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Contents

The Rational Method in Stormwater Management Modelling of Peak Flow Flood Control Systems, II: Computer Program Application

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ABSTRACT

The companion paper's development of the well-known Rational Method is used to prepare a computer program to estimate T-year return frequency peak flow rates for flood control and environmental planning purposes. When applied, the computer program results indicate the usefulness of the Rational Method for estimating peak flow rates, and perhaps explain why the method continues to be widely used in civil engineering. The computer program solves for peak flow rates by solution of the stochastic integral equation representation of the Rational Method procedure, as derived in the companion paper.

Key Words: Peak Flowrate Estimates, Rational Method, Storm Drain Design, Watershed Management Modeling, Uncertainty

INTRODUCTION

The companion paper (Hromadka [1]) presented a rigorous stochastic integral equation interpretation of the well-known Rational Method. The derived key equation provided T-year return frequency estimates of peak flow rate, by

$$Q_T = C\bar{P}_T^{\delta_c} \Psi^{\delta_c} \tag{1}$$

where Q_T is the T-year return frequency estimate of peak flow rate; $\bar{P}_T^{\delta_c}$ is the T-year return frequency mean rainfall intensity corresponding to critical duration (for the peak flow rate criterion variable) δ_c, and $\Psi^{\delta_c} = \max_t (S(t+\delta_c) - S(t))$, where $S(t)$ is the S-graph corresponding to the point of study; and C is a calibration coefficient. In this paper, Eq. (1) is implemented by use of a computer program (Hromadka [2]) designed to solve for Q_T by use of computed time-area diagrams. A time-area diagram defines the cumulative area of the watershed contributing runoff to the subbasin outlet as a function of time.

ESTIMATION OF PEAK FLOW RATES

The previous development involving the time-area diagram to estimate Ψ^{δ_c} values is demonstrated by means of a computational example problem.

Computational Example Problem 1

Figure 1 depicts a conceptual watershed schematic to demonstrate the time-area diagram analysis (see Table 1).

Time-area diagram analysis can be used to illustrate the watershed response with respect to constant rainfall intensity (corresponding to local T-year return frequency depth-duration relationships) and storm duration.

Figures 2 through 4 depict time-area diagrams at three arbitrarily chosen confluence points 3, 6, and 13 as developed from the schematic of Fig. 1. Figure 5 illustrates the time area diagram for the entire watershed (Node 14). The area versus time curve can be constructed by linearly interpolating area to the time of concentration. The peak flow rate (Q) versus time curve can be estimated by the Rational Method equation (e.g., Orange County Hydrology Manual [3])

$$Q(t) = 0.9\,(I(t) - \bar{F}_m)\,A(t) \tag{2}$$

where
- $Q(t)$ = peak flow rate (cfs) at time t.
- $I(t)$ = constant rainfall intensity (in/hr) of duration.
- $\bar{F}_m$ = watershed averaged loss rate (in/hr).
- $A(t)$ = area (Acres) respect to time t.

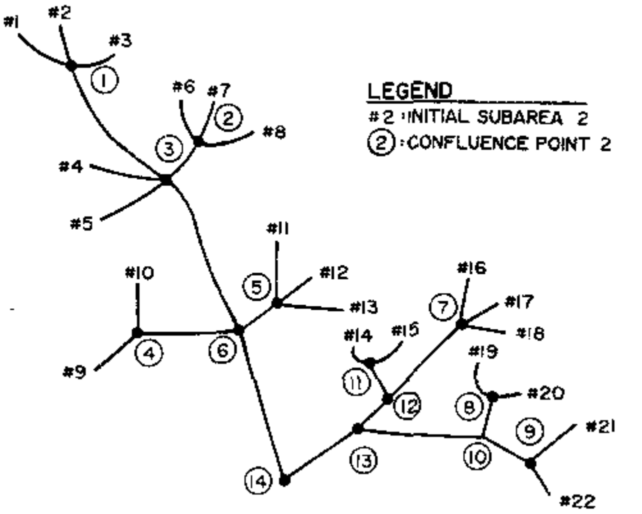

Fig. 1. Conceptual watershed schematic for time-area diagram analysis.

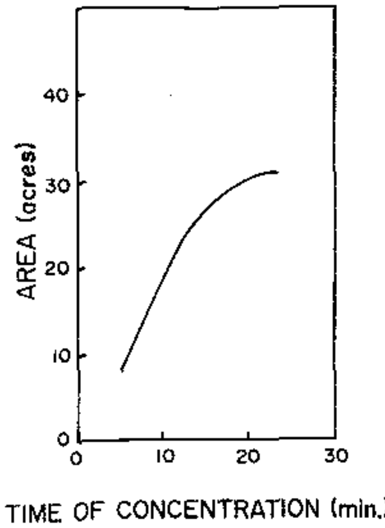

Fig. 2. Time-area diagram at confluence point 3.

Paper received 13 September 1988
and in final form 26 March 1989
Referees: Drs. Aaron A. Jennings and Chi-Yu King

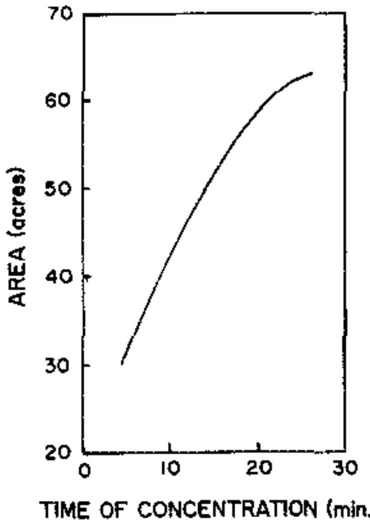

Fig. 3. Time-area diagram at confluence point 6.

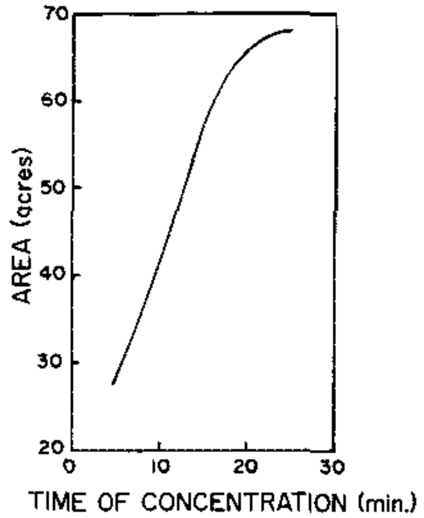

Fig. 4. Time-area diagram at confluence point 13.

Equation (2) is analogous to Eq. (1), if we consider c =0.9, $\bar{P}_T^{\hat{Q}}$ c = I(t) - $\bar{F}_m$, and $\Psi^{\hat{Q}}c$ = A(t).

Figure 5 clearly indicates that the peak flow rate (Q = 318.4 cfs) of the catchment occurs at time-of-concentration equals to 21.5 minutes and contributing catchment area equals to 145.39 Acres. That is, the rate of increase in contributory area versus the rate of decrease in effective rainfall rate maximizes the runoff peak flow rate at 318.4 cfs.

For every watershed, a time-area diagram can be developed for each point where the engineer desires, and the corresponding peak duration can be determined. For example, if a new storm drain is needed from Node 14 to Node 15 (see Fig. 4), the peak duration at Node 14 is 25.16 minutes for a 25-year return frequency storm, and the *corresponding peak flow rate is 65.5 cfs* (see Appendix A). Thus, a storm drain of diameter equal to 45 inches is adequate to carry this peak flow rate. All the above procedures have been implemented into an user-friendly computer program by Hromadka [2].

Computational Example Problem 2

A 25-year return frequency peak flow rate estimate study was conducted on a small watershed as shown in Fig. 6. Three streams are confluenced (i.e., added) at Node 14, then routed to the watershed outlet point (Node 16). *The total study area is 73.6 acres. The peak flow* rate is 92.7 cfs with a contributing area of 64.97 acres

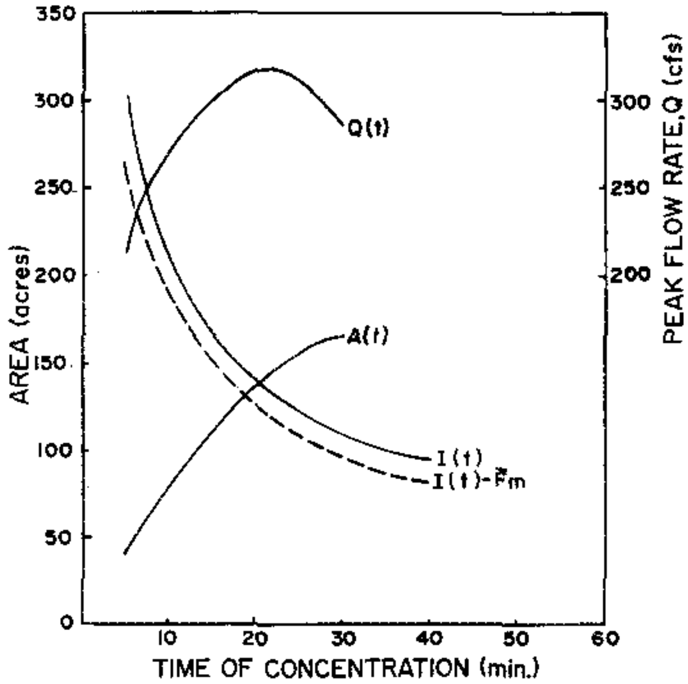

Fig. 5. Time-area diagram at confluence point 14.

TABLE 1
PEAK FLOW RATE DATA FOR EXAMPLE PROBLEM 1

Peak Flow Rate Q (cfs)	Time-of-Concentration Tc (min.)	Effective Area (Acres)
316.28	19.80	136.90
318.43	21.50	145.39
309.01	25.44	157.44
296.83	28.02	160.86
280.81	30.97	162.00*
318.13	20.96	142.83
318.31	22.00	147.67
310.84	24.93	156.41
318.04	20.73	141.75
308.47	25.58	157.69
316.02	23.43	152.70
315.70	23.57	153.11
298.23	27.73	160.63
314.65	19.23	133.54
313.58	24.23	154.80
300.33	27.32	160.22
285.80	30.03	161.86
285.30	30.13	161.89
317.87	22.30	148.91
315.25	23.73	155.53
306.11	26.13	158.59
297.60	27.86	160.74

* indicates total watershed area

at a time-of-concentration of 28.4 minutes. That is, the maximum flow rate occurs when only 64.97 acres of the total 73.6 *acres contributes to the peak flow rate. This* corresponds to a critical storm duration of 28.4 minutes. Figure 7 depicts the time-area diagram for the entire watershed.

Computer Program

The above examples demonstrate the dependency between contributory area and the corresponding storm critical duration, I_c, in maximizing the criterion variable of peak flow rate in free flowing catchment drainage systems. Obviously, the above diagram procedures are time-consuming and a computer program is advantageous. The software developed provides the above described detailed computations.

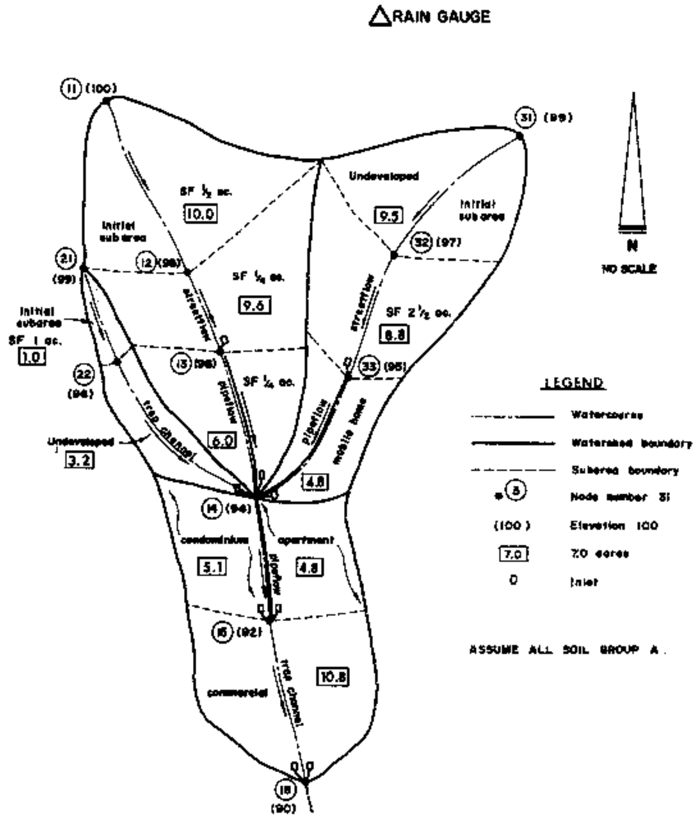

Fig. 6. Watershed schematic for example problem 2.

The computer program evaluates peak flow rates, for all nodal points used in the link-node model, by examining a sequence of storms, each storm of a constant intensity corresponding to the depth-duration data of the region under study [1]. For example, a 100-year 5-minute storm is a rainfall of 5-minute duration and of a constant intensity equal to (for example) 6.2 inches per hour, whereas a 100-year 30-minute storm has a constant intensity of 2.2 inches per hour. The computer program uses a sequence of n-minute storms, for n = 5,6,... until no change in nodal point peak flow rates is observed. It is noted that the nodal points will "maximize" in peak flow rate values for different storms. In [2], details regarding the mechanics of the software are reviewed. The added features afforded over [2] is that a more accurate solution of Eq. (1) is achieved, in conformance to the theory presented in [1].

The computer program provides the following output options: 1) a portion of the detailed subarea calculations printout, 2) summary tabulation output, 3) watershed schematic diagram, and 4) master plan of drainage facility summary. The watershed schematic diagram reflects the conceptual model that was constructed by the modeller. The master plan of drainage facility summary report illustrates the preliminary construction cost of the drainage system (channel and pipe). Appendices contain all four computer output options.

CONCLUSIONS

Hromadka [1] shows that the Rational Method equation is equivalent to a model of a highly discretized catchment with linear routing for channel flow approximation and effective rainfall intensity is uniform and constant over the contributory catchment area. Use time-area diagram and Eq. (2), the peak flow rate (Q) can be estimated. For most of the watershed, the contributory area is less than the total watershed area. The developed Rational Method computer program can be used by public agencies to develop a computerized master plan of drainage for urbanized regions such as presented in [2].

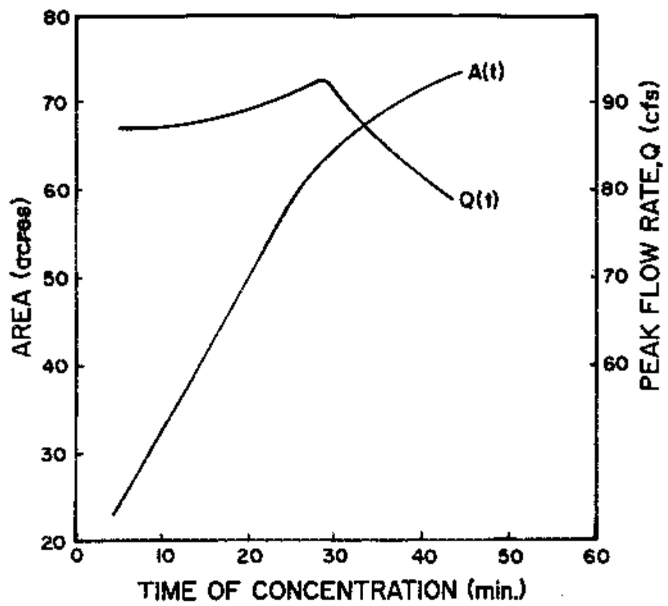

Fig. 7. Time-area diagram for example problem 2.

REFERENCES

1. Hromadka II, T.V., The Rational Method in Stormwater Management Modelling of Peak Flow Flood Control Systems, I: Theoretical Development, Envirosoft, Computational Mechanics Press, 1988.

2. Hromadka II, T.V., Computerized Master Plan of Drainage, I: Development and II: Software System, Microsoftware for Engineers, Vol. 3, No. 1, 22-43, 1987.

3. Orange County Hydrology Manual, OCEMA, Orange County, California, 1986.

APPENDIX A: DETAILED OUTPUT

```
****************************************************************************
          RATIONAL METHOD HYDROLOGY COMPUTER PROGRAM PACKAGE
============================================================================
 USER SPECIFIED HYDROLOGY AND HYDRAULIC MODEL INFORMATION:
============================================================================
 USER SPECIFIED STORM EVENT(YEAR) =   25.00
 SPECIFIED MINIMUM PIPE SIZE(INCH) =  24.00
 SPECIFIED PERCENT OF GRADIENTS(DECIMAL) TO USE FOR FRICTION SLOPE =  .90
 *DATA BANK RAINFALL USED*
****************************************************************************
 FLOW PROCESS FROM NODE    11.00 TO NODE    12.00 IS CODE =   2
----------------------------------------------------------------------------
 >>>>>RATIONAL METHOD INITIAL SUBAREA ANALYSIS<<<<<
============================================================================
 DEVELOPMENT IS  SINGLE FAMILY RESIDENTIAL -> 2 DWELLINGS/ACRE
 TC = K*[(LENGTH** 3.00)/(ELEVATION CHANGE)]** .20
 INITIAL SUBAREA FLOW-LENGTH(FEET) =   800.00
 UPSTREAM ELEVATION(FEET) =    100.00
 DOWNSTREAM ELEVATION(FEET) =    98.00
 ELEVATION DIFFERENCE(FEET) =     2.00
 TC(MIN.) =  .438*[(  800.00** 3.00)/(     2.00)]** .20 =   21.044
   25 YEAR RAINFALL INTENSITY(INCH/HR) =  2.142
 SOIL CLASSIFICATION IS "A"
 RESIDENTIAL-> 2 DWELLINGS/ACRE SUBAREA LOSS RATE, Fm(INCH/HR) =  .2800
 SUBAREA RUNOFF(CFS) =     16.75
 TOTAL AREA(ACRES) =     10.00   PEAK FLOW RATE(CFS) =     16.75
```

```
****************************************************************************
 FLOW PROCESS FROM NODE    12.00 TO NODE    13.00 IS CODE =   6
----------------------------------------------------------------------------
 >>>>>COMPUTE STREET FLOW TRAVEL TIME THRU SUBAREA<<<<<
============================================================================
 UPSTREAM ELEVATION(FEET) =   98.00  DOWNSTREAM ELEVATION(FEET) =   96.00
 STREET LENGTH(FEET) =   350.00   CURB HEIGTH(INCHES) = 8.
 STREET HALFWIDTH(FEET) = 22.00

 DISTANCE FROM CROWN TO CROSSFALL GRADEBREAK(FEET) = 11.00
 INTERIOR STREET CROSSFALL(DECIMAL) =   .020
 OUTSIDE STREET CROSSFALL(DECIMAL)  =   .020

 SPECIFIED NUMBER OF HALFSTREETS CARRYING RUNOFF =  2

      **TRAVEL TIME COMPUTED USING MEAN FLOW(CFS) =   24.47
   STREET FLOW MODEL RESULTS:
      STREET FLOW DEPTH(FEET) =   .58
      HALFSTREET FLOOD WIDTH(FEET) =   20.97
      AVERAGE FLOW VELOCITY(FEET/SEC.) =     2.67
      PRODUCT OF DEPTH&VELOCITY =    1.54
 STREET FLOW TRAVEL TIME(MIN.) =   2.19   TC(MIN.) =  23.23

   25 YEAR RAINFALL INTENSITY(INCH/HR) =  2.025
 SOIL CLASSIFICATION IS "A"
 RESIDENTIAL-> 3-4 DWELLINGS/ACRE SUBAREA LOSS RATE, Fm(INCH/HR) =  .2400
 SUBAREA AREA(ACRES) =    9.60   SUBAREA RUNOFF(CFS) =   15.42
 EFFECTIVE AREA(ACRES) =   19.60   AVERAGED Fm(INCH/HR) =     .26
 TOTAL AREA(ACRES) =   19.60   PEAK FLOW RATE(CFS) =     31.13
 END OF SUBAREA STREET FLOW HYDRAULICS:
 DEPTH(FEET) =  .61   HALFSTREET FLOOD WIDTH(FEET) = 22.00
 FLOW VELOCITY(FEET/SEC.) =  2.97   DEPTH*VELOCITY =   1.80
****************************************************************************
 FLOW PROCESS FROM NODE    13.00 TO NODE    14.00 IS CODE =   3
----------------------------------------------------------------------------
 >>>>>COMPUTE PIPE-FLOW TRAVEL TIME THRU SUBAREA<<<<<
 >>>>>USING COMPUTER-ESTIMATED PIPESIZE (NON-PRESSURE FLOW)<<<<<
============================================================================
 DEPTH OF FLOW IN  36.0 INCH PIPE IS  26.4 INCHES
 PIPE-FLOW VELOCITY(FEET/SEC.) =   5.6
 UPSTREAM NODE ELEVATION(FEET) =     96.00
 DOWNSTREAM NODE ELEVATION(FEET) =    94.00
 FLOW LENGTH(FEET) =   650.00   MANNING'S N =  .013
 ESTIMATED PIPE DIAMETER(INCH) =  36.00    NUMBER OF PIPES =   1
 PIPE-FLOW(CFS) =      31.13
 TRAVEL TIME(MIN.) =   1.93    TC(MIN.) =  25.16
****************************************************************************
 FLOW PROCESS FROM NODE    14.00 TO NODE    14.00 IS CODE =   8
----------------------------------------------------------------------------
 >>>>>ADDITION OF SUBAREA TO MAINLINE PEAK FLOW<<<<<
============================================================================
   25 YEAR RAINFALL INTENSITY(INCH/HR) =  1.934
 SOIL CLASSIFICATION IS "A"
 RESIDENTIAL-> 3-4 DWELLINGS/ACRE SUBAREA LOSS RATE, Fm(INCH/HR) =  .2400
 SUBAREA AREA(ACRES) =    6.00   SUBAREA RUNOFF(CFS) =    9.15
 EFFECTIVE AREA(ACRES) =   25.60   AVERAGED Fm(INCH/HR) =     .26
 TOTAL AREA(ACRES) =   25.60
 PEAK FLOW RATE(CFS) =    38.66
 TC(MIN.) =  25.16
****************************************************************************
 FLOW PROCESS FROM NODE    14.00 TO NODE    14.00 IS CODE =   1
----------------------------------------------------------------------------
 >>>>>DESIGNATE INDEPENDENT STREAM FOR CONFLUENCE<<<<<
============================================================================
 TOTAL NUMBER OF STREAMS =  3
 CONFLUENCE VALUES USED FOR INDEPENDENT STREAM  1 ARE:
 TIME OF CONCENTRATION(MIN.) =  25.16
 RAINFALL INTENSITY(INCH/HR) =   1.93
 AVERAGED Fm(INCH/HR) =   .26
 EFFECTIVE STREAM AREA(ACRES) =   25.60
 TOTAL STREAM AREA(ACRES) =   25.60
 PEAK FLOW RATE(CFS) AT CONFLUENCE =     38.66
```

```
****************************************************************************
 FLOW PROCESS FROM NODE    14.00 TO NODE    15.00 IS CODE =   3
----------------------------------------------------------------------------
 >>>>>COMPUTE PIPE-FLOW TRAVEL TIME THRU SUBAREA<<<<<
 >>>>>USING COMPUTER-ESTIMATED PIPESIZE (NON-PRESSURE FLOW)<<<<<
============================================================================
 DEPTH OF FLOW IN  45.0 INCH PIPE IS  34.9 INCHES
 PIPE-FLOW VELOCITY(FEET/SEC.) =   7.1
 UPSTREAM NODE ELEVATION(FEET) =     94.00
 DOWNSTREAM NODE ELEVATION(FEET) =    92.00
 FLOW LENGTH(FEET) =   550.00   MANNING'S N =  .013
 ESTIMATED PIPE DIAMETER(INCH) =  45.00    NUMBER OF PIPES =   1
 PIPE-FLOW(CFS) =      65.51
 TRAVEL TIME(MIN.) =   1.29    TC(MIN.) =  26.45
****************************************************************************
 FLOW PROCESS FROM NODE    15.00 TO NODE    15.00 IS CODE =   8
----------------------------------------------------------------------------
 >>>>>ADDITION OF SUBAREA TO MAINLINE PEAK FLOW<<<<<
============================================================================
   25 YEAR RAINFALL INTENSITY(INCH/HR) =  1.882
 SOIL CLASSIFICATION IS "A"
 CONDOMINIUMS SUBAREA LOSS RATE, Fm(INCH/HR) =  .1400
 SUBAREA AREA(ACRES) =    5.10   SUBAREA RUNOFF(CFS) =    8.00
 EFFECTIVE AREA(ACRES) =   49.37   AVERAGED Fm(INCH/HR) =     .27
 TOTAL AREA(ACRES) =   58.00
 PEAK FLOW RATE(CFS) =    71.46
 TC(MIN.) =  26.45
****************************************************************************
 FLOW PROCESS FROM NODE    15.00 TO NODE    15.00 IS CODE =   8
----------------------------------------------------------------------------
 >>>>>ADDITION OF SUBAREA TO MAINLINE PEAK FLOW<<<<<
============================================================================
   25 YEAR RAINFALL INTENSITY(INCH/HR) =  1.882
 SOIL CLASSIFICATION IS "A"
 APARTMENTS SUBAREA LOSS RATE, Fm(INCH/HR) =  .0800
 SUBAREA AREA(ACRES) =    4.80   SUBAREA RUNOFF(CFS) =    7.78
 EFFECTIVE AREA(ACRES) =   54.17   AVERAGED Fm(INCH/HR) =     .26
 TOTAL AREA(ACRES) =   62.80
 PEAK FLOW RATE(CFS) =    79.24
 TC(MIN.) =  26.45
****************************************************************************
 FLOW PROCESS FROM NODE    15.00 TO NODE    16.00 IS CODE =   5
----------------------------------------------------------------------------
 >>>>>COMPUTE TRAPEZOIDAL-CHANNEL FLOW<<<<<
 >>>>>TRAVEL TIME THRU SUBAREA<<<<<

============================================================================
 UPSTREAM NODE ELEVATION(FEET) =      92.00
 DOWNSTREAM NODE ELEVATION(FEET) =     90.00
 CHANNEL LENGTH THRU SUBAREA(FEET) =    700.00
 CHANNEL BASE(FEET) =     2.00   "Z" FACTOR =   2.000
 MANNING'S FACTOR =  .015   MAXIMUM DEPTH(FEET) =   3.00
 CHANNEL FLOW THRU SUBAREA(CFS) =     79.24
 FLOW VELOCITY(FEET/SEC.) =   5.86   FLOW DEPTH(FEET) =   2.15
 TRAVEL TIME(MIN.) =   1.99   TC(MIN.) =  28.44

****************************************************************************
 FLOW PROCESS FROM NODE    16.00 TO NODE    16.00 IS CODE =   8
----------------------------------------------------------------------------
 >>>>>ADDITION OF SUBAREA TO MAINLINE PEAK FLOW<<<<<
============================================================================
   25 YEAR RAINFALL INTENSITY(INCH/HR) =  1.806
 SOIL CLASSIFICATION IS "A"
 COMMERCIAL SUBAREA LOSS RATE, Fm(INCH/HR) =  .0400
 SUBAREA AREA(ACRES) =   10.80   SUBAREA RUNOFF(CFS) =   17.17
 EFFECTIVE AREA(ACRES) =   64.97   AVERAGED Fm(INCH/HR) =     .22
 TOTAL AREA(ACRES) =   73.60
 PEAK FLOW RATE(CFS) =    92.71
 TC(MIN.) =  28.44
============================================================================
 END OF STUDY SUMMARY:
 TOTAL AREA(ACRES)       =      73.60  TC(MIN.) =      28.44
 EFFECTIVE AREA(ACRES) =      64.97  AVERAGED Fm(INCH/HR)=   .22
 PEAK FLOW RATE(CFS)    =      92.71
 *** PEAK FLOW RATE TABLE ***
        Q(CFS)    Tc(MIN.)   Fm(INCH/HR)   Ae(ACRES)
 1       92.56      27.08        .219        62.79
 2       92.71      28.44        .221        64.97
 3       79.02      43.58        .233        73.60
============================================================================
============================================================================
 END OF RATIONAL METHOD ANALYSIS
```

APPENDIX B: SUMMARY OUTPUT

```
+------------------------------------------------------------------------------------------------+
|                                                                                                |
|                                                                                                |
|------------------------------------------------------------------------------------------------|
| STUDY NAME:                                                          | CALCULATED BY:          |
|                                                                      |    CHECKED BY:          |
| 25.0-YEAR STORM RATIONAL METHOD STUDY                                | PAGE NUMBER    OF       |
|--------------------(A D V A N C E D   E N G I N E E R I N G   S O F T W A R E)-----------------|
|CONCENTRATION| AREA (ACRES) |SOIL|DEV.| Tt | Tc | I  | Fm | Fm  |  Q  |PATH|SLOPE| V  | HYDRAULICS     |
| POINT NUMBER|SUBAREA| SUM  |TYPE|TYPE|MIN.|MIN.|in/h|    |(Avg)| SUM |(ft)|ft/ft|FPS.| AND NOTES      |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|             |       |      |    |    | .. |    |    |    |     |     | 800|.0025| .. |INITIAL SUBAREA |
|        12.00|   10.0|  10.0| A  |  9 |----|21.0|2.16| .28| .280| 16.8|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 350|.0057| 3.0|*Qav=  24.5cfs  |
| 44.ft-STREET|       |      |    |    |    |    |    |    |     |     |    |     |    |DEPTH= .58 ft.  |
| FLOW TO PT.#|       |      |    |    | 2.2|    |    |    |     |     |    |     |    |FLOODWIDTH=21.0 |
|        13.00|    9.6|  19.6| A  |  8 |----|23.2|2.02|.240| .260| 31.1|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 650|.0031| 5.6|*Qav=  31.1cfs  |
|             |       |      |    |    |    |    |    |    |     |     |    |     |    |n=.0130 Dn= 2.2 |
|             |       |      |    |    | 1.9|    |    |    |     |     |    |     |    |    36.0"-PIPE  |
|        14.00|    6.0|  25.6| A  |  8 |----|25.2|1.93|.240| .256| 38.7|----|-----|----|----------------|
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|        14.00|       |  25.6|    |    |----|25.2|1.93|    |     | 38.7|----|-----|----|FOR CONFLUENCE  |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|             |       |      |    |    | .. |    |    |    |     |     | 400|.0075| .. |INITIAL SUBAREA |
|        22.00|    1.0|   1.0| A  | 10 |----|13.7|2.73| .32| .320|  2.2|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 850|.0026| 1.4|*Qav=   2.2cfs  |
|             |       |      |    |    |    |    |    |    |     |     |    |     |    |n=.0300 Dn= 1.0 |
|             |       |      |    |    |10.1|    |    |    |     |     |    |     |    |B=  .5 Z= 1.0   |
|        14.00|    3.2|   4.2| A  | 16 |----|23.8|2.00|.600| .381|  6.1|----|-----|----|----------------|
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|        14.00|       |   4.2|    |    |----|23.8|2.00|    |     |  6.1|----|-----|----|FOR CONFLUENCE  |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|             |       |      |    |    | .. |    |    |    |     |     | 750|.0027| .. |INITIAL SUBAREA |
|        32.00|    9.5|   9.5| A  | 16 |----|32.6|1.67| .40| .400| 10.9|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 550|.0036| 2.1|*Qav=  15.6cfs  |
| 44.ft-STREET|       |      |    |    |    |    |    |    |     |     |    |     |    |DEPTH= .54 ft.  |
| FLOW TO PT.#|       |      |    |    | 4.4|    |    |    |     |     |    |     |    |FLOODWIDTH=18.9 |
|        33.00|    8.8|  18.3| A  | 11 |----|37.1|1.55|.360| .381| 19.3|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 700|.0014| 3.8|*Qav=  19.3cfs  |
|             |       |      |    |    |    |    |    |    |     |     |    |     |    |n=.0130 Dn= 2.0 |
|             |       |      |    |    | 3.1|    |    |    |     |     |    |     |    |    36.0"-PIPE  |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|        14.00|    6.8|  25.1| A  |  2 |----|60.2|1.49|.100| .322| 26.2|----|-----|----|----------------|
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
| CONFLUENCE  |            PEAK FLOW RATE(CFS) =     65.5                       |                |
|  ANALYSIS   |            TIME OF CONCENTRATION(MIN.) =  26.2                  |    LARGEST     |
| FOR POINT#  |            AVERAGED Fm(IN/HR) =   .29                           |   CONFLUENCE   |
|        14.00|   EFFECTIVE AREA(ACRES) =   44.27  TOTAL AREA(ACRES) =   52.90  |   Q=  65.5     |
|             |      Q        Tc         Fm      Ae                             |                |
|             |      64.71    23.79      .29     42.09                          |                |
|             |      65.51    25.16      .29     44.27                          |                |
|             |      56.77    40.16      .29     52.90                          |                |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 550|.0036| 7.1|*Qav=  65.5cfs  |
|             |       |      |    |    |    |    |    |    |     |     |    |     |    |n=.0130 Dn= 2.9 |
|             |       |      |    |    | 1.3|    |    |    |     |     |    |     |    |    45.0"-PIPE  |
|        15.00|    5.1|  49.4| A  |  4 |----|26.4|1.88|.140| .274| 71.5|----|-----|----|----------------|
|        15.00|    4.8|  54.2| A  |  3 |----|26.4|1.88|.080| .257| 79.2|----|-----|----|----------------|
|-------------|-------|------|----|----|    |----|----|----|-----|-----| 700|.0029| 5.9|*Qav=  79.2cfs  |
|             |       |      |    |    |    |    |    |    |     |     |    |     |    |n=.0150 Dn= 2.1 |
|             |       |      |    |    | 2.0|    |    |    |     |     |    |     |    |B=  2.0 Z= 2.0  |
|        16.00|   10.8|  65.0| A  |  1 |----|28.4|1.81|.040| .221| 92.7|----|-----|----|----------------|
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|        16.00|       |  65.0|    |    |----|28.4|    |    |     | 92.7|----|-----|----|STREAM SUMMARY  |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
| EFFECTIVE AREA(ACRES)=     64.97   TOTAL AREA(ACRES)=      73.60       PEAK FLOW RATE(CFS)=    92.71 |
| TIME OF CONCENTRATION(MIN.)=     28.64  AVERAGED Fm(IN/HR)=    .22                                 |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|             |   PEAK FLOW RATE TABLE                                          |                |
|             |      Q        Tc         Fm      Ae                             |                |
|             |      92.56    27.08      .22     62.79                          |                |
|             |      92.71    28.44      .22     64.97                          |                |
|             |      79.02    43.58      .23     73.60                          |                |
|-------------|-------|------|----|----|----|----|----|----|-----|-----|----|-----|----|----------------|
|             |       |      |    |    |    |    |    |    |     |     |    |     |    |                |
|------------------------------------------------------------------------------------------------|
 *DEV. TYPES:    1=Com,2=MH,3=Apt,4=Con,5=SFR 1)+ 0/AC.6=8-10D/AC,7=5-7D/AC,
 *8=3-4D/AC,9=2D/AC,10=1D/AC,11=0.4D/AC,12=Sch,13=PK,14=Ag,15=PC,16=AC,17=OC
+------------------------------------------------------------------------------------------------+
```

APPENDIX C: WATERSHED SCHEMATIC OUTPUT

```
+-#  11.00( 100.00)-+                          +-#  31.00(  99.00)-+
| INITIAL  SUBAREA  |                          | INITIAL  SUBAREA  |
|...................|                          |...................|
|      2 DU/AC      |                          |      NATURAL      |
| SOIL GROUP  A     |                          | SOIL GROUP  A     |
| LENGTH =  800. FT |                          | LENGTH =  750. FT |
| AREA =   10.0 AC  |                          | AREA =    9.5 AC  |
+-#  12.00(  98.00)-+                          +-#  32.00(  97.00)-+
          |                                              |
          V                                              V
+-#  12.00(  98.00)-+                          +-#  32.00(  97.00)-+
| TWO-SIDED STREET  |                          | TWO-SIDED STREET  |
|...................|                          |...................|
| CURB HEIGHT = 8.IN|                          | CURB HEIGHT = 8.IN|
| HALFWIDTH = 22.0FT|  +-#  21.00(  99.00)-+   | HALFWIDTH = 22.0FT|
| D-CROWN = 11.0 FT |  | INITIAL  SUBAREA  |   | D-CROWN = 11.0 FT |
| C X-FALL = .0200  |  |...................|   | C X-FALL = .0200  |
| O X-FALL = .0200  |  |      1 DU/AC      |   | O X-FALL = .0200  |
| LENGTH =  350.0 FT|  | SOIL GROUP  A     |   | LENGTH =  550.0 FT|
|...................|  | LENGTH =  400. FT |   |...................|
|     3-4 DU/AC     |  | AREA =    1.0 AC  |   |      .4 DU/AC     |
| SOIL GROUP  A     |  +-#  22.00(  96.00)-+   | SOIL GROUP  A     |
| AREA =    9.6 AC  |            |             | AREA =    8.8 AC  |
+-#  13.00(  96.00)-+            V             +-#  33.00(  95.00)-+
          |            +-#  22.00(  96.00)-+             |
          V            |   OPEN  CHANNEL   |             V
+-#  13.00(  96.00)-+  |...................|   +-#  33.00(  95.00)-+
| COMPUTER ESTIMATED|  | BASE WIDTH =  1.FT|   | COMPUTER ESTIMATED|
|     PIPE SIZE     |  | SIDE SLOPE(Z)= 1.0|   |     PIPE SIZE     |
|...................|  | MAX. DEPTH =  2.FT|   |...................|
| LENGTH =  650.0 FT|  | LENGTH =  850.0 FT|   | LENGTH =  700.0 FT|
| MANNING'S n = .013|  | MANNING'S n = .030|   | MANNING'S n = .013|
+-#  14.00(  94.00)-+  +-#  14.00(  94.00)-+   +-#  14.00(  94.00)-+
          |                      |                       |
          V                      V                       V
+-----#  14.00------+  +-----#  14.00------+   +-----#  14.00------+
| SUBAREA ADDITION  |  | SUBAREA ADDITION  |   | SUBAREA ADDITION  |
|...................|  |...................|   |...................|
|     3-4 DU/AC     |  |    AGRICULTURE    |   |    MOBILE HOME    |
| SOIL GROUP  A     |  | SOIL GROUP  A     |   | SOIL GROUP  A     |
| AREA =    6.0 AC  |  | AREA =    3.2 AC  |   | AREA =    4.8 AC  |
+-----#  14.00------+  +-----#  14.00------+   +-----#  14.00------+
          |                      |                       |
          V                      V                       V
+-----#  14.00------+  +-----#  14.00------+   +-----#  14.00------+
|    CONFLUENCE     |  |    CONFLUENCE     |   |    CONFLUENCE     |
|     ANALYSIS      |<=|     ANALYSIS      |<=|     ANALYSIS      |
|...................|  |...................|   |...................|
|    STREAM # 1     |  |    STREAM # 2     |   |    STREAM # 3     |
+-----#  14.00------+  +-----#  14.00------+   +-----#  14.00------+
=====================> CONFLUENCE OF  3 STREAMS <=====================
          |
          V
+-#  14.00(  94.00)-+
| COMPUTER ESTIMATED|                     (1)
|     PIPE SIZE     |                      |
|...................|                      +
| LENGTH =  550.0 FT|          +-#  15.00(  92.00)-+
| MANNING'S n = .013|          |   OPEN  CHANNEL   |
+-#  15.00(  92.00)-+          |...................|
          |                    | BASE WIDTH =  2.FT|
          V                    | SIDE SLOPE(Z)= 2.0|
+-----#  15.00------+          | MAX. DEPTH =  3.FT|
| SUBAREA ADDITION  |          | LENGTH =  700.0 FT|
|...................|          | MANNING'S n = .015|
|    APARTMENTS     |          +-#  16.00(  90.00)-+
| SOIL GROUP  A     |                    |
| AREA =    5.1 AC  |                    V
+-----#  15.00------+          +-----#  16.00------+
          |                    | SUBAREA ADDITION  |
          V                    |...................|
+-----#  15.00------+          |    COMMERCIAL     |
| SUBAREA ADDITION  |          | SOIL GROUP  A     |
|...................|          | AREA =   19.8 AC  |
|   CONDOMINIUMS    |          +-----#  16.00------+
| SOIL GROUP  A     |                    |
| AREA =    4.8 AC  |                    V
+-----#  15.00------+          +-------------------+
          |                    |  END OF RATIONAL  |
          +                    |   METHOD  STUDY   |
         (1)                   +-------------------+
```

MASTER PLAN OF DRAINAGE
FILENAME: RATDOC.DAT FACILITY SUMMARY PAGE 1

UPSTREAM NODE	DOWNSTREAM NODE	EFFECTIVE AREA(ACRES)	RUNOFF (CFS)	LENGTH (FT)	SLOPE (FT/FT)
13.00	14.00	19.6	31.1	650.0	.0031
==> PIPE FLOW SECTION: NUMBER OF PIPE = 1 @ 36.-INCH, n = .013 <==					
32.00	31.00	1.9	2.2	850.0	.0024
==> OPEN CHANNEL SECTION: B = .5, H = 2.0, Z = 1.00, n = .030 <==					
33.00	34.00	18.3	19.3	700.0	.0014
==> PIPE FLOW SECTION: NUMBER OF PIPE = 1 @ 36.-INCH, n = .013 <==					
24.00	25.00	44.0	65.5	550.0	.0036
==> PIPE FLOW SECTION: NUMBER OF PIPE = 1 @ 45.-INCH, n = .013 <==					
25.00	26.00	54.0	79.2	700.0	.0029
==> OPEN CHANNEL SECTION: B = 2.0, H = 3.0, Z = 2.00, n = .015 <==					

Note: 1. EFFECTIVE AREA AND RUNOFF VALUES ARE GIVEN AT THE UPSTREAM NODE.
2. B = BASEWIDTH(FT), H = HEIGHT(FT), Z = CHANNEL SIDE SLOPE

MASTER PLAN OF DRAINAGE
FILENAME: RATDOC.DAT FACILITY SUMMARY PAGE 2

* COST ESTIMATION FOR CHANNEL SECTIONS:

BASEWIDTH (FT)	HEIGHT (FT)	SIDE SLOPE (FT/FT)	MANNING'S FACTOR	UNIT PRICE ($/FT)	LENGTH (FT)	COST
.5	2.0	1.00	.030	10.00	850.0	8500.
2.0	3.0	2.00	.015	10.00	700.0	7000.
					CHANNEL TOTAL : $	15500.

* COST ESTIMATION FOR PIPE FLOW SECTIONS:

DIAMETER (INCH)	MANNING'S FACTOR	UNIT PRICE ($/FT)	LENGTH (FT)	COST
36.0	.013	10.00	1350.0	13500.
45.0	.013	10.00	550.0	5500.
			PIPE TOTAL : $	19000.

* TOTAL ESTIMATED COST FOR CHANNEL AND PIPE FLOW SECTIONS IS $ 34500.

END OF FACILITY SUMMARY