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THE APPLICATION OF DESKTOP COMPUTER PROGRAM TO THE DESIGN OF STORM SEWER SYSTEMS FOR URBAN RESIDENTIAL LAYOUTS

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ABSTRACT

The application of desktop computer to the design of storm sewer systems for urban residential layouts was investigated and outlined. The preliminary design was at full flow conditions, and Manning's Formula was used for routing storm runoff through the system. The hydraulic analysis was based on the standard step-backwater computational technique, which applied Bernoulli's energy equation to estimate frictional losses in the system. The determination of the appropriate pipe sizes was by trial and error procedure, which ran for several man-hours, for a multi-branch system. A desktop computer program was developed for the calculation of the pipe discharges and rainfall intensities for a selected portion of Mokola residential area, Ibadan, from the basic equations. The program proceeded to determine suitable pipe sizes, internal checks for pipe slopes, velocity of flow, fall in pipe levels and invert elevations for both pipe inlets and outlets. The computer outputs were compared with the results obtained using the conventional charts and tables in analyzing the selected area. The results produced using the Q-Basic program were more accurate, and were obtained in a few seconds

Keywords: Storm Sewer Systems, Preliminary Designs, Conventional Analysis, Basic Equations.

INTRODUCTION

The design of drainage systems for small urban areas, where the diameter of the largest sewer is unlikely to exceed 600mm, usually follows the Rational Formula as detailed in Palmer et al (1982), Garcia and James (1988), Archer (1982) and Nelson, (1983). The procedure for computation of storm water runoff, hydraulic design of storm sewers, rainfall intensities and determination of sub-area flows are outlined in McGhee, (1991); Tabors et.al, (1976); and American Iron and Steel Institute, (1980). The recommended minimum and maximum velocities for all conditions as well as minimum and maximum pipe slopes are contained in Ingram, (1983). The procedure described in the references above, uses charts and tables for sizing pipes, together with graphs for determining the time of concentration and intensity of rainfall at the site of the urban drainage system.

The derivation of the appropriate pipe sizes follows a trial and error procedure, which is time consuming.

The use of the desktop computer, which can be programmed with the simple high level language, Q - BASIC, allows the engineer to investigate quickly and inexpensively the effect of modifying system layouts and design criteria to produce an optimum solution.

The use of desktop computer for urban sewer design allows the calculation of pipe discharges and rainfall intensities from the basic equations. These are therefore used in a computer program for the hydraulic design of storm sewer network for a selected portion of Mokola residential layout in Ibadan, Oyo State, Nigeria, in place of the conventional charts, graphs and tables.

Fig. 1 shows the topographical map of the selected area with arrows indicating the drainage route for the storm water.

THEORETICAL BACKGROUND

Intensity of Rainfall

Rainfall intensity (I) is defined as the rate at which rain falls and varies for different localities and duration. Its selection in design requires reasonable judgment since it goes hand in hand with the runoff coefficient, C. In practice, either an average value of C is employed or rainfall intensity duration frequency curves are used.

Several formulae have been formulated for rainfall intensity (I), which have a general form as noted by Nelson (1983):

$$I = \frac{kF^{n_1}}{(t+b)^n} \qquad (1)$$

Where, I = rainfall intensity in mm/hr

F = frequency of occurrence of rainfall in years

t = duration of storm in minutes (time of concentration).

k, b, n, and n_1 = coefficients determined from the rainfall intensity duration frequency curves.

Rational Method

One of the several empirical formulae used in storm sewer design is the Rational formula, also known as rational method.

The Rational formula is expressed as

$$Q = C\,I\,A \qquad (2)$$

Where Q = quantity of storm water runoff in m^3/sec

C = coefficient of runoff

I = average intensity of rainfall in m/sec

A = area of watershed in m^2

The assumptions in the formula are outlined below.

The maximum rate of runoff for particular rainfall intensity occurs if the duration of rainfall is equal to or greater than the time of concentration.
The maximum rate of runoff from a specific rainfall intensity whose duration is equal to or grater than the time of concentration is directly proportional to the rainfall intensity.

The frequency of occurrence of the peak discharge is the same as that of the rainfall intensity from which it was calculated.

The peak discharge per unit area decreases as the drainage area increases, and the intensity of rainfall decreases as its duration increases.

The coefficient of runoff remains constant for all storms on a given watershed
The rainfall intensity is uniform over the entire watershed during the entire storm duration. (American Iron and steel Institute, 1980)

Flow in Storm Sewers

Various formulae have been devised for storm water flow computations of which are the Manning, Chezy, Kutter, Hazen and William's formulae.

Of the four, Manning's equation is mostly preferable to design engineers owing to its manipulative nature in algebraic notations, simplicity and ease of use.

However the Manning and Kutter's formulae are only improvements on Chezy's formulae as both expressed the discharge coefficient, C in terms of the rate of friction loss, hydraulic radius and roughness coefficient. Equations 3, 4, 5 and 6 give the general forms for the Chezy, Manning, Hazen and Williams and Kutter's formulae respectively.

$$V = CR^{1/2} S^{1/2} \qquad (3)$$

$$V = \frac{1.486 R^{1/3} S^{2/3}}{n} \qquad (4)$$

$$V = 1.318 CR^{0.63} S^{0.54} \qquad (5)$$

Where C = discharge coefficient

$$C = 1.486 \times \frac{R^{1/6}}{n}$$

(Mannings formula) (6)

$$C = \frac{(41.65 + 2.81 \times 10^{-3}/s) + 1.8^{11}/n}{(41.65 + 2.81 \times 10^{-3}/s)(n/r^{1/2}) + 1}$$

(Kutters formula) (7)

R = hydraulic radius
S = invert Slope

Values of n for different conduit materials are as outlined in Ingram (1983).

METHODOLOGY

A topographic map showing the existing and proposed roads, buildings, contours and natural watercourse was obtained from the Map Depot, Oyo State Secretariat, Ibadan, to gain a good knowledge of the layout area under consideration. In addition, hydrological data was obtained. The preliminary design stage included a tentative plan of the proposed system. Based on the topography of the site, the proposed sewer conduits were laid out with proper identification of sub-areas, direction of flow and location of manholes at the most advantageous points, with number notations in a sequential order, starting from 1-20, as depicted in Fig. 2. These were, in addition to other important details, prepared on profiles. The final design stage involved computing the pipe sizes, estimating the flow rates, velocities of flow, slope of pipes, etc, based on the Rational Method, Manning's equation and the step-backwater computational procedures.

The major steps used in the manual hydraulic design of the storm sewer system are outlined as follows.

The tributary area was divided into small sub-areas and each was determined using the principles of surveying. Each area was given an identifying designation.

With appropriate engineering judgment, values of runoff coefficient, time of concentration, proposed storm design frequency and rainfall intensities were selected and calculated for each sub-area.
Based on the storm sewer arrangement, the flow to each inlet was determined and consequently the capacities.

The maximum runoff (discharge) was estimated starting at the upstream and moving downstream of the system.

Pipe sizes were selected by trial and error method to accommodate the discharges, putting into consideration the hydraulic limits and making assumptions where necessary.
These were repeated with computations in the reverse direction, i.e. from downstream to upstream. This served as a check on the initially estimated values.

Equivalent hydraulic alternatives were made to determine the equivalent pipe sizes for uncoated corrugated steel pipes (CSP).

The sewer locations were then plotted on a profile diagram, with the elevations of the ground levels, manhole inverts, and dimensions of pipes, clearly indicated.

The steps outlined above were then translated into flowcharts and program listings in Q-BASIC as outlined in Appendix 1 to produce rapid and accurate results. The source code for this computer program, its output and the hydraulic design layout are given in Appendices 2 and 3 respectively.

RESULTS AND DISCUSSION

A 15-year design storm was used as a basis for the design. The results from the 15-year storm frequency curve obtained from storm runoff analysis based on a forty year rainfall intensity duration records from the Federal Ministry of Aviation, Ibadan are summarized in Table 1.

This table enables the interpolation for the runoff intensities corresponding to various times of concentration to be computed. For example the starting manholes (1,4, 7, 10, 14, as indicated in Figure 2) will have their time of concentration corresponding to rainfall intensities of (56.23, 62.81, 77.45, 54.20 and 65.77) mm/hr respectively. From Figure 2, inlets are located at the upstream manhole for each length of conduit and the discharge for each manhole is computed to determine their capacities. Results from these flow calculations are presented in Table 2 below. The coefficient of runoff, C of 0.59 based on Mc Ghee (1991), has been assumed for all sub-catchment areas.

Table 1: Rainfall Intensities (mm/hr) for 15 Year-Return Period for Samonda, Ibadan

Duration (time) (min)	15-year Return Period (mm/hr)
1	226.46
2	159.96
3	128.23
4	111.69
5	98.63
6	89.13
7	81.85
8	76.3 8
9	72.44
10	68.87
11	65.31
12	62.09
13	59.98
14	56.89
15	54.95
16	53.70
17	51.88
18	50.12
19	48.98
20	47.10
21	46.77
22	45.50
23	43.95
24	43.45
25	42.46
26	41.69
27	40.74
28	40.27
29	39.63
30	38.28

Source: Federal Ministry of Aviation, Ibadan (2003).

Table 2: Required Storm Water Inlet Capacities

Sub- Area	Inlet M.H	Area (m^2)	Run-off Coeff.	Intensity mm/hr	Runoff m^3/mi
A	1	4775.25	0.59	56.23	2.64
B	2	4680.00	0.59	56.23	2.59
D	4	3794.00	0.59	62.81	2.35
E	5	4545.00	0.59	62.81	2.82
H	7	2160.00	0.59	77.45	1.64
G	10	4656.00	0.59	54.20	2.48
N	11	4998.63	0.59	54.20	2.66
P	12	5061.00	0.59	54.20	2.70
L	14	3795.88	0.59	65.77	2.46
M	15	4955.75	0.59	65.77	3.22
O	16	5096.50	0.59	65.77	3.31
Q	17	4933.00	0.59	65.77	3.20
S	18	6447.50	0.59	65.77	4.17
C	3	3448.22	0.59	56.23	1.91
F	6	5142.67	0.59	62.81	3.19
I	8	6409.59	0.59	77.45	4.88
J	9	4230.54	0.59	77.45	3.22
K	13	7339.00	0.59	77.45	5.59
R	19	9382.73	0.59	77.45	7.14

Preliminary storm drainage piping-design to determine the discharge carried by each sewer section in the system, moving from the upstream to the downstream, till the peak discharge at the outfall, is presented in a tabular arrangement as shown in Table 3.

The standard step backwater computational method was used for the final hydraulic analyses taking into account the backwater effect and allowing for energy losses within the system. The computations here were made proceeding from downstream to the upstream, considering one sewer section at a time. The design computations are arranged in a tabular form as reflected in Table 4.

CONCLUSIONS AND RECOMMENDATION

The program, which is listed in Appendix 2, will, when run on a desktop computer, allow the calculation of the pipe sizes for a small urban sewer design to be completed in few minutes, whereas the manual method involving charts and tables can take many hours of iterations to obtain the appropriate pipe sizes. Furthermore, provided that the data have been carefully entered into the program and are checked in the tabulated output, the chances of computational errors occurring are minimal, whereas with manual methods, errors can frequently occur.

Changes in pipe diameters due to modification to depths, pipe inverts, pipe lengths, or areas to be drained, can be investigated very quickly by simply retyping one number in the appropriate data statement of the program, using the computer editing facility. A few seconds after the number has been retyped a revised tabular output will be displayed.

It is recommended that the program be enhanced to allow an additional column for the calculation of costs associated with various design layouts. However, to ensure user friendliness, it would be necessary to store input data on separate data files so that data for each layout could be read into the source program.

APPENDIX 1: COMPUTER PROGRAM ALGORITHMS

The algorithms for the Storm Sewer Design Program are as outlined below:

(1) Input the location of the sewer system
(2) Input date of run and name of user.
(3) Read from data statements, five sets of values for N, RC, D and S, as defined.
(4) Read the time of concentration in minutes (IT) and the corresponding rainfall intensity in mm/hr (RI)
(5) Evaluate the current time of concentration C (k).
(6) Evaluate the rainfall intensity for (5) above as CRI (k) in mm/hr.
(7) Convert the value obtained in (6) to m/min.
(8) Read the Manning's coefficient, (kk), coefficient of runoff (RCK) and the return period (T) of storm.
(9) Read the number of branches in the sewer system T1 and the number of pipe lengths T2, following the notation in appendix 2.
(10) Print out the headings for the tabular output and define the output format.
(11) Set the time of concentration at the starting manhole for each branch C (k)
(12) Initialize the values for each branch U of the system; cumulative areas A (U) = 0, and the first trial value for the first pipe diameter D (U) = 200mm.
(13) Set a variable U1 = 0
(14) Perform operations, (15) to (23), within a loop; for each of the T2 pipe lengths
(15) Read from a data statement five numbers relating to a pipe length, i.e., branch number U, pipe length number VI, Pipe slope SL in %, length of the pipe L in metres, impermeable area A in metres, ground elevation at upstream US(J),.ground elevation at downstream DS(J) and dummy variable CONT.
(16) Calculate the cumulative area for each branch.
(17) If the previous pipe formed part of the branch with a higher branch number, then add the total cumulative area for this previous branch.
(18) For each pipe length calculate the discharge Qm^3/mm, using the Manning's equation, the velocity Vm^3/s = (Q / cross sectional area of pipe) x 60; and the time of travel M in minutes.
(19) Check if the pipe length is unproductive. If so M = 0 for this length.
(20) Calculate the time of concentration C (u) in minutes, and then carry out interpolation to obtain the corresponding rainfall intensity.
(21) Use the Rational formula to calculate the discharge the pipe will need to carry if rain falls with intensity I mm/ hr on a total impermeable area of A (U) m^2.
(22) If the discharge the pipe needs to carry is less than 1.1 times the discharge a full pipe can carry, then the selected diameter is satisfactory and a completed row of calculated values can be printed out, the value of U1 made equal to U and the loop, repeated for the next pipe length.

(23) If the pipe will not carry the requisite discharge, then the diameter should be increased by 25mm to the next greater pipe size, the time of concentration should be set back to its previous value, i.e. the time of travel down the small diameter pipe should be subtracted, and then the calculations repeated to check if this larger diameter is satisfactory.

(24) Check if ground elevation at down stream (DS (J)) is less than ground elevation (US (J)) at upstream. If so subtract minimum cover (0.6m) and pipe diameter D (U) from ground elevation at downstream (DS (J)).

(25) Check if ground elevation at downstream (DS (J)) is greater than ground elevation at upstream (US (J)). If so, subtract minimum cover (0.6m) and pipe diameter D (U) from ground elevation at upstream (US (J)).

(26) Check if invert elevation at upstream (USI (J)) is greater than ground elevation upstream. If so determine invert elevation at upstream (USI (J)) by subtracting, minimum cover and D (U) from US (J). Moreover, set invert elevation at downstream to be equal to USI (J) minus fall in pipe FALL (J).

(27) Define the sewers at the junctions. For sewers neither entering nor leaving a junction set CONT = 0: Also for sewer section entering a junction, set CONT = 1. Finally for sewer section leaving a junction set CONT = 2.

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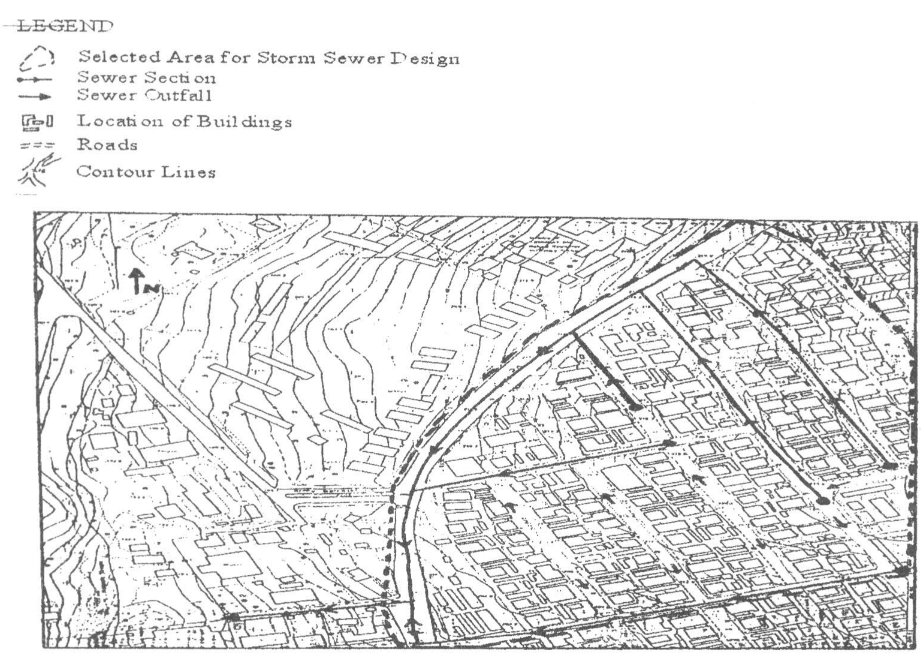
(28) Check if CONT = 0. If so, check if pipe length number (VI) is equal to 0. If so, set drop- in- manhole to be equal to zero.

(29) Check if CONT = I. If so, set CH = DSI (J).

(30) Check if CONT = 2. If so, also check if ground elevation is less than invert elevation at upstream. If so determine invert elevation at upstream by subtracting pipe diameter and cover from upstream elevation. Hence downstream elevation equal to USI (J) minus FALL (J)

(31) Determine Drop (J) by subtracting USI (J) from previous invert elevation at downstream DSI (J-I). If Drop (J) is negative i.e. less than 0 then determine USI (J) by subtracting 0.6 from USI (J).

(32) Check if CH is less than CR. If so, subtract 1.6 from CH. Moreover check if pipe length is equal to 0. If so, drop in manhole is equal to (0). Determine FALL (S) by subtracting DSI (J) from USI (J).



Source: Oyo State Map Depot, Secretariat, Ibadan. (IB SHEET 97-7NE3)

Fig. 1: Topographical Map of Mokola Residential Layout in Ibadan, Oyo State, Nigeria, with Drainage Routes and Catchment Area for Selected Portion, Identified.

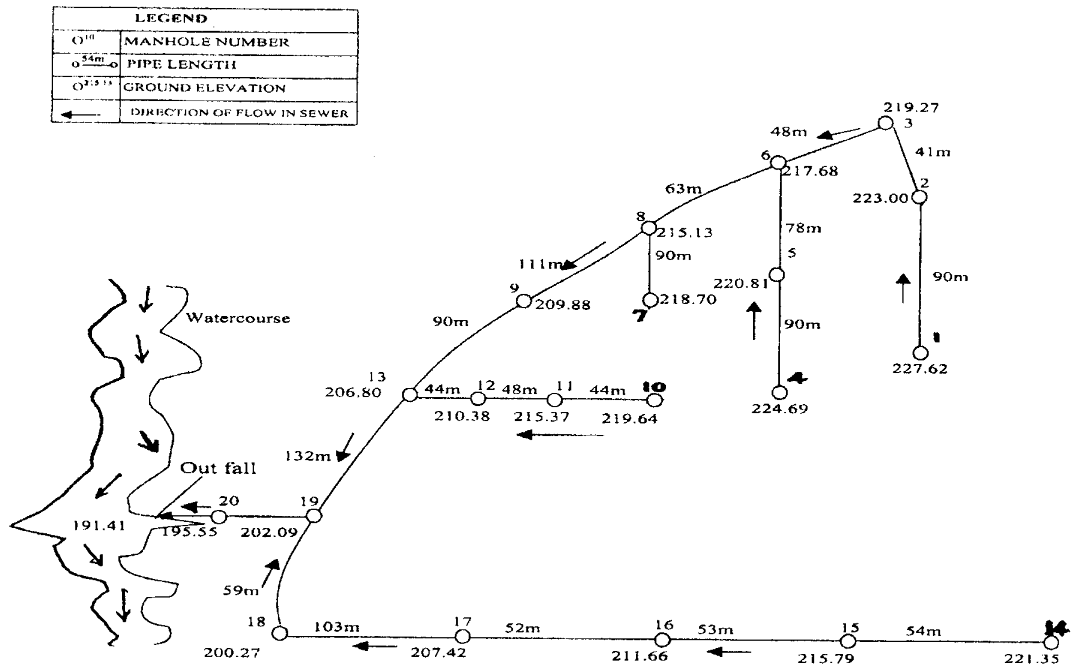


Fig. 2: Schematic Diagram Showing Proposed Storm Sewer Layout for Manual Design.

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APPENDIX 2

Program Listing

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1 PRINT "THE DESIGN OF STORM SEWER SYSTEMS FOR SMALL AREAS "
2 PRINT "PROGRAMMED BY ENGR A. A. ADEGBOLA, WITH INPUTS FROM RAJI, BABAJIDE"
3 OPEN "OU.D" FOR APPEND AS #3
5 CLS : PRINT : PRINT #3, : PRINT #3,
6 PRINT #3, "THE DESIGN OF STORM SEWER SYSTEMS FOR SMALL AREAS USING COMPUTER"
7 PRINT : PRINT "LOCATION OF SEWER SYSTEM"
8 INPUT N$: PRINT
9 PRINT "INPUT DATE OF RUN, ENTER, AND INPUT NAME OF USER "
10 PRINT "RUN ON"; : INPUT SDATE$: PRINT " BY "; : INPUT N$: PRINT : PRINT
11 PRINT #3, "-------------------------------------------------------------"
12 PRINT #3, : PRINT #3,
13 REM DIMENSION VARIABLE-ARRAYS FOR MATHEMATICAL MANIPULATION
40 DIM RI(30), IT(30), CRI(20), COU(5), CKI(20), CKF(30)
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50 DIM DS(30), US(30), DSI(30), USI(30), DROP(30), UKU(30), VV1(30), FALL(30)
60 REM K IS THE NUMBER OF STARTING MANHOLES
70 FOR K = 1 TO 5
75 REM FOUR DATA REPRESENTING: INLET MANHOLE (N(K)), RUNOFF COEFF.(RC(K)),
76 REM DIST. OF OVERLAND FLOW (D(K)), AND SLOPE (S(K)).
80 READ N(K), RC(K), D(K), S(K)
90 NEXT K
100 DATA 1,.59,436.67,2.39
110 DATA 2,.59,236.67,1.73
120 DATA 3,.59,130.00,2.41
130 DATA 4,.59,293.33,1.02
140 DATA 5,.59,363.33,4.20
160 FOR I = 1 TO 30
170 READ IT(I), RI(I)
190 NEXT I
200 DATA 1,226.46,2,159.96,3,128.23,4,111.69,5,98.63,6,89.13
210 DATA 7,81.85,8,76.38,9,72.44,10,68.87,11,65.31,12,62.09
220 DATA 13,59.98,14,56.89,15,54.95,16,53.70,17,51.88
230 DATA 18,50.12,19,48.98,20,47.10,21,46.77,22,45.50
240 DATA 23,43.95,24,43.45,25,42.46,26,41.69,27,40.74
250 DATA 28,40.27,29,39.63,30,38.28
265 FOR K = 1 TO 5
270 C(K) = 1.8 * (1.1 - RC(K)) * (D(K) ^ .5) / S(K) ^ .33
280 NEXT K
285 FOR K = 1 TO 5
290 FOR I = 1 TO 30
315 IF ((C(K)) - IT(I) = 0) THEN CRI(K) = RI(I)
316 IF ((C(K)) - IT(I) = 0) THEN GOTO 410
320 IF IT(I) = CINT(C(K)) AND C(K) > CINT(C(K)) THEN GOTO 340
330 IF IT(I) = CINT(C(K)) AND C(K) < CINT(C(K)) THEN GOTO 370
335 GOTO 400
340 PRI = RI(I)
350 NRI = RI(I + 1)
360 PTC = IT(I)
365 GOTO 395
370 PRI = RI(I - 1)
380 NRI = RI(I)
390 PTC = IT(I - 1)
395 CRI(K) = PRI - ((C(K) - PTC) * (PRI - NRI))
400 NEXT I
410 NEXT K
440 FOR J = 1 TO 5
450 ITT(J) = CRI(J) / 60000: REM CONVERT TO M/MIN.
490 NEXT J
510 REM CONSTANTS FOR PIPE DISCHARGE CALCULATIONS
511 READ KK, RCK, T: REM MANNINGS COEFF.,COEFF. OF RUNOFF AND RETURN PERIOD
512 DATA .013,.59,15
513 READ T1, T2: REM NUMBER OF BRANCHES,PIPE LENGHTS
514 DATA  5,20
515 B$ = "PIPE  SLO  LGH   VEL  TIME TIME  RNFL  TOTAL   CUML     FLOW   PIPE"
516 C$ = " NO    IN              FLOW CONC  INT.  AREA    AREA     RATE   DIA"
517 D$ = "      (%)  (m)   m/s  min  min  mm/hr  M^2     M^2    M^3/min (mm)"
518 A$ = "# #  #.## ###.# ##.## #.## ##.# ###.# #####.# #####.# ###.#   ####"
519 PRINT #3, "RETURN PERIOD OF STORM IN YEARS ="; T
520 PRINT #3, "MANNINGS PIPE COEFFICIENT = "; KK
521 X = 3.142: REM THE VALUE OF PIE
522 FOR K = 1 TO T1
523 PRINT #3, "TIME OF ENTRY ="; C(K); "min. FOR STARTING BRANCH NO."; K
524 NEXT K
525 PRINT #3, : PRINT #3, : PRINT #3, "-----------------------------------------------------
------------"
526 PRINT #3, B$: PRINT #3, C$: PRINT #3, D$
527 PRINT #3, "-----------------------------------------------------------------"
528 FOR U = 1 TO T1: A(U) = 0: D(U) = 200: NEXT U: CR = 10000000: CH = 0
529 U1 = 0: REM BRANCH NUMBER OF THE PREVIOUS BRANCH
531 FOR J = 1 TO 30: DS(J) = 0: US(J) = 0: DSI(J) = 0
532 USI(J) = 0: DROP(J) = 0: UKU(J) = 0: VV1(J) = 0: FALL(J) = 0
533 NEXT J
540 FOR J = 1 TO T2: REM T2 IS THE NUMBER OF PIPE LENGTH CALCULATIONS
550 READ U, V1, S, L, A, US(J), DS(J), CONT: REM (8) DATA VALUES FOR EACH PIPE LENGTH
551 UKU(J) = U: VV1(J) = V1
555 SL = S / 100
556 REM CONVERT SLOPE FROM % TO DECIMAL
560 A(U) = A(U) + A: REM CUMMULATIVE AREA
570 IF U < U1 THEN A(U) = A(U) + A(U1): REM CHECK IF THIS IS A JUNCTION
580 D = D(U) / 1000: REM TRIAL PIPE DIAMETER FOR DISCHARGE CALCULATIONS
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590 R = D / 4: REM HYDRAULIC RADIUS OF PIPE
600 V = (1 / KK) * (R ^ .67) * (SL ^ (.5)): REM MANNINGS FORMULA
610 IF V > 3! THEN D(U) = D(U) + 25: IF V > 3! THEN GOTO 580
620 IF V < .9 THEN SL = SL + .1: IF V < .9 THEN GOTO 600
621 AR = (X * (D ^ 2)) / 4
630 Q = AR * V * 60: REM FLOW RATE INSIDE PIPE IN M^3/MIN.
640 M = L / (60 * V): REM TIME OF TRAVEL DOWN THE PIPE IN MINUTES
650 IF A = 0 THEN M = 0: REM M =0 IF THE PIPE LENGTH IS UNPRODUCTIVE
660 C(U) = C(U) + M: REM TIME OF CONCENTRATION IN MINUTES
670 IF V1 = 0 THEN GOTO 708
671 REM
672 FOR I = 1 TO 30: REM COMPUTATION OF R. INT. FROM CUM. FLOW TIME
673 IF ((C(U)) - IT(I) = 0) THEN CKI(U) = RI(I)
674 IF ((C(U)) - IT(I) = 0) THEN GOTO 689
675 IF IT(I) = CINT(C(U)) AND C(U) > CINT(C(U)) THEN GOTO 678
676 IF IT(I) = CINT(C(U)) AND C(U) < CINT(C(U)) THEN GOTO 682
677 GOTO 689
678 PRI = RI(I)

679 NRI = RI(I + 1)
680 PTC = IT(I)
681 GOTO 685
682 PRI = RI(I - 1)
683 NRI = RI(I)
684 PTC = IT(I - 1)
685 CKF(I) = PRI - ((C(U) - PTC) * (PRI - NRI))
686 ITV = CKF(I) / 60000: REM CONVERSION TO M/MIN.
689 NEXT I
691 REM
707 Q1 = RCK * ITV * A(U): GOTO 709
708 Q1 = RCK * ITT(U) * A(U): REM DISCHARGE FROM RATIONAL F.IN M^3/MIN.
709 IF Q1 < (Q * 1.1) THEN 724: REM IS THE PIPE DIAMETER SATISFACTORY?
710 D(U) = D(U) + 25: REM DIAMETER IS TOO SMALL,INCREASE BY 25 MM
720 C(U) = C(U) - M: REM SET TIME OF CONCENTRATION TO ITS PREVIOUS VALUE
722 GOTO 580: REM CALCULATE AGAIN WITH THE LARGER PIPE
724 I = ITT(U) * 60000
726 REM SELECT AVAILABLE PIPE SIZES IN THE MARKET TO MATCH DESIGN
727 IF D(U) > 200 AND D(U) < 250 THEN D(U) = 250
728 IF D(U) > 250 AND D(U) < 300 THEN D(U) = 300
729 IF D(U) > 300 AND D(U) < 375 THEN D(U) = 375
730 IF D(U) > 375 AND D(U) < 450 THEN D(U) = 450
731 IF D(U) > 450 AND D(U) < 525 THEN D(U) = 525
732 IF D(U) > 525 AND D(U) < 600 THEN D(U) = 600
733 PRINT #3, USING A$; U; V1; S; L; V; M; C(U); I; A; A(U); Q1; D(U)
734 U1 = U: REM PREVIOUS BRANCH NUMBER EQUATED TO PRESENT BRANCH NUMBER
735 IF DS(J) < US(J) THEN GOTO 738
736 IF DS(J) > US(J) THEN GOTO 758
738 DSI(J) = DS(J) - .6 - (D(U) / 1000): USI(J) = DSI(J) + (SL * L)
740 IF USI(J) > US(J) THEN USI(J) = US(J) - .6 - (D(U) / 1000)
742 IF USI(J) > US(J) THEN DSI(J) = USI(J) - (SL * L): IF V1 = 0 THEN GOTO 755
745 IF CONT = 0 THEN GOTO 755
746 IF CONT = 2 THEN GOTO 754
749 IF CONT = 1 THEN CH = DSI(J)
750 IF CH < CR THEN CR = CH - 1.6: GOTO 755
751 IF USI(J) > DS(J - 1) OR USI(J) > US(J) THEN GOTO 758
752 IF USI(J) > US(J) THEN GOTO 758
753 IF CONT = 2 THEN USI(J) = CR: IF CONT = 2 THEN DSI(J) = (USI(J) - (SL * L))
754 IF USI(J) > US(J) THEN GOTO 758
755 IF V1 = 0 THEN DROP(J) = 0: IF V1 = 0 THEN GOTO 772
756 DROP(J) = DSI(J - 1) - USI(J): IF DROP(J) < 0 THEN USI(J) = USI(J) - .6
757 IF DROP(J) < 0 THEN GOTO 762 ELSE 772: GOTO 772
758 USI(J) = US(J) - (.6 + (D(U) / 1000)): DSI(J) = USI(J) - (SL * L)
759 IF DSI(J) > DS(J) THEN DSI(J) = DS(J) - .6 - (D(U) / 1000)
760 IF DSI(J) > DS(J) THEN USI(J) = USI(J) + (SL * L)
761 IF USI(J) > DSI(J - 1) THEN USI(J) = USI(J) - .6
762 DSI(J) = USI(J) - (SL * L): IF DSI(J) > DS(J) THEN DSI(J) = DSI(J) - .6
763 IF CONT = 0 THEN GOTO 768
764 IF CONT = 1 THEN CH = DSI(J)
765 IF CH < CR THEN CR = CH - 1.6
766 IF CONT = 2 THEN USI(J) = CR: IF CONT = 2 THEN DSI(J) = (USI(J) - (SL * L))
768 IF V1 = 0 THEN DROP(J) = 0: IF V1 = 0 THEN GOTO 772
770 DROP(J) = DSI(J - 1) - USI(J): IF DROP(J) < 0 THEN USI(J) = USI(J) - .6
771 IF DROP(J) < 0 THEN GOTO 762
772 FALL(J) = USI(J) - DSI(J)
773 NEXT J
775 PRINT #3, "----------------------------------------------------------------------"
```

```
776 PRINT #3, "SLO = SLOPE; LGH = SEWER LENGTH; TIME CONC = TIME OF CONCENTRATION"
777 PRINT #3, "RNFL INT. = RAINFALL INTENSITY; TOTAL AREA = TOTAL CATCHMENT AREA"
778 PRINT #3, "CUML AREA = CUMULATIVE OF TOTAL CATCHMENT AREA; VEL = VELOCITY"
780 F$ = "PIPE  UPSTREAM  DOWNSTREAM  FALL  UPSTREAM    DOWNSTREAM    MANHOLE"
781 G$ = " NO.  GRD ELEV.  GRD ELEV.  IN    INV.ELEV.   INV.ELEV.     DROP"
782 H$ = "         (m)          (m)     (m)     (m)          (m)          (m) "
783 I$ = "# #   ###.##      ###.##     #.##  ###.##       ###.##         #.##"
784 PRINT #3, : PRINT #3, "DETERMINATION OF INVERT LEVELS OF SEWERS"
785 PRINT #3, : PRINT #3, "-----------------------------------------------------------------
"
786 PRINT #3, F$: PRINT #3, G$: PRINT #3, H$: PRINT #3, "------------------------------------
----------------------------"
787 FOR J = 1 TO T2
788 PRINT #3, USING I$; UKU(J); VV1(J); US(J); DS(J); FALL(J); USI(J); DSI(J); DROP(J)
790 NEXT J
791 PRINT #3, "------------------------------------------------------------------------"
792 END
793 DATA 1,0,1.85,90.00,4775.25,227.62,223.00,0
800 DATA 1,1,6.77,41.00,4680.00,223.00,219.27,0
810 DATA 1,2,3.77,48.00,3448.22,219.27,217.68,1
820 DATA 2,0,1.47,90.00,3794.00,224.69,220.81,0
830 DATA 2,1,1.96,78.00,4545.00,220.81,217.68,1
840 DATA 1,3,1.77,63.00,5142.67,217.68,215.13,2
850 DATA 3,0,.77,90.00,2160.00,218.70,215.13,1
860 DATA 1,4,3.00,111.00,6409.59,215.13,209.88,2
870 DATA 1,5,3.59,90.00,4230.54,209.88,206.80,1
880 DATA 4,0,1.63,44.00,4656.00,219.60,215.37,0
890 DATA 4,1,6.77,53.00,4998.63,215.37,210.38,0
900 DATA 4,2,4.70,44.00,5061.00,210.38,206.80,1
910 DATA 1,6,1.42,132.00,7339.00,206.80,202.09,2
920 DATA 5,0,1.61,54.00,3795.88,221.35,215.79,0
930 DATA 5,1,7.90,53.00,4955.75,215.79,211.66,0
940 DATA 5,2,5.80,52.00,5096.50,211.66,207.42,0
950 DATA 5,3,3.94,103.00,4933.00,207.42,200.27,0
960 DATA 5,4,1.99,59.00,6447.50,200.27,202.09,1
970 DATA 1,7,1.63,90.00,9382.73,202.09,195.55,2
980 DATA 1,8,1.63,75.00,0.00,195.55,191.41,0
```

Program Output

```
THE DESIGN OF STORM SEWER SYSTEMS FOR SMALL AREAS USING COMPUTER
----------------------------------------------------------------
RETURN PERIOD OF STORM IN YEARS = 15
MANNINGS PIPE COEFFICIENT =  .013
TIME OF ENTRY = 14.38958 min. FOR STARTING BRANCH NO. 1
TIME OF ENTRY = 11.7858 min. FOR STARTING BRANCH NO. 2
TIME OF ENTRY = 7.829765 min. FOR STARTING BRANCH NO. 3
TIME OF ENTRY = 15.62007 min. FOR STARTING BRANCH NO. 4
TIME OF ENTRY = 10.89735 min. FOR STARTING BRANCH NO. 5
```

PIPE NO	SLO IN (%)	LGH (m)	VEL m/s	TIME FLOW min	TIME CONC min	RNFL INT. mm/hr	TOTAL AREA M^2	CUML AREA M^2	FLOW RATE M^3/min	PIPE DIA (mm)
1 0	1.85	90.0	1.41	1.07	15.5	56.1	4775.3	4775.3	2.6	200
1 1	6.77	41.0	2.69	0.25	15.7	56.1	4680.0	9455.3	5.0	200
1 2	3.77	48.0	2.33	0.34	16.1	56.1	3448.2	12903.5	6.8	250
2 0	1.47	90.0	1.25	1.20	13.0	62.8	3794.0	3794.0	2.3	200
2 1	1.96	78.0	1.68	0.77	13.8	62.8	4545.0	8339.0	4.7	250
1 3	1.77	63.0	2.10	0.50	16.6	56.1	5142.7	26385.1	13.7	375
3 0	0.77	90.0	0.91	1.65	9.5	77.3	2160.0	2160.0	1.6	200
1 4	3.00	111.0	2.73	0.68	17.2	56.1	6409.6	34954.7	17.7	375
1 5	3.59	90.0	2.98	0.50	17.7	56.1	4230.5	39185.3	19.5	375
4 0	1.63	44.0	1.32	0.56	16.2	54.2	4656.0	4656.0	2.5	200
4 1	6.77	53.0	2.69	0.33	16.5	54.2	4998.6	9654.6	5.0	200
4 2	4.70	44.0	2.60	0.28	16.8	54.2	5061.0	14715.6	7.6	250
1 6	1.42	132.0	2.35	0.94	18.7	56.1	7339.0	61239.9	29.7	525
5 0	1.61	54.0	1.31	0.69	11.6	65.7	3795.9	3795.9	2.5	200
5 1	7.90	53.0	2.91	0.30	11.9	65.7	4955.8	8751.6	5.4	200
5 2	5.80	52.0	2.89	0.30	12.2	65.7	5096.5	13848.1	8.4	250
5 3	3.94	103.0	2.69	0.64	12.8	65.7	4933.0	18781.1	11.1	300
5 4	1.99	59.0	2.22	0.44	13.3	65.7	6447.5	25228.6	14.7	375
1 7	1.63	90.0	2.68	0.56	19.2	56.1	9382.7	95851.3	45.8	600

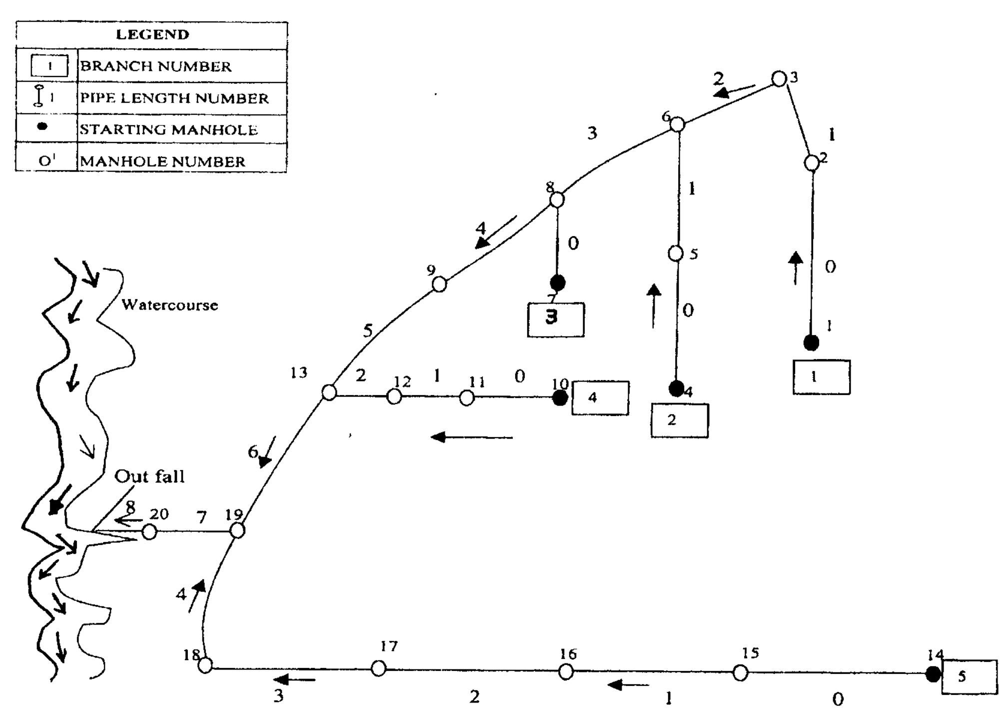
1 8	1.63	75.0	2.76	0.00	19.2	56.1	0.0	95851.3	45.8	600

SLO = SLOPE; LGH = SEWER LENGTH; TIME CONC = TIME OF CONCENTRATION
RNFL INT. = RAINFALL INTENSITY; TOTAL AREA = TOTAL CATCHMENT AREA
CUML AREA = CUMULATIVE OF TOTAL CATCHMENT AREA; VEL = VELOCITY

DETERMINATION OF INVERT LEVELS OF SEWERS

PIPE NO.	UPSTREAM GRD ELEV. (m)	DOWNSTREAM GRD ELEV. (m)	FALL IN (m)	UPSTREAM INV.ELEV. (m)	DOWNSTREAM INV.ELEV. (m)	MANHOLE DROP (m)
1 0	227.62	223.00	1.66	223.86	222.20	0.00
1 1	223.00	219.27	2.78	221.25	218.47	0.95
1 2	219.27	217.68	1.81	218.04	216.23	0.43
2 0	224.69	220.81	1.32	221.33	220.01	0.00
2 1	220.81	217.68	1.53	218.36	216.83	1.65
1 3	217.68	215.13	1.12	215.27	214.15	1.56
3 0	218.70	215.13	0.69	215.02	214.33	0.00
1 4	215.13	209.88	3.33	212.24	208.90	2.10
1 5	209.88	206.80	3.23	208.46	205.22	0.45
4 0	219.60	215.37	0.72	215.29	214.57	0.00
4 1	215.37	210.38	3.59	213.17	209.58	1.40
4 2	210.38	206.80	2.07	208.02	205.95	1.56
1 6	206.80	202.09	1.87	202.84	200.96	3.11
5 0	221.35	215.79	0.87	215.86	214.99	0.00
5 1	215.79	211.66	4.19	214.45	210.26	0.54
5 2	211.66	207.42	3.02	209.59	206.57	0.67
5 3	207.42	200.27	4.06	203.43	199.37	3.14
5 4	200.27	202.09	1.17	199.29	198.12	0.08
1 7	202.09	195.55	1.47	195.82	194.35	2.30
1 8	195.55	191.41	1.22	191.43	190.21	2.92

APPENDIX 3



Schematic Diagram Showing Storm Sewer Layout for the Software Program

Table 3: Preliminary Storm-Sewer Design

Line No.	Sewer Location: Computer code	Street	From M.H	To M.H	Tributary Area: Additional Area Drained (M^2)	Total Area (m^2)	Time of Concentration: Inlet Time (min)	Flow Time (min)	Total (min)	Runoff Coeff-icient	Rainfall Intensity ($^{mm}/_{hr}$)	R (
1	1,0	Okunmade	1	2	4775.25	4775.25	14.35	1.06	15.41	0.59	56.23	
2	1,1	Okunmade	2	3	4680.00	9455.25	15.41	0.25	15.66	0.59	54.45	
3	2,0	Alafia	4	5	3794.00	3794.00	11.76	1.20	12.96	0.59	62.81	
4	2,1	Alafia	5	6	4545.00	8339.00	12.96	0.77	13.73	0.59	60.12	
5	3,0	Gbadebo	7	8	2160.00	2160.00	7.81	1.65	9.46	0.59	77.45	
6	4,0	Ali	10	11	4656.00	4656.00	15.62	0.56	16.18	0.59	54.20	
7	4,1	Ali	11	12	4998.63	9654.63	16.18	0.30	16.48	0.59	53.33	
8	4,2	Ali	12	13	5061.00	14715.63	16.48	0.28	16.76	0.59	52.84	
9	5,0	Bolarinwa	14	15	3795.88	3795.88	10.85	0.69	11.54	0.59	65.77	
10	5,1	Bolarinwa	15	16	4955.75	8751.63	11.54	0.30	11.84	0.59	63.53	
11	5,2	Bolarinwa	16	17	5096.50	13848.13	11.84	0.30	12.14	0.59	62.66	
12	5,3	Bolarinwa	17	18	4933.00	18781.13	12.14	0.64	12.78	0.59	61.80	
13	5,4	Oyo Road	18	19	6447.50	25228.63	12.78	0.44	13.22	0.59	60.44	
14	1,2	Oyo Road	3	6	3448.22	12903.47	15.66	0.34	16.00	0.59	54.08	
15	1,3	Oyo Road	6	8	5142.67	26385.14	16.00	0.50	16.50	0.59	53.70	
16	1,4	Oyo Road	8	9	6409.59	34954.73	16.50	0.68	17.18	0.59	52.84	
17	1,5	Oyo Road	9	13	4230.54	39185.27	17.18	0.50	18.68	0.59	51.52	
18	1,6	Oyo Road	13	19	7339.00	61239.90	17.68	0.94	18.62	0.59	50.70	
19	1,7	R.T.A	19	20	9332.73	95851.26	18.62	0.54	19.16	0.59	49.43	
20	1,8	R.T.A	20	out fall	-	95851.26	19.16	0.45	19.61	0.59	-	

Table 4: Hydraulic Analysis for Storm-Sewer Design Layout

Station	Invert Elevation	Diameter of pipe	w.s	secton	Area A (m^2)	$K = 2gn^2$	V	Q	$V^2/2g$	En gr
0+00	190.21	600	190.81		0.283	0.0033	2.76	46.83	0.39	19
0+75	191.46	600	192.06		0.283	0.0033	2.76	46.83	0.39	19
1+65	193.76	600	194.36		0.283	0.0033	2.76	46.83	0.39	19
2+97	196.21	525	196.73		0.217	0.0033	2.35	30.64	0.28	19
3+87	198.48	375	198.85		0.111	0.0033	2.99	19.92	0.46	19
4+98	202.57	375	202.94		0.111	0.0033	2.73	18.19	0.38	20
5+61	204.76	375	205.13		0.111	0.0033	2.10	13.99	0.22	20
6+09	206.35	250	206.60		0.049	0.0033	2.33	6.86	0.28	20
2+24	195.41	375	195.78		0.111	0.0033	2.25	14.99	0.26	19
3+27	198.46	300	198.76		0.017	0.0033	2.69	11.41	0.37	19
3+79	200.98	250	201.23		0.049	0.0033	2.89	8.51	0.43	20
4+32	204.69	200	204.89		0.031	0.0033	2.19	5.49	0.43	20
4+86	207.69	200	207.89		0.031	0.0033	1.31	2.47	0.09	20
3+41	197.78	250	198.03		0.049	0.0033	2.60	7.66	0.34	19
3+89	200.57	200	200.77		0.031	0.0033	2.69	5.07	0.37	20
4+33	202.79	200	202.99		0.031	0.0033	1.32	2.49	0.09	20
5+88	204.82	200	205.02		0.031	0.0033	0.91	1.72	0.04	20
6+39	206.43	250	206.68		0.049	0.0033	1.68	4.95	0.14	20
7+29	208.16	200	208.36		0.031	0.0033	1.25	2.36	0.08	20
6+50	208.82	200	209.02		0.031	0.0033	2.69	5.07	0.37	20
7+40	213.07	200	213.27		0.031	0.0033	1.41	2.66	0.10	21