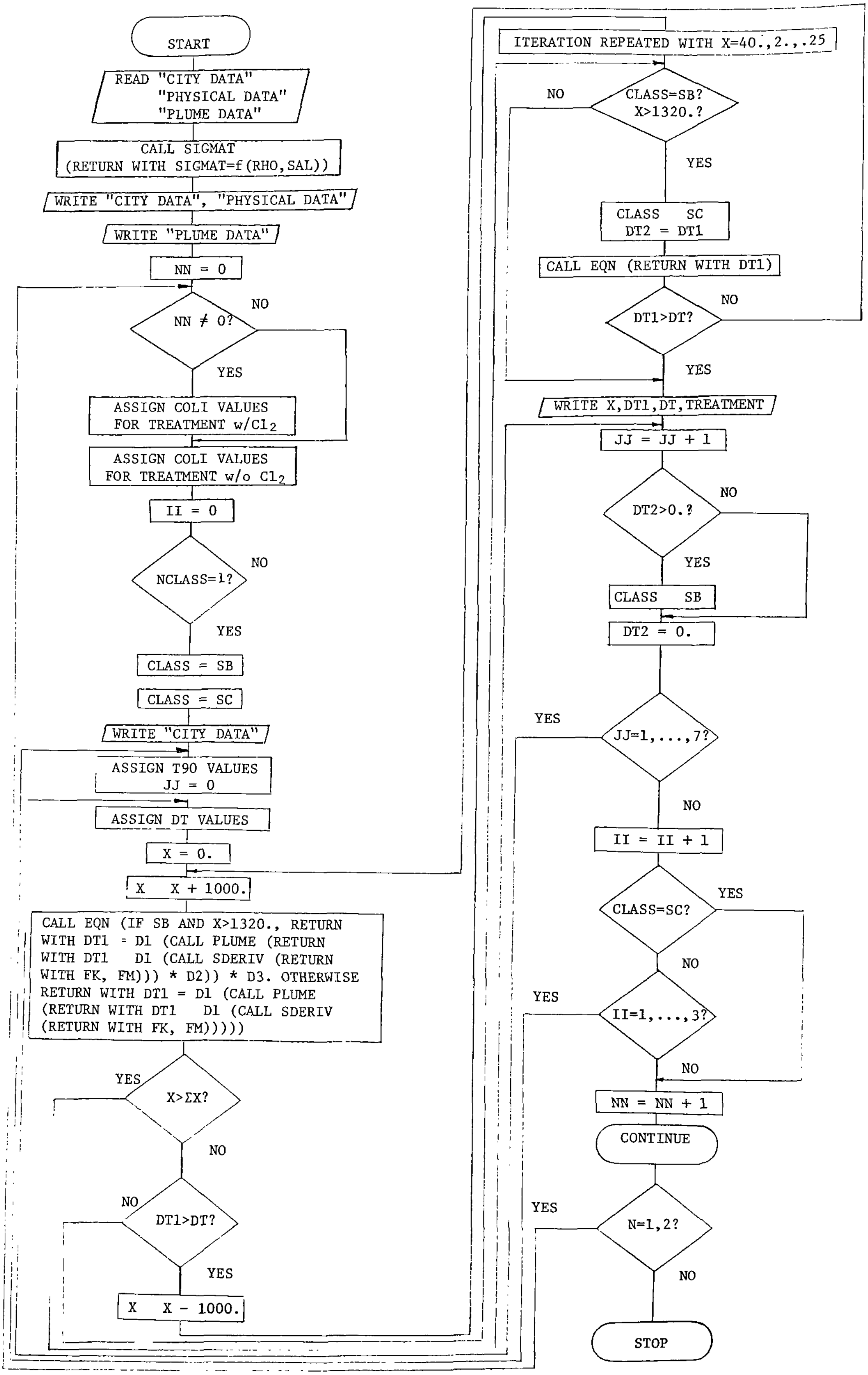
$$D_T \text{ (required)} = \frac{\text{*coliforms/100ml for a corresponding treatment level}}{\text{Water Quality Standard}} \quad (28)$$

In equation (28), the number of coliform organisms pertaining to the corresponding treatment level must be known in order to calculate the required dilution. Lower and upper coliform limits must be taken into account when designing an outfall length, hence that outfall's dilution ability. Table B-4 presents a summary of effluent coliform data obtained from five different wastewater treatment plants in Ohio and New Jersey. These data are presented herein because there are few data indicating the range of effluent coliform values for different wastewater treatment processes, although there are many data indicating mean values.[10] A final summary of the data presented in Table 1 is shown as Table 2, these data are used in the example problem.

Having assigned the D_T values, the program now iterates the outfall length (X) by 1000 feet from the shoreline. Subroutine EQN is called, which calculates D_1 by the PLUME subroutine. PLUME must, in turn, call subroutine SDERIV to complete its calculations of D_1. It is obvious in an ocean situation that the depth of the bottom is some function of its distance from shore. Therefore, in subroutine EQN, depth (DEPTH) is computed as shown diagramatically in Figure 2. For more than three changes in bottom slope, the following equation can be used:

*A listing of the program is in Appendix A and a flow chart is on page 10.

FLOW CHART



START
READ "CITY DATA"
"PHYSICAL DATA"
"PLUME DATA"
CALL SIGMAT
(RETURN WITH SIGMAT=f(RHO,SAL))
WRITE "CITY DATA", "PHYSICAL DATA"
WRITE "PLUME DATA"
NN = 0
NN ≠ 0?
NO
YES
ASSIGN COLI VALUES
FOR TREATMENT w/Cl2
ASSIGN COLI VALUES
FOR TREATMENT w/o Cl2
II = 0
NCLASS=1?
NO
YES
CLASS = SB
CLASS = SC
WRITE "CITY DATA"
ASSIGN T90 VALUES
JJ = 0
ASSIGN DT VALUES
X = 0.
X X + 1000.
CALL EQN (IF SB AND X>1320., RETURN
WITH DT1 = D1 (CALL PLUME (RETURN
WITH DT1 D1 (CALL SDERIV (RETURN
WITH FK, FM))) * D2)) * D3. OTHERWISE
RETURN WITH DT1 = D1 (CALL PLUME
(RETURN WITH DT1 D1 (CALL SDERIV
(RETURN WITH FK, FM)))))
YES
X>ΣX?
NO
NO
DT1>DT?
YES
X X - 1000.
ITERATION REPEATED WITH X=40.,2.,.25
NO
CLASS=SB?
X>1320.?
YES
CLASS SC
DT2 = DT1
CALL EQN (RETURN WITH DT1)
NO
DT1>DT?
YES
WRITE X,DT1,DT,TREATMENT
JJ = JJ + 1
NO
DT2>0.?
YES
CLASS SB
DT2 = 0.
YES
JJ=1,...,7?
NO
II = II + 1
YES
CLASS=SC?
NO
YES
II=1,...,3?
NO
NN = NN + 1
CONTINUE
YES
N=1,2?
NO
STOP

$$Y_n = Y_1 + Y_2 + \ldots + Y_{m-1} + X_n - (X_1 + X_2 + \ldots + X_{m-1}))*Y_m/X_m \qquad (29)$$

where m and n are integers. After D_1 is calculated by EQN and PLUME, the generated X value is tested to see if it exceeds the total distance from shore read into the program. If this occurs, a message indicating this is the case is printed and the program goes to the next level of treatment.

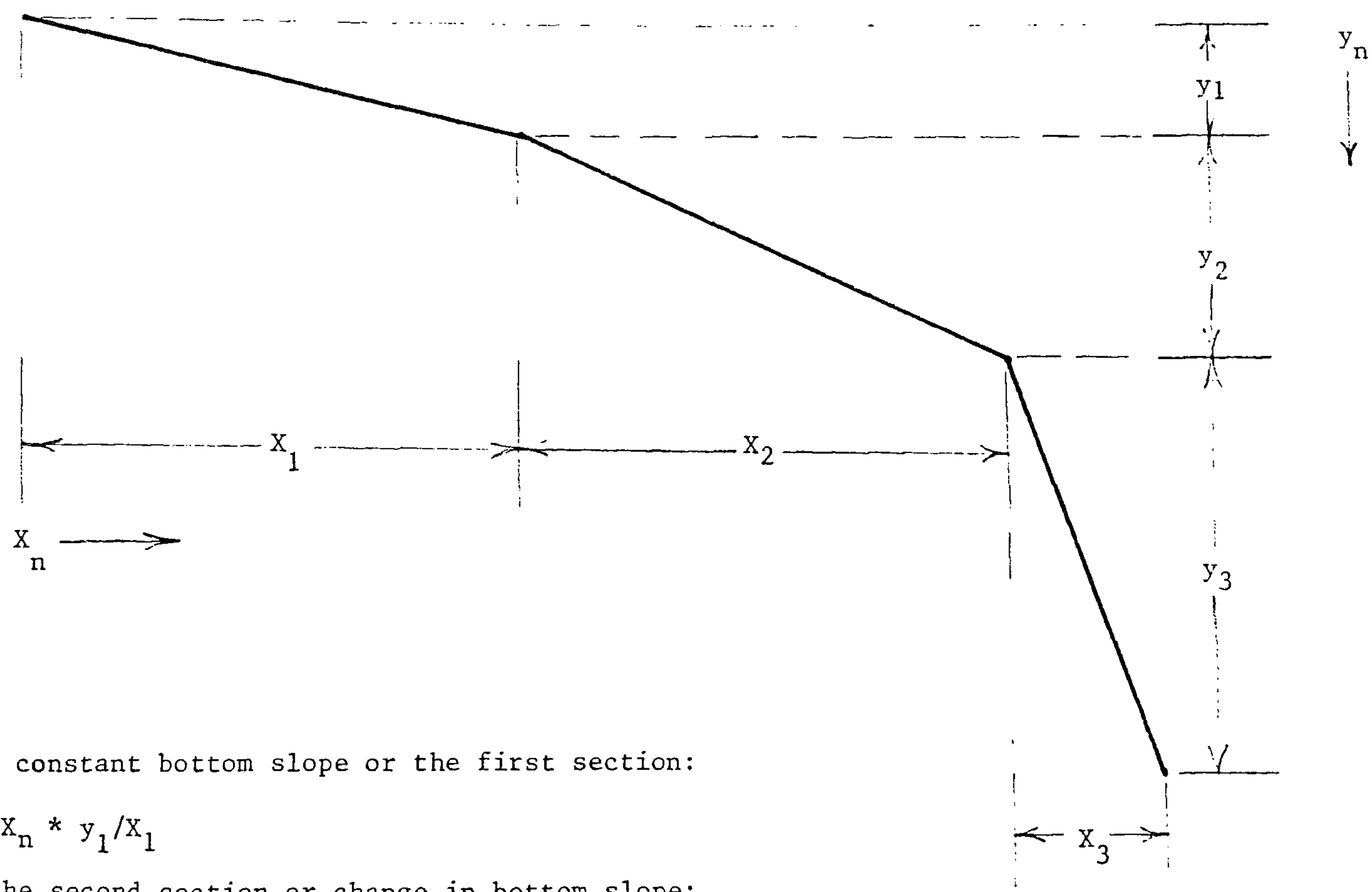
The dilution calculated is then compared to the dilution required. If the dilution at the first depth (i.e. - 1000 feet) is greater than that needed, the 1000 is subtracted and the same iteration proceeds with X=40 feet. This iteration is repeated in the same manner with X=2 feet and X=0.25 feet, until the outfall length needed is within 0.25 feet of that required.

Now, the water quality classifications play an important role. The program can evaluate two different situations: (1) where water quality standards must be met directly over the end of the outfall, and (2) where water quality standards must be met over the end of the outfall but when part of the wastewater field is carried onshore by the currents where a stricter water quality standard exists, that stricter standards must be met at the boundary line between the two standards. For example, if a standard of 70 coliforms/100ml exists from the shore to 0.1 mile in the ocean and after the 0.1 boundary a standard of 10,000 coliforms exists, and the outfall is longer than 0.1, the number of coliforms in the wastewater must be reduced from 10,000 to at least 70 if the field drifts inside the 0.1 mile interface.

The model tests for this by the mechanism of SB, which can be any coliform value (SB is the lower standard, SC is the higher standard). If the class is SB (inside of the boundary because the higher standard is assumed to be used outside the boundary). If X is greater than the boundary limit, then the standard is changed to SC and X1 is stored in X2. DT1 is again computed by EQN and PLUME and a second test is conducted. However, this time EQN uses subroutine PLUME and ERF to compute D_T as presented in equation(1). If D1 is greater than DT, the values are printed and the next higher level of treatment is investigated. (JJ is increased by 1). If DT1 is still less than DT, X is again increased by 1000 feet, and the iteration begins again. For clarification, the D_1 value is calculated for the port closest shore. The program also assumes that the plume from each individual port does not overlap with any adjacent plume during its period of rise. Any overlap may tend to reduce the dilution. Therefore, the required outfall length would have to be longer than the program indicated in cases of significant plume overlap.

FIGURE 2.

BOTTOM PROFILE: DISTANCE FROM SHORE VS. DEPTH



For a constant bottom slope or the first section:

$$y_n = X_n * y_1/X_1$$

For the second section or change in bottom slope:

$$y_n = y_1 + (X_n - X_1) * y_2/X_2$$

For the third section or change in bottom slope:

$$y_n = y_1 + y_2 + (X_n -(X_1 + X_2)) * y_3/X_3$$

TABLE 1

E. COLI CONCENTRATIONS IN THE EFFLUENTS OF SEWAGE TREATMENT PLANTS

PLANT	LOCATION	TREATMENT	NO. SAMPLING DAYS	MEMBRANE FILTER RESULTS LOW	MEDIAN	HIGH
Keasby	Raritan, N.J.	Primary+Cl_2	39	10	7,224	10,000
Keasby	Raritan, N.J.	Primary+Cl_2	5	20	4,042	10,000
Coleran Hgts.	Cincin., Ohio	Second.+Cl_2	11	1	21	99
Coleran Hgts.	Cincin., Ohio	Secondary	11	8700	217,391	677,000
Norbrook	Cincin., Ohio	Second.+Cl_2	10	1	12,759	113,000
Norbrook	Cincin., Ohio	Secondary	10	17,600	162,830	546,000
Florence	Cincin., Ohio	Second.+Cl_2	9	2	445	1888
Florence	Cincin., Ohio	Secondary	9	36,180	251,620	587,000
Keyport	Keyport, N.J.	Primary+Cl_2	106	10	18,545	1,000,000

Sources of Information: Mr. Edwin Geldrich, National Environmental Research Center, Cincinnati, Ohio.
U.S. Environmental Protection Agency
Mr. Francis Brezenski, National Environmental Research Center, Edison, N.J.
U.S. Environmental Protection Agency

TABLE 2

EFFLUENT COLIFORM DATA

TREATMENT LEVEL	E. COLI CONC. WITH CHLORINATION	REFERENCE
Raw: upper	1.0×10^7	(1)
Raw: lower	5.0×10^5	(2)
Primary: upper	1.0×10^6	(3)
Primary: lower	10.0	(4)
Secondary: upper	1.13×10^5	(5)
Secondary: lower	2.0	(5)
Tertiary: upper	1.0×10^3	(7)
Tertiary: lower	2.0	(7)

	E. COLI CONC. WITHOUT CHLORINATION	
Raw: upper	2.2×10^8	(1)
Raw: lower	1.2×10^5	(2)
Primary: upper	1.65×10^8	(8)
Primary: lower	9.0×10^4	(8)
Secondary: upper	6.77×10^5	(6)
Secondary: lower	8.7×10^3	(6)
Tertiary: upper	1.0×10^5	(7)
Tertiary: lower	1.0×10^3	(7)

References:

(1) Keyport, N.J. Plant Sampling Days = 4
(2) Keyport, N.J. Plant Sampling Days = 30
(3) Keyport, N.J. Plant Sampling Days = 106
(4) Keasby Plant, Raritan, N.J. Sampling Days = 39
(5) Norbrook Plant, Cincinnati, Ohio Sampling Days = 10
(6) Coleran Hgts Plant, Cincinnati, Ohio Sampling Days = 11
(7) Personal Communication with Dr. Don Reasoner, EPA-NERC, Cincinnati, Ohio
(8) Calculated using 25 percent as reduction in coliform concentration resulting from primary treatment without chlorination.

In the event, JJ is increased by 1 and DT2 is tested for being greater than 0. If it is, the CLASS is reassigned as SB and DT2 is set equal to 0. The next higher level of treatment then is investigated. II is increased by 1 and the class is again tested. If the water has the higher standard, CLASS=SC, then NN is increased by one, the program continues once more and stops. If CLASS=SC, II is then used to increase the T_{90} value, and the program starts over.

Any T_{90} values can be used. If only one T_{90} value is desired, statements OUTFL062-OUTFL069 and OUTFL169-OUTFL171 can be eliminated from the program. Only the maximum coliform values were used (MAX) because they generated longer outfall lengths, based on public health constraints.

SUBROUTINE EQN

The CALL and SUBROUTINE statements for EQN are:

```
    CALL EQN(X,V1,V2,V1,X1,Y2,X2,Y3,X3,
             QW,T90,DT,CLASS, DT1,
             XSTOR1,SC,SB,DT2)

SUBROUTINE EQN (X,V1,V2,Y1,X1,Y2,X2,
                Y3,X3,QW,T90,DT,CLASS,DT1,
                XSTOR1,SC,SB,DT2)
```

Equations for DEPTH are computed using those given in Figure 2, and D_1 is computed by subroutine PLUME. D_2 is computed using the distance, X-1320 feet to equal the distance from the end of the outfall to the boundary demarkation. $D_2 * D_3$ is computed by multiplying equations (17) and (20) and D_T is found by using equation (1). The erf (as shown in equation (17) is calculated by subroutine ERF.

RESTRICTIONS

If the $\sum\limits_{x_1 \to x_n} x$ is less than the iterative value of X, a termination of that step in the program will result. If this happens, X has been extrapolated in the following manner:

```
IF(X.GT. (X1+X2)) DEPTH = Y1+Y2+(X-(X1+X2))*Y3/X3
```

SUBROUTINE PLUME

The CALL and SUBROUTINE statements for PLUME are:

```
CALL PLUME(DEPTH, DT1)

SUBROUTINE PLUME(DEPTH, DT1)
```

This subroutine has been described in the Theory section, and more information can be gleamed in detail from reference (7). Basically, it calculates D_1 based on the behavior of a plume in density stratified surroundings. These type of conditions are very common in most aquatic environments. Hence, PLUME gives more reliability to D_1 than does equation (2). If desired, the program can be easily modified to convert to the Pearson formula as follows:

```
IF(CLASS.EQ.SC)  DT1=THETA1*V1*DEPTH                    (30)
```

and so forth.

SUBROUTINE SDERIV

The CALL and SUBROUTINE statements for SDERIV are:

```
CALL SDERIV  (SPDS2,E+.5*FK,R+.5*FM)
CALL SDERIV  (S+DS,E+FK,R+FM)
CALL SDERIV  (S,E,R)
```

SUBROUTINE SDERIV (S,E,R)

Subroutine SDERIV calculates the derivatives de/ds and dr/ds which are the incremental changes of bouyancy and monentum as the plume develops. Incremental angle changes of the centerline are also a by-product of this subroutine.

FUNCTION ERF

The FUNCTION and call statements for FUNCTION are:

ERF (ARG)

FUNCTION ERF (ARG)

This program calculates the error function, which is a mathematical series expansion based on the following formulas:[23]

Case I, $0 \leq X \leq 3$:

$$\text{erf } x = 1 - \text{erfc } x \quad (31)$$

$$\text{erfc } x = 1/(1+a_1x+a_2x^2+a_3x^3+a_4x^4+a_5x^5)^8 \quad (32)$$

where a_1=0.14112821 a_4=0.00039446

a_1=0.08864027 a_5=0.00328975

a_3=0.02743349

and Case II, $X \geq 3$:

$$\operatorname{erfc} x = \frac{e^{-x^2}}{\sqrt{\pi}} \left(1 - \frac{1}{2x^3} + \frac{3}{2^2x^5} - \frac{15}{2^3x^7} + \frac{105}{2^4x^9} - \frac{945}{2^5x^{11}} + \frac{10365}{2^6x^{13}}\right) \qquad (33)$$

This function subroutine was developed for the use in several oceanographic computer programs by EPA.[24]

INPUT REQUIREMENTS AND DATA DESCRIPTION

Column	Variable	Description	Format
Card One:	"City Data"		
1-64	A	Degree of treatment	16A4
65-67	NCIT	Number of Cities	I3
Card Two:	"City Data"		
1-12	CIT(1-3)	City Names 1-3	3A4
13-14	NCLASS	Water Quality CLASS: SB=1; SC=b̸	I2
Card Three:	"Physical Data"		
1-4	V1	Avg. velocity of ocean water in effective mixing region	F4.1
6-9	V2	Ocean current velocity	F4.1
11-20	X1	Distance from shore to first slope change	E9.3
22-26	Y1	Depth at first slope change	F4.0
28-33	QW	Design Discharge	F5.1
35-39	Y2	Depth at second slope change	F4.0
40-49	X2	Distance from shore to second slope change	E9.3
51-56	Y3	Depth at third slope change	F5.0
58-67	X3	Distance from shore to third slope change	E9.3
Card Four:	"Plume Data"		
1	NDC	(Blank)	L1
2	METERS	Logical: T=MKS Units; b̸=FPS Units	L1
3-5	NPTS	Number of ambient density points	I3

Column	Variable	Description	Format
6-10	ANGLE	Port Angle from horizontal	F5.0
21-30	DIA	Port Diameter	F10.0
31-40	RHOJ	Density of Effluent	F10.0
41-50	RFD	(BLANK)	F10.0
51-60	Q	Design Discharge	F10.0
61-70	FN	Number of Ports (BLANK)	F10.0
71-80	PS	Desired data Printout along Centerline	F10.0

Card Five through Card NDP: "Density Data"

Cards are read until the number of density points is reached. Example card:

1-10	DP	Depth corresponding to its respective density point	F10.0
11-20	RHO	Ambient density of seawater	F10.0

NOMENCLATURE

Variable Name		Description	Units
Program	Other		
A		Degree of treatment	
ANGLE		Angle of port orientation from horizontal	Degrees
ARG	Equation(24)	Error Function Argument	
CIT		City Name	
CLASS		Water Quality Classification	E Coli/100 ML
COL		Coliform Number Corresponding to various degrees of treatment	
DEPTH	d	Depth of water over the diffuser	ft
DIA		Port Diameter	ft
DP		Depth corresponding to its respective density point	ft
DT	D_T	Total dilution required to meet water quality standard	
DT1	D_T	Total dilution calculated in subroutine EQN with varying X values	
DT2	D_T	Total dilution calculated if different water quality standard exists past a given distance from shore	
METERS		If "T", MKS units used If "Ø", FTS units used	
NCIT		Number of cities included in model	
NCLASS		Number designating water quality classification	
NPTS		Number of density profile points	
PS		Printout interval	ft
Q, QW	Q_W	Design Discharge	ft^3/sec

NOMENCLATURE -cont.-

Variable Name Program	Other	Description	Units
RHO	ρ	Ambient Density of water	gm/cm^3
RHOJ	ρ_j	Density of wastewater plume	gm/cm^3
T90	T_{90}	Time required for a 90 percent reduction in bacterial concentration	hrs.
V1	V_1	Average velocity of ocean water in effective mixing region	cm/sec
V2	V_2	Ocean current velocity	cm/sec
X	X	Distance from shore to end of outfall along water surface	ft
X1	X_1	Distance from shore to first slope change	ft
X2	X_2	Distance from shore to second slope change	ft
X3	X_3	Distance from shore to third slope change	ft
XXX		X - 1320 ft (1/4 mile)	ft
Y1	y_1	Depth at first slope change	ft
Y2	y_2	Depth at second slope change	ft
Y3	y_3	Depth at third slope change	ft

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APPENDIX A

(Listing of Source Deck)

APPENDIX 1 - LISTING

```
      COMMON/CRITCH/NPTS,ANGLE,DIA,RFD,Q,FN,PS,RHOJ
      COMMON/WOOD/ZD(50),DG(50),RHO(50),DP(50)
      DIMENSION A(16)
      LOGICAL NDC,METERS
      NOCASE=0
      READ(5,103)(A(I),I=1,16),NCIT
  103 FORMAT(16A4,I3)
      DO 9000 KK=1,NCIT
      DT2=0.
C     ASSIGNING T90 CONSTANT VALUES
C     MECHANICAL LOOP
    7 READ(5,1111)CIT1,CIT2,CIT3,NCLASS
      READ(5,5000) V1,V2,X1,Y1,QW,Y2,X2,Y3,X3
   20 READ(5,73,END=74)NDC,METERS,NPTS,ANGLE,DIA,      RHOJ,RFD,Q,FN,PS
   73 FORMAT(2L1,I3,F5.0,10X,6F10.0)
      DO 102 I=1,NPTS
      READ(5,75)DP(I),RHO(I),SAL
      IF(SAL.EQ.0.)GO TO 102
      RHO(I)=1.+.001*SIGMAT(SAL,RHO(I))
  102 CONTINUE
   75 FORMAT(8F10.0)
      WRITE(6,888)CIT1,CIT2,CIT3,V1,V2,X1,Y1,QW,Y2,X2,Y3,X3
  888 FORMAT('1',40X,'INPUT DATA FOR THE CITY OF ',3A4,/// ,25X,       '
     1V1          V2            X1           Y1          QW           Y2            X2
     1     Y3           X3',//,20X,9(E9.4,1X))
 1111 FORMAT(3A4,I2)
      Q=QW
      FN=14.*.646*Q/10.
      IF(NDC)WRITE(6,104)
  104 FORMAT('0    UNITS  NON DIMENSIONAL')
      IF(.NOT.NDC.AND.METERS)WRITE(6,105)
  105 FORMAT('0    UNITS  MKS')
      IF(.NOT.NDC.AND..NOT.METERS)WRITE(6,106)
  106 FORMAT('0    UNITS  FPS')
      WRITE(6,108)ANGLE,                PS,       RHOJ
  108 FORMAT(
     *40H-   PORT ANGLE . . . . . . . . . . . . . . .,F7.1/
     *40H    PRINTOUT INTERVAL  . . . . . . . . . . .,F8.2/
     *40H    DISCHARGE DENSITY  . . . . . . . . . . .,F11.5)
      IF(.NOT.NDC)WRITE(6,62)Q,FN,   DIA
   62 FORMAT(
     *40H    FLOWRATE . . . . . . . . . . . . . . . .,E15.5/
     *40H    NUMBER OF PORTS  . . . . . . . . . . . .,F5.0/
     *40H    PORT DIAMETER. . . . . . . . . . . . . .,E15.5)
      WRITE(6,24)((DP(I),RHO(I)),I=1,NPTS)
   24 FORMAT('-DENSITY STRATIFICATION DEPTH   RHO'//10(23X,F7.2,F11.5/))
 1038 FORMAT('1')
      WRITE(6,1038)
      NN=0
      DO 9000 N=1,2
      IF(NN.NE.0) GO TO 8990
C     ESTABLISHING A LOOP TO CALCULATE TOTAL DILUTION FACTORS FOR
C     DIFFERENT LEVELS OF SEWAGE TREATMENT,WITH A CORRESPONDING
C     EFFLUENT COLIFORM CONCENTRATION. NOW, E. COLI VALUES WILL BE
```

```
C       DEFINED                                                         OUTFL054
  500 COL1=2.2E+8                                                       OUTFL055
  510 COL2=1.2E+5                                                       OUTFL056
  520 COL3=5.5E+7                                                       OUTFL057
  530 COL4=3.0E+4                                                       OUTFL058
  540 COL5=6.77E+5                                                      OUTFL059
  550 COL6=8.7E+3                                                       OUTFL060
  560 COL7=1.0E+5                                                       OUTFL061
  570 COL8=1.0E+5                                                       OUTFL062
      GO TO 8980                                                        OUTFL063
 8990 COL1=1.0E+7                                                       OUTFL064
      COL2=5.0E+5                                                       OUTFL065
      COL3=1.0E+6                                                       OUTFL066
      COL4=10.0                                                         OUTFL067
      COL5=1.13E+5                                                      OUTFL068
      COL6=1.0                                                          OUTFL069
      COL7=1.0E+3                                                       OUTFL070
      COL8=1.0                                                          OUTFL071
 8980 II=0                                                              OUTFL072
      SC=10000.                                                         OUTFL073
      SB=70.                                                            OUTFL074
    8 IF(NCLASS.EQ.1)GO TO 33                                           OUTFL075
      IF(NCLASS.EQ.0)CLASS=SC                                           OUTFL076
      WRITE(6,11) CIT1,CIT2,CIT3                                        OUTFL077
   11 FORMAT('1','THIS PROGRAM CALCULATES THE CORRECT OUTFALL LENGTH COROUTFL078
     1RESPONDING TO DIFFERENT DEGREES OF TREATMENT FOR THE CITY OF ',3A4OUTFL079
     1,/'                        CLASS=SC')                             OUTFL080
      GO TO 23                                                          OUTFL081
   33 CLASS=SB                                                          OUTFL082
      WRITE(6,12) CIT1,CIT2,CIT3                                        OUTFL083
   12 FORMAT('1','THIS PROGRAM CALCULATES THE CORRECT OUTFALL LENGTH COROUTFL084
     1RESPONDING TO DIFFERENT DEGREES OF TREATMENT FOR THE CITY OF ',3A4OUTFL085
     1,/'                        CLASS=SB')                             OUTFL086
   23 IF(NN.EQ.0) PRINT 9500                                            OUTFL087
      IF(NN.GT.0) PRINT 9600                                            OUTFL088
 9500 FORMAT('0','E.COLI. VALUES ARE FOR EFFLUENTS RECEIVING NO CHLORINAOUTFL089
     1TION')                                                            OUTFL090
 9600 FORMAT('0','E.COLI. VALUES ARE FOR EFFLUENTS RECEIVING CHLORINATIOOUTFL091
     1N')                                                               OUTFL092
      IF(CLASS.EQ.SC)GO TO 7001                                         OUTFL093
      PRINT 7002                                                        OUTFL094
      GO TO 886                                                         OUTFL095
 7001 PRINT 7000                                                        OUTFL096
 7002 FORMAT('-','DISTANCE(SB)   DILUTION        DISTANCE(SC)   DILUTION OUTFL097
     2   T90',31X,'LEVEL OF TREATMENT')                                 OUTFL098
 7000 FORMAT('-','DISTANCE',5X,'DILUTION CALCULATED',5X,'DILUTION KNOWN OUTFL099
     1               ',30X,'LEVEL OF TREATMENT')                        OUTFL100
  886 T90=2.                                                            OUTFL101
      JJ=0                                                              OUTFL102
      GO TO 1                                                           OUTFL103
    2 T90=4.                                                            OUTFL104
      JJ=0                                                              OUTFL105
      GO TO 1                                                           OUTFL106
    3 T90=5.                                                            OUTFL107
```

```
      JJ=0
      GO TO 1
    4 T90=10.
      JJ=0
    1 CONTINUE
C     FINDING TOTAL DILUTION FACTORS
  200 DT=COL1/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  202 DT=COL2/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  203 DT=COL3/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  204 DT=COL4/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  205 DT=COL5/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  206 DT=COL6/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  207 DT=COL7/CLASS
      IF(DT.LT.1.0) GO TO 900
      GO TO 201
  208 DT=COL8/CLASS
      IF(DT.LT.1.0) GO TO 900
  201 CONTINUE
C     ESTABLISHING THE ITERATION SERIES TO CALCULATE DT EQUAL TO THE
C     KNOWN DT, WHICH WAS CALCULATED ABOVE.
      X=0.
   28 DO 25 I=1,50
      X=X+1000.
      CALL EQN(X,V1,V2,Y1,X1,Y2,X2,Y3,X3,QW,T90,DT,CLASS,DT1,XSTOR1,SC,S
     1B,DT2)
      IF(X.GT.(X1+X2+X3)) GO TO 304
      IF(DT1.GT.DT) GO TO 30
      IF(DT1.EQ.DT) GO TO 905
      D=DT1
   25 CONTINUE
      LM=2*JJ+1
      LL=LM+1
      WRITE(6,4000) X,A(LM),A(LL)
 4000 FORMAT('0 OUTFALL LOCATION EXCEEDS',F7.0,' FEET  WHICH IS THE PRES
     1ENT LIMIT OF THIS INVESTIGATION',9X,2A4)
      GO TO 210
  304 LM=2*JJ+1
      LL=LM+1
      WRITE(6,6000) X,A(LM),A(LL)
 6000 FORMAT('0 OUTFALL IS LOCATED AT',F7.0,' FEET , WHICH IS BEYOND THE
     1 POINT AT WHICH DEPTHS HAVE BEEN INPUT',2X,2A4)
      GO TO 210
```

```
   30 X=X-1000.
      DO 50 J=1,25
      X=X+40.
      CALL EQN(X,V1,V2,Y1,X1,Y2,X2,Y3,X3,QW,T90,DT,CLASS,DT1,XSTOR1,SC,S
     1B,DT2)
      IF(DT1.GT.DT) GO TO 60
      IF(DT1.EQ.DT) GO TO 905
   50 CONTINUE
   60 X=X-40.
      DO 80 K=1,20
      X=X+2.
      CALL EQN(X,V1,V2,Y1,X1,Y2,X2,Y3,X3,QW,T90,DT,CLASS,DT1,XSTOR1,SC,S
     1B,DT2)
      IF(DT1.GT.DT) GO TO 90
      IF(DT1.EQ.DT) GO TO 905
   80 CONTINUE
   90 X=X-2.
      DO 110 L=1,8
      X=X+0.25
      CALL EQN(X,V1,V2,Y1,X1,Y2,X2,Y3,X3,QW,T90,DT,CLASS,DT1,XSTOR1,SC,S
     1B,DT2)
      IF(DT1.GE.DT) GO TO 905
  110 CONTINUE
  900 X=1.
      DT1=DT
  905 IF(CLASS.EQ.SB.AND.X.GT.1320.) GO TO 901
      GO TO 6990
  901 CLASS=SC
      Y=X
      RT=DT
      DT=DT*SB/CLASS
      DT2=DT1
      CALL EQN(X,V1,V2,Y1,X1,Y2,X2,Y3,X3,QW,T90,DT,CLASS,DT1,XSTOR1,SC,S
     1B,DT2)
      IF(DT1.GE.DT)GO TO 6990
      GO TO 28
 6990 LM=2*JJ+1
      LL=LM+1
      IF(CLASS.EQ.SC.AND.DT2.LE.0.) WRITE(6,8000)X,DT1,DT,A(LM),A(LL)
      IF(CLASS.EQ.SB.AND.DT2.EQ.0.)WRITE(6,8888)X,DT1,T90,A(LM),A(LL)
                             IF(DT2.GT.0.)WRITE(6,8889)Y,DT2,X,DT1,T90,A(LM),A(
     1LL)
 8000 FORMAT('0',3(E11.5,10X),33X,2A4)
 8888 FORMAT('0',2E13.5,31X,F6.0,32X,2A4)
 8889 FORMAT('0',2(2E13.5,5X),F6.0,32X,2A4)
C     ESTABLISHING END OF ITERATION
  210 JJ=JJ+1
      IF(DT2.GT.0.)CLASS=SB
      DT2=0.
      IF(JJ.EQ.1) GO TO 203
      IF(JJ.EQ.2) GO TO 205
      IF(JJ.EQ.3) GO TO 207
C     ENDING INITIAL LOOP
C     NOW, THE MAIN PROGRAM IS ENDED BY FINISHING THE PRINCIPAL
```

```
C     MECHANICAL DO-LOOP.                                                OUTFL216
 1000 II=II+1                                                            OUTFL217
      IF(CLASS.EQ.SC) GO TO 89                                           OUTFL218
      IF(II.EQ.1) GO TO 2                                                OUTFL219
      IF(II.EQ.2) GO TO 3                                                OUTFL220
 5000 FORMAT(F4.1,1X,F4.1,1X,E9.3,1X,F4.0,1X,F5.1,1X,F4.0,1X,E9.3,1X,F5.OUTFL221
     $0,1X,E9.3)                                                         OUTFL222
   89 CONTINUE                                                           OUTFL223
      NN=NN+1                                                            OUTFL224
 9000 CONTINUE                                                           OUTFL225
   74 STOP                                                               OUTFL226
      END                                                                OUTFL227
      SUBROUTINE EQN(X,V1,V2,Y1,X1,Y2,X2,Y3,X3,QW,T90,DT,CLASS,DT1,XSTOREQN  000
     $1,SC,SB,DT2)                                                       EQN  001
      COMMON/CRITCH/NPTS,ANGLE,DIA,RFD,Q,FN,PS,RHOJ                      EQN  002
      THETA1=.210                                                        EQN  003
      THETA2=   .07071                                                   EQN  004
      THETA3=.0195                                                       EQN  005
      KK=0                                                               EQN  006
      LL=0                                                               EQN  007
      IF(X.LE.X1) DEPTH=X*Y1/X1                                          EQN  008
      IF(X.LE.(X1+X2).AND.X.GT.X1) DEPTH=Y1+(X-X1)*Y2/X2                 EQN  009
      IF(                   X.GT.(X1+X2)) DEPTH=Y1+Y2+(X-(X1+X2))*Y3/X3EQN  010
      IF(CLASS.EQ.SC) CALL PLUME(DEPTH,DT1)                              EQN  011
      IF(CLASS.EQ.SB.AND.X.LE.1320.) CALL PLUME(DEPTH,DT1)               EQN  012
      IF(CLASS.EQ.SB.AND.X.GT.1320.) GO TO 35                            EQN  013
      GO TO 39                                                           EQN  014
   35 XXX=X-1320.                                                        EQN  015
      ARG=1.+THETA2*QW**(-2./3.)*XXX/V2                                  EQN  016
      ARG=ARG**3                                                         EQN  017
      ARG=ARG-1.                                                         EQN  018
      ARG=1.5/ARG                                                        EQN  019
      ARG=ARG**(1./2.)                                                   EQN  020
      CALL PLUME(DEPTH,DT1)                                              EQN  021
      DT1=(DT1            *EXP(THETA3*XXX/(T90*V2)))/ERF(ARG)            EQN  022
   39 RETURN                                                             EQN  023
      END                                                                EQN  024
      FUNCTION ERF(ARG)                                                  ERF  000
C     THE ERROR FUNCTION                                                 ERF  001
C    **** THIS IS A FUNCTION SUBPROGRAM ****                             ERF  002
      XX=ARG                                                             ERF  003
      NEG=0                                                              ERF  004
      IF(XX.LT.0.0) NEG=1                                                ERF  005
      IF(XX.GE.3.0.OR.XX.LE.(-3.0)) GO TO 10                             ERF  006
      SUM=XX                                                             ERF  007
      Y=XX                                                               ERF  008
      FMULT=1.0                                                          ERF  009
      DO 5 N=1,50                                                        ERF  010
      FMULT=FMULT+2.0                                                    ERF  011
      FN=N                                                               ERF  012
      Y=-Y*XX*XX/FN                                                      ERF  013
      TERM=Y/FMULT                                                       ERF  014
      SUM=SUM+TERM                                                       ERF  015
      IF( ABS(TERM/SUM).LT.1.E-7) GO TO 6                                ERF  016
```

```
    5 CONTINUE
      STOP 5
    6 ERF=1.1283792*SUM
      GO TO 20
   10      SUM=1./XX
      Y=1./XX
      YLAST=1./XX
      FNUM=1.0
      DO 15 N=1,50
      Y=-Y*FNUM/2./XX/XX
      IF( ABS(Y/YLAST).GT.1..OR. ABS(Y/SUM).GT.1.E-7) GO TO 16
      YLAST=Y
      SUM=Y+SUM
      FNUM=FNUM+2.0
   15 CONTINUE
      STOP 15
   16 IF(XX.GT.30.) GO TO 18
   17 ERFC=(.5641896*EXP(-(XX*XX)))*SUM
      GO TO 19
   18 ERFC=0.
   19 ERF=1.-ERFC
   20 IF(NEG.EQ.1) ERF=-ERF
      RETURN
      END
      SUBROUTINE PLUME(DEPTH,    D1)
      COMMON/CRITCH/NPTS,ANGLE,DIA,RFD,Q,FN,PS,RHOJ
      COMMON/WOOD/ZD(50),DG(50),RHO(50),DP(50)
      COMMON/BLECH/G,FK,FM,COSTH,SINTH,COSTHE,DS,C1,C2,E13,FLAG,GRAV
      LOGICAL NDC,TRAPPD,FLAG,CHGDEN,METERS
C
C   PROGRAM PLUME, VERSION OF 4/6/72
C
      FD=ABS(RFD)
      METERS=.FALSE.
      NDC=.FALSE.
      IF(NPTS.NE.1)GO TO 76
      NPTS=2
      DP(2)=DEPTH
      RHO(2)=RHO(1)
   76 NOCASE=NOCASE+1
   75 FORMAT(8F10.0)
      GRAV=32.172
      IF(METERS)GRAV=9.80665
      DO 55 I=1,NPTS
      IF(DP(I).GE.DEPTH)GO TO 56
   55 CONTINUE
      WRITE(6,59)NOCASE
   59 FORMAT('-NO DENSITY INFORMATION FOR JET LEVEL.  EXECUTION FOR',
     *  ' CASE NO.',I2,' DELETED.')
      GO TO 20
   56 NP=I
      NM=I-1
      RHOB=(DEPTH-DP(NM))*(RHO(NP)-RHO(NM))/(DP(NP)-DP(NM))+RHO(NM)
      DISP=RHOJ-RHOB
```

```
      DO 54 I=1,NM
      J=NP-I
      ZD(I)=(DEPTH-DP(J))/DIA
   54 DG(I)=(RHO(J+1)-RHO(J))*DIA/(DISP*(DP(J+1)-DP(J)))
      IF(NDC)GO TO 58
      U0=Q/(FN*.7853982*DIA*DIA)
      RFD=U0*U0*RHOJ/(-DISP*DIA*GRAV)
      FD=ABS(RFD)
   58 IF(FD.LE.4.01.OR.FD.GE.9.99)GO TO 61
      S=.113*FD+4.
      GO TO 62
   61 IF(FD.LE.4.01)S=2.8*FD**.333333
      IF(FD.GT.10.)S=5.6*FD/SQRT(FD*FD+18.)
   62 TEMP=ATAN(1.416667*S/FD)
      THETA0=.0111*ANGLE*(1.5708-TEMP)+TEMP
      COSTHE=COS(THETA0)
      SINTHE=SIN(THETA0)
      DSI=DEPTH/(177.*DIA)
      IF(DG(1).EQ.0.)GO TO 77
      DGTEMP=.01/DG(1)
      IF(DGTEMP.LE.0.)DGTEMP=-DGTEMP
      DSI=.12*1.6**(ALOG10(FD/10.))*2.**(ALOG10(DGTEMP))
   77 NPO=IFIX(PS/(DSI*DIA)+.5)
      N=0
      Z=S*SINTHE
      X=S*COSTHE
      E=(4./S)**3
      R=.25
      C1=E**.6666667
      C2=.75/RFD
      IPTS=1
      G=DG(IPTS)
      ZLIM=ZD(IPTS)
      CHGDEN=.FALSE.
      FLAG=.FALSE.
      TRAPPD=.FALSE.
      XP=X*DIA
      ZP=DEPTH-Z*DIA
      DSIP=DSI*DIA
      SP=S*DIA
C**
C  SET INITIAL CONDITIONS
C**
      DS=DSI
      GO TO 16
   11 DS=DSI
   45 DELX=COSTH*DS
      DELZ=SINTH*DS
      DELE=FK
      DELT=FM
      SPDS2=S+DS/2.
      DO 10 I=1,2
      CALL SDERIV(SPDS2,E+.5*FK,R+.5*FM)
      DELX=DELX+2.*COSTH*DS
```

```
      DELZ=DELZ+2.*SINTH*DS
      DELE=DELE+2.*FK
      DELT=DELT+2.*FM
   10 CONTINUE
      CALL SDERIV(S+DS,E+FK,R+FM)
      ZLAST=Z
      ZINCR=(DELZ+SINTH*DS)/6.
      Z=Z+ZINCR
      IF(CHGDEN)GO TO 41
      IF(Z.GT.ZLIM)GO TO 40
   43 X=X+(DELX+COSTH*DS)/6.
      E=E+(DELE+FK)/6.
      R=R+(DELT+FM)/6.
      S=S+DS
      IF(E.LE.0.)FLAG=.TRUE.
C
C     THIS STOPPING CRITERIA IS BASED ON VELOCITY GOING TO ZERO
C
      IF(FLAG)GO TO 13
   16 CALL SDERIV(S,E,R)
      IF(TRAPPD)GO TO 14
      IF(R.GT.0.)GO TO 15
      RAT=R/(RO-R)
      E13TRP=E13+(E13-E130)
      ZTRAP=DEPTH-(Z+ZINCR*RAT)*DIA
      SMTRAP=.245*(S+DS*RAT)*E13TRP
      TRAPPD=.TRUE.
      GO TO 14
   15 RO=R
      E130=E13
   14 N=N+1
      IF(N-(N/NPO)*NPO.NE.0)GO TO 11
   13 XP=X*DIA
      ELEV=Z*DIA
      ZP=DEPTH-ELEV
      SP=S*DIA
      DILN=.245*S*E13
      THETA=ARCOS(COSTH)*57.2958
      IF(.NOT.TRAPPD)GO TO 72
      D1=       SMTRAP
   71 IF(.NOT.FLAG) GO TO 11
      GO TO 20
   72 D1=DILN
      GO TO 71
C
C     FIND NEXT STRATIFICATION AND RECOMPUTE LAST STEP IF NECESS)
C
   40 DS=DS*(ZLIM-ZLAST)/(Z-ZLAST)
      CALL SDERIV(S,E,R)
      CHGDEN=.TRUE.
      Z=ZLAST
      GO TO 45
   41 CHGDEN=.FALSE.
      IPTS=IPTS+1
```

```
      IF(IPTS.GT.NM)GO TO 42                                            PLUME138
      G=DG(IPTS)                                                        PLUME139
      ZLIM=ZD(IPTS)                                                     PLUME140
      GO TO 43                                                          PLUME141
   42 FLAG=.TRUE.                                                       PLUME142
      GO TO 43                                                          PLUME143
   20 RETURN                                                            PLUME144
   74 STOP                                                              PLUME145
      END                                                               PLUME146
      SUBROUTINE SDERIV(S,E,R)                                          SDERV000
      COMMON/BLECH/G,FK,FM,COSTH,SINTH,COSTHE,DS,C1,C2,E13,FLAG,GRAV    SDERV001
      LOGICAL FLAG                                                      SDERV002
      E13=0.                                                            SDERV003
      IF(E.LE.0.)GO TO 3                                                SDERV004
      E13=E**.3333333                                                   SDERV005
      COSTH=COSTHE*C1/(E13*E13)                                         SDERV006
      IF(COSTH.LT.1.)GO TO 1                                            SDERV007
C                                                                       SDERV008
C   THIS STOPPING CRITERIA IS BASED ON PLUME BECOMING HORIZONTAL        SDERV009
C   AGAIN                                                               SDERV010
C                                                                       SDERV011
      FLAG=.TRUE.                                                       SDERV012
      SINTH=0.                                                          SDERV013
      COSTH=1.                                                          SDERV014
      GO TO 3                                                           SDERV015
    1 SINTH=SQRT(1.-COSTH*COSTH)                                        SDERV016
    3 FK=C2*S*R*SINTH*DS                                                SDERV017
      FM=.109*S*E13*G*DS                                                SDERV018
      RETURN                                                            SDERV019
      END                                                               SDERV020
      FUNCTION SIGMAT(SAL,T)                                            SIGMT000
      SIGO     = (((6.8E-6*SAL)-4.82E-4)*SAL+.8149)*SAL-.093            SIGMT001
      B        = 1.E-6*T*((.01667*T-.8164)*T+18.03)                     SIGMT002
      A        = .001*T*((.0010843*T-.09818)*T+4.7867)                  SIGMT003
      SUMT     = (T-3.98)*(T-3.98)*(T+283.)/(503.57*(T+67.26))          SIGMT004
      SIGMAT   = (SIGO+.1324)*(1.-A+B*(SIGO-.1324))-SUMT                SIGMT005
      RETURN                                                            SIGMT006
      END                                                               SIGMT007
```

APPENDIX B

(Example Problem)

The design of outfalls for ten different coastal cities on the Island of Puerto Rico can be modelled using OUTFALL. The cities chosen are listed as follows: Aguadilla, Arecibo, Barceloneta, Carolina, Guayanilla, Humacao, Mayaguez, Ponce, San Juan, and Yabucoa. As shown in Figure B-1, the current patterns for Puerto Rico flow basically from east to west except for a recirculation current which appears during the summer near the northern coast. During the summer, the southeast winds cause the current to run northward through Vieques Passage, but in the winter, the northeast wind produces a southern current through the Passage. Table B-1 indicates the location of the proposed outfalls and their true azimuth in degrees perpendicular from their respective location on shore. Basic outfall sites, also shown in Figure B-1, are located in areas of widely differing environmental conditions. Water quality standards, promulgated by the Puerto Rico Environmental Quality Board, change the amount of the dilution of the wastewater needed to meet those standards in each area. This factor is incorporated within OUTFALL as the variable CLASS, as indicated in the section concerning the computer program. SB class waters are defined as those waters having less than 70 coliform organisms per 100 milliliters of seawater, and SC class waters are defined as those waters having less than 10,000 coliform organisms per 100 milliliters of seawater.

In equation (26), the final expression for total dilution involving the Pearson, Brooks and first order decay equations, D_T is a function of six variables: the average velocity of ocean water in the effective mixing region (V_1), the ocean current velocity (V_2), the distance from the shore to the end of the outfall along the water surface (X), the design discharge of the treatment plant (Q_W), the depth of water over the diffuser (d), and the T_{90} decay value. These variables are presented in Table B-2, along with the water quality classification for each outfall location.

As sources for the data given in Table B-2, V_1 and V_2 were taken from a recent study conducted by the Puerto Rico Department of Natural Resources and Engineering Science, Incorporated[12], and Q_W values were obtained from the Puerto Rico Aqueduct and Sewer Authority.[13] The T_{90} values presented a special problem, as several conflicting studies have been conducted. A summary of the results of ten different studies encompassing seven geographical locations is presented as Table B-3. In the Puerto Rico situation, standards must be met at the maximum point of rise over the end of the outfall in the areas, regardless of the type of water quality standard. Therefore, only initial dilution (D_1) needs to be calculated in these cases. A boundary of one-quarter mile (1320 feet) was assumed for the Puerto Rico water quality standards (in other words, the standard would extend from the shoreline out to a distance of one-quarter mile). After that distance is reached, it is assumed that all waters outside of one-quarter mile limit would be SC class waters, i.e., discharges must comply with the lowest water quality standards (Class SC). If the outfall extends greater than this boundary, D_2 and D_3 must be also calculated. Thus, T_{90} values must be assumed for SB class waters. The outfall locations at Barceloneta, Carolina, and Humacao have SB class standards. Data were extrapolated from Table B-3 and are presented in Table B-2.

Density data and water depth used in the PLUME subroutine are presented in Table B-4 for each city. RHO is inputed as gm/cm^3, and the depth is in feet.[11] Other data used in the PLUME subroutine were assumed as indicated in Table B-5.

Finally, the data are punched onto computer cards as described on page and as shown in Table B-6, and OUTFALL is run. The resulting output is attached.

The necessary outfall length needed to meet the water quality standard and corresponding to a certain level of treatment is listed in the "DISTANCE" column. The dilution calculated (essentially a modification of equation 26) and the known dilution (equation 28 appear in their respective columns. Three other messages may appear in the output. If either "OUTFALL IS LOCATED AT X FEET, WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT" or "OUTFALL LOCATION EXCEEDS X FEET, WHICH IS THE PRESENT LIMIT OF THIS INVESTIGATION" appears, it means that either in-plant chlorination must be added or a higher degree of treatment must be attained in order to meet water quality standards within the limit of X. If the following message appears in the output, it indicates that more bottom slope (depth/distance) data is needed to be inputed: "NO DENSITY INFORMATION FOR JET LEVEL EXECUTION FOR CASE NO. **DELETED".

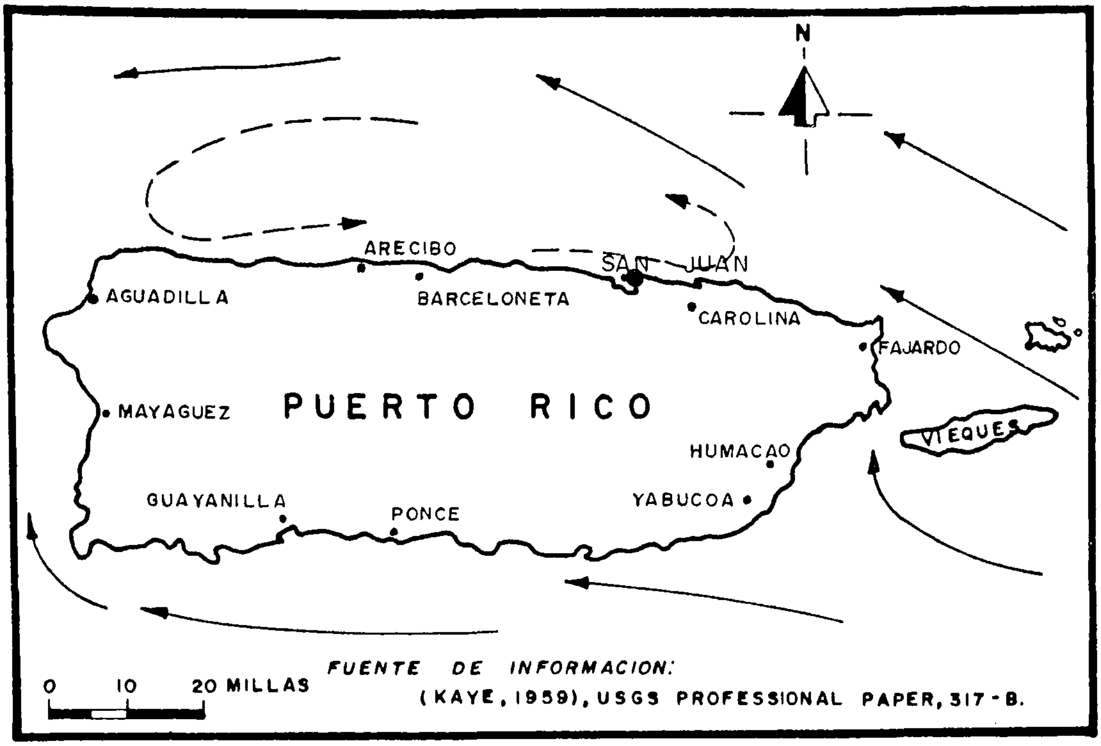

FIGURE B-1

TABLE B - 1

OCEAN OUTFALL LOCATIONS

City	Outfall Location	True Azimuth from Point on Shore
Aguadilla	0.22 mi. NE of Río Culebrinas	331°
Arecibo	3.78 mi. SW of Pta. Caracoles	335°
Barceloneta	3.78 mi. E of Pta. Palmas Altas	357°
Carolina	0.018 mi. W of Río Grande de Loíza	9.5°
Guayanilla	8.2 mi. NE of Pta. Ventana	177°
Humacao	7.58 mi. NE of Río Humacao	137°
Mayaguez	0.01 mi. N of Quebrada del Oro	279°
Ponce	0.125 mi. W of Río Matilde	178°
San Juan	From Puerto Nuevo Plant	1^{st} Sect. - 312° 2^{nd} Sect. - 331°
Yabucoa	3.79 mi. SW of Cano Santiago	135°

TABLE B-2

PHYSICAL AND BIOLOGICAL PARAMETERS

CITY	V_1 cm/sec	V_2 cm/sec	Q_w cfs	T_{90} hrs	X_1/y_1 feet	X_2/y_2 feet	X_3/y_3 feet	CLASS (Water Quality)
Aguadilla	10.0	19.0	27.8		3160/60	1425/60	4250/480	SC
Arecibo	8.5	17.5	46.4		4390/120	2630/180	1760/300	SC
Barceloneta	8.5	17.5	46.4	5	1770/60	1770/60	6130/480	SB
Carolina	22.0	33.0	92.8	2,4	6350/18	1600/42	13400/540	SB
Guayanilla	9.5	15.5	92.8		3530/108	48400/12	4860/1200	SC
Humacao	11.0	14.0	18.6	2,4	24700/60	3490/60	2690/1255	SB
Mayaguez	12.0	16.0	46.4		14700/120	2800/78	6500/402	SC
Ponce	21.5	27.5	46.4		10800/60	7610/1	1900/540	SC
San Juan	10.0	15.5	290.8		20300/30	5600/60	5020/480	SC
Yabucoa	11.0	14.0	18.6		30800/30	4840/12	1795/558	SC

TABLE B-3

ESTIMATES OF COLIFORM

DIE-OFF (T_{90}) BY LABORATORY

AND FIELD STUDIES IN PUERTO RICO

CITY	T_{90} (hrs)	STUDY
AGUADILLA	2.1 - 4.9	Weston (1970)[14]
ARECIBO	18	Bogert (1972)[15]
BARCELONETA	5	Black & Veatch (1971)[16]
HUMACAO	0.95 - 4.0	O'Kelly (1971)[17]
ISABELA	18	Bogert (1970)[18]
MAYAGUEZ	0.9 - 1.3	Engineering Science (1972)[12]
MAYAGUEZ	2.9	Engineering Science (1972)[12]
MAYAGUEZ	1.5	Guzman (1970)[19]
MAYAGUEZ	1.3 - 3.1	Black & Veatch (1971)[20]
PONCE	1.45 - 1.55	Hazen & Sawyer (1970)[21]
GUAYAMA	(Apparent Regrowth)	Engineering Science (1972)
GUAYAMA	11	Heres (1971)[22]

TABLE B - 4

DENSITY STRATIFICATION DATA FOR

VARIOUS COASTAL CITIES IN PUERTO RICO

	DEPTH (feet)	RHO (gm/cm^3)
AGUADILLA:	0	1.02267
	2.00	1.02300
	8.00	1.02310
	20.00	1.02320
	44.00	1.02330
	54.00	1.02340
	62.00	1.02350
	96.00	1.02400
	120.00	1.02450
	137.00	1.02500
	149.00	1.02550
	158.00	1.02600
	200.00	1.02600
ARECIBO:	0	1.02310
	6.00	1.02330
	17.00	1.02340
	26.00	1.02350
	54.00	1.02400
	72.00	1.02450
	92.00	1.02500
	119.00	1.02550
	200.00	1.02550
BARCELONETA:	0	1.02300
	6.00	1.02310
	13.00	1.02320
	26.00	1.02340
	38.00	1.02350
	76.00	1.02400
	98.00	1.02450
	118.00	1.02500
	200.00	1.02500

TABLE B - 4 (CONT.)

	DEPTH (feet)	RHO (gm/cm^3)
CAROLINA:	0	1.02370
	2.00	1.02380
	10.00	1.02390
	37.00	1.02410
	56.00	1.02420
	70.00	1.02430
	84.00	1.02440
	92.00	1.02450
	102.00	1.02460
	112.00	1.02470
	119.00	1.02480
	123.00	1.02490
	130.00	1.02500
	134.00	1.02510
	138.00	1.02520
	142.00	1.02530
	144.00	1.02540
	148.00	1.02550
	152.00	1.02560
	154.00	1.02570
	158.00	1.02580
	160.00	1.02590
	200.00	1.02600
GUAYANILLA:	0	1.02307
	6.00	1.02310
	18.00	1.02320
	24.00	1.02330
	31.00	1.02340
	40.00	1.02350
	90.00	1.02400
	122.00	1.02450
	144.00	1.02500
	200.00	1.02500
MAYAGUEZ:	0	1.02299
	6.00	1.02300
	20.00	1.02310
	40.00	1.02320
	58.00	1.02330
	66.00	1.02340
	74.00	1.02350
	100.00	1.02400
	120.00	1.02450
	136.00	1.02500
	156.00	1.02550
	200.00	1.02550

TABLE B - 4 (CONT.)

	DEPTH (feet)	RHO (gm/cm^3)
PONCE:	0	1.02169
	10.00	1.02186
	24.00	1.02200
	59.00	1.02250
	76.00	1.02300
	84.00	1.02350
	88.00	1.02400
	90.00	1.02450
	108.00	1.02500
	124.00	1.02550
	200.00	1.02550
SAN JUAN:	0	1.02208
	4.00	1.02300
	6.00	1.02320
	8.00	1.02340
	10.00	1.02360
	12.00	1.02380
	23.00	1.02400
	32.00	1.02410
	38.00	1.02420
	49.00	1.02430
	58.00	1.02440
	67.00	1.02450
	76.00	1.02460
	84.00	1.02470
	91.00	1.02480
	98.00	1.02490
	104.00	1.02500
	110.00	1.02510
	116.00	1.02520
	121.00	1.02530
	126.00	1.02540
	131.00	1.02550
	136.00	1.02560
	140.00	1.02570
	145.00	1.02580
	149.00	1.02590
	200.00	1.02590
YABUCOA/HUMACAO:	0	1.02267
	2.00	1.02300
	10.00	1.02350
	42.00	1.02400
	70.00	1.02450
	92.00	1.02500
	115.00	1.02550
	153.00	1.02600
	200.00	1.02600

TABLE B-5

SUBROUTINE PLUME

ASSUMPTIONS OF INITIAL CONDITIONS

VARIABLE	VALUE
METERS	4=FPS units used.
ANGLE	0 degrees
DIA	1.0 ft.
RHOJ	0.999 gm/cm^3
PS	2.0 ft.

Appendix C

INPUT DATA FOR THE CITY OF BARCELONETA

V1	V2	X1	Y1	QW	Y2	X2	Y3	X3
.8500E+01	.1750E+02	.1770E+04	.6000E+02	.4640E+02	.6000E+02	.1770E+04	.4800E+03	.6130E+04

UNITS FPS

PORT ANGLE 0.0
PRINTOUT INTERVAL 2.00
DISCHARGE DENSITY 0.99900
FLOWRATE . . . . 0.46400E+02
NUMBER OF PORTS . . . . 42.
PORT DIAMETER. . . . . 0.10900E+01

DENSITY STRATIFICATION DEPTH RHO

DEPTH	RHO
0.0	1.02300
19.68	1.02310
42.65	1.02320
85.30	1.02340
124.67	1.02350
249.35	1.02400
321.53	1.02450
387.15	1.02500
656.19	1.02500

THIS PROGRAM CALCULATES THE CORRECT OUTFALL LENGTH CORRESPONDING TO DIFFERENT DEGREES OF TREATMENT FOR THE CITY OF BARCELONETA
CLASS=SB

E.COLI. VALUES ARE FOR EFFLUENTS RECEIVING NO CHLORINATION

DISTANCE(SB)	DILUTION	DISTANCE(SC)	DILUTION	T90	LEVEL OF TREATMENT
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					RAW MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					PRI MAX
0.74595E+04	0.96746E+04	0.74595E+04	0.87529E+02	2.	SEC MAX
0.46845E+04	0.14287E+04	0.46845E+04	0.10276E+03	2.	TER MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					RAW MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					PRI MAX
0.85997E+04	0.96742E+04	0.85997E+04	0.29644E+03	4.	SEC MAX
0.72895E+04	0.14286E+04	0.72895E+04	0.77042E+02	4.	TER MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					RAW MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					PRI MAX
0.89352E+04	0.96728E+04	0.89352E+04	0.39357E+03	5.	SEC MAX
0.75620E+04	0.14289E+04	0.75620E+04	0.96787E+02	5.	TER MAX

THIS PROGRAM CALCULATES THE CORRECT OUTFALL LENGTH CORRESPONDING TO DIFFERENT DEGREES OF TREATMENT FOR THE CITY OF BARCELONETA
CLASS=SB

E.COLI. VALUES ARE FOR EFFLUENTS RECEIVING CHLORINATION

DISTANCE(SB)	DILUTION	DISTANCE(SC)	DILUTION	T90	LEVEL OF TREATMENT
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					RAW MAX
0.76815E+04	0.14286E+05	0.76815E+04	0.11026E+03	2.	PRI MAX
0.48392E+04	0.16146E+04	0.48392E+04	0.10291E+03	2.	SEC MAX
0.63950E+03	0.14294E+02			2.	TER MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					RAW MAX
0.89042E+04	0.14289E+05	0.89042E+04	0.38532E+03	4.	PRI MAX
0.73960E+04	0.16146E+04	0.73960E+04	0.83079E+02	4.	SEC MAX
0.63950E+03	0.14294E+02			4.	TER MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					RAW MAX
OUTFALL IS LOCATED AT 10000. FEET , WHICH IS BEYOND THE POINT AT WHICH DEPTHS HAVE BEEN INPUT					PRI MAX
0.76437E+04	0.16144E+04	0.76437E+04	0.10600E+03	5.	SEC MAX
0.63950E+03	0.14294E+02			5.	TER MAX