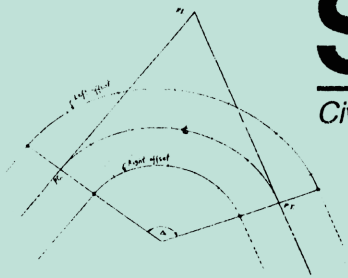
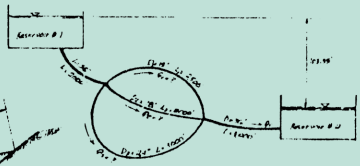
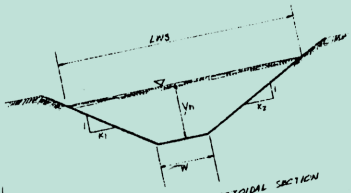
SUPER CE

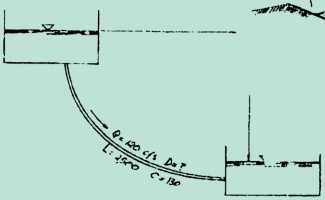
Civil Engineering Programs for the HP48GX

User's Guide

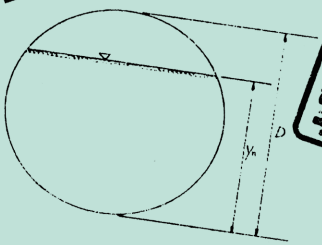


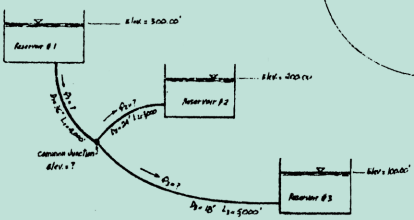


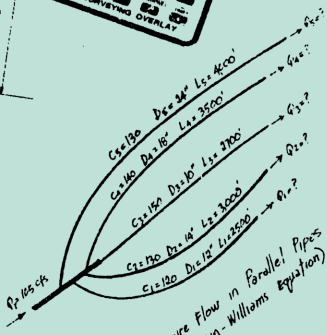


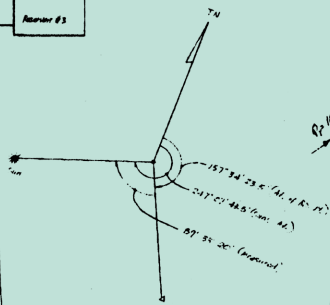


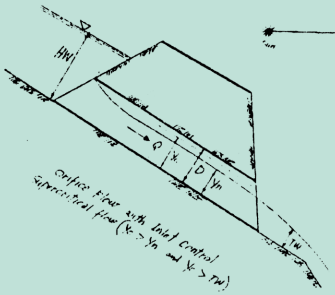












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SMI Publications Division
412 Payne Ridge Road
Church Hill, TN 37642

Super CE is a compilation of programs for the HP48SX and GX calculators, covering:

- Civil Engineering
- Geodetic Survey
- Sun and Polaris Observation
- Utilities

These programs were developed and written by Jose L. Martinez.

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CHAPTER 1

Introduction

An overview of the programs and routines of the Super CE card

The 48 CE(S) module is a compilation of selected programs in Civil Engineering (with emphasis in Hydrology), Geodetic Surveying, Astronomic Observation for Azimuth and Position, and Utilities. These programs are equally suited for for engineering students and professionals alike, and assist in accurately and quickly solving repetitious and complex programs. All programs in this module are convertible, at the user's option, to either English or metric system. This makes these programs readily adaptable to any country in the world, except those having specific US criteria.

The advent of powerful handheld computers like the HP48 series have made it possible to create sophisticated programs that could otherwise be handled only by large office computers. Now an engineer or surveyor can solve computing problems where they matter most: in the field. Complex equations involving iterative solution, linearization of statistical data, screen plotting, and matrix problems are just some of the functions available.

There are 51 main programs included in this module. For more details about a particular program, please refer to the list of programs and their descriptions. A detailed discussion of individual programs, including description, formatting of input data, and sample program runs, are found in the following chapters.

ACCESSING 48 CE(S) PROGRAMS

With the HP48 off, insert the program card into port 1.

After the card is in place, turn on the calculator. At this point, you can immediately access and run any of the programs.

☞
Once the program card is inserted in the HP48, each program becomes an additional command or function that can be executed at any time.

RUNNING A PROGRAM

There are 2 ways to run or execute a program after accessing the 48-CE(S) module:

(1) Press the [LIBRARY] key, then the [CE48-S] soft key. After the soft key is pressed, the screen will display the program menu; the first page of the menu is as follows:

[PRINT] [QUIT] [VERTC] [PIPE] [CHNL] [HC.SO]

Succeeding pages of the program menu are accessed by pressing the [NXT] key.

Press the soft key found directly below the name of the program you wish to run. (Soft keys are the 6 white keys labeled A thru F).

☞
Even if a program name doesn't appear in the current menu, you can still run it by typing its name and pressing [ENTER].

(2) Type the name of the program on the screen (command line) and press the [ENTER] key. by typing (onto the command line) the name of the particular program, then pressing the [ENTER] key.

☞
You must press the alpha key [α] twice to activate the alpha keys; this will enable you to type the program name.

Each program will prompt you what to do, such as what type of input data to enter, its unit measure, and format. You should read and become familiar with the required input data descriptions, or practice running the program using the example problems.

In most programs, you have the option to bypass the program's input prompting. This is done by first entering all the required input data in the stack prior to executing a particular program. This option is intended for those users who are already familiar with the program and have run it a number of times.

FORMATTING AND PRINTING OUTPUT DISPLAY

There are 2 kinds of output display used in this module: the String and the Tagged stack display. Either display can automatically be printed via an IR printer, and by running the routine called **PRINT**, prior to running a particular program.

The **PRINT** routine controls the number of decimal places of Distances and Angular quantities. For a string output, distances are displayed up to a maximum of 4 places, while Angles are displayed with fractional seconds carried to a maximum of 2 places.

The Default display for Distances is 2 places, while Angles are displayed to the nearest whole second. A 4-decimal place display can also be accomplished by manually setting Flag 4 prior to running a particular program. For a tagged output stack display, and at the option of the user, the number of decimal places can be varied by using the **FIX** function.

Another way to activate automatic printing is to manually set Flag 5. A compatible IR printer such as the HP82240B must be on and configured to receive the infrared transmission. In contrast to the string output display, the tagged output stack display can be printed even if Flag 5 was not previously set; use the **PRST** function.

GENERAL NOTES

(1) All programs included in this module are convertible to either English or Metric units.

(2) Use the **QUIT** routine to terminate program execution at any time; Or, use the following keys to do the same: [ON] [CLR] [CLR]. On some programs, pressing the [ON] key once will terminate program execution and clear the screen.

(3) All programs in the 48-CE(S) card can be executed by simply typing its name on the screen followed by the [ENTER] key, irregardless of which directory you are on.

(4) Multiple input data are entered in the same sequence as the program's input prompt; separate each value by commas or spaces.
The [ENTER] key is pressed after you've keyed in all the required input data.

☞ You'll find that a space is more convenient to use than a comma.

(5) All angular quantities, when used as input or as output display, use the following form: degrees, decimal point, minutes, seconds, and decimal seconds (dd.mmssss).
Degrees may vary from 1 to a maximum of 3 digits. Minutes are always entered or displayed as 2 digits, as are whole seconds.
For example, 132 degrees, 7 minutes 9.3544 seconds is entered as follows: **132.07093544**.

☞ Always put a zero before a single-digit number. For example, note that 7 minutes is entered as 07; 9 seconds is entered as 09.

List of Routines and Programs:
Descriptions and Functions

1. **PRINT** - used for automatic printing of the output during or after the running of the program. It also sets a 4- or 2-decimal display at the option of the user (default display is 2 decimal places). 4-decimal place display can also be accomplished by setting Flag 4.

2. **QUIT** - used to end program execution during a pause for input prompt. It can also be executed via its soft key or by typing the word **QUIT** in the command line. **QUIT** clears all existing stack display.

3. **VERTC** - used in the design of Symmetrical Vertical curve in highway or railroad elevation profile. The program computes the following:
   (a) station and elevation of the high or low point;
   (b) station and elevation of PVC, PVI, and PVT;
   (c) station and elevation of any given station in the vertical curve or in either tangent;
   (d) when a contour elevation is input, it will find the station where that contour is located;
   (e) automatically prints out station and elevation of successive stations given the starting station, ending station, and station interval in the vertical curve of either tangent.

4. **PIPE** - used in the design and analysis of any pipe flowing full or partially full, and applies only to flows without pressure. There are 6 parameters; given any 4, the remaining 2 will be computed plus the normal and critical depths of flow and velocities. The 6 parameters include rate of flow, velocity, pipe diameter, roughness coefficient, ratio in percent of depth of flow and diameter, and slope of pipe in percent.

5. **CHNL** - used in the design and analysis of open channel flow. pplicable channel cross section includes trapezoidal, V-shape, triangular, and rectangular. There are 8 parameters; given any 6, the remaining 2 will be computed plus the normal and

critical depths of flow and velocities. The parameters include rate of flow, velocity, slope, Manning's n, bottom width, depth of flow, left side slope, and right side slope.

6. **HC.SO** - used in horizontal curve layout featuring the use of direct angle and distance tie to points in the centerline, and the left and right offset. When a starting station, ending station, and station interval are entered, the program will print out stakeout data of successive stations. Given any odd station within the curve and, its offset distance, a direct angle and distance tie to that station is computed. This program is useful in staking out curb and gutter, sidewalk, drainage structures, and utilities.

7. **POL1** - computes the true azimuth of a reference line by observing Polaris (North Star) at any time it is visible to the observer. The program has a built-in subroutine for generating the star's ephemeris, given a date and universal time. If the HP48's clock is set to UT, the only measurement needed is the horizontal angle between the reference line and Polaris. Additional output display includes the star's zenith angle, GST, GHA of Aries, and true azimuth of Polaris.

8. **POL2** - computes the latitude of the observer. It has the same function as the **POL1** program except that the observer's longitude must be known and the altitude of Polaris is measured. The altitude reading is automatically corrected for refraction, parallax, pressure, temperature, and index error (if any).

9. **E.ALT** - computes the true azimuth of a reference line, the latitude and longitude of the observer by taking vertical and horizontal readings, of the sun before and after local high noon. The program has a built-in *perpetual* ephemeris that computes the sun's declination and GHA at any instant. This program can be used anywhere in the world and will give accurate latitude and longitude position. Additional output includes local standard time and local high noon mean time.

☞
The longer you make the interval between 2 sunshots, the more accurate your results will be.

10. **LL.AZ** - A new and unique sunshot program with a built-in *perpetual* solar ephemeris. The sunshot consist of taking double altitude observations and horizontal angle measurements within a minimum of 5 minutes apart, at any time of the day, to obtain the following:
    (a) True Azimuth of a Reference Line
    (b) Latitude and longitude of the observer
    (c) Local Standard Time
    (d) Sun's True Azimuth
    This program can be used anywhere in the world, and would be most useful when surveying uncharted and remote areas.

11. **SUN2** - computes the true azimuth of a reference line when the latitude and longitude of the observer is known. It has a built-in solar ephemeris for computing the sun's declination and GHA at any instant.
    If the HP48's clock is set to UT, the only field measurement required is the horizontal angle between the reference line and the sun.

12. **SUN3** - this has the same function as the **SUN2** program except that the sun's altitude is measured and the observer's latitude must be known. Output data includes the observer's longitude, the sun's true azimuth, and the true azimuth of the Reference Line.

13. **C.CUL** - determines the diameter of a Concrete Pipe Culvert using the FHWA criteria. This program is applicable only when inlet condition controls. A trial diameter is entered, and a computed Headwater depth must not exceed the maximum Headwater depth in order for the trial diameter to be accepted. Output data includes normal and critical depths of flow and velocities.

14. **D.CUL** - directly computes the minimum diameter of a Concrete Pipe Culvert. The computed Headwater will be equal or less than the required Headwater depth at the inlet using the FHWA criteria. This program is applicable only when inlet condition controls. It also determines whether the culvert flows as a weir or an orifice.

15. **D.HWF** - used in the design and analysis of pipes flowing full and under pressure. The program is applicable in turbulent flow and considers headloss due to friction only. The program can also be applied to a pipe connecting 2 reservoirs and the headloss is made equal to the elevation difference of the 2 reservoirs. When any 4 of the 5 parameters are known, the remaining parameter can be solved.

16. **PPHW** - computes velocity and rate of flow of each pipe connected in parallel using the Hazin-Williams equation. The program can compute up to 6 parallel pipes of different sizes and roughness coefficients carrying fluid under pressure.

17. **PPIPE** - computes velocity and rate of flow of each pipe connected in parallel using the Darcy-Weisbach equation. The program can compute up to 6 parallel pipes of varying sizes but of the same friction factor.

18. **PP.RS** - computes the rate of flow of each pipe in parallel connecting 2 reservoirs. Up to 5 parallel pipes and 1 main pipe in series can be entered. The program assumes all pipes having similar friction factors.

19. **RS3.P** - used in the solution of the 3-Reservoir problem. Three Reservoirs having 3 different water surface elevations are connected by pipes of unequal sizes and lengths, meeting at a common junction. The elevation of the junction and the rate of flow out or into each reservoir are computed.

20. **G↔G** - converts latitude/longitude coordinates to UTM Grid coordinates and vice versa using either a user defined ellipsoid or one of 8 Reference Ellipsoids available for selection. Additional output includes the scale factor and mapping angle of a point.

21. **DZUT** - computes the distance and azimuth between 2 points when either grid or geodetic coordinates are given. Both grid and geodetic azimuths and distances are included in the output display.

22. **SETEZ** - used to set or change a Reference Ellipsoid Datum and the Central Meridian, before executing either the G'G or the DZUT program. This routine may not be executed again until the user decides to change to a different ellipsoid datum and/or central meridian.

☞
Caution! Do not execute the C.FLG routine if it may affect other programs using flags. You can selectively clear any flag using the CF command.

23. **FLGS** - used to recall and display all previously set flags, including systems flags. The purpose of running this Routine is to keep track of all current flags that are being used in some programs.

24. **C.FLG** - clears all previously set Flags and systems Flags.

25. **S.INV** - computes azimuth and distance between 2 points on a given ellipsoid datum. Input data include the geodetic coordinates of both points. The accuracy of the algorithm is within a millimeter for distances not exceeding 150 km.

    You have the option to choose from among 20 built-in ellipsoid reference datums, or any ellipsoid reference datum whose semi-major axis (a) and semi-minor axis (b) are known.

26. **S.FOR** - computes geodetic coordinates of another point given the forward azimuth and distance from a known point. 20 ellipsoid reference datum are available plus any datum that the user may choose.

27. **G.TRA** - computes geodetic coordinates of an observed point using field observation without the need to reduce these data to a spheroid (ellipsoid) reference datum.

28. **G.TAD** - this is similar to the **G.TRA** program except it uses a backsight point and a horizontal angle to compute the geodetic coordinates of the observed point.

29. **SETL** - used to set up ellipsoid datum for S.INV, S.FOR, G.TRA, and G.TAD programs. Its main function is to change the previously set datum to another datum.

30. **QRGS** - computes peak runoff of a watershed using the USGS Regression Equation.

31. **QSCS** - computes peak runoff of a watershed using the Soil Conservation Service Graphic Peak Method. The program has a built-in data on rainfall types and percentage of pond and swamp values so that that there is no need to use tables and graphs.

32. **QRAT** - computes peak runoff of a watershed using the Rational Method.

33. **QAND** - computes peak runoff of a watershed using the Anderson Method.

34. **QGS3** - computes peak urban runoff using the USGS 3-Parameter Equation Method. This method is used by the FHA to estimate runoff from ungaged stream in urban areas.

35. **QGS7** - this is similar to the **QGS3** program except that it uses 7-parameter equation method.

36. **QSNY** - computes peak runoff of a watershed using the Snyder Method.

37. **INFLO** - generates and plots Inflow Hydrograph coordinates using either the SCS or the Unit Hydrograph. It also computes the Rate of Inflow when any time interval is input. Coordinates of Time vs. Inflow are printed for plotting purposes.

38. **OS.HY** - generates Hydrograph coordinates of Outflow vs. Storage Rate + Outflow, when the outflow structure and reservoir data are known. Hydrograph Coordinates are printed at the end of the run for plotting purposes.

39. **SΔTH** - generates hydrograph coordinates of water elevation above a spillway and storage flow rate ($2S/\Delta t$). Reservoir storage data, such as storage volume vs. water surface elevation must be known.

40. **OTFH** - generates Hydrograph Coordinates using the rate of outflow of a given weir or spillway vs. water elevation above the outflow structure.

41. **S.PAR** - this is based on a paper written by Alfred R. Pagan, in which he proposed the *Storage Parameter Method* used in Flood Routing through a small basin.

42. **ERTW** - computes cross-sectional Areas and Earthwork Volumes of an all-cut or an all-fill section.

43. **TTSF** - computes the Time of Concentration in runoff involving Sheet Flow.

44. **TCCN** - computes the Time of Concentration using the SCS Method.

45. **TCSM** - computes Time of Concentration using the Snyder Method.

46. **TCKW** - computes Time of Concentration using the Kinematic Wave Formula.

47. **SPRL.** - used to stake out a standard highway spiral using both the tangent/offset and the angle/distance method. Also computes layout data, left and right of the spiral centerline.

48. **SPL.3** - this is similar to the **SPRL.** program except that it prints stakeout data of successive stations given the starting and ending stations, plus the station interval.

49. **XOEQ** - solves for an unknown variable in a constrained vertical curve. For example, it will solve for beginning grade (G1) when the length of curve (L), the ending grade (G2), the horizontal distance (Xo) and the elevation of the high or low point (Yo) are known.

50. **VCSN** - this is similar to the **XOEQ** program except that it uses the horizontal distance and elevation of any point in the Vertical Curve in the solution of other parameters.

51. **TNGL** - solves for any parameter covering all 5 Triangle configurations. When 3 parameters are known, the other 3 can be solved.

52. **ARAD** - computes an area of a closed figure defined by horizontal angles and distance readings.

53. **ACXS** - computes area of a closed figure given the coordinates of the corners. It is also used to find the area of a Vertical cross section of a roadway or tunnel using elevation and offset data.

54. **RSCC** - solves a Resection or a 3-point problem. Input includes the coordinates of the 3 control points being observed and the 2 horizontal angles taken from an unknown and occupied position.

55. **BLTI** - computes the coordinates of 2 occupied points by observing 2 known control points. A total of 4 horizontal angles are taken (2 from each point) and the coordinates of the 2 known points are the required input data.

56. **CHCP** - computes all the elements of a highway circular curve when the curve is constrained or made to pass through a certain point. The location of the point to be held is defined by station and offset from either tangent.

57. **CURV.** - computes all the elements of a Circular Curve when any 2 of the 8 parameters are given. For instance, the value of the tangent and the middle ordinate can be given to solve for the remaining parameters.

CHAPTER 2

VERTC

Symmetrical Vertical Curve

This program is used in the Design of a Highway or Railroad Vertical Curve Profile. After the 5 initial data are entered, the program does the following:

1. Computes station and elevation of the high or low point.
2. Computes station and elevation of PVC, PVI, and PVT.
3. Computes station and elevation of any odd station located in the Vertical Curve or in either Tangent Grade.
4. Finds the locations of any contour or odd elevation by computing the 2 stations where that particular elevation occurs.
5. Automatically displays and prints out station and elevation data of successive stations given the starting station, ending station, and any station interval in the Vertical Curve or in either Tangent Grade.
6. Computes elevations of sequential stations in a Tangent Grade independent of the Vertical Curve.

Required Input Data

1. PVC or PVI Station - if PVI station is selected, it must be entered as a negative value.
2. PVC or PVI Elevation - elevation of either PVC or PVI, depending on which station was previously selected.
3. Beginning Grade in Percent - if the slope runs from a higher to a lower elevation, it must be entered as a negative value.
4. Ending Grade in Percent - if the slope runs from a higher to a lower elevation, it must be entered as a negative value.
5. Length of Vertical Curve - horizontal distance between the PVC and PVT.

☞
If you wish to use metric units, the stations, elevations, and length of curve must be in meters.

Explanation of symbols and initials used in the input prompt and output display

STA? = Input prompt for a station value
EL? = Input prompt for an elevation
B & E. STA? = Input prompt for a Beginning and an Ending station
INT? = Input prompt for a station interval
PVC = Beginning Point of Vertical Curve
PVI = Point of Intersection of 2 tangent grades in a Vertical Curve
PVT = Point of Tangency and ending point in a Vertical Curve
G1 = Starting Grade } a negative value indicates either tangent going
G2 = Ending Grade } from higher to lower elevation
V.C.L. = Length of Vertical Curve
[ENTER] = A key used to terminate input data entry
H.P. = Highest point in the vertical curve
L.P. = Lowest point in the vertical curve

Running the VERTC program

The following example will show how this program is used. We'll assume the following data:

1. PVC station	=	1+00.00
2. PVC elevation	=	335.68 ft.
3. Beginning Grade (G1)	=	1.15%
4. Ending Grade (G2)	=	- 4.79%
5. Length of Vertical Curve	=	600 ft.

Press [VERTC]. The display will prompt you with:
ENTER THE FOLL. DATA
(1) ±STA = ? (PVC or -PVI)
(2) ELEV = ? (PVC or PVI)

Key in: **100 [SPC] 335.68 [ENTER]**

The display will show:
(3) BEG. GRADE = ? (±%)
(4) END. GRADE = ? (±%)
(5) LENGTH OF V.C. = ?

Key in: **1.15 [SPC] 4.79 [±] [SPC] 600 [ENTER]**

After you've entered the above data, the display will show:
OPTIONS:
[ENTER] [STA?] [EL? 1] [B&E. STA? INT?]
[B&E. STA INT? 1]

Explanation of options

[ENTER] pressing this key will result in the display of the following:

G1 = 1.15 %
G2 = -4.79 %
V.C.L. = 600.00

HIGH POINT
STA 02 + 16.16
ELEV. = 336.35

PVC
STA 01 + 00.00
ELEV. = 335.68

PVI
STA 04 + 00.00
ELEV. = 339.13

PVT
STA 07 + 00.00
ELEV. = 324.76

☞
You may select any of the 5 options shown here. To help illustrate these options, we'll choose each, one at a time. Please note that each option is shown enclosed by brackets.

☞
If you are not using an IR (infrared) printer with these programs, press any key to view the output.

[STA?] - this input prompt calls for entry of a single value: any station within or outside the vertical curve. You can even enter station values that are located on either Tangent grade.

For example, station 0 + 92.15 would have an elevation of 335.59; station 1 + 65.19 would have an elevation of 336.22; and station 7 + 35.68 would have an elevation of 323.05.

[EL? 1] - this input prompt calls for entry of 2 values: a contour elevation, or an odd elevation, plus any 1-digit number.

The purpose of this option is to find the loca-

tion of a particular elevation by computing the station or stations where it occurs. For example, elevation 336.00 occurs at station 1+32.32 and station 3+00.00.

However, if you enter an elevation higher or lower than the highest or lowest point respectively of the vertical curve, the program will print an error message saying "Elevation not located."

[B&E. STA? INT?] - this input prompt calls for entry of 3 values: the beginning station, ending station, and the station interval.

For example, if the beginning station is 1+00, the ending station is 3+00, and the interval is 50, the printed output will be:

☞
If a printer is available, the output display is automatically printed. If a printer is not available, press any key to view the output.

STA 01 + 00.00
ELEV. = 335.68

STA 01 + 50.00
ELEV. = 336.13

STA 02 + 00.00
ELEV. = 336.34

STA 02 + 50.00
ELEV. = 336.29

STA 03 + 00.00
ELEV. = 336.00

[B&E STA? INT? 1] - this prompt calls for 4 input items: the beginning station, ending station, station interval, and a 1-digit code number.

This option is used to compute and display sequential stations and their corresponding elevations on either TANGENT GRADE ONLY. For example, you can display elevations of stations from 0+00 through 1+00 (PVC station) at 50-ft

intervals by entering the following data:

0 [SPC] 100 [SPC] 50 [SPC] 1 [ENTER]

Output display will be as follows:

STA 00 = 00.00
ELEV.= 334.53

(Press a key to continue).

STA 00 + 50.00
ELEV. = 335.11

STA 01 + 00.00
ELEV. = 335.68

☞
The first tangent grade (at 1.15%) begins at any station before the PVI and ends at any station before (but never after) the PVI. The other tangent grade (at -4.79%) begins at or after the PVI, and ends at any station beyond the PVI.

Computing sequential elevations on a tangent grade

In this example, we want to display stations and elevations from station 12+50.00 through station 15+50.00. We'll use the following given data:

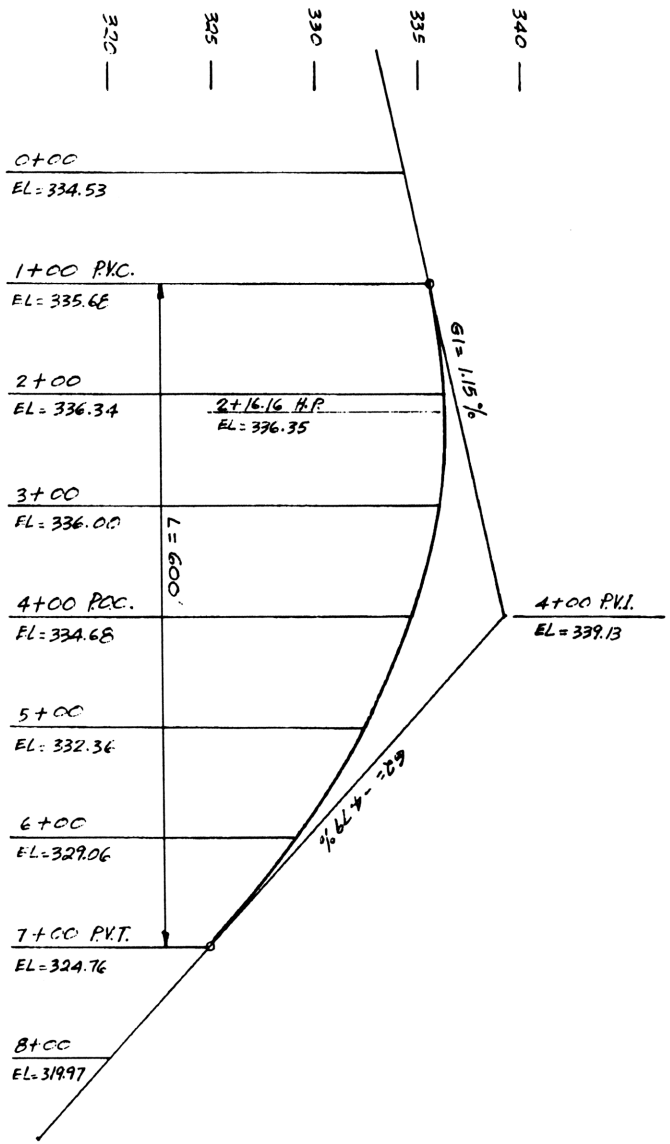
(1) Beginning Station = 12+50.00
(2) Starting Elevation = 459.32
(3) Beginning Grade = 3.44 %
(4) Ending Station = 15+50.00
(5) Station Interval = 50

Press [VERTC] (or type **VERTC** and press [ENTER].

The display will prompt you for the following:
ENTER THE FOLL. DATA:
(1) ±STA=? (PVC or -PVI)
(2) ELEV=? (PVC or PVI)

Key in: **1250 [SPC] 459.32 [ENTER]**

Figure 2.1: VERTC program



You'll then be prompted for:
(3) BEG. GRADE=?(± %)
(4) END GRADE=?(± %)
(5) Length of V.C.=?

Key in: **3.44 [SPC] 3.44 [SPC] 0 [ENTER]**

The display will prompt you with:
OPTIONS: [ENTER] [STA?]
[EL?1] [B&E. STA? INT?]
[B&E. STA?, INT?1]

Key in: **1250 [SPC] 1550 [SPC] 50 [SPC] 1 [ENTER]**

☞
You have to press a key to view the next display if a printer is not being used with this program.

Output display will be as follows:

STA 12 + 50.00
ELEV. = 459.32

STA 13 + 00.00
ELEV. = 461.04

STA 13 + 50.00
ELEV. = 462.76

STA 14 + 00.00
ELEV. = 464.48

STA 14 + 50.00
ELEV. = 466.20

STA 15 + 00.00
ELEV. = 467.92

STA 15 + 50.00
ELEV. = 469.64

☞
To quit the program, press the [QUIT] soft key or type QUIT and press [ENTER].

CHAPTER 3

PIPE

Non-pressure flow in a pipe flowing full or partially full

This program is used in the design and analysis of a circular pipe flowing full or partially full.

There are 6 parameters used in this program; it can solve for any 2 unknown parameters if the 4 remaining parameters are known. The program also computes both the normal and critical depths of flow and velocities.

You have the option to choose either a steady or unsteady flow condition when prompted by the program; enter 1 for steady, or a value between 0 and 1 for unsteady.

The 6 parameters for this program are:

1. Q - rate of flow in cubic feet per second or cubic meters per second
2. V - velocity of flow in feet per second or meters per second
3. D - inside diameter of pipe in inches or centimeters
4. N - Manning's roughness coefficient (dimensionless)
5. Hw - ratio (in percent) of the normal depth of flow (Yn) over the pipe's inside diameter (D)
6. S - longitudinal slope in percent

Required input data

All 6 parameters are displayed in the Input Prompt. The numerical values of the 4 known parameters are entered, while the 2 unknown parameters to be solved, are replaced by their respective alpha symbol (or any alpha character). These are all entered in the same sequence as the program's Input Prompt. Each entry must be separated by either a space or a comma.

Output data

All known and solved parameters, including the normal and critical depths of flow and velocities are displayed in the stack.

Example problem: partial flow in a pipe

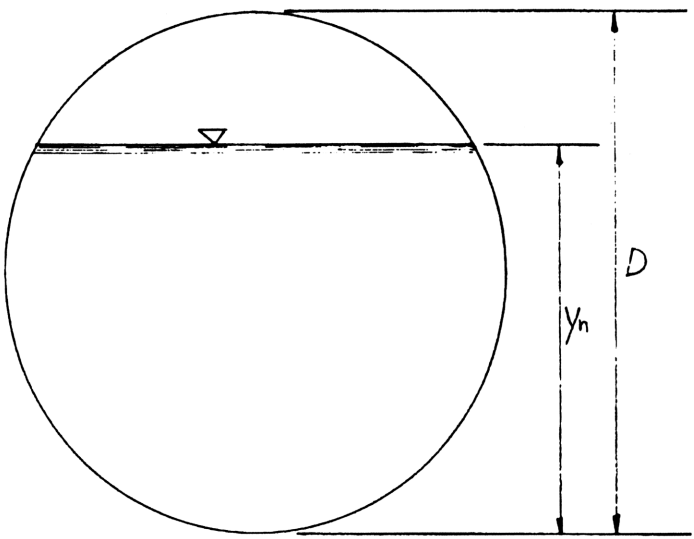
Find the following:

1. Velocity of Flow (V)
2. Ratio of height of water over Diameter in percent (Hw)
3. Normal depth of Flow (Yn)
4. Critical dept of Flow (Yc)

Our known data is:
Q = 40 cfs, n = 0.012, D = 27", S = 1.00%

To start the program, press [PIPE]. Or key in **PIPE** and press [ENTER].

Figure 3.1: PIPE program



Partial flow in a pipe

$$Hw = \frac{Yn}{D} (100)\ \%$$

The display will show the following input prompt:
(1) Q=? (2) V=? (3) D=?
(4) n=? (5) Hw(%)=? (6) S(%)=?

Using the known data (above) and the order shown by the input prompt, key in:
40 [SPC] X [SPC] 27 [SPC] .012 [SPC] X [SPC] 1 [ENTER]

The next input prompt will be the Velocity Distribution factor. If velocity distribution is steady, key in **1** and press [ENTER].

If velocity distribution is unsteady, enter a value between zero and less than 1.

☞
The parameters to be solved (in this case, V and Hw) are replaced by X (or any alpha symbol). The known values are entered in the same order as shown in the input prompt. Separate each value using a space or comma

Output data

9	Hw (%): 93.818	Yn/D in percent
8	Coeff (n): 0.012	
7	Slope (S%): 1.000	
6	Q(cfs): 40.000	
5	Vn(fps): 10.325	Normal Velocity
4	D(in): 27.000	Diameter in inches
3	Yn(ft): 2.111	Normal depth of flow
2	Yc(ft): 2.190	Critical depth of flow
1	Vc(fps): 10.134	Critical velocity

☞
There will be a delay of a few seconds before the output is printed, since the solution involves an iterative process.

Example problem: pipe flowing full

Find the values for the following variables:
1. Q
2. V
3. Yn
4. Yc

When these variables are known:
n = 0.012, Hw = 100%, S = 1.00%, D = 27”

Press [PIPE].

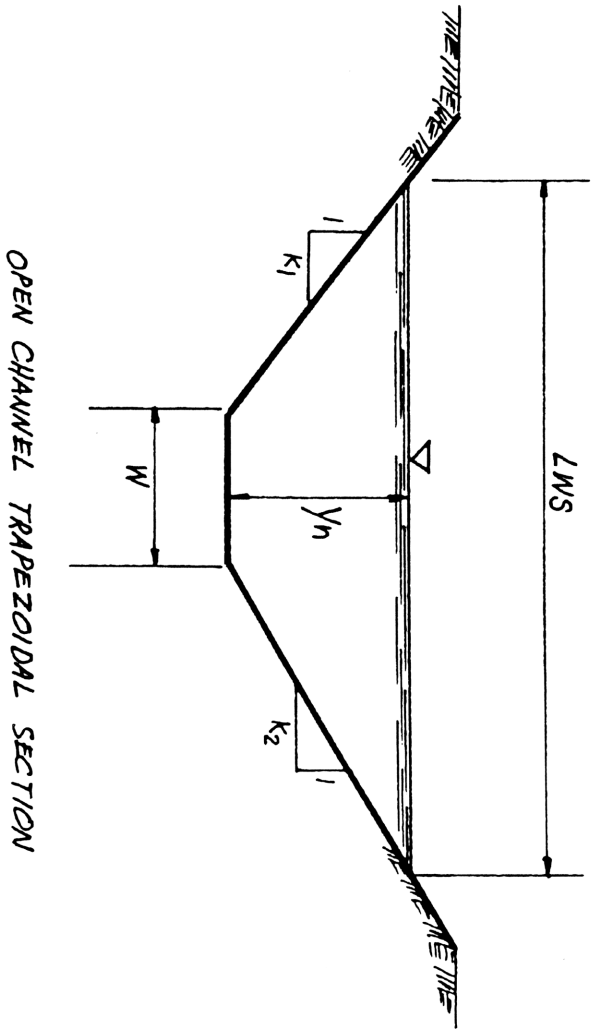
The input prompt will show:
(1) Q=? (2) V=? (3) D=?
(4) n=? (5) Hw(%)=? (6) S(%)=?

Key in: **X [SPC] X [SPC] 27 [SPC] .012 [SPC] 100 [SPC] 1 [ENTER]**

Output data

9 Hw(%): 100.000
8 Coeff.(n): 0.012
7 Slope(S%): 1.000
6 Q(cfs): 33.551
5 Vn(fps): 8.438
4 D(in): 27.000
3 Yn(ft): 2.250
2 Yc(ft): 2.004
1 Vc(fps): 8.971

Figure 4.1: CHNL program



CHAPTER 4

CHNL

Design and analysis of prismatic open channel sections carrying steady fluid flow

This program is used in the design and analysis of various types of open channels. It is applicable to Trapezoidal, V-shape, Triangular, and Rectangular channel cross sections. It can also be used in the analysis of curb and gutter flow where the 2 side slopes are the cross slope and face of curb. Any 2 unknown parameter combination can be solved if the remaining 6 parameters are known. Additional output data includes critical depth of flow and velocity. The following are the list of parameters:

1. Q = Rate of flow in cu. ft. per second or cu. meters per second
2. V = Velocity of flow in feet per second or meters per second
3. S = Longitudinal slope of stream bed (in %)
4. n = Manning's roughness coefficient
5. W = Bottom width in feet or meters (W= 0 for V-shape or Triangular sections)
6. Yn = Normal depth of flow in feet or meters
7. K1 = Horizontal component of left side slope
8. K2 = Horizontal component of right side slope

☞ For rectangular sections, K1=K2=0.

Required input data

All 8 parameters are displayed in the Input Prompt. The 2 Parameters to be solved are replaced by X, (or any alpha character) while the values of the known Parameters are entered in the same sequence as shown in the Input Prompt.

Example problem: a trapezoidal drainage channel

Find the following:
1. Normal and critical depths of flow
2. Normal and critical velocities
3. Length of water surface (LWS) across

When we know the following:
Q = 450.00 cfs
B.W. = 15.00 ft
Slope = 1.15%
n = 0.025
Left side slope (K1) = 2:1
Right side slope (K2) = 3:1

Press [CHNL]. Or key in **CHNL** and press [ENTER].

The display will show the following input prompt:
Q=? V=? S(%)=? n=?
W=? Yn=? K1=? K2=?

Using the known data and the order shown in the input prompt, key in:
450[SPC] X [SPC] 1.15 [SPC] .025 [SPC] 15 [SPC] X [SPC] 2 [SPC] 3 [ENTER]

☞
The 2 unknown variables, V and Yn, are replaced by the letter X (or any alpha character). Separate each variable using a space or comma.

Output Data

11 Lt. S/S: 2.000
10 Rt. S/S: 3.000
9 LWS(ft): 26.639
8 Slope(S%): 1.15
7 Coeff(n): 0.025
6 B.W.(ft): 15.000
5 Q(cfs): 450.00
4 Vn(fps): 9.285
3 Yn(ft): 2.328
2 Yc(ft): 2.606
1 Vc(fps): 8.026

Yn and Yc denote normal and critical depths of flow respectively;
Vn and Vc denote normal and critical velocities respectively; and
LWS denotes length of water surface across the cross section.

Example problem: rectangular drainage channel

Find the best hydraulic cross section:
1. Normal depth(Yn)
2. Botton width(W)

We'll assume the following known data:
Q = 400 cfs
Slope = 0.01%
n = 0.02

Press [CHNL]. Or type **CHNL** and press [ENTER].

The display will show the following input prompt:
Q=? V=? S(%)=? n=?
W=? Yn=? K1=? K2=?

Since it is a rectangular channel, the side slopes are perpendicular and equal to zero; in other words, K1 = K2 = 0.

The velocity of flow (V) in this case is not needed in the computation, therefore, we can assign any value to it: let V=1

Using the known data and the order shown in the input prompt, key in:
400 [SPC] 1 [SPC] .01 [SPC] .02 [SPC]
X [SPC] X [SPC] 0 [SPC] 0 [ENTER]

☞
The 2 unknown variables, W and Yn, are replaced by the letter X (or any alpha character). V=1, and K1=K2=0. Separate each variable using a space or comma.

Output data

11 Lt. S/S : 0.000
10 Rt. S/S: 0.000
9 LWS (ft): 19.389
8 Slope (S%): 0.010
7 Coeff. (n): 0.020
6 B.W. (ft): 19.389
5 Q (cfs): 400.000
4 Vn (fps): 2.128
3 Yn (ft): 9.694
2 Yc (ft): 2.364
1 Vc (fps): 8.725

In a rectangular channel, the best hydraulic section is having the bottom width equal to twice the normal depth of flow, or **B.W. = 2Yn**.

Example problem: gutter flow

Find the spread (or LWS) on a gutter flow. Also find other parameters.

We'll assume the following known data:
Q = 3.00 cfs
B.W. = 0
Slope = 0.69 %
n = 0.013
Left side slope = 48:1 (cross slope)
Right side slope = 0 (face of curb)

The cross sectional outline of a gutter is assumed to form a wide V, the left side slope of which is almost horizontal and the right side slope is the face of a curb. The bottom width (B.W.) = 0.

Press [CHNL]. Or type **CHNL** and press [ENTER].

The display will show the following input prompts:
Q= ? V= ? S(%)= ? n= ?
W= ? Yn= ? K1= ? K2 = ?

☞
The 2 unknown variables, V and Yn, are replaced by the letter X (or any alpha character). Separate each variable using a space or comma.

Using the known data and the order shown in the input prompt, key in:
3 [SPC] X [SPC] .69 [SPC] .013 [SPC]
0 [SPC] X [SPC] 48 [SPC] 0 [ENTER]

Output data

11 Lt. S/S : 48.000
10 Rt. S/S: 0.000
9 LWS (ft): 11.312
8 Slope (ft): 0.690
7 Coeff(n): 0.013
6 B.W.(ft): 0.000
5 Q(cfs): 3.000
4 Vn(fps): 2.251
3 Yn (ft): 0.236
2 Yc(ft): 0.250
1 Vc(fps): 2.005

Remarks

The normal depth of flow (Yn) = 0.236 feet.
The spread or length of the water surface (LWS) = 11.312 feet.

CHAPTER 5

HC.SO

Horizontal curve stakeout

This program is used for staking out the centerline of a horizontal curve, including the left and right offset points. It features the use of direct angle and distance tie to any point, in contrast to the traditional Deflection Angle Method.

Field setup consists of the instrument occupying the starting point of curvature (PC) and the Point of Intersection (PI) as the backsight point. A short chord for both the 25-ft. and 50-ft. station interval is included in the output display, so that even obstructed or distant points can be set. Any point can be staked by simply entering its corresponding centerline station with or without offset.

This program is ideal for staking out curb and gutter, utilities, or any structure left or right of the centerline.

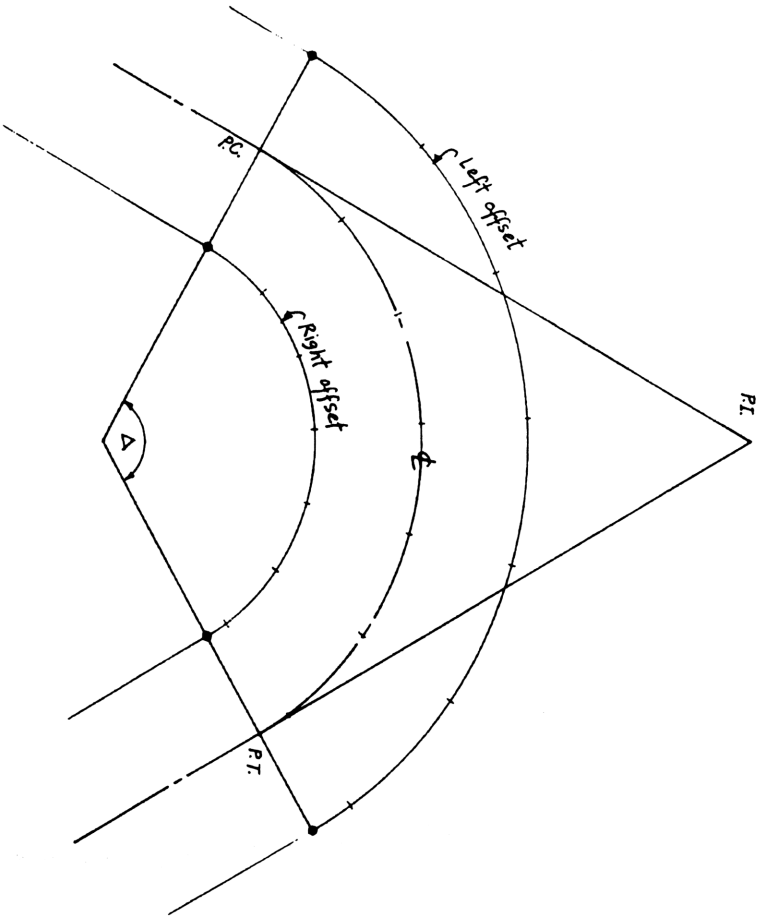
Required Input Data (Initial)

1. PC or PI station - If PI station is chosen, it must be entered as a negative number. Station values are entered as numbers. For example, station 123+08.35 is entered as 12308.35
2. Radius or Degree of Curve - If Degree of Curve is input, it must be entered as a negative number, and in degrees-minutes-seconds format (dd.mmss).
3. Delta - Central angle of a curve in degrees-minutes-seconds format (dd.mmss). If the curve runs counter-clockwise, the value of Delta must be entered as a negative number.
4. Left Offset - Uniform distance to the left of the centerline when facing towards increasing stations.
5. Right Offset - Uniform distance to the right of the centerline when facing towards increasing stations.

Symbols and initials used for input prompts and in output display

R	Radius of Curve
D	Central Angle or Delta
A	Arc
T	Tangent
CH or Ch	Chord
DC	Degree of Curve
P.I. or PI	Point of Intersection of 2 tangents
P.T.	Point of Tangency at end of curve
P.C.	Point at the beginning of curve
STA	Station
STA?	Input prompt asking for the station value
B.STA?	Input prompt asking for the beginning station
E.STA?	Input prompt asking for the ending station
INT?	Input prompt asking for the station interval
(±) O/S =	A negative offset distance indicates a point to the left of the centerline. No algebraic sign is required if the offset distance is to the right of the centerline
[ENTER]	Enters the data that has been keyed in
Oc=PC	Occupied point is the P.C.
Bs=PI	Backsight Point is the P.I.
Fs=O/S Pt	Foresight point is the offset point left or right
Fs=C.L.	Foresight point is the centerline of curve
Fs=R. O/S	Foresight point is the right offset
Fs=L. O/S	Foresight point is the left offset
∠ RT	Angle to the right (clockwise direction)
℄ STA	Centerline station
℄ CH	Centerline chord
R. Ch	Right chord
L. Ch	Left chord
C.L. or ℄	Centerline

Figure 5.1: HC.SO program



Running the HC.SO program

Let's stake out a horizontal curve, using the following known values:
1. P.C. STA = 12+00
2. Radius = 850.00
3. Delta= 56°25'34"
4. Left O/S = 12.00
5. Right O/S = 18.00

Press [HC.SO]. Or key in **HC.SO** and press [ENTER].

The display will show the following prompt:
(1) ENTER P.C. STA=?
OR (NEG.) P.I. STA=?
Press ANY Key to CONT.

Key in: **1200 [ENTER]**

The display will prompt:
(2) RADIUS=? OR
(NEG.) DEGREE of
CURVE=? (dd.mmss)

Key in: **850 [ENTER]**

The display will prompt:
(3) ±DELTA=? (dd.mmss)
ENTER NEG. IF CURVE
RUNS C. CLOCKWISE

Key in: **56.2534 [ENTER]**

The display will prompt:
(4) LEFT O/S=?
(5) RIGHT O/S=?

Key in: **12 [SPC] 18 [ENTER]**

After you've entered the above data, curve data will automatically be displayed as follows:

☞ This data will be printed automatically to an IR printer if you set Flag 5 before running this program.

P.C. STA 12 + 00.00
R = 850.00 Δ = 56°25'34"
A = 837.10 T = 456.02
CH = 803.68
DC = 06°44'26"
P.I. STA 16+56.02
P.T. STA 20+37.10

Press any key (except the 5 lower left keys) to continue. The display will then prompt:
OPTIONS:
[ENTER] [STA?(±)O/S]
[STA? 0 0] [B.STA? E.STA? INT?]

☞ 4 options are available; each is enclosed in brackets. To illustrate their functions, we'll select each, one at a time.

[ENTER] - pressing this key will result in the printing or display of the curve data as shown above.

[STA? (+/-) O/S] - this prompt calls for input of 2 items: a station, and its left or right offset distance. A left offset is entered as a negative number.

This option is used to stake out individual points with their respective offsets from the centerline. For example, a manhole with a centerline station of 12+44.07 and an offset distance of 22.35 left will have the following output:

STA 12+44.07
O/S = -22.35
Oc = PC Bs = PI Fs = O/S pt
∠ Rt. = 334°53'58"
DIST. = 49.92

[STA? 0 0] - this prompt calls for input of 3 items: a station number, followed by 2 zeros.

This option is used to stakeout 3 points in one given station. These 3 points are the centerline and the specified left and right offsets.

For example, to stakeout points at STA 12+50.00, key in: **1250 [SPC] 0 [SPC] 0 [ENTER]**

The output display will be as follows:

STA 12+50.00
C.L. O/S = 0
Oc = PC Bs = PI Fs = C.L.
∠ Rt = 01°41 07"
DIST. = 49.99
25' ℄ STA -> ℄ Ch = 25.00
50' ℄ STA -> ℄ Ch = 49.99

Press any key to continue.

STA 12+50.00
Right O/S = 18.00
Oc = PC Bs = PI Fs = R. O/S
∠ Rt. = 21°40'26"
DIST. = 52.63
25' ℄ STA -> R.Ch = 24.47
50' ℄ STA -> R.Ch = 48.93

Press any key to continue.

STA 12+50.00
Left O/S = 12.00
Oc = PC Bs = PI Fs = L. O/S
∠ Rt. = 348°17'04"
DIST. = 51.75
25' ℄ STA -> L. Ch = 25.35
50' ℄ STA -> L. Ch = 50.70

[B.STA? E.STA? INT?] - this input prompt is used to print out stakeout data of consecutive station with a specific interval. It calls for input of 3 items: beginning station, ending station, and station interval.

For example, let's say our beginning station is 12+00, ending station is 13+00, and interval is 50.

Key in: **1200 [SPC] 1300 [SPC] 50 [ENTER]**

Output display:

STA 12 + 00.00
C.L. O/S = 0
Oc = PC BS = PI Fs = C.L.
∠ Rt. = 270° 00' 00"
DIST. = 0.00
25' ℄ STA -> ℄ Ch = 25.00
50' ℄ STA -> ℄ Ch = 49.99

STA 12 + 00.00
Right O/S = 18.00
Oc = PC Bs = PI Fs = R. O/S
∠ Rt. = 90° 00' 00"
DIST. = 18.00
25' ℄ STA -> R. Ch = 24.47
50' ℄ STA -> R. Ch = 48.93

STA 12 + 00.00
Left O/S = 12.00
Oc = PC Bs = PI Fs = L. O/S
∠ Rt. = 270° 00' 00"
DIST. = 12.00
25' ℄ STA -> L. Ch = 25.35
50' ℄ STA -> L. Ch = 50.70

STA 12 + 50.00
C.L. O/S + 0
Oc = PC Bs = PI Fs = C.L.
∠ Rt. = 01° 41' 07"
DIST. = 49.99
25' ℄ STA -> ℄ Ch = 25.00
50' ℄ STA -> ℄ Ch = 49.99

STA 12 + 50.00
Right O/S = 18.00
Oc = PC Bs = PI Fs = R. O/S
∠ Rt. = 21° 40' 26"
DIST. = 52.63
25' ℄ STA -> R. Ch = 24.47
50 ℄ STA -> R. Ch = 48.93

STA 12 + 50.00
Left O/S = 12.00
Oc = PC Bs = PI Fs = L. O/S
∠ Rt. = 348°17' 04"
DIST. = 51.75
25' ℄ STA -> L. Ch = 25.35
50' ℄ STA -> L. Ch = 50.70

STA 13 + 00.00
C.L. O/S = 0
Oc = PC Bs = PI Fs = O/S
∠ Rt. = 03° 22' 13"
DIST. = 99.94
25' ℄ STA -> ℄ Ch = 25.00
50' ℄ STA -> ℄ Ch = 49.99

STA 13 + 00.00
Right O/S = 18.00
Oc = PC Bs = PI Fs = R. O/S
∠ Rt. = 13° 40' 10"
DIST. = 100.50
25' ℄ STA -> R. Ch = 24.47
50' ℄ STA -> R. Ch = 48.93

STA 13 + 00.00
Left O/S = 12.00
Oc = PC Bs = PI Fs = L. O/S
∠ Rt. = 356° 34' 58"
DIST. = 101.36
25' ℄ STA -> L. Ch = 25.35
50' ℄ STA -> L. Ch = 50.70

☞
If an IR printer is not used, press any key to continue display of this output.

CHAPTER 6

POLARIS

Polaris observation programs for azimuth and observer's position using self-generating ephemeris routines

The 2 programs in this chapter pertain to Polaris or North Star observation. The algorithm for the Polaris ephemeris is derived from the works of R.C. Gunn O.L.S. and M.R. Craymer of Erindale College, University of Toronto, Ontario, Canada.

The azimuth of Polaris using this algorithm gives an accuracy of one second of arc.

The span of validity of the algorithm for Polaris is unlimited; however, it is dependent in the changes in the system of astronomical constant.

Each program can be used anywhere in the world, using the date and time as common input data. The time of observation when entered manually, can either be in the past, present, or future; it also can be in GMT (UT) or LST, in which case the time zone number must also be known. If the observation is done in real time, the date and UT should be kept by the HP48 internal clock. In this setup, the observer need only to press the [ENTER] key when the Polaris is sighted. Before doing a Polaris observation, you should synchronize the HP48 clock with the Radio or Telephone Time signals from the U.S. Naval Observatory or other Government Agencies that broadcast official UT or LST.

POL1

This program is used for computing the true azimuth of a Reference Line by observing Polaris or North Star. A built-in subroutine computes Polaris' position at any instant, thereby sparing the need to use an almanac or ephemeris. If the HP48 clock is set to Universal or Greenwich Mean Time, the only measurement needed is the horizontal angle between the Reference Line and Polaris. Pressing [ENTER] the instant Polaris is sighted will register the time in the program. Additional output includes the star's zenith angle, Greenwich Sidereal Time, GHA of Aries, and the azimuth of Polaris. The program prompts you for all the necessary input data, for an error-free execution.

☞
You should press [ENTER] the same instant Polaris is sighted. If UT is kept by the calculator, be sure it is synchronized with the U.S. Naval Observatory time signal before the observation.

Required Input Data

1. Date: enter dates using the format *month.day year* (mm.ddyyyy). For example, June 8, 1994 should be entered as 6.081994. If the current date is kept by the HP48, press [ENTER] when prompted to automatically register the correct date in the program.
2. GMT or LST: time is entered using 24-hour format in *hours.minutes seconds* (hh.mmss). For example, 8:25:07 pm should be entered as 20.2507. If the current GMT or LST is kept by the calculator, press [ENTER] to register the time in the program.
3. If LST is used or manually entered, the Time Zone number of the place of observation must also be entered. If GMT time is used, simply press [ENTER] when prompted by the program.
4. Latitude: enter in *degrees.minutes seconds* format (dd.mmss).
5. Longitude: enter in dd.mmss format. East longitudes are entered with a negative sign.

6. Horizontal Angle: enter in dd.mmss format. This is the measured horizontal angle between the Reference Backsight and Polaris.

Field setup

1. A Transit or Theodolite occupies one end of the Reference Line, the other end is used as a backsight.
2. A horizontal angle is carefully measured between the Backsight point and Polaris.
3. Exact time is noted at the very instant when Polaris is sighted. This is done by the instrument man who signals the HP48 operator that same instant when Polaris' sight picture is acquired. As simultaneous as possible, the HP48 operator presses the [ENTER] key to automatically register the correct time into the program.

☞
A line azimuth is obtained for each horizontal angle measured. In practice, several horizontal angle readings are taken; the corresponding azimuths are added, and a mean value is obtained.

Running the POL1 program

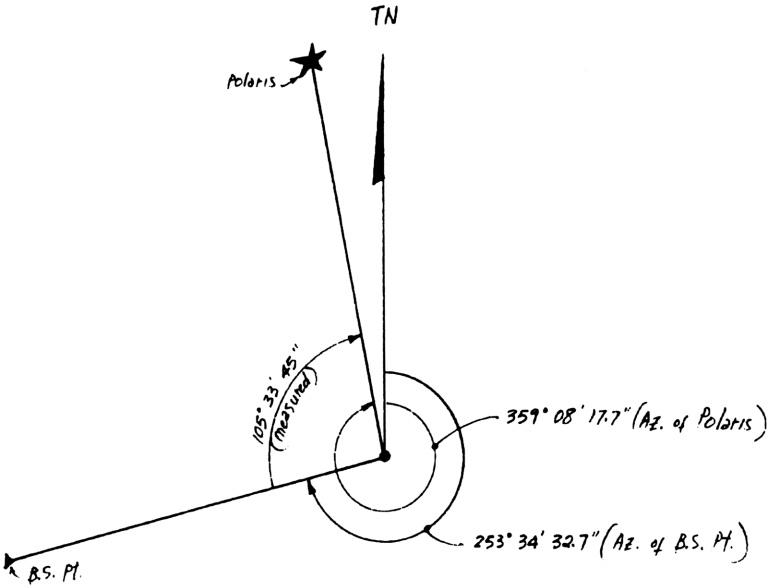
Example Problem #1 – Input Data:
1. Date = May 3, 1993
2. Time = 19h 26m 40s (LST)
   Time Zone No. = 5
3. Latitude = 37°55'28"N
4. Longitude = 75°51'48"W
5. Hor. Angle fr. B.S. pt. to Polaris = 105°33'45"

Press [POL1]. Or type **POL1** and press [ENTER].

The display will prompt you with:
DATE=? (mm.ddyyyy)
OR Key [ENTER] IF
TODAY'S DATE

Key in: **5.031993 [ENTER]**

Figure 6.1: POL1 program



Example problem #1

The display will prompt:
UT or LST=? (hh.mmss)
or Key [ENTER]
if HP48 TIME

Key in: **19.2640 [ENTER]**

The display will then show:
IF LST WAS USED,
TIME ZONE No.=?
or ELSE, Key [ENTER]

Key in: **5 [ENTER]**

The display will prompt:
LATITUDE=? (dd.mmss)

Key in: **37.5528 [ENTER]**

The display will prompt:
LONGITUDE=? ± (dd.mmss)
(NEG. IF EAST)

Key in: **75.5148 [ENTER]**

The display will prompt:
HOR. ANGLE (Rt.)=?
(dd.mmss) fr. B.S.
Pt. to POLARIS

Key in: **105.3345 [ENTER]**

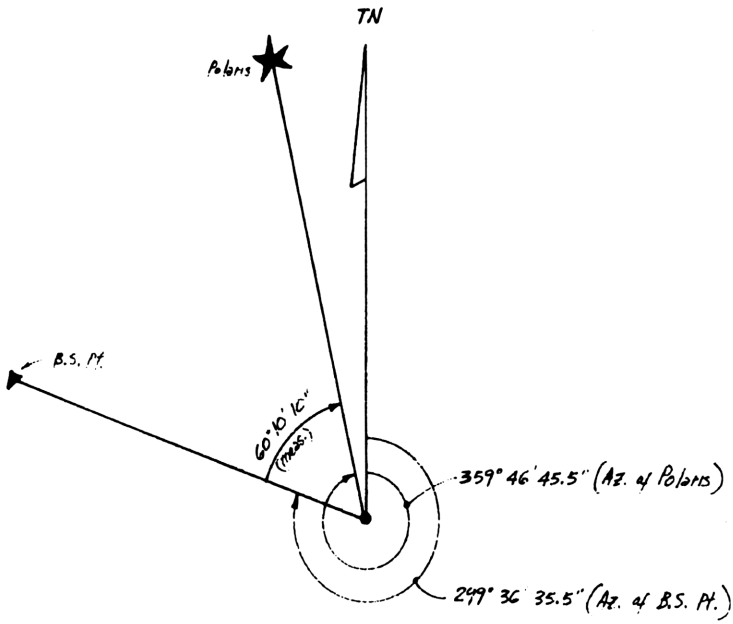
When you've completed entering the above data, the program will give you the following output (explanatory notes are added in parentheses):

12 DATE: 5/4/1993
11 GMT: 0.2640
(Greenwich Mean Time = 00h 26m 40s)
10 LAT.(N): 37.5528
9 LON.(W): 75.5148
8 HOR. ∠: 105.3345
7 R.A.(h.ms): 2.23311
(Right Ascension = 2h 23m 31.1s)
6 DECL: 89.14046
(Declination of Star = 89°14'04.6")
5 ZENITH ∠ : 52.25271
4 GAST: 15.14183
(Greenwich Apparent Sidereal Time)
3 GHA °: 228.34347
(Greenwich Hour Angle of Aries)
2 POL. AZ: 359.08177
(Azimuth of Polaris = 359°08'17.7")
1 B.S. AZ: 253.34327
(Azimuth of Backsight Point)

☞
The True Azimuth of the Reference Line as shown in this example is 253°34'32.7" (see Figure 6.1).

☞
If you are using an infrared printer, type **PRST** to print the output shown here.

Figure 6.2: POL1 program



Example problem #2

Example Problem #2:
The following input and output data are taken from an example program run by M.R. Craymer in his Technical Report No. 3 dated October 1984 entitled "Azimuth Determination from Observations on Polaris and the Sun." These data are presented here for output comparison only.

Input data:
Latitude (D-M-S) = 43-40-10
Longitude (D-M-S) = 79-30-00
Date = Nov. 20, 1972
UT (H-M-S) = 4-10-20
HOR. ANGLE (D-M-S) = 60-10-10

Output data:
Zenith Dist. (D-M-S) = 45-29-23
GAST (H-M-S) = 8-07-26.4
RA (H-M-S) = 2-07-03.7
DEC (D-M-S) = 89-08-39.9
AZ of STAR (D-M-S) = 359-46-45.9
AZ of R.O (D-M-S) = 299-36-35.9

☞
Press [POL1] to execute this program. The display prompts and the data you key in will be similar to those in problem #1, above.

The program will give you the following data (see also Figure 6.2):

12 DATE: 11/20/1972
11 GMT: 4.1020
10 LAT.(N): 43.4010
9 LON.(W): 79.3000
8 HOR. ∠: 60.1010
7 R.A. (h.ms): 2.07022
6 DECL.: 89.0840
5 ZENITH ∠: 45.29233
4 GAST: 8.07264
3 GHA °: 121.51366
2 POL. AZ.: 359.46455
1 B.S. AZ.: 299.36355

☞
Angular quantities are formatted as dd.mmss. Time quantities (i.e. GMT, R.A., and GAST) are formatted as hh.mmss.

POL2

This program computes the latitude of the observer and the azimuth of the Reference Line. It has the same function as the POL1 program, except that the longitude of the observer must be given and the altitude of Polaris is measured.

The instant Polaris is sighted, time should be entered or registered in the program. As with the POL1 program, POL2 uses a built-in subroutine to compute Polaris' position at any instant; thus, there is no need to consult an ephemeris. The measured altitude reading is automatically corrected for Refraction, parallax, pressure, temperature, and index error, if any.

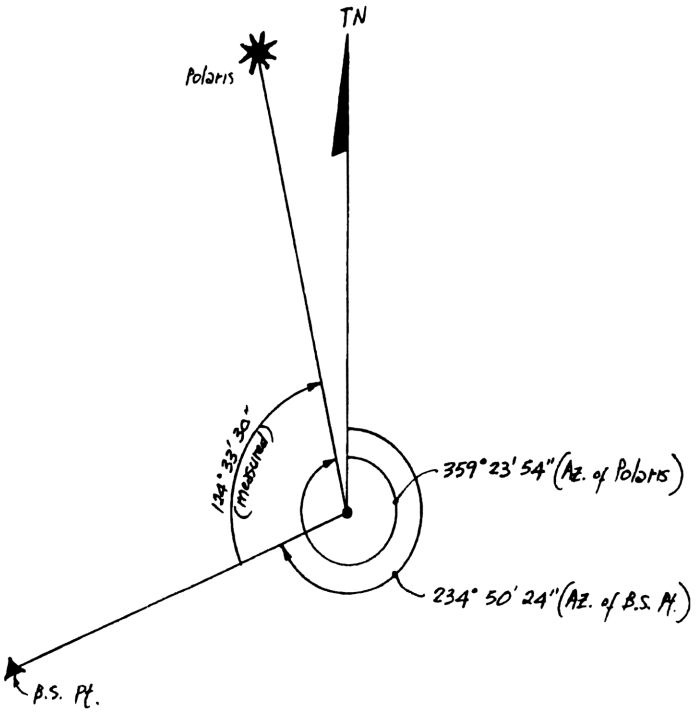
Required Input Data

1. Date: the format for manually entering a date is *month.day year* (mm.ddyyyy). For example, October 23, 1993 should be entered as 10.231993. If the current date is kept by the HP48, press [ENTER] when prompted to automatically register the correct date in the program.
2. GMT or LST: time is entered in 24-hr. format in *hours.minutes seconds* (hh.mmss). For example, 9:08:35 pm should be entered as 21.0835. If the current GMT or LST is kept by the calculator, simply press the [ENTER] key when prompted.
3. If LST is used or manually entered, the time zone number of the place of observation must also be entered. If GMT is chosen, press [ENTER] when prompted for the time zone.
4. Measured vertical angle of Polaris: enter in *degrees.minutes seconds* (dd.mmss) format. This is the actual measured angle from the horizontal plane to the center of Polaris.

☞
The [ENTER] key should be pressed the instant Polaris is sighted.

5. Index Error: enter in ± dd.mmss format. If index error is to be subtracted from the measured angle, it must be entered negative. If there is no Index error, simply press the [ENTER] key.
6. Air Temperature in degrees centigrade, and atmospheric pressure in equivalent inches of Mercury. These two variables, if necessary for correction, must be entered together and separated by a space (use the [SPC] key). These two variables are used only when the temperature and pressure are extremely high or low. If they are not applicable, which is usually the case, simply press [ENTER] to by-pass the prompt.
7. Longitude: enter in ±dd.mmss. If the observer happens to be in the Eastern Hemisphere, the longitude value must be negative. If the observer is located in the Western Hemisphere, simply enter the value without any algebraic sign.
8. Measured Horizontal Angle: enter in dd.mmss. This is the right or clockwise angle from the Reference Backsight to the center of Polaris.

Figure 6.3: POL2 program



Running the POL2 program

Example Problem/Input Data:

1. Date = May 7, 1993
2. UT = 1h 50m 37s
3. Altitude of Polaris = 37°50'28"
4. Index Error = N/A
5. Air Temp & Atmospheric Pressure = N/A
6. Longitude = 75°03'45"W
7. Hor. Angle fr. BS. pt. to Polaris = 124°33'30"

Press [POL2]. Or type **POL2** and press [ENTER].

The display will prompt:
DATE=? (mm.ddyyyy)
OR Key [ENTER] IF
TODAY'S DATE

Key in: **5.071993 [ENTER]**

The display will prompt:
UT or LST=? (hh.mmss)
or Key [ENTER]
if HP48 TIME

Key in: **1.5037 [ENTER]**

The display will prompt:
IF LST WAS USED,
TIME ZONE No.=?
or ELSE, Key [ENTER]

Key in: **[ENTER]**

The display will prompt:
MEASURED VERTICAL
ANGLE of POLARIS=?
(dd.mmss)

Key in: **37.5028 [ENTER]**

The display will prompt:
INDEX ERROR=±(0.mmss)
(-) to DEDUCT fr. V. ∠
Key [ENTER] if N/A

Key in: **[ENTER]**

The display will prompt:
AIR TEMP.=? (°C) &
ATM. PRESS.=? (InHg)
Key [ENTER] if N/A

Key in: **[ENTER]**

The display will prompt:
LONGITUDE=? ± (dd.mmss)
(NEG. IF EAST)

Key in: **75.0345 [ENTER]**

The display will prompt:
HOR. ANGLE (RT.)=?
(dd.mmss) fr. B.S.
Pt. to POLARIS

Key in: **124.3330 [ENTER]**

Output data

(See also Exhibit 6.3)

14 DATE: "5/7/1993"
13 GMT: 1.50370
12 VERT. ∠: 37.50280
11 V. ∠ (ctd): 37.49111
10 HOR. ∠: 124.33300
9 RA (h.ms): 2.23328
8 DECL: 89.14036
7 ZENITH ∠: 52.10489
6 GAST: 16.50188
5 GHA°: 252.34415
4 LAT. (N): 38.25176
3 LON. (W): 75.03450
2 P.AZ: 359.23540
1 B.S. AZ: 234.50240



GMT and UT are the same; either may be used in place of the other.

CHAPTER 7

SOLAR

Solar observation programs for azimuth and observer's position using self-generating ephemeris routines

The 4 programs included in this chapter pertain to Solar observation. The algorithm for computing the sun's declination, GHA, and semi-diameter correction is derived from an article written by G.G. Bennett entitled "A Solar Ephemeris for Use with Programmable Calculators" published in Australian Surveyor, September 1980, Vol. 30, No. 3. The maximum error in the sun's declination and right ascension is 1.2 and 0.5 arc seconds respectively.

The length of validity for the Solar ephemeris algorithm is up to the year 2000; however, solar observations made beyond that year will not be seriously affected.

These programs can be used anywhere in the world, with the date and time as common input data. The time of observation when entered manually, can either be in the past, present or future; and can be in GMT (UT) or LST, in which case the time zone number must also be known. If the observation is done in real time, it is suggested that the date and UT be kept by the HP48 internal clock. In this setup, the observer need only to press the [ENTER] key when the sun is sighted. Before doing a sun observation, you should synchronize the HP48 clock with the Radio or Telephone Time signals from the U.S. Naval Observatory or other Government Agencies that broadcast official UT or LST.

E.ALT

This program computes the true azimuth of a reference line, and the Geodetic Coordinates of the observer by Equal Altitude Method, without the use of a Solar Almanac. It also computes the time of meridian crossing and the True Azimuth of the sun at that instant. All the necessary sight corrections such as index error, semi-diameter, parallax, refraction, unequal declination, and non-standard atmospheric pressure and temperature, are included in the program. The program accepts input data in the past, or in real-time mode. In the real-time mode, the results are obtained as soon as the last field data is entered.

The algorithm used in generating the sun's ephemeris is based on G.G. Bennett's paper published in the Australian Surveyor Journal on September 1980 issue, in which the calculated accuracy of the sun's declination and right ascension is 1.2 and 0.5 arc seconds respectively. The accuracy of the final result is dependent on the equipments used and the care in which field measurements are obtained.

This method involves taking horizontal and vertical angle readings of the sun before and after local high noon. A series of angle and time readings can be employed to obtain a mean and final result. A built-in subroutine computes the sun's declination, GHA, and semi-diameter correction, so that there is no need for an ephemeris. This program could be useful in remote and uncharted areas and will give accurate latitude and longitude position anywhere in the world.

Required input data

1. Date: the format for entering a date is *month.day year* (mm.ddyyyy). For example, December 9, 1996 would be entered as 12.091996. If the current date is kept by the HP48, press [ENTER] when prompted to automatically register the correct date in the program.
2. AM Sunshot – GMT? or LST?: the program is asking for the exact time when the sun is sighted and acquired in the instrument's crosshairs. Either GMT or LST can be used and kept by a separate chronometer or by the HP48. If the latter is used, simply press the [ENTER] key. When time is entered manually, the format must be hh.mmss in 24-hr. mode. For example, if the time is given as 1h 08m 38s in the afternoon, the input format is 13.0838.
3. If Local Standard Time (LST) is used, the time zone number of the place of observation must also be entered.
4. Horizontal Angle: enter in dd.mmss from Reference Backsight point to the morning sun.
5. Vertical Angle: enter in ±dd.mmss format. If the sun is sighted at its center, the vertical angle must be entered as a negative number. If NE quadrant pointing is used, the vertical angle is entered without algebraic sign.

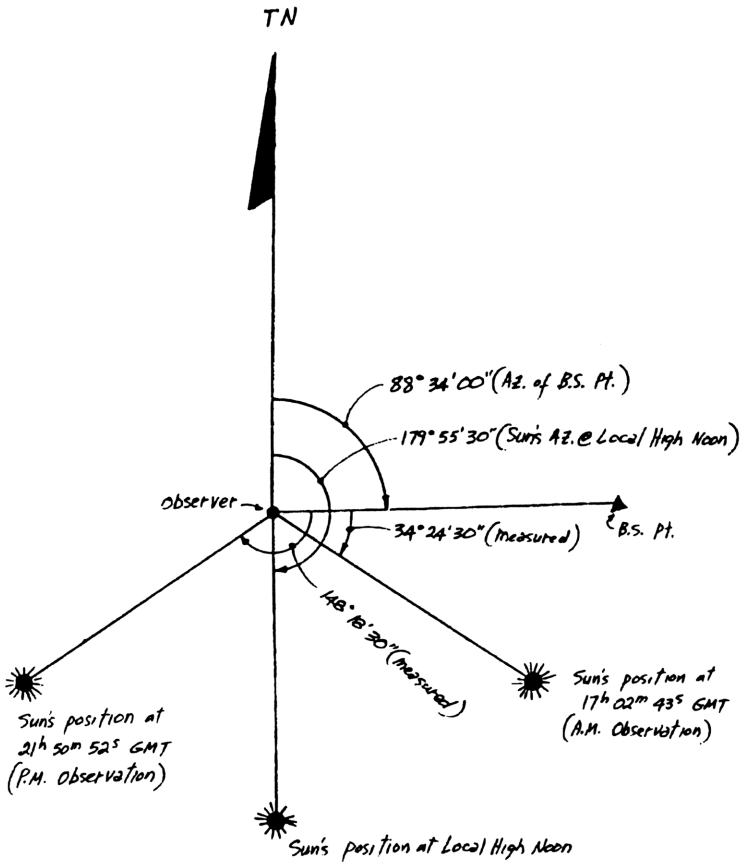
   There are 2 ways to sight the sun: the NE quadrant pointing and the Direct or Center pointing.When the NE quadrant pointing method is used in both the am and pm sightings, the sun is "placed" on the NE quadrant formed by the vertical and horizontal crosshairs of the telescope. The left and bottom edges of the sun are tangent to the vertical and horizontal hairline respectively.

☞
There are 2 ways to sight the sun: the NE quadrant pointing and the Direct or Center pointing.

Direct pointing to the sun's center can only be done if the instrument's telescope is equipped with solar filter and augmented circular reticule.

6. Index Error: enter in ±dd.mmss (if any). If index error is to be deducted from the verical angle reading, it must be entered as a negative number. If not applicable, press [ENTER].
7. Air Temperature in degree centigrade and atmospheric pressure in equivalent inches of Mercury: these two variables are used only when necessary, and when the temperature and pressure are in the high or low extremes. If these two corrections are to be applied at all, they must be entered together and separated by a space (use the [SPC] key). If they are not applicable, simply press [ENTER].
8. PM Sunshot: enter in hh.mmss and 24-hour format (GMT or LST). This is the exact moment when the sun's altitude is precisely the same as its altitude in the morning. Both am and pm sunshots must use the same method of pointing. After the am sunshot, the sun is tracked until the sight picture obtained is identical with the one in the morning.
9. Horizontal Angle: enter in dd.mmss format. This is the angle measured from the same reference line as the am reading to the sun's pm position.

Figure 7.1: E.ALT program



Running the E.ALT program

Given data (see also Figure 7.1) – *source is "Surveying Sixth Edition" by Moffitt & Bouchard (p. 540). These data are used only to compare the accuracy of the azimuth obtained.*

AM Observation:

1. Date = August 17, 1974
2. Time = 10h 02m 43s (LST
3. Hor. Angle = 34°24'30" (Angle between Ref. Line & am Sun)
4. Vertical Angle = 46°38'00"

PM Observation:

5. Time = 14h 50m 52s (LST)
6. Hor. Angle = 148°18'30" (Angle between Ref. Line and pm Sun)
7. Method of Pointing = NE qd.
8. Time Zone No. = 7

Result: Azimuth of Reference Line = 88°34'04"

Press [E.ALT]. Or type **E.ALT** and press [ENTER].

The display will prompt:
DATE=? (mm.ddyyyy)
or Key [ENTER] if
TODAY'S DATE

Key in: **8.171974 [ENTER]**

The display will prompt:
A.M. SUNSHOT: UT=? or
LST=? or Key [ENTER]
if HP48 TIME

Key in: **10.0243 [ENTER]**

The display will prompt:
IF LST WAS USED,
TIME ZONE No.=?
or ELSE, Key [ENTER]

Key in: **7 [ENTER]**

The display will prompt:
HOR. ANGLE=? (dd.mmss)
clockwise fr. Ref.
B.S. Pt. to A.M. SUN

Key in: **34.2430 [ENTER]**

The display will prompt:
VERT. – =? (dd.mmss)
(-) if CENTER SUNSHOT
(+) if N.E. Qd SUNSHOT

Key in: **46.3800 [ENTER]**

The display will prompt:
INDEX ERROR=? ±(0.mmss)
(-) to DEDUCT fr. V
or Key [ENTER] if N/A

Press **[ENTER]**

The display will prompt:
AIR TEMP.=? (°C)
ATM. PRESS.=? (InHg)
Key [ENTER] if N/A

Press **[ENTER]**

The display will prompt:
P.M. SUNSHOT:
(LST) TIME=? (hh.mmss
24-hr. Format)

Key in: **14.5052 [ENTER]**

The display will prompt:
HOR. ANGLE=? (dd.mmss)
clockwise fr. Ref.
B.S. Pt. to P.M. SUN

Key in: **148.1830 [ENTER]**

Output data

13 DATE: 8/17/1974
12 EP.DT: 8/17/1974
(Ephemeris date)
11 GMT1: 17.0243
10 GMT2: 21.5052
9 AM H ∠: 34.2430
8 PM H ∠: 148.1830
7 V. ∠: 46.3800
6 LMT: 12.0402
(Local Mean Time at meridian crossing)
5 LST: 14.5052
(Local Standard Time at 2nd observation)
4 (Noon) AZ: 179.5530
(Sun's Azimuth at local high noon)
3 LAT. (N) : 43.3122
2 LON. (W): 110.4123
1 B.S. AZ: 88.3400
(True Azimuth of Reference Line)

☞
After the a.m. sunshot, tighten the instrument's vertical clamp screw. This holds the same vertical angle until a certain time in the afternoon, when the Sun attains the same altitude and sight picture as the morning observation.

LL.AZ

This is a new and unique sunshot program which involves taking a double observation of the Sun within minutes apart, to determine the following:

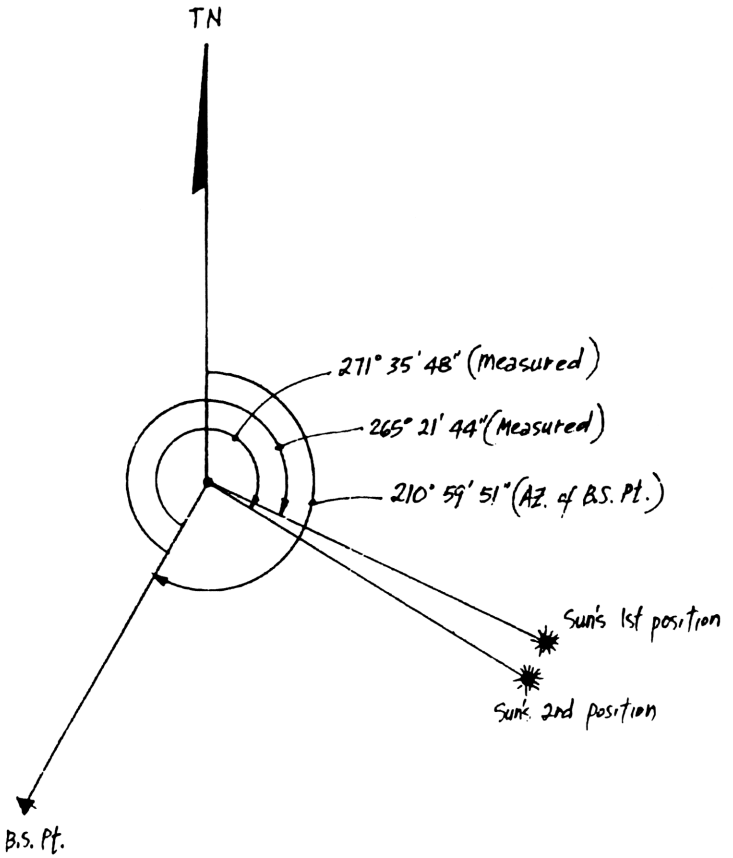
1. True azimuth of a reference line
2. Latitude and longitude of the observer
3. True azimuth of the Sun at the instant of 2nd sighting
4. Local Standard Time at the place of observation at the instant of the 2nd sighting.

The program has a built-in "perpetual" Solar Ephemeris Routine for computing the Sun's declination, GHA, and semi-diameter at any instant. Altitude readings are automatically corrected for semi-diameter, parallax, refraction, pressure, temperature, and the instrument's index error (if any). This program is most useful when surveying uncharted and remote areas. It could also be used for navigation and for determining the observer's latitude and longitude using either a sextant or a surveyor's transit. Multiple Altitude and Time readings are averaged in order to obtain a more accurate and reliable result.

Required Input Data

1. Date: enter the date using *month.day year* format (mm.ddyyyy). For example, May 16, 1993 is entered as 5.161993. If the current date is kept by the HP48, press [ENTER] to automatically register the correct date in the program.

Figure 7.2: LL.AZ program



☞
You should press [ENTER] precisely when you obtain a desired sight picture of the Sun.
If LST Time is used, the Time Zone number must also be given.

2. GMT or LST Time of First Sunshot: enter the time manually in hh.mmss and 24-hour format. If the current time is kept by the HP48, simply press [ENTER] when prompted. Make sure the HP48 clock is synchronized with an official time signal.
3. Horizontal Clockwise Angle: enter in dd.mmss format. This is the angle from a reference line to the Sun's first position.
4. Sun's Altitude: this is a measured vertical angle from the horizontal plane to the Sun's first position. The angular format is dd.mmss and must be entered as a negative value if the sun is sighted at its center. No algebraic sign is needed for a NE quadrant sight.
5. Index Error (if any): this refers to the instrument's vertical plate. If there is an index error that must be deducted from the vertical readings, enter it as a negative value; otherwise, no algebraic sign is needed. Press [ENTER] if no error correction is needed.
6. Air Temperature (°C) and Atmospheric Pressure (Hg): these two corrections must be entered together, and only if both are well above or below normal. Press [ENTER] if not applicable.
7. Time of Second Sunshot: enter in hh.mmss/ 24-hour format.
8. Second Altitude Reading: enter in dd.mmss format. Enter a negative value if the Sun is sighted at its center. No algebraic sign is needed for a NE quadrant sight.

☞
Use a magnetic compass to determine your heading.

9. If the observer is facing approximately South during the time of observation, press [ENTER]. If facing approximately North, press the [±] key followed by the [ENTER] key.
10. Horizontal Angle: enter in dd.mmss. This is the clockwise angle from the reference line to the Sun's second position.

Running the LL.AZ program

Example problem – given data:
Date = May 20, 1993 (San Diego, CA)
Time of first Sunshot = 10h 25m 33s (LST)
Time Zone = 8
Sun's first Altitude = 68°13' 58" (to the sun's center)
Temperature and Pressure = Normal
Index error = none
First horizontal angle clockwise fr. Ref. B.S. to Sun = 265° 21' 44"
Time of 2nd Sunshot = 10h 30m 33s
Sun's 2nd Altitude = 69° 07' 45" (to the sun's center)
2nd hor. angle clockwise fr. Ref. B.S. to Sun = 271° 35' 48"
Observer facing South (approximately) during the 2 observations.

☞
Altitude readings are entered as negative if the sight is directly to the sun's center.

When the observer's latitude is greater than the sun's declination at the time of observation, the observer is generally facing south and the relative path of the sun is from left to right.

Press [LL.AZ]. Or type **LL.AZ** and press [ENTER].

The display will prompt you to enter:
DATE=? (mm.ddyyyy)
or Key [ENTER] if
TODAY'S DATE

Key in: **5.201993 [ENTER]**

The display will prompt:
1st SUNSHOT: UT=? or
LST=? or Key [ENTER]
when SUN IS SIGHTED

Key in: **10.2533 [ENTER]**

The display will prompt:
IF LST WAS USED,
TIME ZONE No.=?
or ELSE, Key [ENTER]

Key in: **8 [ENTER]**

The display will prompt:
HOR. ANGLE (1)=?
(dd.mmss) CLOCK-WISE
fr. B.S. Pt. to SUN

Key in: **265.2144 [ENTER]**

The display will prompt:
VERT. – (1)=? ±(dd.mmss)
(-) if CENTER SUNSHOT
(+) if N.E. Qd SUNSHOT

Key in: **68.1358 [±] [ENTER]**

The display will prompt:
INDEX ERROR=? ±(0.mmss)
(-) to DEDUCT fr. V
or Key [ENTER] if N/A

Press **[ENTER]**

The display will prompt:
AIR TEMP.=? (°C)
ATM. PRESS.=? (InHg)
Key [ENTER] IF N/A

Press **[ENTER]**

The display will prompt:
BEGIN 2nd SUNSHOT:
LST=? (hh.mmss 24-hr
Format)

Key in: **10.3033 [ENTER]**

The display will prompt:
VERT. –(2)=? ±(dd.mmss)
(-) if CENTER SUNSHOT
(+) if N.E. Qd SUNSHOT

Key in: **69.0745 [±] [ENTER]**

The display will prompt:
LOOKING -> N or S? (est.)
Key [ENTER] IF SOUTH
[±] [ENTER] IF NORTH

Press **[ENTER]**

The display will prompt:
HOR. ANGLE (2)=?
(dd.mmss) CLOCK-WISE
fr. B.S. Pt. to SUN

Key in: **271.3548 [ENTER]**

Output data

(See also exhibit 7.2)

12 DATE: 5/20/1993
11 GMT1: 18.2533
10 H. ∠ (1): 265.2144
9 V. ∠ (1): 68.1358
8 GMT2: 18.3033
7 H. ∠ (2): 271.3548
6 V. ∠ (2): 69.0745
5 AZ. (2): 122.3539
(Sun's azimuth for the 2nd observation)
4 LST: 10.3033
(LST 2nd observation)
3 LAT. (N): 32.4318}
(Geodetic coordinates of observer)
2 LON. (W): 117.0924}
1 B.S. AZ.: 210.5951
(Azimuth of Reference Object)

SUN2

This Sunshot Program is used to find the True Azimuth of a Reference Line using the Hour Angle method. Given the observer's latitude and longitude, and with the HP48 clock set to Universal or GMT Time, the program computes the True azimuth of a designated Reference Line, the Sun's altitude, and the Local Standard Time, by taking a horizontal angle measurement between the Reference Line and the Sun. To obtain more reliable and accurate results, multiple observations must be taken to obtain a mean and final azimuth value.

A built-in subroutine automatically computes the Sun's declination and GHA, so there is no need to use an ephemeris.

Required input data

1. Date: enter manually using *month.day year* format (mm.ddyyyy). For example, March 22, 1994 is entered as 5.221994. If the current date is kept by the HP48, press [ENTER] when prompted to automatically register the correct date in the program.
2. Time: you may use GMT or LST. Manually enter time using a 24-hour clock and *hours.minutes seconds* format (hh.mmss). For example, if the time of observation is 3:35:08 pm, enter it as 15.3508. If LST is used, the time zone number must also be given. If the HP48 keeps either GMT or LST, simply press the [ENTER] key. Make sure the HP48's time is synchronized to an official time standard.
3. If LST is used, the Time Zone number must also be entered. If not, simply press [ENTER].

☞ You should press [ENTER] precisely when the Sun is sighted.

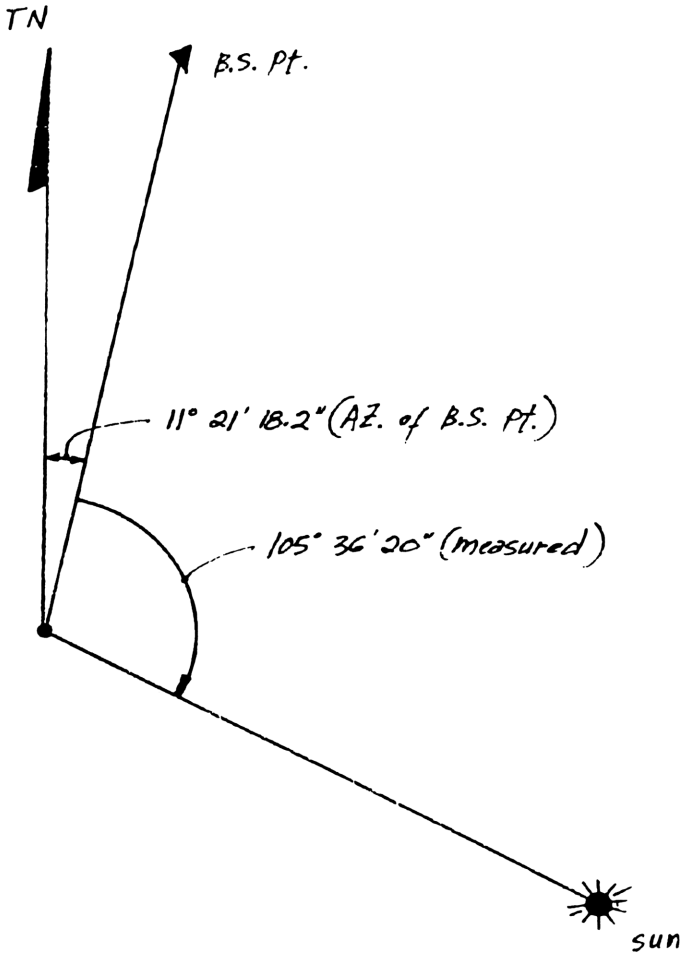
4. Latitude: enter in *degrees.minutes seconds* format (dd.mmss). If the latitude of the observer is south of the equator, latitude must be entered as a negative value.
5. Longitude: enter in dd.mmss format. If the longitude of the observer is in the Eastern hemisphere, longitude must be entered as a negative value.
6. Horizontal Angle: enter in dd.mmss format. This is the measured angle between the reference line and the Sun. If the sighting is direct, or to the Sun's center, the measured horizontal angle must be entered as a negative value. In this case, correction for semi-diameter is *not* applied.

   If the NE quadrant method of pointing is used, the horizontal angle must be entered without any algebraic sign; in this case, the semi-diameter correction is in effect.

☞ Field Procedures using a combination of direct and reversed methods of telescope pointings are beyond the scope of this manual.

There are 2 ways to sight the Sun: the Direct Sunshot method, and the NE Quadrant method. The Direct Sunshot Method involves the use of a reticuled telescope attachment to permit direct pointing of the Sun's center. The NE Quadrant Method uses the vertical and horizontal crosshairs, with the Sun's trailing edge tangent to the vertical hairline and the Sun's bottom edge tangent to the horizontal hairline.

Figure 7.3: SUN2 program



Running the SUN2 program

Example problem/given data:
Date = June 27, 1993
Time (LST) = 10h 25m 33s
Time Zone No. = 5
Latitude = 37°55'40"N
Longitude = 75°48'35"W
Hor. Angle = 105°36'20" (clockwise from reference line to Sun's center)

Press [SUN2]. Or type **SUN2** and press [ENTER].

The display will prompt you with the following:
DATE=? (mm.ddyyyy)
or Key [ENTER] if
TODAY'S DATE

Key in: **6.271993 [ENTER]**

The display will prompt:
UT or LST=? (hh.mmss
24-hr) or Key [ENTER]
if HP48 TIME

Key in: **10.2533 [ENTER]**

The display will prompt:
IF LST WAS USED,
TIME ZONE No.=?
or ELSE, Key [ENTER]

Key in: **5 [ENTER]**

The display will prompt:
LATITUDE=? ± (dd.mmss)
(NEG. if SOUTH)

Key in: **37.5540 [ENTER]**

The display will prompt:
LONGITUDE=? ± (dd.mmss)
(NEG. if EAST)

Key in: **75.4835 [ENTER]**

The display will prompt:
HOR. –=? ± (dd.mmss)
(-) if CENTER SUNSHOT
(+) if N.E. Qd SUNSHOT

Key in: **105.3620 [±] [ENTER]**

☞
Since the method of pointing is to the Sun's center, the measured horizontal angle must be entered as a negative value.

Output data

(See also exhibit 7.3.)

12 DATE: 6/27/1993
11 GMT: 15.2533
10 DECL (N): 23.18151
9 GHA: 50.3727
8 S.D.: 0.15451
7 SUN'S ALT: 63.59329
6 HOR. ∠: 105.3620
5 LST: 10.2533
4 LAT. (N): 37.5540
3 LON. (W): 75.4835
2 SUN'S AZ.: 116.57382
1 B.S. AZ: 11.21182
(The azimuth of the reference line as shown above is 11°21'18.2")

☞
To print the output display, use the **PRST** function.

SUN3

This program has the same function as the SUN2 program except that SUN3 is used to compute for the unknown longitude of the observer when the latitude is known. The program calls for the measurement of the Sun's altitude and the time of observation. The measured vertical angle is automatically adjusted for refraction, parallax, and semi-diameter corrections, plus the instrument's index error (if any).

A built-in subroutine automatically computes the sun's declination, GHA, and semi-diameter at any instant, so there is no need to use an ephemeris. This method of azimuth determine is the Altitude Method in which the time of observation is not critical; time is required only to the nearest minute.

Required input data

1. Date: enter manually using mm.ddyyyy format. For example, June 19, 1993 is entered as 6.191993. If the current date is kept by the HP48, press [ENTER] when prompted to automatically register the correct date in the program.
2. GMT or LST Time: enter manually using the 24-hour clock and in hh.mmss format. For example, an observation at 3:35:08 pm is entered as 15.3508. If LST is used, the time zone number of the place of observation must also be given. If the HP48 keeps GMT or LST, simply press the [ENTER] key at the instant the Sun is sighted.

☞
Make sure your HP48 is synchronized with an official time standard, such as the US Naval Observatory time signal.

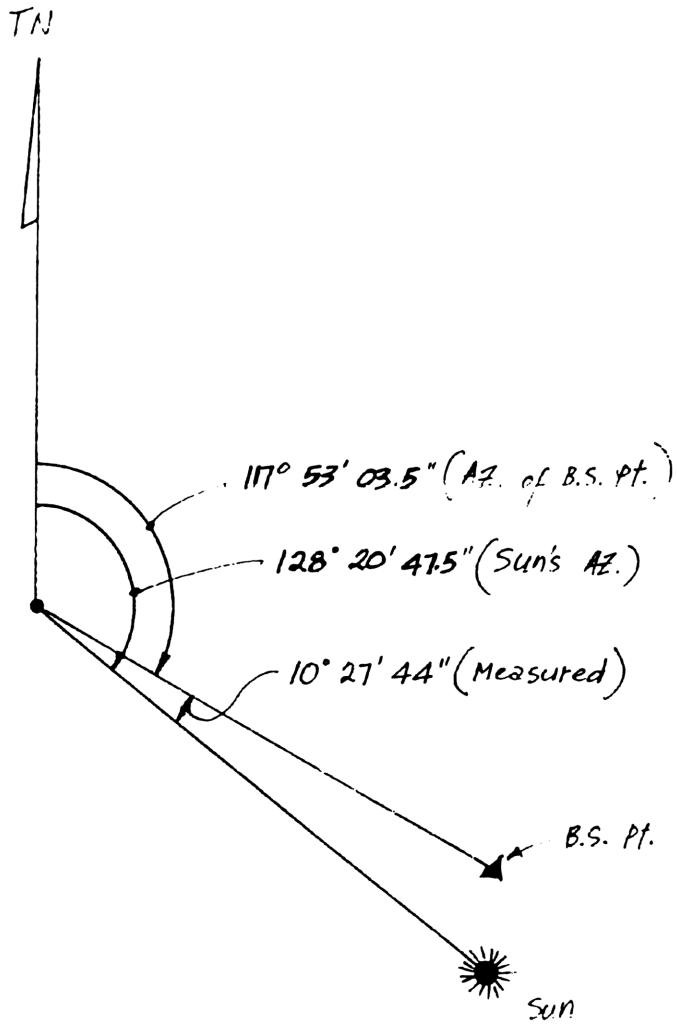
3. Vertical Angle: enter in ± dd.mmss format. If the Sun is sighted at its center, the angle must be entered as a negative value. If NE Quadrant pointing is used, the angle is entered without regard to the algebraic sign.
4. Index Error: enter in ± dd.mmss format. If it is to be subtracted from the vertical angle reading, it must be entered as a negative value. If not applicable, simply press [ENTER].
5. Air Temperature (°C) and Atmospheric Pressure (Hg): these two data are to be used only when both temperature and pressure are in the extreme; for practical purposes, these 2 data are rarely applied. Press [ENTER] if not applicable.
6. Latitude: enter in ± dd.mmss format. If the observer's latitude is south of the equator, it must be entered as a negative value; otherwise, no sign is required.
7. Time: if time of observation is done in the morning, simply press [ENTER]. If the observation is done in the afternoon, press [±] [ENTER].
8. Horizontal Angle: enter in dd.mmss. This is the horizontal clockwise angle from the reference line to the Sun at the same instant of observation as the measurement of the Sun's Altitude.

☞ Several measurements of vertical and horizontal angles are taken and then averaged to obtain a more reliable and accurate result.

Output data

In addition to the true azimuth of the reference line, other output data include the longitude of the observer, the Sun's true azimuth, LST, Sun's declination, GHA, and semi-diameter.

Figure 7.4: SUN3 program



Example problem #1

Running the SUN3 program

Example problem #1

Find the azimuth reference line and longitude.

Input data
Date: May 16, 1993
Time (LST): 10:25:33 am
Time Zone: 6
Latitude: 39°08'27"
Sun's Altitude: 61°48'53" (center shot)
Hor. Angle from ref line to Sun's Center:
10°27'44"

Press [SUN3]. Or type **SUN3** and press [ENTER].

The display will prompt you with:
DATE=? (mm.ddyyy)
or Key [ENTER] if
TODAY'S DATE

Key in: **5.161993 [ENTER]**

The display will prompt:
GMT or LST=? (hh.mmss
24-hr) or Key [ENTER]
if HP48 TIME

Key in: **10.2533 [ENTER]**

The display will prompt:
IF LST WAS USED,
TIME ZONE No. =?
or ELSE, Key [ENTER]

Key in: **6 [ENTER]**

The display will prompt:
VERT. ∠ =? ± (dd.mmss)
(-) if CENTER SUNSHOT
(+) if N.E. Qd SUNSHOT

☞
Since the Sun is sighted at its center, you must enter its altitude as a negative value.

Key in: **61.4853 [+/-] [ENTER]**

The display will prompt:
INDEX ERROR=? ± (0.mmss)
(-) to DEDUCT fr. V
Key [ENTER] if N/A

Press [ENTER].

The display will prompt:
AIR TEMP.=? (°C)
ATM. PRESS.=? (InHg)
Key [ENTER] if N/A

Press [ENTER].

The display will prompt:
LATITUDE=? ± (dd.mmss)
(NEG. if SOUTH)

Key in: **39.0827 [ENTER]**

The display will prompt:
Key [ENTER] if A.M.
or Key [±] [ENTER]
IF P.M. SUNSHOT

Press [ENTER].

The display will prompt:
HOR. ∠ =? (dd.mmss)
(clockwise fr. B.S.
Pt. to SUN)

Key in: **10.2744 [ENTER]**

Output data

13 DATE: 5/16/1993
12 GMT: 16.2533
11 DECL (N): 19.12299
10 GHA: 67.18257
9 S.D.: 0.15504
8 MEAS. V. ∠: 61.4853
7 ADJ. V. ∠: 61.4825
6 HOR. ∠: 10.2744
5 LST: 10.2533
4 LAT. (N): 39.0827
3 LON. (2): 90.24328
2 SUN'S AZ: 128.20475
1 B.S. AZ: 117.53035

Example Problem #2

The following solar observation data was taken from a paper entitled "Combined Solar Ephemeris and Azimuth Program" written by P. Done, W.R. Mohammed, and M. Jones in ***Survey Review****, April 1987, pages 29 and 224. These data and the resulting azimuth are cited here for comparison only.*

Find the azimuth of the reference object (or B.S.); should equal 157°34'24".

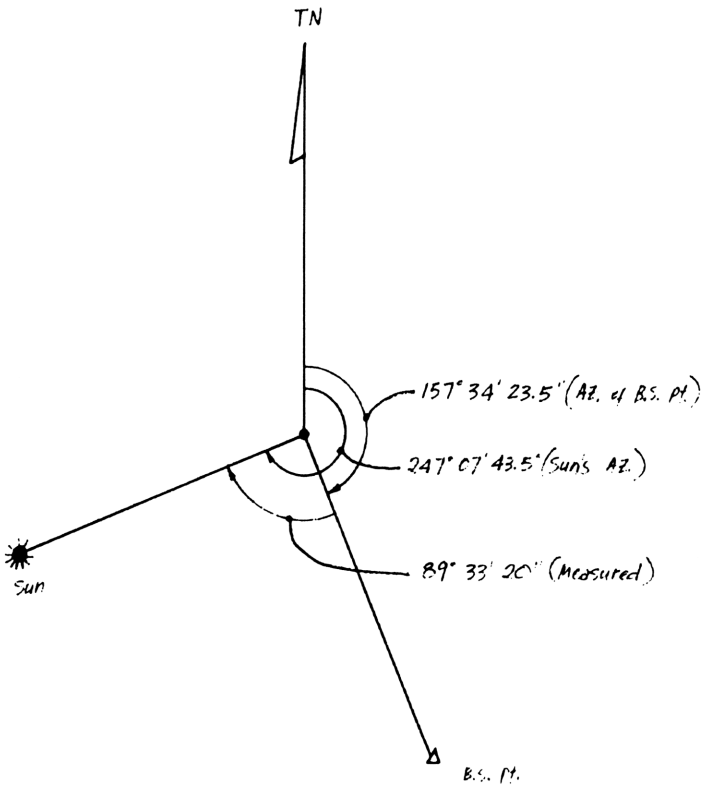
Input data
Date: February 12, 1986 (Port of Spain, Trinidad)
Time of observation: 19:26:00 (GMT or U.T.)
Mean Vertical Angle: 38°55'14"
Local Observation Time: PM
Latitude: 10°38'00" N
Mean Hor. Angle clockwise from ref object to Sun: 89°33'20"

☞ Since the Sun is sighted at its center, enter the mean vertical angle as a negative value.

☞ This problem uses the same prompts and similar input data as shown in problem #1, above.

Press [SUN3]. Or type **SUN3** and press [ENTER].

Figure 7.5: SUN3 program



Example problem #2

Output data

13 DATE: 2/21/1986
12 GMT: 19.26000
11 DECL (S): 10.27033
10 GHA: 108.05253
9 S.D.: 0.16117
8 MEAS. V. ∠: 38.55140
7 ADJ. V. ∠: 38.54067
6 HOR. –∠: 89.33200
5 LST: 15.26000
4 LAT. (N): 10.38000
3 LON. (W): 61.16351
2 SUN'S AZ: 247.07435
1 B.S. AZ: 157.34235

Notes

CHAPTER 8

CULVERTS

Analysis and design of circular concrete culverts

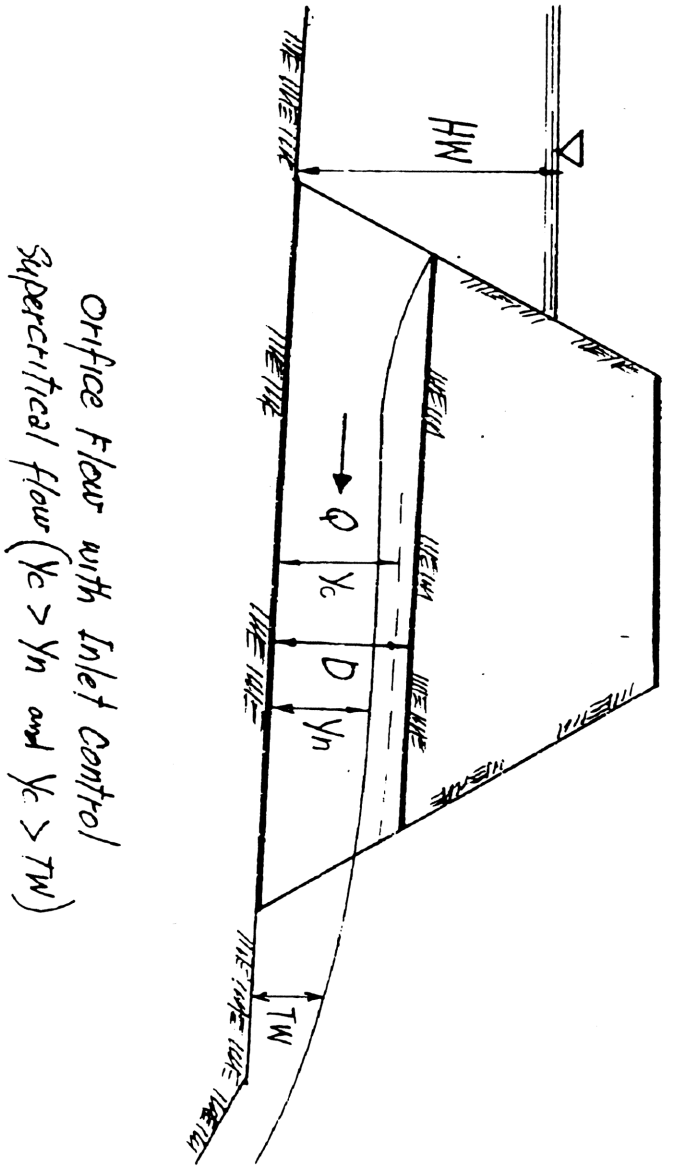
There are 2 programs included in this chapter. Both are used in finding the size of a circular concrete culvert when inlet control conditions apply. These programs use the FHWA emperical equations and criteria, applicable to both weir or orifice flow conditions. Values of constants for square edge and groove end projecting inlets are built into the program; however, constants for other inlet types can also be valid input.

C.CUL

This program is used in the design and analysis of a Circular Concrete Culvert, using emperical equations derived from experiments at the FHWA laboratory. (See "Hydraulic Design of Highway Culverts," Sept. 1985).

Values of constants for Weir and Orifice Flows, and Square Edge and Groove end projecting inlets are built into the program; however, any other constant for other types of inlet structures can also be entered. A trial culvert Diameter and the Required Headwater Depth (HWr) at the inlet are input to obtain a Computed Headwater Depth (HWc). If HWc is less than HWr, then the trial Diameter is acceptable.

Figure 8.1: C.CUL program



Other output values include normal and critical depts of flow and velocities, ratio of the depth of flow over diameter in percent, and type of flow.

Required input data

1. Q in cfs or -cms
2. Slope (S) in percent
3. Trial Diameter in Inches or - cm.
4. Required Headwater Depth (HWr) in feet or meters
5. Manning's n

Output data
Includes normal and critical depths of flow, normal and critical velocities, and computed Headwater depth.

Running the C.CUL program

Example problem #1

Find:
1. Computed Headwater Depth (HWc) for a Trial Diameter of 66"
2. Weir or Orifice Flow?
3. Normal and critical depths and velocities

Given data
Q: 175 cfs
n: 0.02
Entrance: Square Edge
Slope: 5%
Trial diameter: 66"
HWr not to exceed 5.50 ft.

Press [C.CUL]. Or type **C.CUL** and press [ENTER].

The display will prompt you with:
Q=? (cfs or -cms)
SLOPE=? (%)
TRIAL D=? (In or -cm)

Key in: **175 [SPC] 5 [SPC] 66 [ENTER]**

The display will prompt:
Req'd. HEADWATER
(HWr)=?
(ft. or -m.)

Key in: **5.5 [ENTER]**

The display will prompt:
Manning's (n)=?

Keyin: **.02 [ENTER]**


Wait several seconds for the next prompt.

The display will prompt:
SELECT ENT. EDGE TYPE:
[1= Sq. EDGE] [2=Groove
END] [OR ENTER K=?]

Key in: **1 [ENTER]**

Output data

14 Q/A $\sqrt{D}$: 3.14
13 n: 0.02 (Manning's Roughness Coefficient)
12 S (%): 5.00 (Slope of culvert in percent)
11 Yn/D (%): 41.39 (Ratio of normal depth over Diameter)
10 Q (cfs): 175.00 (Rate of flow)
9 Yn (ft.): 2.28 (Normal depth of flow)
8 Vn (fps): 18.84 (Normal velocity)
7 Yc (ft): 3.65 (Critical depth of flow)
6 Vc (fps): 10.44 (Critical velocity)
5 "WEIR" FLOW
4 D (in): 66.00 (Diameter in inches)
3 HWc (ft): 5.74 (Computed Headwater)
2 HWr (ft): 5.50 (Required Headwater)
1 "HWc > HWr Not OK"

☞ Since the computed (HWc) is greater than allowable (HWr), the Trial Diameter of 66 inches is not adequate. Try the next larger Diameter of 72 inches.

Example problem #2

Find:
1. HWc = computed Headwater Depth
2. Type of Flow (Weir or Orifice Flow)
3. Normal and critical depths and velocities

Given data
Q = 175 cfs S = 5% n = 0.02
Trial Diameter = 72 inches
Entrance = Square Edge
HWr not to exceed 5.50 ft.

Press [C.CUL]. Or type **C.CUL** and press [ENTER].

☞ This problem uses the same prompts and similar input data as shown in problem #1, above.

Output data

(See problem #1 for explanatory notes for the following data)

14 Q/A √D: 2.53
13 n: 0.02
12 S (%): 5.00
11 Yn/D (%): 36.49
10 Q (cfs): 175.00
9 Yn (ft.): 2.19
8 Vn (fps): 18.75
7 Yc (ft): 3.57
6 Vc (fps): 9.98
5 "WEIR" FLOW
4 D (in): 72.00
3 HWc (ft): 5.34
2 HWr (ft): 5.50
1 "HWc < HWr OK"

☞ HWc did not exceed HWr; therefore, the 72-inch diameter pipe is adequate.

D.CUL

This program directly computes the diameter of a circular concrete culvert that would satisfy the Required Headwater Depth (HWr) when Inlet conditions apply. The program uses FHWA empirical equations applicable to both weir or orifice flow conditions.

The program automatically determines whether the culvert entrance flows as a weir, or orifice, depending on the given Headwater requirement, and the computed diameter. Values of inlet edge constants are built into the program; however, other inlet constants can also be entered as an option. This program eliminates the need for the Nomograph and Trial and Error Methods.

Required input data

1. Q: Rate of flow in cfs or cms - Q is negative if Metric units are used
2. S: Slope in percent
3. HWr: Required Headwater depth in ft. or m. (negative if metric)
4. 1-digit code for inlet constants for either weir or orifice flow

Output data

Includes computed diameter, type of flow, and Q/A $\sqrt{D}$ value.

Running the D.CUL program

Example problem #1

Find the minimum diameter of a circular concrete culvert that can carry a flow of 250 cfs under an embankment without exceeding the Headwater depth of 7.5 ft. at the entrance.

☞
This program is applicable only when inlet controls or tailwater do not affect inlet conditions.

Given data
Slope of Culvert: 2%
Entrance edge type: square edge (code 1)

Press [D.CUL]. Or type **D.CUL** and press [ENTER].

The display will prompt you with:
Q=? (cfs or -cms)
SLOPE=? (%)

Key in: **250 [SPC] 2 [ENTER]**

The display will prompt:
Req'd. HEADWATER
(HWr) =?
(ft. or -m)

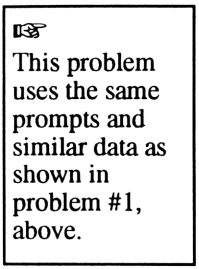
Key in: **7.5 [ENTER]**

The display will prompt:
SELECT ENT. EDGE TYPE:
[1=Sq. Edge] [2=Groove End] or [c=? & y=?]

Key in: **1 [ENTER]**

Output data

6 S (%): 2.00
5 Q (cfs): 250.00
4 "ORIFICE FLOW"
3 Q/A $\sqrt{D}$: 4.03
2 HW (ft.): 7.50
1 D (in): 68.90, say 72"



Example Problem #2/given data
Q = 175 cfs
S = 5.00
HW = 5.50 ft
Entrance = square edge (code 1)

Output data

6 S (%): 5.00
5 Q (cfs): 175.00
4 "WEIR FLOW"
3 Q/A $\sqrt{D}$: 2.77
2 HW (ft): 5.50
1 D (in): 69.39, say 72"

CHAPTER 9

PRESSURE FLOW

Analysis of pressure flow in single and parallel pipes

There are 5 programs included in this chapter, all pertaining to pressure flow in single and parallel pipes. Some of the problems covered by these programs include design and analysis of a single pipe flowing full and under pressure, determination of the rate and velocity of flow in parallel pipes, and the 3-reservoir problem. The programs use the Darcy-Weisbach and Hazin-William equations to solve the various parameters related to pressure flow.

D.HWF

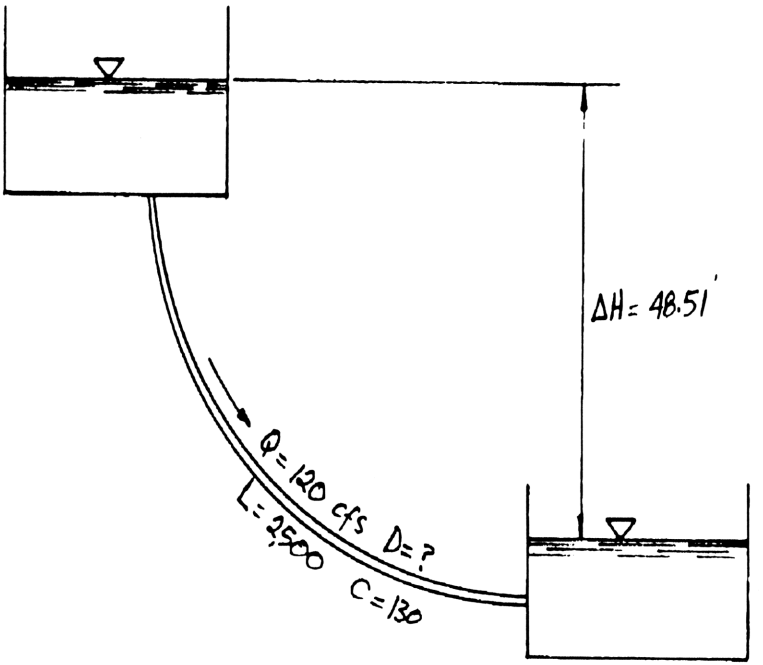
This program is derived from Hazin-Williams emperical formula used in the design and analysis of pipes flowing full and under pressure. The formula is applicable in turbulent flow and considers headloss due to friction or elevation difference only. There are 5 parameters; given any 4, any parameter can be solved.

☞ To solve for any unknown parameter, enter X (or any alpha character) for the unknown value. Values of the remaining 4 parameters are entered in the same sequence as the Input Prompts and are separated by spaces.

Required input data

1. Q = Rate of flow in cfs or cms
2. D = Diameter of pipe in inches or cm
3. L = Length of pipe in feet or meters
4. C = Hazin-Williams roughness coefficient
5. H = Friction head loss in feet or meters. This parameter can also be the difference in water surface elevations of 2 reservoirs connected by the pipe being considered.

Figure 9.1: D.HWF program



Pressure Flow Between 2 Reservoirs

Running the D.HWF program

Example problem

Find the diameter of pipe

Given data
DH: 48.51' (this is the difference in water surface elevations of 2 Reservoirs connected by a pipe)
Length of pipe: 2,500.00 ft
Rate of Flow required, Q: 120 cfs
C: 130 for a concrete lined circular pipe

Press [D.HWF]. Or type **D.HWF** and press [ENTER].

The display will prompt you with:
ENTER X for 1 UNKNOWN:
Q(cfs)=? D(in)=?
C=? L(ft)=? DH(ft)=?

☞
The unknown parameter D is replaced by letter X and the values of the known parameters are entered as shown above.

Key in: **120 [SPC] X [SPC] 130 [SPC] 2500 [SPC] 48.51 [ENTER]**

Output data

5 C: 130.00
4 DH (ft): 48.51
3 L (ft): 2500.00
2 Q(cfs): 120.00
1 D(in): 36.00

If Metric system is used, the following units apply:
1. Q = cubic meters per second (cms)
2. D = centimeters
3. C = dimensionless
4. L = meters
5. H = meters

Typical values of roughness coefficient (C) used in programs D.HWF and PPHW

Source: ***Fundamentals of Hydraulic Engineering Systems*** *by H. C. Hwang, 1981*

Types of Material	Roughness Coeff. (C)
Asbestos cement	140
Brick sewer	100
Concrete lined	120 - 140
Copper	130 - 140
Galvanized iron	120
Plastic	140 - 150
Steel (depends on lining)	145 - 150

PPHW

Using the Hazin-Williams equation, this program computes the velocity and rate of flow in each pipe connected in parallel. The program can compute up to 6 parallel pipes of different sizes and roughness coefficients, while carrying fluid under pressure.

Required input data

1. Rate of Flow (Q) in cfs or cms - the value of Q must be entered as a negative value if the units used are in cubic meters per second (cms).
2. Roughness Coefficient (C) of pipes, depending on the material used in the pipe's lining.
3. Diameter of each Pipe in inches or centimeters
4. Length of each pipe in feet or meters

Output data

Velocity and Rate of flow in each pipe.

Running the PPHW program

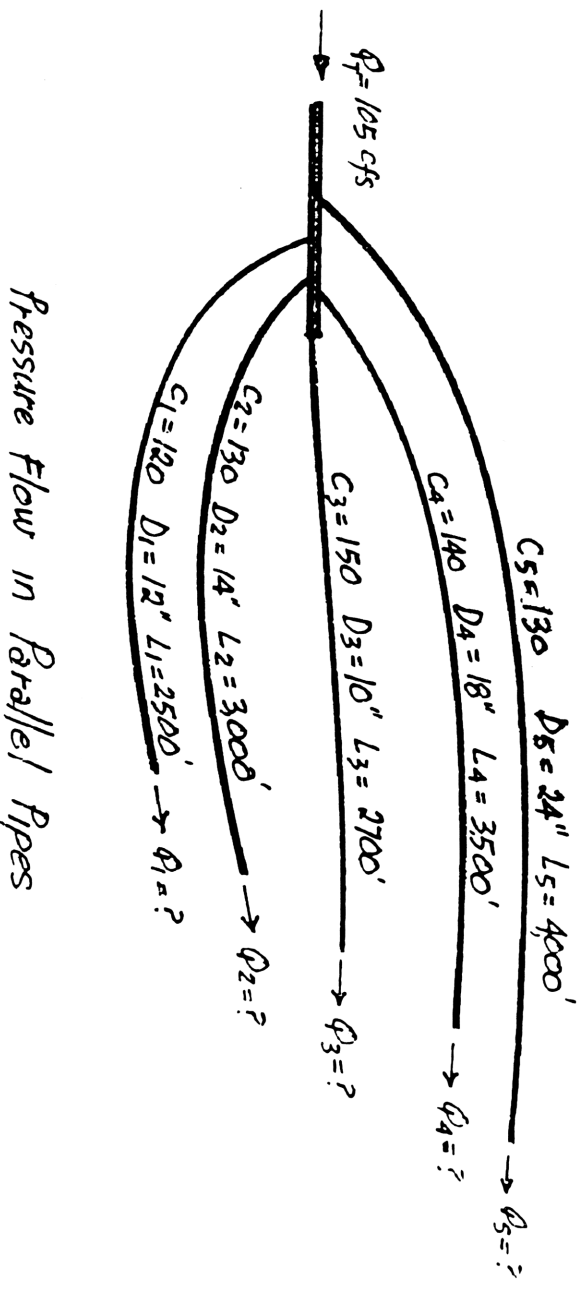
Example problem

A waterline main carrying 105 cfs branches into 5 different pipes with the following data (also see Figure 9.2):

	C	Dia. (in.)	Length (ft.)
Pipe 1	120	12	2500
Pipe 2	130	14	3000
Pipe 3	150	10	2700
Pipe 4	140	18	3500
Pipe 5	130	24	4000

Find velocity and rate of flow in each pipe.

Figure 9.2: PPHW program



Press [PPHW]. Or type **PPHW** and press [ENTER].

The display will prompt you with:
Total (±) Q=?
(cfs or -cms)

Key in: **105 [ENTER]**

The display will then prompt:
C1=? D1=? L1=?
C2=? D2=? L2=?
Cn=? Dn=? Ln=?

☞
All known data are entered as shown here. Use the [SPC] (space) key to separate each value. Press [ENTER] to end data entry.

Key in: **120 [SPC] 12 [SPC] 2500 [SPC]**
130 [SPC] 14 [SPC] 3000 [SPC] 150 [SPC]
10 [SPC] 2700 [SPC] 140 [SPC] 18 [SPC]
3500 [SPC] 130 [SPC] 24 [SPC] 4000 [ENTER]

Output data

10 V1: 11.89
9 Q1: 9.34 (Velocities are in fps)
8 V2: 12.86
7 Q2: 13.75 (Rates of Flow are in cfs)
6 V3: 12.71
5 Q3: 6.93
4 V4: 14.93
3 Q4: 26.39
2 V5: 15.47
1 Q5: 48.59

PPIPE

This program computes the velocity and rate of flow in each pipe connected in parallel using the Darcy-Weisbach equation. The program can compute up to 6 parallel pipes of different sizes, but of equal friction factor (f).

Required input data

1. Total Rate of Flow (Q) in cfs or cms - the value of Q must be entered as a negative value if it is in cubic meters per second.
2. Diameter (D) of each pipe in inches or centimeters
3. Length of Pipe (L) in feet or meters

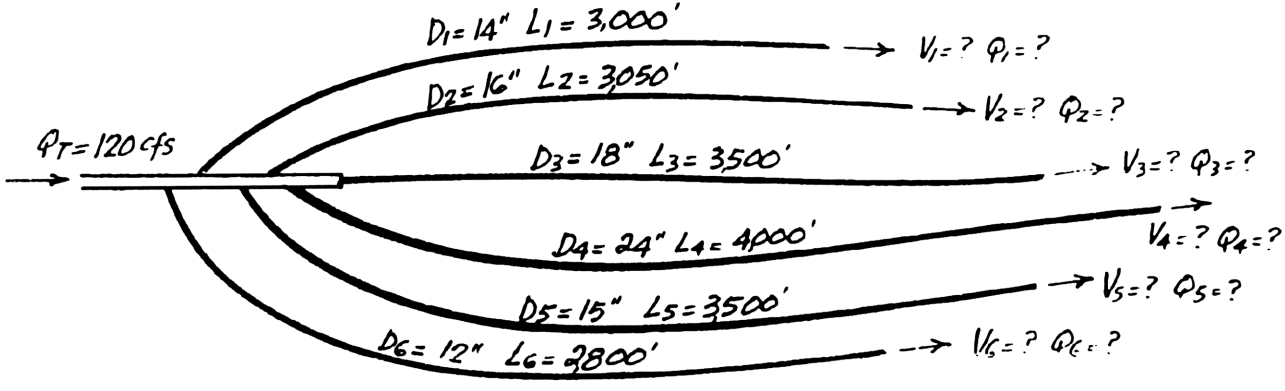
Running the PPIPE program

Example problem

A water main carrying 120 cfs branches into 6 steel pipes, given the following data (pipe sizes are in inches and the lengths are in ft.; also see Figure 9.3):

D1 = 14	L1 = 3000
D2 = 16	L2 = 3050
D3 = 18	L3 = 3500
D4 = 24	L4 = 4000
D5 = 15	L5 = 3500
D6 = 12	L6 = 2800

Find the Velocity and Rate of Flow in each pipe.



Pressure Flow in Parallel Pipes
(Darcy-Weisbach Equation)

Figure 9.3: PIPE program

Press [PPIPE]. Or type **PPIPE** and press [ENTER].

The display will prompt you with:
Total (±) Q=?
(cfs or -cms)

Key in: **120 [ENTER]**

The display will then prompt:
D1=? L1=?
D2=? L2=?
Dn=? Ln=?

Key in: **14 [SPC] 3000 [SPC] 16 [SPC] 3050 [SPC] 18 [SPC] 3500 [SPC] 24 [SPC] 4000 [SPC] 15 [SPC] 3500 [SPC] 12 [SPC] 2800 [ENTER]**

☞
All known data are entered as shown here. Use the [SPC] (space) key to separate each value. Press [ENTER] to end data entry.

Output data

12 V1: 12,13
11 Q1: 12.96
10 V2: 12.86
9 Q2: 17.95
8 V3: 12.73
7 Q3: 22.50
6 V4: 13.75
5 Q4: 43.20
4 V5: 11.62
3 Q5: 14.26
2 V6: 10.39
1 Q6: 8.16

☞
Velocities are in fps; Rate of Flow is in cfs.
If metric system is desired, all pipe diameters must be in centimeters, the lengths in meters, and the rates of flow in cubic meters per second.

PP.RS

This program computes the rate of flow (Q) in parallel pipes connecting two reservoirs. Up to 5 parallel pipes and 1 main pipe can be entered. The algorithm assumes all pipes have similar friction factor (f).

Required input data

1. Difference in water surface elevation of the 2 Reservoirs: in feet (or -meters)
2. Friction factor (f): assumed equal for all pipes
3. Diameter of Main Pipe: in inches (or -cm)
4. Length of Main Pipe: in feet (or -meters); enter zero if there is no main pipe
5. Diameter and the respective Length of each pipe in parallel: diameter in inches (or -cm) and length in feet (or -meters)

☞
If you're using metric figures, enter the metric data as negative values.

Output data
Rate of Flow in each pipe

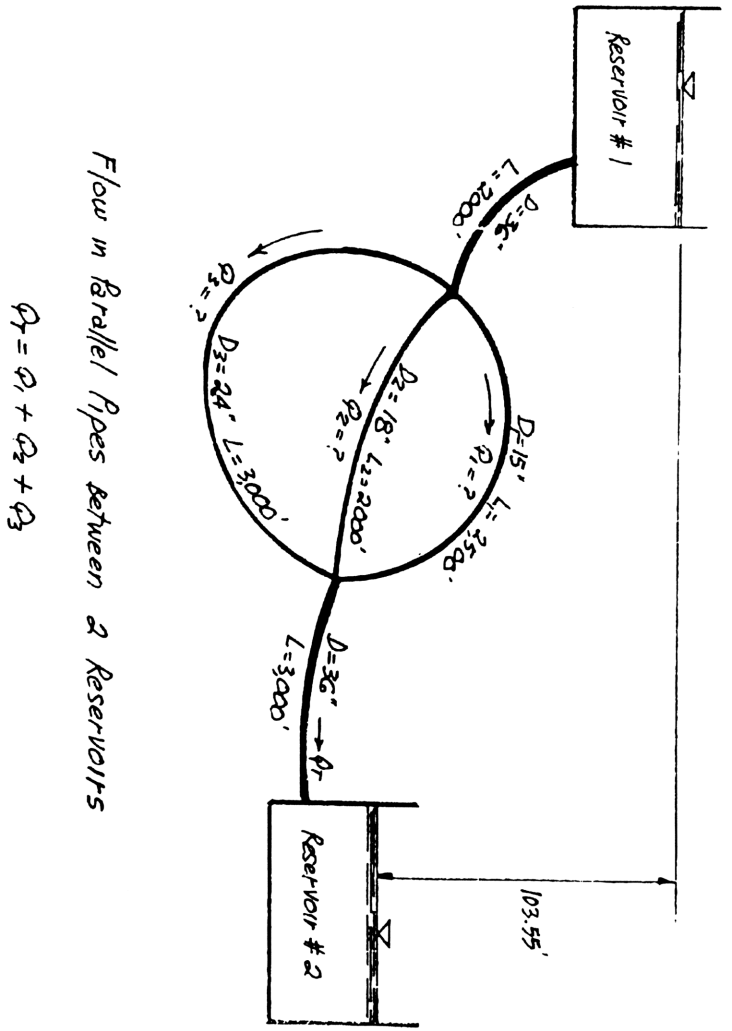
Running the PP.RS program

Example problem

Two reservoirs are connected by a 36-inch main pipe that branches to 3 parallel pipes that differ in diameter and length (also see Figure 9.4).
Friction factor (f) for all pipes = 0.03
Total length of the 36-inch main pipe = 5,000 ft.
Difference in water surface elevation between the 2 Reservoirs = 103.55 ft.
D1=15" L1=2500'
D2=18" L2=2000'
D3=24" L3=3000'

Find the rate of flow (Q) in each pipe.

Figure 9.4: PP.RS program



Press [PP.RS]. Or type **PP.RS** and press [ENTER].

The display will prompt you with:
DIFF. in WATER SUR-
FACE ELEV.=?
(ft or -m)

Key in: **103.55 [ENTER]**

The display will prompt:
FRICTION FACTOR (f)=?
(same f for all pipes)

Key in: **.03 [ENTER]**

The display will prompt:
DIA. OF MAIN PIPE=?
(ft. or -m)
Enter 0 if N/A

Key in: **36 [ENTER]**

The display will prompt:
LENGTH of MAIN PIPE
(ft or -m)
Enter 0 if N/A

Key in: **5000 [ENTER]**

The display will then prompt you with:
D1=? L1=? D2=? L2=?
...Dn=? Ln=?
D(in/-cm) & L(ft/-m)

Key in: **15 [SPC] 2500 [SPC] 18 [SPC] 2000 [SPC] 24 [SPC] 3000 [ENTER]**

Output data

Q1 (cfs): 9.59
Q2 (cfs): 16.91
Q3 (cfs): 28.33

☞
The sequence in which the diameters and lengths of the pipes are entered is also the same sequence in which the corresponding Rates of Flow (Q) are displayed.

The Rate of flow in the 36-inch pipe is equal to the sum of the rate of flow in the 3 parallel pipes.

RS3.P

This program is used to find the Rate of Flow in each pipe in a 3-Reservoir problem. The 3 pipes from each reservoir are connected to a common junction whose elevation is to be determined.

Assumptions

1. Directions of flow are as shown in Figure 9.5
2. Q1 = Q2 + Q3
3. No exchange of flow between Reservoirs 2 and 3

Required input data

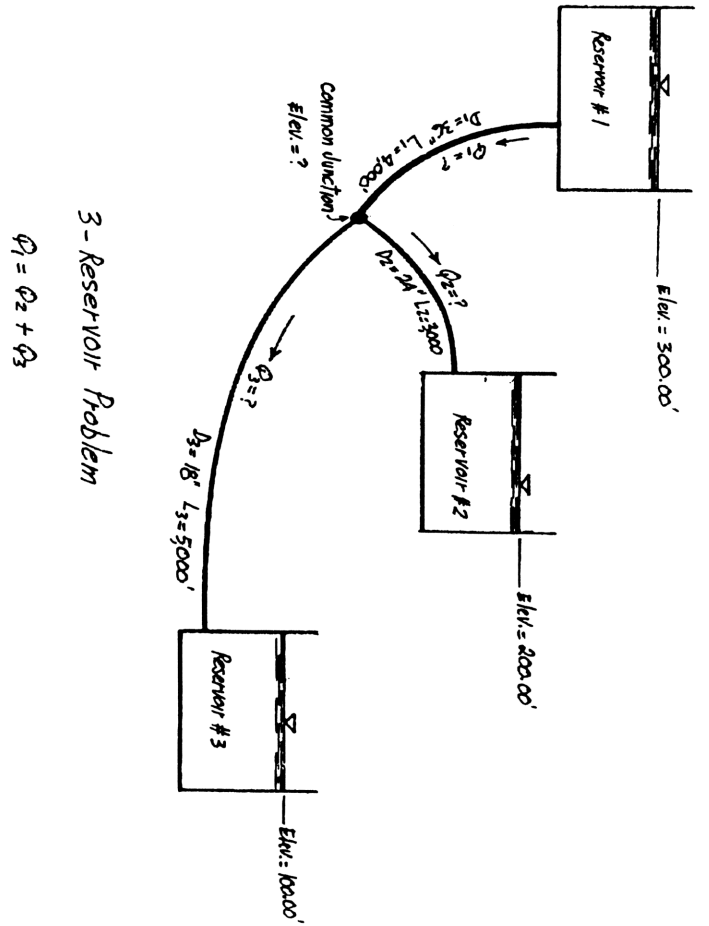
1. n = Manning's Roughness Coefficient
2. Water surface elevation on each Reservoir in feet or meters
3. Diameters and Lengths of the 3 pipes - Diameters are in inches (or -cm) and lengths are in feet (or -meters) respectively

☞ All metric units are entered as negative values.

Output data

1. Elevation of the common junction
2. Rate of flow in each pipe

Figure 9.5: RS3.P program



Running the RS3.P program

Example problem/given data
(See also Figure 9.5)

1. E1=300 ft. - W.S. Elev. at Reservoir #1
2. E2=200 ft. - W.S. Elev. at Reservoir #2
3. E3=100 ft. - W.S. Elev. at Reservoir #3
4. Manning's n = 0.012
5. D1 = 36" L1 = 4000
   D2 = 24" L2 = 3000
   D3 = 18" L3 = 5000

Find:
1. Elevation at common junction O.
2. Rate of Flow in each pipe.

Press [RS3.P]. Or type **RS3.P** and press [ENTER].

The display will prompt you with:
Manning's (n)=?
(same for 3 pipes)

Key in: **.012 [ENTER]**

The display will prompt:
RESERVOIRS W.S. ELEV:
E1=? E2=? E3=?
(ft. or -m)

Key in: **300 [SPC] 200 [SPC] 100 [ENTER]**

The display will prompt:
D1=? L1=? D2=? L2=?
D3=? L3=? D(in. or
-cm) & L(ft or -m)

Key in: **36 [SPC] 4000 [SPC] 24 SPC]**
3000 [SPC] 18 [SPC] 5000 [ENTER]

Output data

4 El. @ O (ft): 272.98
3 Q1 (cfs): 59.41
2 Q2 (cfs): 38.24
1 Q3 (cfs): 21.17

CHAPTER 10

CONVERT/ INVERSE

Universal transverse Mercator (UTM) projection coordinate conversion and inverse programs

There are 2 programs included in this chapter. One is used to convert coordinates, and the other to inverse for distance and azimuth, between two known points on a given ellipsoid datum.

There are 8 Ellipsoid Reference Data whose semi-major and semi-minor axes (a and b) are pre-stored in the program. The user has the option to use other Ellipsoid types, as long as its semi-major axis (a) and semi-minor axis (b) are known.

The following are the names of the Ellipsoids and their corresponding code numbers:

GRS 80 - 1	BESSEL - 5
INTERNATIONAL - 2	EVEREST - 6
CLARKE 1866 - 3	CLARKE 1880 - 7
WGS 72 - 4	NWL 90 - 8
	USER DEFINED - 9

These 2 programs are applicable worldwide and can be made compatible with any UTM Map. A routine called **SETEZ** is used to set or change the ellipsoid datum and the central meridian or zone number.

G↔G

This program converts latitude and longitude coordinates to UTM grid coordinates and vice versa. The program is applicable to both north and south hemispheres, and to all 60 zones of the globe. Additional output data includes the scale factor and mapping angle of the given point.

☞
You can run the SETEZ routine independently to select Ellipsoid Reference Datum and Central Meridian or Zone Number, prior to running either the G↔G or DZUT program.

Required input data

1. Ellipsoid: a code number is entered corresponding to the chosen Ellipsoid. Code 9 is used to select a User Defined Ellipsoid.
2. Zone Number or Central Meridian: if zone number is input, it must be appended by an alpha character.

   For example, Zone 18 is entered as 18Z. A Central Meridian can be used in lieu of its zone number or vice versa. Central Meridians in the Western Hemisphere are entered as negative values. Both Western and Eastern Meridians start at 3 then increment by 6; succeeding CM values are 9, 15, 21, and so on, up to and including 177.

   If the program is executed for the first time, it will ask and prompt for an Ellipsoid Reference Datum and Central Meridian or Zone Number. On subsequent runs, these two prompts will not be repeated until you decide to change to another datum and zone number; in this case, the SETEZ routine is used to modify your data.
3. Latitude and Longitude or Northing and Easting: either pair can be valid input. The units for latitude and longitude are in degrees, minutes, seconds, and decimal seconds (dd.mmssss). South latitudes are entered as negative values.

   Northing and Easting are in meters.

Running the G↔G program

Example problem/given data
Ellipsoid Reference Datum: GRS-80 (Code 1)
Zone Number: 18
C.M.: 6 (Zone No.) - 183 = 6 (18) - 183 = -75°W
Coordinates of a Point: Lat. = 38°25'33"N;
Long. = 74°50'45"W

Required

UTM Grid Coordinates

Press [G↔G]. Or type **G↔G** and press [ENTER].

The display will prompt you with the following:
(±)LAT.=? (-) if South
& LONG.=? OR
NORTH=? & EAST=?

Key in: **38.2533 [SPC] 74.5045 [ENTER]**

Output data

10 "UTM-GRS 80"
9 North Hemisphere
8 Zone #: 18
7 C.M. (WEST): 75
6 ϕ (N): 38°25'33"
5 λ (W): 74°50'45"
4 N: 4253075.08216
3 E: 513456.782608
2 γ: 00°45'44.93361" <- mapping angle
1 S.F.: .99960223

DZUT

This program is used to compute grid and geodetic distances and azimuths between two points whose grid or geodetic coordinates are known. It also converts known coordinates to either grid or geodetic and vice versa. Scale factors of the two known points are averaged and applied to the computed grid distance.

Required input data

You must first execute the **SETEZ** routine to establish the Ellipsoid Reference Datum and the Central Meridan or Zone Number. If you are running **DZUT** for the first time and the Ellipsoid and Central Meridian have not been set previously, then the initial input data is automatically prompted and there is no need to run the **SETEZ** routine.

1. Ellipsoid Reference Datum: selection is made by entering a Code Number corresponding to the Ellipsoids listed above.
2. Zone Number or Central Meridian: use the same description as the **G↔G** input prompt #2, above.
3. Latitude and Longitude or Northing and Easting of the First Point: either coordinate pairs are valid input. Both latitude and longitude are entered in degrees, minutes, seconds, and decimal seconds format (dd.mmssss). South latitudes are entered as negative values.
   Northing and Easting coordinates are entered in meters.
4. Latitude and Longitude or Northing and Easting of the Second Point: see #3, above.

Running the DZUT program

Example problem/given data
Ellipsoid Type = GRS-80
Zone No.=8
Cooordinates of First Point:
Lat.= 37°40'22"N by Long. = 74°55'40"W
Coordinates of Second Point:
Lat.= 38°03'18"N by Long. = 75°02'37"W

Find the grid and geodetic distances and azimuths.

Press [DZUT]. Or type **DZUT** and press [ENTER].

The display will prompt you with the following:
LAT.=? & LONG.=? OR
N=? & E=? (1st. Pt.)

Key in: **37.4022 [SPC] 74.5540 [ENTER]**

The display will prompt:
LAT.=? & LONG.=? OR
N=? & E=? (2nd Pt.)

Key in: **38.0318 [SPC] 75.0237 [ENTER]**

Output data

16 "UTM-GRS 80"
15 "NORTH HEMISPHERE"
14 ZONE #: 18
13 C.M. (WEST): 75°
12 ϕ 1: 37°40'22.00000"
11 λ 1: 74°55'40.00000"
10 ϕ 2: 38°03'8.0000"
9 λ 2: 75°02'37.00000"
8 N1: 4169512.49934
7 E1: 506368.989945
6 N2: 4211918.31045
5 E2: 496173.922314
4 GR. D: 43614.1286729
3 GR. AZ: 346°28'54.087130"
2 GEO. D: 43631.5664667
1 GEO. AZ: 346°31'33.306420"

SETEZ

This routine is used to set or modify Ellipsoid Reference Datum and Central Meridian, prior to running either the **G↔G** or the **DZUT** program. Once the Ellipsoid Reference Datum and Central Meridian have been set, this routine need not be executed again until you wish to change to another Ellipsoid Datum and/or Central Meridian.

Required input data

1. Code Number: following are the types of Ellipsoid Reference Data and their corresponding Code Numbers:

> ☞
> When Code 9 is chosen, the semi-major axis (a) and the semi-minor axis (b) of the Ellipsoid must be known.

GRS 80 or WGS 84: 1	EVEREST: 6
INTERNATIONAL: 2	CLARKE 1880: 7
CLARK 1866: 3	NN/NL - 90: 8
WGS-72: 4	USER DEF: 9
BESSEL: 5	

Zone Number or Central Meridian - either may be entered in lieu of the other. Zone numbers range from 1 thru 60 and must be followed by an alpha character (i.e. Zone 18 is entered as 18Z).

Central Meridians in the Western Hemisphere are entered as negative values. Both Western and Eastern C.M. start at 3 and increment by 6; succeeding C.M. are 9, 15, 21, and so on, up to and including 177.

To find the C.M. for Zone 18, the following conversion formula is used:

C.M. = 6Z - 183
C.M. = 6(18) - 183 = -75

where C.M. = Central Meridian and Z = Zone number.

A negative value of C.M. denotes that the given point is in the Western Hemisphere; if positive, the point is in the Eastern Hemisphere.

To convert C.M. to Zone Number:

$$Z = \frac{C.M. + 183}{6} = \frac{-75 + 183}{6} = 18$$

CHAPTER 11

GEODESY

Programs to solve geodetic problems

Global Positioning System (GPS) – using orbiting satellites to locate a point on the earth's surface – has been with us now for a number of years. GPS surveying instruments are now available that can locate a point on the earth's surface with an accuracy of a few centimeters.

When it comes to surveying, GPS does have one drawback: some GPS surveying instruments give geodetic coordinates (latitude and longitude) instead of the familiar plane coordinates.

Geodetic coordinates are not popular with surveyors, as the mathematics involved are far more complicated and tedious than plane coordinates. Thus, there is a need for programs that can uncomplicate and solve geodetic problems accurately and quickly.

This chapter includes 4 programs: the first two are the Inverse and Forward Programs; the last two are the Traverse and Angle Traverse Programs.

Inverse/Forward

The **Inverse** program is used to find the Distance and Azimuth between two points whose geodetic coordinates are known.

The **Forward** program computes the geodetic coordinates of another point, given the forward azimuth and distance from a known point.

The algorithms used in these two programs were derived from B.R. Bowring's paper published in the *Surveying and Mapping Journal* Vol. 41 No. 2, 1981. The algorithm gives accurate results of 2 mm for lines up to 150 km. in length, and can be used on lines of up to 500 km. with a reduction in distance accuracy of 10 cm, and azimuth accuracy of 0.1 of a second.

For navigational purposes, lines of up to 5,000 km. will yield an error of less than 1 meter in distance, and about 4 seconds in azimuth. Inversed distances are given in meters, miles, and nautical miles. Azimuths are always referenced clockwise from True North. An Ellipsoid Reference Datum is selected by running the routine called **SETL** (see below).

☞
See the end of this chapter for details and lists of Ellipsoids and their corresponding code numbers.

Traverse/Angle Traverse

The **Traverse** program is used to compute the geodetic coordinates of another point using measured field data.

The **Angle Traverse** program is similar to the Traverse program except that it uses a backsight and a horizontal angle to find the geodetic coordinates of another point.

The algorithms used in these two programs were derived from a paper authored by Mohammad Id Ozone entitled "Non-Iterative Geodetic Traverse" in *Survey Review*, April 1991. The algorithm was modified slightly to allow input of known coordinates in either the western or eastern hemisphere, and to specify the latitude as being north or south of the equator.

S.INV

This program computes the distance and azimuth between two points on a given ellipsoid reference datum when their geodetic coordinates are known.

☞
Latitudes and Longitudes are entered in dd.mmssss format. South latitudes and East longitudes are enteres as negative values.

Required input data

1. Latitude and longitude of the first point
2. Latitude and longitude of the second point

An Ellipsoid Reference Datum must be set prior to running this program. The routine called **SETL** is provided for this purpose. See the end of this chapter for details and a list of ellipsoids and their corresponding code numbers.

Running the S.INV program

Input data

1. Reference Ellipsoid: GRS-80
   Code No.: 21
2. First point: Latitude = 32°40'56.93641"
   by Longitude = 117°07'34.31023"

(3) Second Point: Latitude = 32°59'46.182248"
   by Longitude = 117°14'28.49810"

Find:

1. Distance between the 2 points
2. Forward Azimuth (pt. 1 to pt. 2)
3. Back Azimuth (pt. 2 to pt. 1)

Press [S.INV]. Or type **S.INV** and press [ENTER].

Enter data as prompted by the program display(s).

Output data

12 "GRS-80"
11 "ELLIPSOID"
10 "CODE 21"
 9 ϕ 1: 32.405693641
 8 λ 1: 117.073431023
 7 ϕ 2: 32.594618225
 6 λ 2: 117.142849810
 5 D (m): 36416.9855628 (Distance in meters)
 4 D (mi): 22.628422319 (Distance in miles)
 3 D (nmi): 19.6635613
   (Distance in nautical miles)
 2 F. AZ: 342.493653277 (AZ fr. 1st to 2nd point)
 1 B. AZ: 162.45519240 (AZ fr. 2nd to 1st point)

S.FOR

This program is used to compute the geodetic coordinates of another point, given the coordinates of the starting point, the forward azimuth, and the distance. It also computes the back azimuth of a line connecting the computed point back to the starting point.

Required input data

☞ South latitudes and East longitudes are entered as negative values.

1. Latitude and longitude of the starting point: enter in degrees, minutes, seconds, decimal seconds (dd.mmssss) format.
2. Forward azimuth: horizontal angle reckoned from True North in dd.mmssss format. A *negative* entry indicates that the azimuth is reckoned counterclockwise from True North.
3. Distance from starting point to observed point in meters.

Running the S.FOR program

☞
An Ellipsoid Reference Datum must be set prior to running this program; use **SETL**, below.
Also use **SETL** when when you wish to modify the ellipsoid reference datum. Otherwise, the last reference ellipsoid will be used until you change it.

Example problem/given data
Reference ellipsoid: GRS-80; Code No. =21
Starting Point: Latitude = 32°40'56.93641"
by Longitutde = 117°07'34.31023"
Forward Azimuth: 342°49'36.53277"
Distance: 36416.9855628 meters

Find:
1. Latitude and longitude of 2nd point
2. Back azimuth from 2nd to first point

To execute this program, press [S.FOR]. Or type **S.FOR** and press [ENTER].

Enter data as prompted by the display. Angular quantities are entered and displayed in *degrees.minutes seconds/decimal seconds* format (dd.mmssss).
For example, F. AZ of 342°49'36.53277" is entered as 342.493653277.

Output data

10 "GRS - 80"
9 "ELLIPSOID"
8 "CODE - 21"
7 ϕ 1: 32.405693641
6 λ 1: 117.073431023
5 F. AZ: 342.49 36.53277
4 D (km): 36.416985563
3 ϕ 2: 32.5946182247
2 λ 2: 117.142849810
1 B. AZ: 162.455192399

G.TRA (Geodetic Traverse)

This program computes geodetic coordinates of an observed point from a known point, using field observation data without the need to reduce these data to a spheroid reference datum. The algorithm allows direct input of observed slope distance, azimuth, and vertical angle to find the geodetic coordinates of the observed point.

This program is based on a paper by Mohammad Id Ozone entitled "Non-Iterative Geodetic Traverse" in *Survey Review*, April 1991. The algorithm was modified slightly to allow input of known points in either Western or Eastern hemisphere and to specify the latitude as north or south of the equator. The user has the option to choose from among 20 Ellipsoid Data.

Required input data

1. Latitude of occupied point: enter in dd.mmssss format; South latitudes are entered as negative values.
2. Longitude of occupied point: enter in dd.mmssss format; East longitudes are entered as negative values.
3. Azimuth: enter in dd.mmssss format. This is the measured clockwise angle from True North (zero azimuth) to the observed point. The observed azimuth must be corrected for deviation of the vertical.
4. Vertical angle: enter in dd.mmssss format. This observed vertical angle must be corrected for atmospheric refraction and for deviation of the vertical.
5. Height of occupied point: enter in meters. This is the elevation of the occupied point above the spheroid reference datum.

6. Measured slope distance: enter in meters. This measured distance is not reduced to the spheroid and can be used directly for input when running this program.

Running the G.TRA program

Example problem #1/given data
Spheroid Reference Datum: GRS-80 Code No. 21
Latitude of Occupied Point: 37°52'10.102"N
Longitude of Occupied Point: 124°03'22.921"W
Height or Elevation of Occupied Pt. above the Spheroid: 1350.00 meters
Azimuth to point being observed: 214°18'09.474"
Observed Vertical Angle: -00°52'38.4" (corrected for the deviation of the vertical and atmospheric refraction)
Measured slope distance: 139,267.215 meters

Find:
Latitude, longitude, and elevation of Observed Point

☞
Before running this program, execute the **SETL** routine and enter Code 21.

Press [G.TRA]. Or type **G.TRA** and press [ENTER].

The display will prompt you with:
LAT=?(-) if South
LON=?(-) if East
of occupied pt.

Key in: **37.5210102 [SPC] 124.0322921 [ENTER]**

The display will prompt:
AZIMUTH=? (clockwise
fr. True North to
Pt. observed)

Key in: **214.1809474 [ENTER]**

The display will prompt:
VERT. ∠=?(corrected
for vert. deviation
& atm. refraction)

Key in: **.52384 [±] [ENTER]**

The display will prompt:
HEIGHT of Occupied
Pt.=? (meters)

Key in: **1350 [ENTER]**

The display will prompt:
Measured SLOPE
DIST.=? (meters)

Key in: **139267.215 [ENTER]**

Output data

9 ϕo (N): 37.5210102
8 λo (W): 124.0322921
7 AZ: 214.1809474
6 V.∠: -0.5238400
5 Ho: 1350.0000
4 D: 139267.2150
3 LAT (N): 36.4947061
2 LON (W): 124.5609557
1 ELEV: 740.20499

Example Problem #2

The following data were taken from an example problem in *Survey Review* 31, 240 (April 1991), pages 84-85 by Mohammad Id Ozone. These data are presented here so you can compare the results between this program and that of Mr. Ozone.

Given Data
STATION P (Generoso, Switzerland)
Latitude: 45°55'56.9045"N
Longitude: 11°34'53.4734"E
Height of STA P above the Spheroid:
1700.17 meters
Spheroid Reference Datum: Intl? (use Code 22)
Observed STATION Q (Gaebris, Switzerland)
Azimuth to STA Q: 11°50'37.9967"
Observed Vertical Angle: -00° 53' 50.3"
(Negative Value)
Measured Sope Distance (STA P to STA Q):
164856.215 meters

☞ Observed vertical angle is corrected for deviation of the vertical and atmospheric refraction.

Find the latitude, longitude, and height of STA Q.

Results per Mr. Ozone's paper:
Latitude of STA Q = 47.38268785 (degrees)
or 47°22'57.67626"
Longitude of STA Q = 12.029454039 (degrees)
or 12°01'46.03454"
Height of STA Q = 1251.117 meters

Results per **G.TRA** program:
Latitude = 47°22'57.67630"N
Longitude = 12°01'46.03453"E
Height of STA Q = 1251.124 meters

G.TAD (Geodetic Traverse by Angle and Distance)

This program is similar to the G.TRA program, except that it uses a backsight point and horizontal angle for direction to compute the geodetic coordinates of the observed point.

Required input data

1. Latitude: South latitudes are entered as negative values.
2. Longitude: East longitudes are entered as negative values.
3. Azimuth: enter
   (a) azimuth to backsight point; or
   (b) latitude and longitude of backsight point.
4. Measured horizontal angle: clockwise fr. B.S. to F.S.
5. Vertical angle: corrected for vertical deviation and atmospheric refraction.
6. Height of occupied point: enter in meters. Elevation of occupied point above a reference ellipsoid.
7. Measured slope distance: enter in meters. There is no need to reduce this data to the spheroid reference datum.

Running the G.TAD program

Given data
Spheroid Reference Datum: GRS-80
Code No.: 21
Latitude of occupied point: 37°22'39.783"
Longitude of occupied point: 77°48'53.431"
Azimuth towards B.S. point: 15°36'27.328"
Measured Hor. Angle: 56°39'44.275"
Vertical Angle: 00°34'26.54" (corrected for deviation and atmospheric refraction
Height of occupied point: 1100.00 meters
Slope distance: 46,985.263 meters

☞ You must first execute the **SETL** routine to establish a reference datum (see below).

Find:
1. Latitude and longitude of observed point
2. Elevation

Press [G.TAD]. Or type **G.TAD** and press [ENTER].

The display will prompt you with the following:
LAT=? (-) if South
LON.=? (-) if East
of Occupied Pt.

Key in: **37.2239783 [SPC] 77.4853431 [ENTER]**

The display will prompt:
AZIMUTH=? (B.S. Pt.)
or its LAT=? LON.=?

Key in: **15.3627328 [ENTER]**

The display will prompt:
HOR. ANGLE (Rt.)=?
(fr. B.S. to F.S.)

Key in: **56.3944275 [ENTER]**

The display will prompt:
VERT. Angle=? (crtd.
for Deviation & Refr.)

Key in: **.342654 [ENTER]**

The display will prompt:
HEIGHT=? (m)
of Occupied Pt.

Key in: **1100 [ENTER]**

The display will prompt:
SLOPE DIST.=? (m)

Keyin: **46985.263 [ENTER]**

Output data

10 H. ∠: 56.3944275
9 ϕo (N): 37.2239783
8 λo (W): 77.4853431
7 AZ: 72.1611603
6 V. ∠: 0.3426540
5 Ho: 1100.000
4 D: 46,985.263
3 LAT (N): 37.3019864
2 LON (W): 77.1831844
1 ELEV: 1743.5926860

SETL

This routine is used to set or change the Ellipsoid Reference Datum for the following programs: S.INV, S.FOR, G.TRA, and G.TAD.

There are a total of 20 Ellipsoid Reference Data stored in the main program, plus an option to enter any other datum selected by the user.

Required input data

There is only one input for this routine: a code number corresponding to the chosen ellipsoid datum. A list of these codes and reference datums is found at the end of this chapter.

If code 41 is chosen, the ellipsoid's semi-major axis (a) and semi-minor axis (b) must be known.

Once an Ellipsoid Reference Datum is set, you do not need to execute the **SETL** routine again, until you wish to change to another reference datum.

List of ellipsoid data and their corresponding code numbers included in the SETL routine.

This data is used in programs S.FOR, S.INV, G.TRA, and G.TAD.

Cd #	Semi-major axes (a) in meters	Semi-minor axes (b) in meters	Types of Ellipsoid
21	6378137	6356752.31414	GRS-80 (WGS-84)
22	6378388	6356911.94613	International
23	6378206.4	6356583.8	Clarke 1866
24	6378135	6356750.52	WGS-72
25	6377397.155	6356078.96283	Bessel
26	6377276.345	6356075.41315	Everest
27	6378249.145	6356514.86955	Clarke 1880
28	6378145	6356759.76948	NWL-90
29	6378145	6356759.76948	WGS-66
30	6378160	6356774.7192	Australian Natl
31	6377563.396	6356256.90923	Airy
32	6378293.645	6356617.93764	Clarke 1858
33	6377104.43	6355847.41524	Danish
34	6378166	6356784.28361	Fisher 1960 (Mercury)

Cd #	Semi-major axes (a) in meters	Semi-minor axes (b) in meters	Types of Ellipsoid
35	6378155	6356773.32049	Fisher 1960 (South Asia)
36	6378150	6356768.33724	Fisher 1968
37	6378200	6356818.16963	Helmert
38	6378270	6356794.34345	Hough
39	6378160	6356774.7192	S. America (1969)
40	6378298.3	6356509.28521	Struve
41	?	?	a&b at user's option

CHAPTER 12

PEAK

Programs for estimating peak runoff

This chapter includes 7 programs that estimate peak runoff due to rainfall. These programs are independent of each other, and are presented here as tools to help in the design of storm drainage and water detention structures.

At best, estimating and determining water runoff volumes are an exercise of the designer's experience and educated judgment, due to a number of factors affecting runoff, and the unique characteristics of each site. Therefore, careful consideration should be exercised in the use of these programs as well as in applying them to a particular site and prevailing conditions.

One program worth noting is **QSCS**, which is gaining acceptance and popularity among designers. This program is derived from the Soil Conservation Service Technical Release No. 55. Results obtained from this program very much agree with the TR-55 Graphical Peak Discharge Method.

Several graphs and figures are with the discussions of each program to help you obtain values for the required input data.

QRGS

This program computes peak runoff using the USGS Regression Equation Method. This method features the use of the *Regional Factor Parameter* which is used as a multiplier in the equation. The Regional Factor value may be obtained from a special USGS map, which includes a wealth of hydrologic information, including the location of gauging stations and watershed boundaries.

☞ Before using this program, you should be familiar with this particular method and its applicability to the site being considered.

Required input data

1. Drainage Area in sq. miles or sq. km. Areas can be obtained from a map or by survey. Enter km as a negative value.
2. Stream slope in ft per mile or meter per km. Stream slope is computed using the following formula, where the numerator is in feet (or meters) and the denominator is in miles (or km):

$$SL = \frac{EL\ @\ 85\%\ L - EL\ @\ 10\%\ L}{0.85L - .1L}$$

$$= \frac{EL85 - EL10}{0.75L}$$

3. Regional Factor (RF). This parameter can be obtained from a USGS Hydrologic map which includes the area under consideration.
4. Storm Frequency in years. Valid input may include:2, 5, 10, 25, 50, or 100.

Running the QRGS program

Given data
Drainage Area = 5.5 sq. miles
Stream Slope = 23.50 feet per mile
Regional Factor = 1.35
Storm Frequency = 10 years

Find: Runoff, Q

Press [QRGS]. Or type **QRGS** and press [ENTER].

The display will prompt you with:
DRAINAGE AREA=?
(sq. m. or -sq. km.)

Key in: **5.5 [ENTER]**

The display will prompt:
STREAM SLOPE=? (ft/mi)
or -m/km) based on
10% ->85% of Length

Key in: **23.5 [ENTER]**

The display will prompt:
REGIONAL FACTOR=?
(Taken fr. a map of
individual state)

Key in: **1.35 [ENTER]**

The display will prompt:
STORM FREQ.=? (yrs.)
ENTER one of the Foll:
2, 5, 10, 25, 50, 100

Key in: **10 [ENTER]**

Output data

6 "REGRESSION EQ."
5 A (sq. mi): 5.50
4 SL (ft./ mi): 23.50
3 R.F.: 1.35
2 FREQ: 10.00
1 Q (cfs): 885.04

QSCS

This program computes peak runoff using the Soil Conservation Service Graphic Peak Method, as described in Chapter 4 of the TR-55 Manual. It has built-in data on rainfall types, percentage of pond, and swamp values; this minimizes the need to use tables and graphs.

This program is applicable only to non-composite or homogeneous areas (areas belonging to a single hydrologic soil group). The accompanying tables were taken from an SCS TR-55 Manual to be used only in the selection of the Runoff Curve Number (CN) and as input requirement in the program.

Required input data

1. A: drainage areas, entered in acres or square miles (or hectares or square km). Square miles and square km are entered as negative values.
2. CN - Runoff Curve Number: this is dependent on types of hydrologic soil group and ground cover (see tables, below).
3. Tc - Time of Concentration: enter in minutes or hours (hours are entered as negative values).
4. Percentage of Pond and Swamp Areas: the values of these percentages range from 0 to a maximum of 5 percent.
5. P = Rainfall Precipitation: amount of rainfall in a 24-hour period in inches or centimeters (cm must be entered as negative value).

6. Type of Rainfall: 4 class types of rainfall are built into the program. Enter either I, IA, II, or III.

Running the QSCS program

Example problem/given data
Location - Dyer County, Tennessee
Drainage Area = 0.39 sq. miles
Runoff Curve Number - CN = 75
Time of Concentration = 1.53 hrs.
Pond & Swamp Areas in % = 0.00%
Rainfall Precipitation (24-hr.) = 6.00 inches
Type of Rainfall = Class II

Find: Peak Q

Press [QSCS]. Or type **QSCS** and press [ENTER].

The display will prompt you with:
DRAINAGE AREA=?
Acres or -sq.mi. or
Hectares or -sq.km.

Key in: **.39 [±] [ENTER]**

The display will prompt:
IF Hectares or -Sq.
km. was INPUT, ENTER
1: ELSE, key [ENTER]

Press [ENTER].

The display will prompt:
RUN-OFF CURVE NUMBER:
CN=?

Key in: **75 [ENTER]**

The display will prompt:
(Tc) TIME of
CONCENTRATION=?
(Min. or -Hrs.)

Key in: **1.53 [±] [ENTER]**

The display will prompt:
POND/SWAMP AREAS=?(%)
(Select fr. 0% to 5%)

Key in: **0 [ENTER]**

The display will prompt:
PRECIPITATION (P)=?
(In or -cm per 24-hr)

Key in: **6 [ENTER]**

The display will prompt:
RAINFALL TYPE=?
ENTER I or IA
or II or III

Key in: **II [ENTER]**

Output data

13 "SCS METHOD"
12 TYPE: II
11 A (sq. mi): 0.390
10 CN: 75.000
9 Tc (hr.): 1.530
8 PS (%): 0.000
7 Fp: 1.000 <- swamp/pond factor
6 P (in): 6.000
5 Ia/P: 0.111 <- initial obstraction over P
4 Co: 2.548 } *Coefficients for unit peak*
3 C1: - 0.616 } *discharges for SCS Type I, IA,*
2 C2: - 0.161 } *II & III Rainfall*
1 Qp (cfs): 343.85 <- Computed Peak Runoff

Table 12.1: runoff curve numbers for urban areas
(source: 210-VI-TR-55, Second Ed., June 1986)

Cover description		Curve #s for hydrologic soil group			
Cover type/ hydrology condition	Avg % imperv area	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, etc.):					
poor condition (grass cover <50%)		68	79	86	89
fair condition (grass cover 50-75%)		49	69	79	84
good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
paved parking lots, roofs, drives, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
paved; curbs, storm sewers (excluding right-of-way)		98	98	98	98
paved; open ditches (incl rght-o-way)		83	89	92	93
gravel (incl right-of-way)		76	85	89	91
dirt (incl right-of-way)		72	82	87	89
Western desert urban areas:					
natural landscaping (perv areas)		63	77	85	88
artificial landscaping (imperv weed barrier, desert shrub w/ 1- to 2-inch sand or gravel mulch and basin borders		96	96	96	96
Urban districts:					
commercial/business	85	89	92	94	95
industrial	72	81	88	91	93
Residential districts by avg lot size:					
≤ 1/8 acre (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in table 12.3)					

Average % pervious area shown was used to develop composite CNs. Other assumptions: imper areas are directly connected to the drainage system; imperv areas have CN of 98; and perv areas are considered equivalent to open space in good hydrologic condition.

Table 12.2: Runoff curve numbers for cultivated agricultural lands

Cover description			Curve #s for hydrologic soil group			
Cover type	Treatment	Hydrologic condition	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cvr (CR)	poor	76	85	90	93
		good	74	83	88	90
Row crops	straight (SR)	poor	72	81	88	91
		good	67	78	85	89
	SR + CR	poor	71	80	87	90
		good	64	75	82	85
	contoured (C)	poor	70	79	84	88
		good	65	75	82	86
	C + CR	poor	69	78	83	87
		good	64	74	81	85
	C & terraced (T)	poor	66	74	80	82
		good	62	71	78	81
	C&T + CR	poor	65	73	79	81
		good	61	70	77	80
Small grain	SR	poor	65	76	84	88
		good	63	75	83	87
	SR + CR	poor	64	75	83	86
		good	60	72	80	84
	C	poor	63	74	82	85
		good	61	73	81	84
	C + CR	poor	62	73	81	84
		good	60	72	80	83
	C&T	poor	61	72	79	82
		good	59	70	78	81
	C&T + CR	poor	60	71	78	81
		good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	poor	66	77	85	89
		good	58	72	81	85
	C	poor	64	75	83	85
		good	55	69	78	83
	C&T	poor	63	73	80	83
		good	51	67	76	80

Crop residue cover applies only if residue is on at least 5% of surface throughout year. Hydrology condition is based on combination of factors that affect infiltration and runoff, including: density and canopy of vegetative areas; amount of year-round cover; amount of grass or close-seeded legumes in rotations; % of residue cover on land surface (good $\geq$ 20%); degree of surface roughness.

Table 12.3: Runoff curve numbers for other agricultural lands[1]

Cover description		Curve #s for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range–continuous forage for grazing[2]	poor	68	79	86	89
	fair	49	69	79	84
	good	39	61	74	80
Meadow–continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush–brush-weed-grass mixture with brush the major element[3]	poor	48	67	77	83
	fair	35	56	70	77
	good	[4]30	48	65	73
Woods–grass combination (orchard or tree farm)[5]	poor	57	73	82	86
	fair	43	65	76	82
	good	32	58	72	79
Woods[6]	poor	45	66	77	83
	fair	36	60	73	79
	good	[4]30	55	70	77
Farmsteads–buildings, lanes, driveways, and surrounding lots	—	59	74	82	86

[1] Average runoff condition = 0.2S

[2] poor: <50% ground cover (or heavily grazed with no mulch)
fair: 50-75% ground cover (and not heavily grazed)
good: >75% ground cover (lightly or only occasionally grazed)

[3] poor: <50% ground cover
fair: 50-75% ground cover
good: >75% ground cover

[4] actual curve # is <30; use CN=30 for runoff computations

[5] CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pastures

[6] poor: forest litter, small trees, brush destroyed by heavy grazing or regular burning
fair: woods are grazed but not burned, and some forest litter covers the soil
good: woods are protected from grazing, and litter and brush adequately cover the soil

Table 12.4: Runoff curve numbers for arid and semi-arid rangelands[1]

Cover description		Curve #s for hydrologic soil group			
Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous–mixture of grass, weeds, and low-growing brush, with brush the minor element	poor		80	87	93
	fair		71	81	89
	good		62	74	85
Oak-aspen–mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	poor		66	74	79
	fair		48	57	63
	good		30	41	48
Pinyon-juniper–pinyon, juniper, or both: grass understory	poor		75	85	89
	fair		58	73	80
	good		41	61	71
Sagebrush with grass understory	poor		67	80	85
	fair		51	63	70
	good		35	47	55
Desert shrub–major plants include saltbush, greasewood, creosote-bush, blackbrush, bursage, palo verde, mesquite, and cactus	poor	63	77	85	88
	fair	55	72	81	86
	good	49	68	79	84

[1] Average runoff condition = 0.2S. For range in humid conditions, use table 12.3

[2] poor: <30% ground cover (litter, grass, and brush overstory)
fair: 30-70% ground cover
good: >70% ground cover

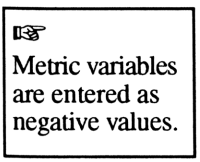
[3] curve numbers for group A have been developed only for desert shrub

QRAT

This program computes Peak Runoff using the Rational Method. This method is used primarily for watershed areas less than 200 acres. It is the simplest method to use; however, the selection of runoff coefficients requires proper consideration and sound judgment. The determination of rainfall intensity must also be given some consideration, as it is dependent on the Time of Concentration which, in turn, requires proper selection of various parameters.

Required input data:

1. Correction Factor (Cf): this corrects for ground saturation and varies directly with the storm frequency. Recommended Cf values for storm frequencies of 10, 25, 50, and 100 years are 1, 1.1, 1.2, and 1.25 respectively.
2. Weighted Runoff Coefficient (C): this correction factor depends on the type of surface the runoff will traverse. Generally, the "C" value varies from 0.20 (forest/lawns) to 0.90 (paved/impervious areas). A weighted "C" value is determined from different individual surface types; a listing is provided below.
3. Rainfall Intensity (I): enter in inches (or -cm) per hour. This value is obtained by first finding the Time of Concentration, then using a chart involving 3 parameters: Rainfall Intensity, Duration, and Storm Frequency Curves. This chart is furnished by the National Weather Service and must cover and include the area being considered. Charts for each state may be found in the state's DOT Drainage Manual.
4. Drainage Area (A): enter in acres (or -hectares). The area is obtained by planimeter or map scaling or actual survey.



Running the QRAT program

Given data

Storm Frequency - 10 years	Cf = 1.00
Weighted Runoff Coefficient	C = 0.55

Rainfall Intensity I = 4.4 inches per hr.
Drainage Area A = 187.00 Acres

Find: Rate of Flow, Q

Press [QRAT]. Or type **QRAT** and press [ENTER].

The display will prompt you with:
CORR. FACTOR (Cf)=?
or ENTER 1 if N/A

Key in: **1 [ENTER]**

The display will prompt:
(Weighted) RUNOFF
COEFF. (C)=?

Key in: **.55 [ENTER]**

The display will prompt:
RAINFALL INTENSITY=?
(In or -cm per hr.)

Key in: **4.4 [ENTER]**

The display will prompt:
DRAINAGE AREA=?
(Acres or -Hectares)

Key in: **187 [ENTER]**

Output data

6 "RATIONAL METHOD"
5 Cf: 1.00
4 C: 0.55
3 I (in/hr): 4.40
2 A (ac): 187.00
1 Qp (cfs): 452.54

Runoff coefficients (C) for QRAT program

Source: Drainage Manual VDOT

Business, Industrial/Commercial		0.80-0.90
Apartments		0.65-0.75
Schools		0.50-0.60
Residential -	lots 10,000 ft^2	0.40-0.50
	lots 12,000 ft^2	0.40-0.45
	lots 17,000 ft^2	0.35-0.45
	lots 1/2 acre +	0.30-0.40
Parks, Cemeteries, Unimproved Areas		0.20-0.35
Paved and Roof Areas		0.90
Cultivated Areas		0.50-0.70
Pasture		0.35-0.45
Forest		0.20-0.30
Steep Grass (2:1)		0.70
Shoulder and Ditch Areas		0.50
Lawns		0.20

QAND

This program computes Peak Runoff using the Anderson Method. This method is the result of extensive analysis of drainage areas in Northern Virginia that was done in 1968 by D.G. Anderson of the USGS Water Resources Division.

This method can also be applied to urbanized and natural rural watershed areas of up to 570 square miles.

The Anderson formula and a description of the various parameters can be found in Exhibit 12.1, below.

Required input data

1. Upper Elevation (EL85): this is the elevation of a point located at 85 percent of the total length (L) of the main water channel measured from the lowest extreme end. Enter in feet (or -meters).
2. Lower Elevation (EL10): this is the elevation of a point located at 10 percent of the total length (L) of the main water channel, measured from the lowest extreme end. Enter in feet (or -meters).
3. Total Length (L) of the main channel: enter in miles (or -kilometers).
4. Code number for the type of Basin, as prompted by the program: 1 = rural area; 2 = partially developed area; 3 = completely developed area.
5. Area of the Watershed (A): this may be obtained using topo maps or actual survey. Enter in square miles (or -square kilometers).
6. Impervious Area (I) in percent included in the watershed.
7. Flood Frequency Ratio (R): this value is graphically obtained (see Figure 12.1) with Recurrence Interval (Flood Frequency) in years, and amount of Imperviousness in %.



Metric variables must be entered as negative values.

Exhibit 12.1: Anderson method formula

A method used to determine PEAK DISCHARGE of a drainage basin up to 570 square miles in area. This method is applicable both in urban developed areas and in natural rural areas.

$$Q = 230\ RK(A)^{.82}(T)^{-.48}$$

Where:

Q = peak discharge in cfs at a given site usually along the lowest point of the watercourse

R = flood frequency ratio, determined from a graph involving 2 other parameters: recurrance interval in years (i.e. 25-year storm); and area of impervious surface for the whole basin in percent

K = coefficient of imperiousness, expressed in formula: K = 1 + 0.015(I), where I is expressed as a % of the basin covered with imperious surface

A = area of drainage basin in square miles, determined by planimeter or other means from a map

T = lag time in hours, defined as the average time between the centroids of rainfall excess and direct runoff. T varies with the type of basin being considered as follows:

a. $T = 4.64(L/\sqrt{S})^{0.42}$ for natural rural basins

b. $T = 0.90(L/\sqrt{S})^{0.50}$ for partially channeled developed basins

c. $T = 0.56(L/\sqrt{S})^{0.52}$ for completely sewered and developed basins

L = total length of the stream or watercourse in miles within the limits of the drainage basin boundary. L is determined by scaling from a map.

S = slope of the bed of the stream in feet per mile. Defined as a ratio of the difference of the high and low elevations between 85% of L and 10% of L respectively over the difference between 85% of L and 10% of L:

$$S = \frac{\text{Elev. @ 85\% of L - Elev. @ 10\% of L}}{\text{85\% of L - 10\% of L}} \qquad S = \frac{EL_{85} - EL_{10}}{0.75L}$$

Where:

EL_{85} = elevation of stream bed at 85% of L determined from a topo map or actual field survey of upper portion of the stream.

EL_{10} = elevation of stream bed at 10% of L determined from a topo map or actual field survey of lower portion of the stream.

Running the QAND program

Given data

1. Upper elevation @ 85% of the total length of the main channel = 395.00 ft.
2. Lower elevation @ 10% of the total length of the main channel = 282.00 ft.
3. Total length of the main water channel = 3.40 miles
4. Type of channel = partially developed (use Code 2)
5. Area of watershed = 2.81 sq. miles
6. Impervious area, in % of the watershed, I = 40%
7. Flood Frequency Ratio = 2.34 (Obtained graphically Using F.R. = 25 yrs. and I = 40)

Find: Rate of Flow, Q

Press [QAND]. Or type **QAND** and press [ENTER].

The display will prompt you with the following:
UPPER ELEV=?
(ft. or -m) @ 85% L
of Channel

Key in: **395 [ENTER]**

The display will prompt:
LOWER ELEV=?
(ft. or -m) @ 10%L
of Channel

Key in: **282 [ENTER]**

The display will prompt:
Length of Channel=?
(mi. or -km)

Key in: **3.4 [ENTER]**

The display will prompt:
SELECT BASIN TYPE:
1= RURAL 2= PARTLY DEV.
3= COMPLETELY DEV.

Key in: **2 [ENTER]**

The display will prompt:
AREA OF WATERSHED=?
(sq. mi. or -sq. km.)

Key in: **2.81 [ENTER]**

The display will prompt:
IMPERVIOUS AREA(%)=?

Key in: **40 [ENTER]**

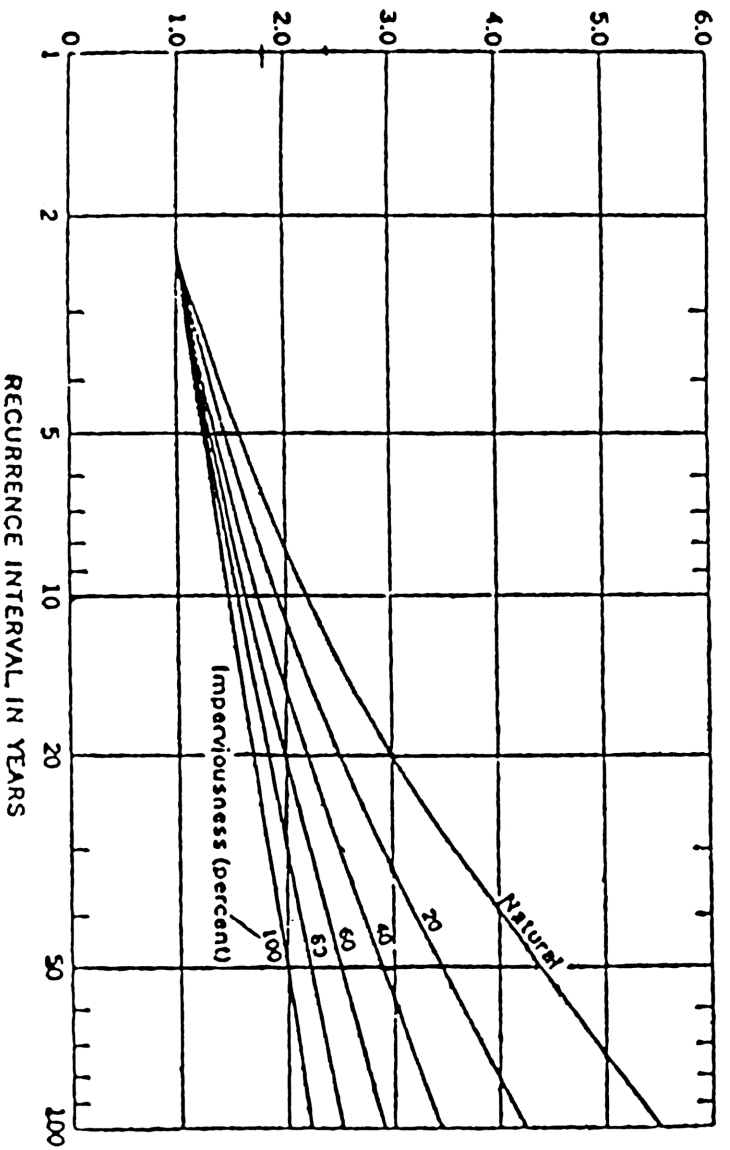
The display will prompt:
FLOOD FREQ. RATIO=?
(obtain fr. graph)

Key in: **2.34 [ENTER]**

Output data

9 "ANDERSON METHOD"
8 EL (85% L): 395.000
7 EL (10%L): 282.000
6 L (mi): 3.400
5 A (sq. mi): 2.810
4 I.A. (%): 40.000
3 R: 2.340 <- taken from Exhibit 25
2 T (hrs): 0.643 <- Lag time in hours
1 Q (cfs): 2483.111 <- Computed Peak Runoff

Figure 12.1: Ratio to average Flood



Flood frequency curves for selected degrees of basin imperviousness

QGS3

This program computes urban peak runoff using the USGS 3 - Parameter Equation Method.

☞
You should be familiar with this method and its applicability to the subject locality before using this program.

This method is used by the Federal Highway Adminstration in estimating runoff from ungauged streams in urban watershed areas. For further details about this method, please consult the U.S. Geological Survey Water Supply Paper 2207-1983.

☞
Metric variables must be entered as negative values.

Required input data

1. Drainage Area (A): enter in sq. miles (or -km^2).
2. Basin Development Factor (BDF): this is a dimensionless parameter whose value ranges from 0 to 12. This parameter is a measure of the hydraulic efficiency of the drainage system in a specific watershed area. A detailed explanation of how to obtain a compatible BDF value is found below.
3. Rural Discharge (RQ) value: this parameter is the pre-development discharge or the discharge as if the watershed is still in its rural condition. This rural discharge is easily obtained using the Rational or other methods. Enter in cfs (or -cms).
4. Storm frequency: enter in years. Valid input includes 2, 5, 10, 25, 50, 100, and 500 years.

Figuring the Basin Development Factor (BDF)

A certain amount of subjectivity is involved in the determination of the final BDF value because it is dependent on the careful evaluation of four factors by which the entire drainage system is evaluated.

First, the whole watershed is arbitrarily partitioned into 3 more or less equal parts. Then, within each

partition, four factors of the drainage system are evaluated; each partition is assigned a value of either a 1 or 0. These assigned values are then added together to obtain the final BDF value.

Factors:

1. Channel improvements - A BDF value of 1 is assigned if at least 50% of the main and tributary channels are improved by enlarging, straighthening, dredging, etc.; otherwise, it is assigned a BDF of 0.
2. Channel Linings - A BDF value of 1 is assigned if more than 50% of the main and tributary channels has been lined with impervious materials such as concrete. If less than 50%, BDF is 0.
3. Storm drains or sewers - A BDF of 1 is assigned if more than 50% of the secondary tributaries coming directly from streets and parking lots are served by drainage conveyances such as concrete storm pipes and man-made open channels. If less than 50%, the BDF is 0.
4. Curb and Gutter Streets - If more than 50% of each third subarea is covered by residental and/or commercial development, and if more than 50% of the streets and highways are provided with curb and gutter, then a BDF of 1 is assigned; otherwise, the BDF is 0.

Running the QGS3 program

Given data
Drainage Area A = 45.30 sq. miles
Basin Development Factor BDF = 4.0
Rural Discharge Qr = 730.0 cfs
Storm frequency = 50 years

Find: Rate of Flow, Q

Press [QGS3]. Or type **QGS3** and press [ENTER].

The display will prompt you with:
DRAINAGE AREA=?
(sq. mi or -sq. km)
(Range= .2 →100 sq. mi)

Key in: **45.30 [ENTER]**

The display will prompt:
BASIN DEV. FACTOR=?
(Range= 0 →12)

Key in: **4 [ENTER]**

The display will prompt:
RURAL DISCHARGE=?
(cfs or -cms)

Key in: **730 [ENTER]**

The display will prompt:
STORM FREQ.=? (yrs.)
ENTER one of the foll:
2, 5, 10, 25, 50, 100, 500

Key in: **50 [ENTER]**

Output data

6 "USGS 3-P. METHOD"
5 A (sq. mi): 45.300
4 BDF: 4.00
3 Qr (cfs): 730.000
2 Freq.(yrs): 50.00
1 Qp (cfs): 1470.97 <- Computed Peak Runoff

QGS7

This program computes urban peak runoff using the USGS 7 - Parameter Equation Method. This method is used by the Federal Highway Administration in estimating runoff from ungauged urban areas. For further readings on this method, please consult the U.S. Geological Survey Water Supply Paper 2207-1983.

☞ You should be familiar with this method and its applicability to the particular site before using this program.

Required input data

1. Drainage Area (A): applicable areas range from 0.2 to 100 square miles. Enter in square miles (or -km^2).
2. Stream Slope: enter in feet per mile (or -meters per km). This parameter ranges in value from 3 to a maximum of 70. If the stream slope exceeds to an equivalent of 70 feet per mile, then a limiting value of 70 is used. Stream slope is obtained using the following formula, where the numerator is in feet and the denominator is in miles:

$$SL = \frac{\text{Elev @ 85\%L - Elev @ 10\%L}}{.85L - .1L}$$

$$= \frac{EL85 - EL10}{0.75L}$$

3. Rainfall Intensity: enter in inches (or -cm). Rainfall intensity values range from 0.2 to 2.8 inches, and are subject to a 2-year 2-hr. rainfall intensity applicable to the watershed being considered.
4. Percent Pond and/or Swamp Areas: this is the amount of area (in %) where some of the runoff is permanently detained or stored. These areas could be in the form of lakes, swamps, wetlands, ponds, etc. The value of this parameter ranges from 0 to 11%.

☞ Metric variables must be entered as negative values.

5. Basin Development Factor (BDF): this is a dimensionless parameter whose value ranges from 0 to 12. A detailed explanation is found in the **QGS3** program notes.
6. Percent Impervious Areas: this is the amount of impervious areas (in %) included in the watershed. Its value ranges from 3 to 50%.
7. Rural Discharge (Qr): enter in cfs (or -cms). This is the amount of runoff if the watershed were in rural condition. This value can easily be determined by Rational or other convenient methods.
8. Storm Frequency: enter in years. Valid input includes 2, 5, 10, 25, 50, 100 and 500 years.

Running the QGS7 program

Given data
Drainage Area, A = 50.00 sq. mi
Stream Slope, SL = 45 feet per mile
Rainfall Intensity, R.I. = 0.80
Total amount of pond & swamp areas = 3.50%
Basin Development Factor, BDF = 4.00
Impervious Area = 15.00%
Rural Discharge, Qr = 2450.00
Storm Frequency = 10 years

Find: Rate of Flow, Q

Press [QGS7]. Or type **QGS7** and press [ENTER].

The display will prompt you with the following:
DRAINAGE AREA=?
(sq. mi or -sq. km)
(Range=.2→100 sq. mi)

Key in: **50 [ENTER]**

The display will prompt:
STREAM SLOPE=?
(ft/mi OR -m/km)
(Range=3→70 ft/mi)

Key in: **45 [ENTER]**

The display will prompt:
RAINFALL INTENSITY=?
(in. or -cm)
(Range= .2→2.8 in.)

Key in: **.8 [ENTER]**

The display will prompt:
% POND/SWAMP AREA=?
(Range=0→11%)

Key in: **3.5 [ENTER]**

The display will prompt:
BASIN DEV. FACTOR=?
(Range=0→12)

Key in: **4 [ENTER]**

The display will prompt:
% IMPERVIOUS AREA=?
(Range=3→50%)

Key in: **15 [ENTER]**

The display will prompt:
RURAL DISCHARGE=?
(cfs or -cms)

Key in: **2450 [ENTER]**

The display will prompt:
STORM FREQ.=? (yrs.)
ENTER one of the foll:
2, 5, 10, 25, 50, 100, 500

Key in: **10 [ENTER]**

Output data

10 "USGS 7-P. METHOD"
9 A (sq. mi): 50.00
8 S (ft/mi): 45.00
7 R.I. (in): 0.80
6 A (%-Pond): 3.50
5 BDF: 4.00
4 I.A. (%): 15.00
3 Qr (cfs): 2450.00
2 FREQ. (yrs): 10.00
1 Qp(cfs): 2901.61

QSNY

This program computes Peak Runoff using the Snyder Method. This method involves the use of 3 different graphs or figures to obtain 2 of the required input data used in this program. You must be familiar with the different parameters and the applicability of this method to the watershed under consideration before using this program.

Required input data

1. Drainage Area: enter in square miles (or -km^2).
2. Time of Concentration: this parameter is obtained using the time of Concentration Program (see TCSM program, below) or other methods. Enter in minutes or hours; hours must be entered as a negative value.
3. Total Runoff (P): enter in inches (or -cm). This parameter is obtained using a graph of the site being considered, with the Tc and storm frequency as the two arguments (see Figure 12.2; the graph shown is used only for illustration purposes in our example problem). After the Total Runoff (P) is determined, it is used in Figure 12.3 to obtain the Percent Direct Runoff of Natural Areas which, in turn, is used in Figure 12.4 to obtain the Percent Adjusted Runoff.
4. Percent Adjusted Runoff (Ra): this parameter is obtained using Figure 12.4 with Percent Direct Runoff and Percent Impervious area as the two arguments.

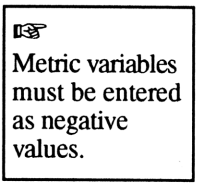
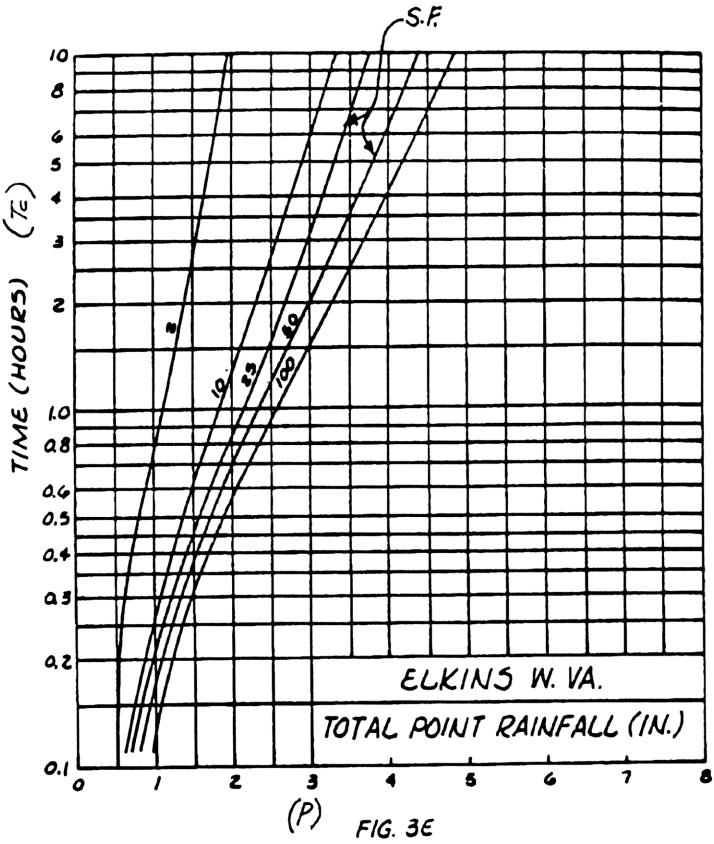

Metric variables must be entered as negative values.

Figure 12.2: Total point rainfall



Example:

Given: Tc=1.5 hrs.
S.F.=100 yrs.

Find: P=3.00

Figure 12.3: Total runoff/%direct runoff

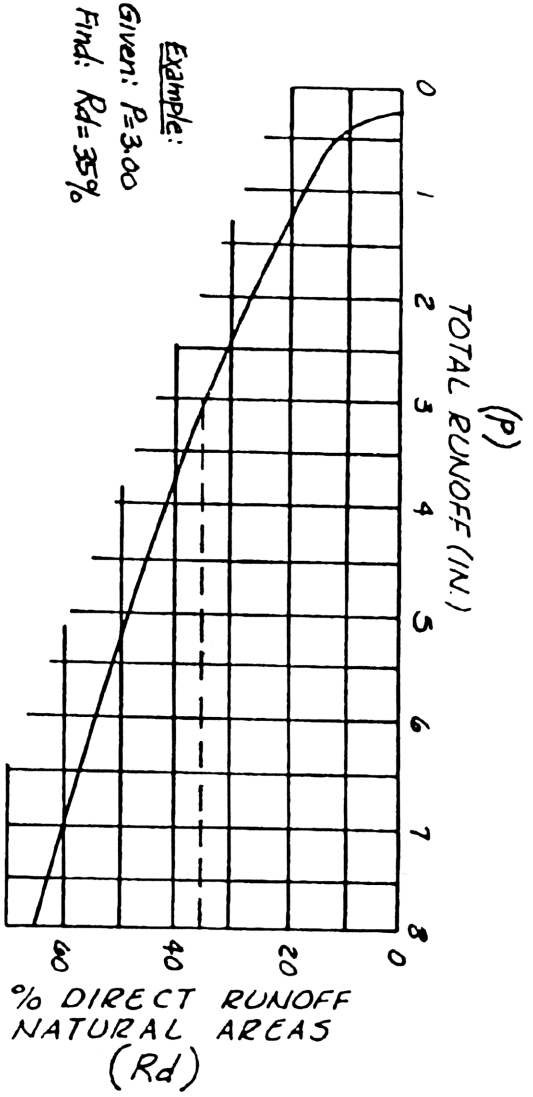
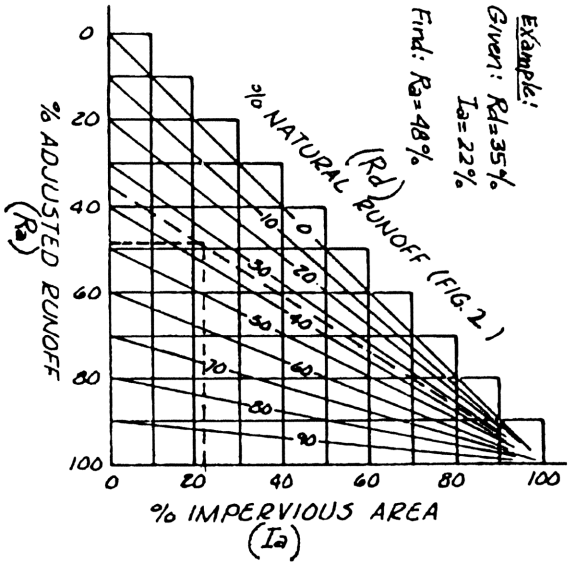
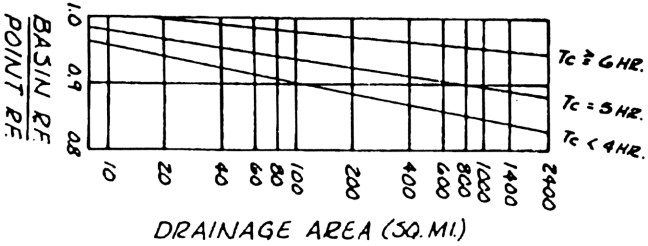


Figure 12.4: % natural runoff/
Figure 12.5: drainage area





Running the QSNY program

Example problem/given data

Drainage Area = 2.65 sq. miles (Elkins, W. Va.)
Time of Concentration -Tc = 1.50 hrs.
Storm Frequency = 100 yrs.
Percent Impervious Area - Ia = 22%

Find: Rate of Flow, Q

Solution procedures

1. Using Figure 12.2, find the Total Runoff (P) using the Time of Concentration (Tc) = 1.5 hrs. and Storm Frequency = 100 yrs. as the 2 arguments. (P = 3.00 inches)
2. Using Figure 12.3, find Percent Direct Runoff (Rd) Natural Areas using the Total Runoff (P) = 3.00 inches as the lone argument. (Rd = 35%)
3. Using Figure 12.4, find Percent Adjusted Runoff (Ra) using Percent Impervious Area (Ia) = 22% and Percent Natural or Direct Runoff (Rd) = 35% as the 2 arguments. (Ra = 48%)

The Total Runoff (P) and Percent Adjusted Runoff (Ra) are the third and fourth required input data respectively. The product of Ra and P divided by 100 is the effective Runoff (Qx) in inches as shown in the output display.

Press [QSNY]. Or type **QSNY** and press [ENTER].

The display will prompt you with the following:
DRAINAGE AREA=?
(sq. mi or -sq. km)

Key in: **2.65 [ENTER]**

The display will prompt:
TIME of
CONCENTRATION=?
(min. or -hrs.)

Key in: **1.5 [±] [ENTER]**

The display will prompt:
TOTAL RUNOFF=?
(in. or -cm)
(See Fig. 12.3)

Key in: **3 [ENTER]**
% ADJ. RUNOFF=?
(See Fig. 12.4)

Key in: **48 [ENTER]**

Output data

5 "SNYDER METHOD"
4 A (sq. mi): 2.65
3 Qx (in): 1.44
2 Tc (hrs): 1.50
1 Qp (cfs): 1272.00

CHAPTER 13

FLOOD

Flood routing and hydrograph programs

As rural areas become urbanized and developed, there is a need to control the effects of increased runoff. One of the most effective methods is to use a Water Detention Structure. The purpose of this structure is to delay and store peak discharges so that water can be released at a safer rate, thus reducing the risk of soil erosion and/or unwanted flooding.

Some of the problems and topics covered by these programs include the following:

1. Generation of Time and Rate of Inflow hydrograph coordinates using either a Unit or an SCS Unit hydrograph.
2. Hydrograph coordinates of Rate of Outflow versus Rate of Storage plus Outflow using a weir or spillway as an outflow conveyance and given the heights of water in the pond and the respective storage capacities.
3. Hydrograph coordinates of Rate of Storage versus Height of Water above a spillway.
4. Hydrograph coordinates of Rate of Outflow versus Height of Water above a spillway.
5. Solution to flood routing on a small drainage basin using the Storage Parameter Method. A storage parameter curve is used to find values of peak inflow, peak outflow, and storage capacity of a reservoir.

INFLO

This program generates and plots Hydrograph coordinates and finds the Rate of Inflow using the time interval from the start of runoff to any instant before or after peak runoff for a Detention Reservoir. Hydrograph coordinates consist of Time in hours as the abscissa and Rate of Inflow (Q) as the ordinate. You may use either the Unit Hydrograph or the Soil Concervation Service Unit Hydrograph. The program prints out a list of values of coordinate pairs for plotting purposes.

Required input data

1. Peak Inflow: enter in cfs (or cms), as determined from any runoff computation method.
2. Time of Concentration (Tc): enter in minutes or hours (if hours, enter as a negative value).
3. Option to use SCS or Unit Hydrograph.
4. Time interval or Routing period: in minutes.
5. Time interval from start of Inflow to any instant during the Inflow process. If a certain Time Lapse is keyed in, the program outputs a corresponding Inflow value.

Output data

1. Momentary plot of the Bell-shaped Inflow Hydrograph
2. Display of Time in hours and the corresponding Inflow value
3. List of coordinate pairs for plotting.

Running the INFLO program

Example problem/given data
Peak Inflow (Qp) = 250 cfs
Time of Concentration (Tc) = 55 minutes
Hydrograph - Unit Hydrograph: press Code 2
Time Interval or Routing Period = 10 minutes

Required
Hydrograph Coordinates (Time lapsed vs. Inflow)

After all the input data are entered, the program will momentarily plot the shape of the Unit Hydrograph. Then it will prompt for an input of Time lapsed in minutes (or in -hours); this is the time interval from the start of Inflow to any stage during the Inflow Process. For a given time lapse, a corresponding value of Inflow is computed. For example, if T = 40 minutes, Inflow (Qi) = 210 cfs.

A list of coordinates of Time vs. Q will be displayed.

☞
If Flag 5 is set prior to running the program, all output data will be printed automatically via the infrared Printer.

Press [INFLO]. Or type **INFLO** and press [ENTER].

The display will prompt you with the following:
PEAK INFLOW (Qp)=?
(cfs or cms)

Key in: **250 [ENTER]**

The display will prompt:
TIME OF
CONCENTRATION=?
(min. or -hrs.)

Key in: **55 [ENTER]**

The display will prompt:
CHOOSE 1? OR 2?
1=SCS UNIT HYDROGRAPH
2=UNIT HYDROGRAPH

Key in: **2 [ENTER]**

The display will prompt:
TIME INTERVAL
or ROUTING PERIOD
(minutes)

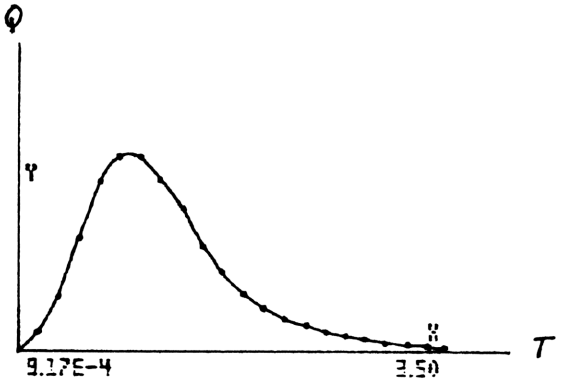
Key in: **10 [ENTER]**

☞
A graph of T vs. Q will be momentarily displayed.

The display will prompt:
TIME LAPSED=?
(fr. 0 to any Time
in min. or -hrs.)

Key in as many time lapses as you want. Press the [ON] key to quit.

Output data



24: "INFLOW COORD."
23: "(T(hrs), Q)"
22: (9.17E-4, 0.00)
21: (0.17, 20.00)
20: (0.33, 67.50)
19: (0.50, 140.00)
18: (0.67, 210.00)
17: (0.83, 247.50)
16: (1.00, 247.50)
15: (1.17, 217.50)
14: (1.33, 180.00)
13: (1.50, 130.00
12: (1.67, 97.50)
11: (1.83, 72.50)
10: (2.00, 52.50)
9: (2.17, 40.00)
8: (2.33, 30.00)
7: (2.50, 22.50)
6: (2.67, 17.50)
5: (2.83, 12.50)
4: (3.00, 10.00)
3: (3.17, 7.50)
2: (3.33, 5.00)
1: (3.50, 2.50)

OS.HY

This program generates and plots Outflow (O) vs. Storage Rate + Outflow ($2S/\Delta t + 0$) Hydrograph when the outflow structure and reservoir data are known. It computes either the Outflow or Storage Rate + Outflow when either value is input, using a linear regression equation derived from the generated Hydrograph coordinates. These coordinates consist of the $2S/\Delta t + 0$ as the abscissa – or X axis – and the Outflow (O) as the ordinate – or Y axis.

Required input data

1. Weir or Spillway Data: enter width of gate in feet or meters.
2. Weir Discharge Coefficient.
3. Maximum height of water above the Weir: enter in feet or meters.
4. Head Interval or increment of height above the weir: enter in feet or meters.
5. Dam or Reservoir Data - Height of Water (H1): enter in feet or meters.
6. Storage Volume (S1): enter in cu. ft. or cu. m.; corresponds to the height of water (H1), above.
7. Height of Water (H2): enter in feet or meters.
8. Storage Volume (S2): enter in cu. ft. or cu. m.; corresponds to the height of water (H2), above.
9. Time interval of one routing period, in minutes.

Output data

1. Momentary Plotting of Output (O) vs. $2S/\Delta t + O$
2. Any value of Outflow will give corresponding value of Storage Rate + Outflow.
3. Hydrograph coordinates of O and $2S/\Delta t + O$

Running the OS.HY program

Example problem/given data
Width of Weir or Spillway, L = 50 ft.
Weir Discharge Coefficient = 3.33
Max. Head (H) above weir = 6 ft.
Head Interval = 0.50 ft.

Reservoir data
If height H1 = 1 ft ...
    Storage Volume S1 = 20,000 cu. ft.
If height H2 = 6 ft ...
    Storage Volume S2 = 275,000 cu. ft.
H2 = 6; max. head above weir
Time interval of 1 routing period = 15 minutes

Press [OS.HY]. Or type **OS.HY** and press [ENTER].

The display will prompt you with the following:
WEIR/SPILLWAY DATA;
WIDTH of GATE=?
(ft or m)

Key in: **50 [ENTER]**

The display will prompt:
WEIR DISCHARGE COEFF;
3.33=SHARP or 3=BROAD
or OTHER COEFF.(Cf)=?

Key in: **3.33 [ENTER]**

The display will prompt:
MAX. HEAD (H)
ABOVE WEIR=?
(ft. or m.)

Key in: **6 [ENTER]**

The display will prompt:
HEAD INCREMENT=?
(ft. or m.)

Key in: **.5 [ENTER]**

The display will prompt:
DAM/RESERVOIR DATA:
Ht. (H1) ABOVE WEIR=?
(ft. or m.)

Key in: **1 [ENTER]**

The display will prompt:
STORAGE VOL. (S1)=?
when Ht. = H1
(cu. ft or cu. m)

Key in: **20000 [ENTER]**

The display will prompt:
Ht. (H2) above WEIR=?
(ft. or m.)

Key in: **6 [ENTER]**

The display will prompt:
STORAGE VOL. (S2)=?
when Ht.=H2
(cu. ft or cu. m)

Key in: **275000 [ENTER]**

The display will prompt:
TIME INTERVAL
or ROUTING PERIOD=?
(minutes)

Key in: **15 [ENTER]**

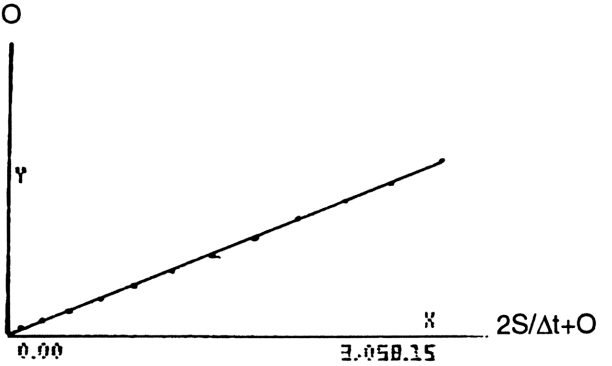
☞
A graph of Outflow (O) vs. Storage Rate plus Outflow (2S/Δt+O) will be momentarily displayed.

☞
You may find either O or 2S/Δt + O by assigning a value to either. However, the Outflow (O) value must be entered negative. If one is input, the other is output.

The display will prompt:
ENTER EITHER VALUE:
2S/Δt+O=? or (-) O=?

If 2S/Δt+O is Input, O is Output or vice versa; the value of 0 must be *negative*.

Output data



15: "(2S/Δt+0, 0)"
14: "COORDINATES"
13: (0.00, 0.00)
12: (81.09, 58.87)
11: (210.94, 166.50)
10: (406.99, 305.88)
9: (628.71, 470.93)
8: (872.59, 658.15)
7: (1136.27, 865.16)
6: (1418.00, 1090.23)
5: (1716.44, 1332.00)
4: (2030.51, 1589.40)
3: (2359.30, 1861.53)
2: (2702.07, 2147.62)
1: (3058.15, 2447.04)

SΔTH

This program generates Hydrograph coordinates of water height above a spillway (H) vs. Storage Rate (2S/Δt). A time interval (in minutes) for a given Routing period, plus the Height Increment and Reservoir storage data will produce a list of hydrograph coordinates to be used in plotting.

Required input data

1. Height increment: enter in feet or meters
2. Routing period: enter in minutes
3. Height of water above spillway (H1): enter in feet or meters
4. Storage volume (S1): enter in cu. ft. or cu. m. corresponding to H1 above.
5. Height of water above spillway (H2): enter in feet or meters
6. Storage volume (S2): enter in cu. ft. or cu. m. corresponding to H2 above.

Output data

Hydrograph coordinates of H vs. 2S/Δt.

Running the SΔTH program

Example problem/given data
Height increment= 0.5 ft.
Routing Period = 15 minutes
Height H1 = 1.0 ft
Storage S1 = 20,000 cu. ft. > when H1 = 1.0 ft.
Height H2 = 6.0 ft
Storage S2 = 275,000 cu. ft. > when H2 = 6.0 ft.

Press [SΔTH]. Or type **SΔTH** and press [ENTER].

The display will prompt you with the following:
Ht. INCREMENT=?
(ft. or m.)

Key in: **.5 [ENTER]**

The display will prompt:
TIME INTERVAL
or ROUTING PERIOD=?
(Minutes)

Key in: **15 [ENTER]**

The display will prompt:
HT. (H1) Above
SPILLWAY=?
(ft. or m.)

Key in: **1 [ENTER]**

The display will prompt:
STORAGE VOL. (S1)=?
WHEN HT.=H1
(cu ft or m)

Key in: **20000 [ENTER]**

The display will prompt:
Ht. (H2) Above
SPILLWAY=?
(ft or m)

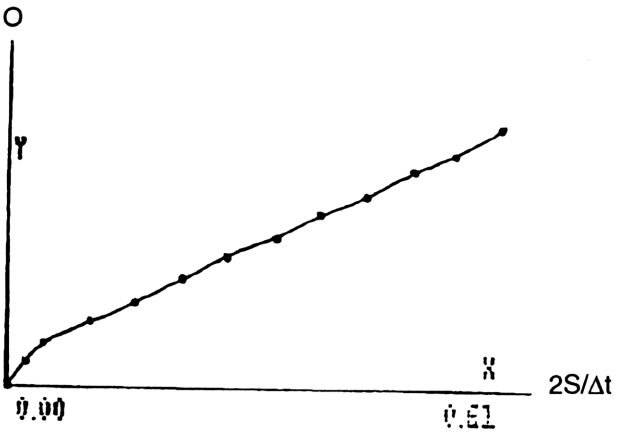
Key in: **6 [ENTER]**

☞
A graph showing a plot of Height (H) vs. Rate of Storage ($2S/\Delta t$) will be momentarily displayed

The display will prompt:
STORAGE VOL.(S2)=?
WHEN HT.=H2
(cu ft or m)

Key in: **275000 [ENTER]**

Output data



☞ If a paper print of the graph is desired, Flag 5 must be set and an IR printer available prior to running the program.

15: "STORAGE Q"
14: "COORD (2S/Δt, H)"
13: (0.00, 0.00)
12: (22.22, 0.50)
11: (44.44, 1.00)
10: (101.11, 1.50)
9: (157.78, 2.00)
8: (214.44, 2.50)
7: (271.11, 3.00)
6: (327.78, 3.50)
5: (384.44, 4.00)
4: (441.11, 4.50)
3: (497.78, 5.00)
2: (554.44, 5.50)
1: (611.11, 6.00)

OTFH

This program generates Hydrograph coordinates for a Weir or Spillway Outflow structure. The coordinates consist of the Height Increment above a Weir or Spillway as the abscissa or X axis, and the Rate of Outflow as the ordinate or Y axis.

Required input data

1. Weir coefficient: 3.33 = sharp; 3 = broad
2. Length (L) of Weir opening: enter in feet or meters
3. Limiting Head (H): enter in feet or meters
4. Head Increment: enter in feet or meters

Output data

1. Momentary graph of Head (H) vs. Outflow (Qo)
2. List of Hydrograph coordinates consisting of H vs. Qo

Example problem/given data
Sharp crested weir with coeff. = 3.33
Length of weir opening = 100 ft.
Maximum or limiting Head above weir = 3 ft.
Head increment = 0.50 ft

Press [OTFH]. Or type **OTFH** and press [ENTER].

The display will prompt you with the following:
WEIR DISCHARGE COEFF:
3.33=SHARP or 3-BROAD
or OTHER COEFF.=?

Key in: **3.33 [ENTER]**

The display will prompt:
LENGTH of WEIR
OPENING=?
(ft or m)

Key in: **100 [ENTER]**

The display will prompt:
MAX. HEAD
Above WEIR=?
(ft or m)

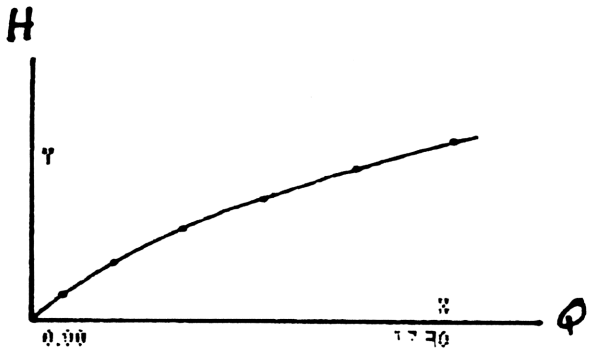
Key in: **3 [ENTER]**

The display will prompt:
HEAD INCREMENT=?
(ft or m)

Key in: .5 [ENTER]

☞
A graph of Outflow (Q) vs. Height (H) will be momentarily displayed.

Output data



9: "COORDINATES"
8: "OUTFLOW (Q, H)"
7: (0.00, 0.00)
6: (117.73, 0.50)
5: (333.00, 1.00)
4: (611.76, 1.50)
3: (941.87, 2.00)
2: (1316.30, 2.50)
1: (1730.32, 3.00)

S.PAR

Flood routing for small drainage basin; the storage parameter method

This program is based on a paper written by Alfred R. Pagan in the *Civil Engineering–ASCE 10/75* entitled "Usefulness of Storage Parameter for Small Drainage Basins."

In that paper, a Storage Parameter Curve was constructed using the usual storage and routing equations based on some known or assumed Flow Hydrograph. The ordinate – or Y axis – of the resulting graph consisted of the ratio of the Peak Outflow over the Peak Inflow (Qo/Qi) in percent; the abscissa – or X axis – was the ratio of Peak Storage in cubic units over the Peak Inflow in cubic units per second (Sp/Qi).

By dimensional analysis, the ratio Sp/Qi will have a resulting dimensional unit in seconds.

Using this program, you can solve for either the ordinate or abscissa. If you key in the ordinate, the program will compute and display the abscissa, and vice versa. Therefore, there is no need to use the graph and interpolate values, as is the case when using Mr. Pagan's method.

Required input data:
Enter either the ordinate or Y value in percent (Qo/Qi), or the abscissa or X value (Sp/Qi) to obtain the other.

The ratio (Qo/Qi) must be in *percent*, and must be entered as a *negative* value.

For example, if you enter Qo/Qi = -55 percent, program will compute and display the following solution:

T = Sp/Qi = 1875 seconds

Please note that the result obtained using this program should not be used as a substitute for a more accurate and definitive solution using the Storage and Routing equations. This program is intended only as a quick check and a time-saving tool for those who make preliminary design or conduct design checks and reviews.

Running the S.PAR program

Example problem # 1:

Given data
1. Peak Inflow (Qi) = 250 cfs
2. Ratio of Peak Outflow (Qo) over Peak Inflow (Qi) is set at 75%:

$$\frac{Qo}{Qi} = .75$$

Find:
1. Peak Storage (Sp)
2. Peak Outflow (Qo)

Solution
Qo = .75
Qi = .75 (250) = 187.50 cfs

Press [S.PAR]. Or type **S.PAR** and press [ENTER].

The display will prompt you with the following:
ENTER Sp/Qi = ? (Time
in Seconds) OR
- (Qo/Qi) = ?(Ratio in %)

☞
You can avoid going through the program's input prompt by entering -75 in the stack, then pressing the [S.PAR] soft key.

Key in: **75 [±] [ENTER]**

Output data

Qo/Qi (%)=: 75.00
T (Sec)= Sp/Qi= : 962.96

Since T=Sp/Qi = 962.96 seconds, and Qi=250 cfs:

Sp = Qi(T)

Sp = 250(962.96) = 240,740.74 cu.ft.

Example problem #2:

It takes 2,354 seconds for a Reservoir to reach its maximum storage capacity of 300,000 cubic ft.

Find:
1. Peak Inflow (Qi)
2. Peak Outflow (Qo) to maintain the maximum storage level.

Solution

Qi can easily be solved by using the following equation:

Sp/Qi = T,
where T = 2,354 seconds and Sp = 300,000 cu. ft.

Qi = Sp/T = 300000/ 2354

Qi = 127.44 cfs

Press [S.PAR]. Or type **S.PAR** and press [ENTER].

The display will prompt you with the following:
ENTER Sp/Qi = ? (Time
in Seconds) OR
- (Qo/Qi) = ?(Ratio in %)

Key in: **2354 [ENTER]**

Output data

T (Sec) = Sp/Qi =: 2354.00
Qo/Qi (%) =: 47.19

Qi can now be solved using the following equation:

Qo/Qi = .4719,
where Qi = 127.44

Qo = .4719(Qi)

Qo = .4719(127.44)

Qo = 60.14 cfs

CHAPTER 14

ERTW

Volume of an all-cut or all-fill section using the average end area method

This earthwork program computes the area and volume of each cross section, given the elevation and offset at each grade break and the station value of the 2 sections. All cross sections must either be all-fill or all-cut sections in order for the computed volume to be valid. Accumulated volume from beginning station to the last station is also computed.

Required input data

1. Starting Station: if metric units are used, the starting station must be entered negative; otherwise, no algebraic sign is needed.
2. Elevation and Offset: if the starting station in #1 was entered negative, the elevation and offset must be entered in meters. Elevation and offset pair defines each corner or grade break of a given cross section. Multiple input data are separated by a space and entered clockwise or counterclockwise around the cross-section figure. Offset data are referenced from a common baseline.
3. Next Station: any number of sections can be entered as long as they are either all-cut or all-fill cross sections. Station values can be entered either in ascending or descending order.

Output data
1. Elevation/offset data
2. Station and area of each cross section
3. Volume in cubic feet or cubic meters
4. Accumulated volume

☞
If there are any more stations to enter after the last accumulated volume has been displayed, press any key to continue.

Running the ERTW program

Example problem
Following are the cross sectional views of 3 cut sections with the corners or angle breaks being defined by elevation and offset values (see Figure 14.1). The common baseline of the 3 sections is as shown in the accompanying figures. All offset values are reckoned from the baseline and all sections are identified by their respective station values.

☞
If you desire a printout of the output display, set Flag 5 before running the program; an infrared printer also must be available.

Given data:
Please refer to Figure 14.1.

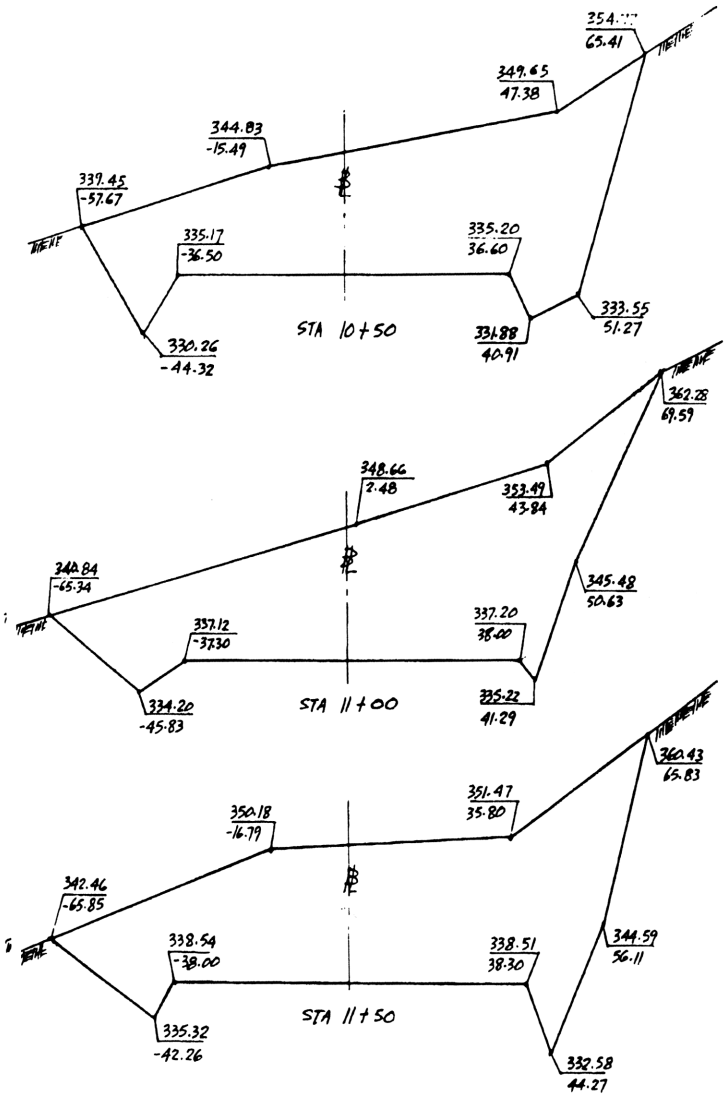
Input data:
1. All offset distances to the left of the common baseline are entered as negative values.
2. Elevations, offsets, and station values are entered in feet.

Press [ERTW]. Or type **ERTW** and press [ENTER].

Enter data as prompted by the display(s).

☞
To quit the program, execute the Routine "QUIT" or press the ON and CLEAR keys.

Figure 14.1: ERTW program



Output data

☞
This data is shown as it actually would be printed by an IR printer.

```
  ELEV/OFFSET DATA:

{ 335.17 -36.5 330.26 -4
4.32 339.45 -57.67 344.8
3 -15.49 349.65 47.38 35
4.77 65.41 333.55 51.27
331.88 40.91 335.2 36.6 }

  STA 10 + 50.00
AREA(X-Sect)=1287.71

  ELEV/OFFSET DATA:

{ 337.12 -37.3 334.2 -45
.83 340.84 -65.34 348.66
 2.48 353.49 43.84 362.2
8 69.59 345.48 50.63 335
.22 41.29 337.2 38 }

  STA 11 + 00.00
AREA(X-Sect)=1286.04

  STA 10 + 50.00
  CU.FT.= 64343.80
  CU.YD.= 2383.10
  STA 11 + 00.00

  ACCUM. VOLUME
  CU.FT.= 64343.80
  CU.YD.= 2383.10

  ELEV/OFFSET DATA:

{ 338.54 -38 335.32 -42.
26 342.46 -65.85 350.18
-16.79 351.47 35.8 360.4
3 65.83 344.59 56.11 332
.58 44.27 338.51 38.3 }

  STA 11 + 50.00
AREA(X-Sect)=1431.88

  STA 11 + 50.00
  CU.FT.= 67948.02
  CU.YD.= 2516.59
  STA 11 + 50.00

  ACCUM. VOLUME
  CU.FT.= 132291.82
  CU.YD.= 4899.70
```

CHAPTER 15

Tc

Programs for computing time of concentration (Tc) used in determining peak runoff

One of the required parameters used to compute Peak Runoff in a given watershed is the Time of Concentration (Tc). Tc is dependent upon the size and shape of the watershed, slope, type of ground cover, rainfall intensity, soil imperviousness, and various other factors that are inherent in a specific site or locality. Therefore, careful judgment must be exercised when dealing with time of concentration problems. The use of charts and nomographs have been the usual procedure; however, there are several formulas (emperical and otherwise) that give more accurate and reliable results.

This chapter included 4 programs. Each is short and easy to use, as all the required input data are identified and prompted during program execution.

TTSF

This program is used to compute Time of Concentration in a Sheet Flow. With sheet flow, Manning's friction factor *n* is somewhat altered, due to the effect of raindrop impact, and because shallow sheet flow usually occurs on plane surfaces. A list of various surfaces and their corresponding Manning's Roughness Coefficients are included below.

Required input data:

1. Manning's Roughness Coefficient (n) - see below.
2. Length of Surface: enter in feet (or -meters); this is the length of the surface where sheet flow occurs.
3. Rainfall Intensity: enter in inches (or -cm). This is the amount of rainfall in a 2-year frequency and 24-hour duration; please refer to NOAA Atlas maps of your state showing Rainfall Intensity contour.
4. Average Slope: enter in percent. This is the mean or average slope of the ground in the entire watershed under consideration.

☞ Enter metric variables as negative values.

Running the TTSF program

Given data:
n = 0.24 (dense grass)
Length of Flow = 285.0 ft.
Rainfall intensity = 2.30 inches
Avg. Ground Slope = 1.17%

Press [TTSF]. Or type **TTSF** and press [ENTER].

Enter data as prompted by the display(s).

Output data

Tt (hrs.): 0.804

List of surface types and corresponding Roughness Coefficients (Manning's n)

Source: SCS TR-55 2nd Ed. June 1986

Smooth surfaces (concrete, asphalt, gravel or base soil)	0.011
Fallow (no residue)	0.050
Cultivated Soils:	
Residue cover equal or less than 20%	0.060
Residue cover greater than 20%	0.170
Grass:	
Short prairie grass	0.150
Dense grasses (bluegrass, buffalo grass, lovegrass, etc)	0.240
Bermuda grass	0.410
Range (natural)	0.130
Woods (brush not over 10' in height):	
Light underbrush	0.400
Dense underbrush	0.800

TCCN

This program is used to compute the Time of Concentration using the SCS Runoff Curve Number Method. The value obtained in this program is used to find Peak Discharge by graphical solution.

☞ See Chapter 12 for CN tables (QSCS program).

Required input data:

1. Weighted Runoff Curve Number (CN) for future condition.
2. Length of Watershed: enter in feet (or -meters).
3. Average watershed land slope: enter in percent. A minimum slope of 0.10 percent will be used if the ground is relatively flat.

☞ Enter metric variables as negative values.

Running the TCCN program

Given data:
Weighted CN = 72
Locality: Hypothetical
Average slope = 0.83%
Length of watershed = 2,870 ft.

Press [TCCN]. Or type **TCCN** and press [ENTER].

Enter data as prompted by the display(s).

Output data

Tc (hrs.): 1.707

TCSM

This program is used to compute the Time of Concentration using the Snyder Method, which features the use of empirical constants. For more information about this method, refer to a handbook entitled *Synthetic Flood Frequency* by Franklin F. Snyder – Proceedings ASCE Vol. 84 No. HYS, October 1958.

Required input data:

1. Correction factor (Cf) - Select a value of 1.7 for rural or 0.42 for a developed watershed. Otherwise, enter 0, and Cf is computed using 2 parameters: the amount of sewered area and the amount of natural channels eliminated.
2. Length of Principal Drainage channel: enter in miles (or -km).
3. Manning's Roughness Coefficient (n)
4. Weighted Slope (Sw): enter in percent. The formula for Sw is:

$$Sw = \frac{(Eu - El)/2}{L/2}(100) = \frac{E4 - El}{L}$$

where:
Eu = elevation at upper end of channel (ft or m)
El = elevation at lower end of channel (ft or m)
L = total length of channel (ft or m)
Sw = weighted slope in percent

☞ Enter metric variables as negative values.

Running the TCSM program

Example problem #1/given data:
Ct = 1.7 (Rural area)
Length of channel = 1.07 miles
Manning's n = 0.025
Weighted slope(Sw) = 0.87%

Output data

Tc (hrs): 0.804

Example problem #2/given data:
The area being considered is neither rural nor fully developed and has the following characteristics:

1. Amount of Area storm sewered = 26%
2. Amount of natural channel eliminated = 15%
3. Length of channel = 2.20 miles
4. Manning's n = 0.045
5. Weighted Slope (Sw) = 1.12%

☞ Enter 0 when prompted for the Cf coefficient.

Press [TCSM]. Or type **TCSM** and press [ENTER].

The display will prompt you with the following:
SELECT COEFF. (Cf)=?
1.7=Rural OR .42=Dev.
ENTER 0 IF OTHERWISE

Key in: **0 [ENTER]**

The display will prompt:
% of AREA
STORM SEWERED=?

Key in: **26 [ENTER]**

The display will prompt:
% of NATURAL
CHANNEL ELIMINATED=?

Key in: **15 [ENTER]**

The display will prompt:
Channel Length=?
(mi. or -km.)

Key in: **2.2 [ENTER]**

The display will prompt:
Manning's (n)=?

Key in: **.045 [ENTER]**

The display will prompt:
(Weighted) SLOPE=? (%)

Key in: **1.12 [ENTER]**

Output data

Tc (hrs): 1.381

TCKW

This program is used to compute the Time of Concentration of overland flow using the Kinematic Wave formula. This program can be used in lieu of the Nomograph method.

Required input data:

1. Rainfall intensity: enter in inches (or -cm) per hour. Rainfall intensity can be obtained using graphs with duration and storm frequency as arguments. These graphs can be found in most handbook dealing with hydrology.
2. Length of Strip: enter in feet (or -meters). This parameter is the length of ground surface where overland flow occurs.
3. Manning's Roughness Coefficient (n): a list of surface types and their corresponding Manning's n can be found below.
4. Slope of the strip: enter in percent.

☞ Enter metric variables as negative values.

Running the TCKW program

Given data:
Rainfall intensity = 2.2 inches per hr.
Length of strip = 465 feet
Manning's n = 0.24 (dense blue grass)
Slope of the strip = 0.88%

Press [TCKW]. Or type **TCKW** and press [ENTER].

Enter data as prompted by the display(s).

Output data

Tc (min.): 47.51

Average values of Manning's Roughness Coefficients used in Kinematic Wave Formula, to find the Time of Concentration in overland flow

Source: VDOT Drainage Manual 1986

Type of Surface	Manning's n
Dense Growth	0.4 - 0.5
Pasture	0.3 - 0.4
Lawns	0.2 - 0.3
Bluegrass Sod	0.2 - 0.5
Short Grass Prairie	0.1 - 0.2
Sparse Vegetation	0.05 - 0.13
Bare Clay - Loam Soil (eroded)	0.01 - 0.03
Concrete/Asphalt - very shallow	
Depths < 1/4 inch	0.10 - 0.15
Small Depths (1/4 to several inches)	0.05 - 0.10

CHAPTER 16

SPRL.

Spiral curve stakeout

This program is used for staking out a standard highway spiral, using both the Tangent-offset and Angle-distance Methods. The output for both methods are displayed so that if a sight obstruction is encountered in one, the other can still be used. The program also computes stakeout data for a "parallel" spiral left and right of the centerline. This feature is useful when staking out structures and utilities. A companion program called **SPL.3** is included, for automatically staking out points on successive stations.

Field setup requires the instrument to occupy the point of change from tangent to spiral (Ts) and the backsight point set to the P.I. of the 2 tangents. Therefore, points along the centerline and those left and right of the centerline are staked out using the tangent as reference line, with the 0+00 station as the occupied point at the Ts.

The program prompts for station values along the centerline, with 0+00 station set at the Ts. If you are using the station-offset stakeout data, the station values in the output display are stations along the tangent and not along the centerline itself, although both have a common 0+00 station at the Ts.

Required input data:

1. Spiral Angle (0s): enter in degrees.minutes seconds format (dd.mmss).
2. Total length of Spiral (Ls): enter in feet or meters
3. Left and Right offsets (if desired): enter in feet or meters. Enter zero (0) if there are no offsets.
4. Spiral centerline station: as prompted, enter the station that you want to stake, including the points left and right of the centerline.

☞
Use the **SPL.3** program to find stakeout data of successive stations. Required input data are the starting and ending stations, then the station interval.

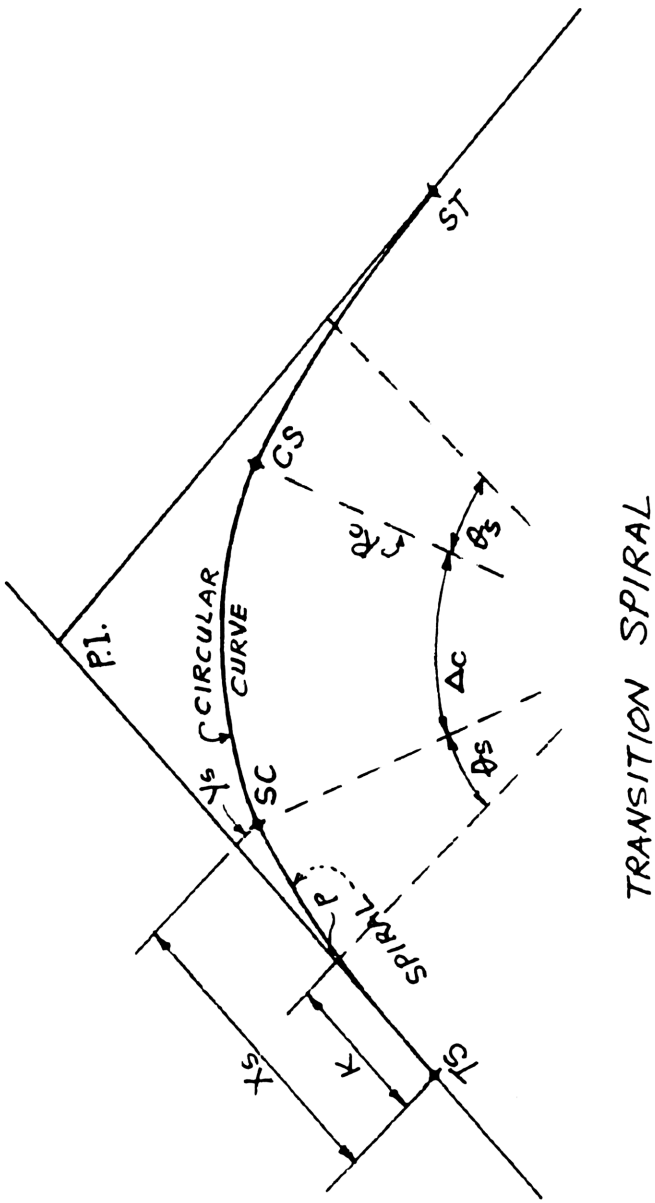
Field setup

The instrument occupies the point of Tangency (Ts) with a reference station = 0+00. Backsight point (BS) is the point of Intersection (P.I.) of the 2 tangents. Points on the centerline and left and right of the spiral can be staked out in 2 ways:

1. By station and offset, with station 0+00 as the point occupied (also the Ts point) and station values increasing towards the P.I. Negative offset values indicate points to the left of the Tangent; positive offset values indicate points to the right.
2. By Direct angle and Distance ties - the point occupied is the Ts and the backsight point is the P.I. All angles are clockwise, with the P.I. at zero reference.

Both methods are shown on the output screen display so that either method can be used interchangeably if you encounter any sight obstruction while using one or the other.

Figure 16.1: SPRL. program



Running the SPRL. program

Example problem/given data:
Spiral Angle (0s) = 20°
Left offset = 10 ft.
Spiral Length (Ls) = 600 ft.
Right offset = 15 ft.

Press [SPRL.]. Or type **SPRL.** and press [ENTER].

Enter data as prompted by the display(s).

After the above data are entered, the program will prompt with the following:
SPIRAL C.L. STA. = ?
(ft or m)

At this point, you may enter any station ranging from 0 to 600. For this example, we'll enter **37.55**.

Note that the C.L. STA being prompted above refers to the stations along the centerline of the spiral itself, as opposed to the output display in which the station values are along the tangent. In other words, stations along the tangent and its respective offset distance will set the point using the centerline stations as input.

The next screen(s) display:
SPRL. ∠ = 20° 00' 00"
SPRL (Ls) = 600.00
RADIUS (Rc) = 859.44
Left o/s = 10.00
Right o/s = 15.00
Press a KEY to CONT.

Xs = 592.73
O/S (Ys) = 69.21
O/S (P) = 17.38
K = 298.79
Press a KEY to CONT.

STA. 0 + 37.55
C.L. O/S = 0.02
∠ RT. = 00° 01' 34"
DIST. = 37.55
Press a KEY to CONT.

☞
Station values shown are along the Tangent with 0+00 at the Ts or the point occupied.

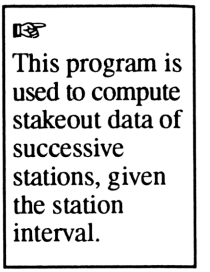
(Ts) is at Sta 0 + 00
LEFT STA 0 + 37.56
LEFT O/S = -9.98
∠ RT. = 345° 07' 02"
DIST.= 38.87
Press a KEY to CONT.

RT STA 0 + 37.53
RT O/S = 15.02
∠ RT.= 21° 48' 30"
DIST. = 40.42
Press a KEY to CONT.

Next Spiral
C.L STA. = ?
(ft or m)

Key in another station, or press [ON] to exit.

Running the SPL.3 program


This program is used to compute stakeout data of successive stations, given the station interval.

Example problem/given data:
Spiral Angle (0s) = 20°
Left o/s = 10 ft.
Spiral Length (Ls) = 600 ft
Right o/s = 20 ft.
Beginning Sta. = 0 + 00
Ending Sta. = 2 + 00
Station Interval = 50

Press [SPL.3]. Or type **SPL.3** and press [ENTER].

Enter data as prompted by the display(s).

Output data

The following are output screen displays:

STA 0 + 00.00
C.L. O/S = 0.00
∠ RT. = 00° 00' 00"
DIST. = 0.00
Press a KEY to CONT.

Left STA 0 + 00.00
Left O/S = -10.00
∠ RT. = 270° 00' 00"
DIST. = 10.00
Press a KEY to CONT.

RT STA 0 + 00.00
RT O/S = 20.00
∠ RT. = 90° 00' 00"
DIST. = 20.00
Press a KEY to CONT.

STA 0 + 50.00
C.L. O/S = 0.04
∠ RT. = 00° 02' 47"
DIST. = 50.00
Press a KEY to CONT.

Left STA 0 + 50.02
Left O/S = -9.96
∠ RT. = 348° 44' 24"
DIST. = 51.01
Press a KEY to CONT.

RT STA 0 + 49.95
RT O/S = 20.04
∠ RT. = 21° 51' 38"
DIST. = 53.82
Press a KEY to CONT.

STA 0 + 99.9991
C.L. O/S = 0.32
∠ RT. = 00°11' 07"
DIST. = 100.00
Press a KEY to CONT.

LEFT STA 1 + 00.10
LEFT O/S = -9.68
∠ RT. = 354° 28' 42"
DIST. = 100.56
Press a KEY to CONT.

LEFT STA 1 + 00.10
LEFT O/S = -9.68
∠ RT. = 354° 28' 42"
DIST. = 100.56
Press a KEY to CONT.

RT STA 0 + 99.81
RT O/S = 20.32
∠ RT. = 11° 30' 33"
DIST. = 101.85
Press a KEY to CONT.

STA 1 + 49.99
C.L. O/S = 1.09
∠ RT. = 00° 25' 00"
DIST. = 150.00
Press a KEY to CONT.

LEFT STA 1 + 50.21
LEFT O/S = -8.91
∠ RT. = 356° 36'24"
DIST. = 150.47
Press a KEY to CONT.

RT STA 1 + 49.56
RT O/S = 21.09
∠ RT. = 08° 01'31"
DIST. = 151.04
Press a KEY to CONT.

The program will automatically stop upon reaching the specified ending station.

☞
If you desire a print of this output display and have a compatible IR printer, set Flag 5 prior to running the program.

CHAPTER 17

VCURVE

Vertical curve solutions: solving for missing parameters for a constrained vertical curve

XOEQ

This program is used to solve for any parameter of a Vertical Curve that involves using as input data the location (Xo) and/or elevation (Yo) of the high or low point. The other 4 parameters are: Starting Grade (G1), Ending Grade (G2), Length of Vertical Curve (L), and PVC Elevation (Ec).

Required input data:

1. G1 = Beginning grade
2. G2 = Ending grade
3. Xo = Location of the high or low point with respect to the point of beginning of the vertical curve (PVC). It is also the horizontal distance between that point and the PVC.
4. Yo = Elevation of the high or low point
5. Ec = Elevation of the PVC
6. L = Length of Vertical Curve

☞
The program prompts you to choose which parameter you want to solve; you are then prompted to enter the required data.

Output data:
Results are tagged and displayed in the stack.

Running the XOEQ program

Example problem #1/given data:

1. Horizontal distance between the PVC and the high or low point: Xo = 142.3448
2. Starting grade in percent: G1 = 2.58%
3. Ending grade in percent: G2 = -4.67%

Find: the length of a vertical curve (L).

Press [XOEQ]. Enter data as prompted.

Output data

L = 400.00

Example problem #2/given data:

1. G1 = 2.58%
2. G2 = -4.67%
3. L = 400.00
4. PVC Elev. (Ec) = 335.00

Find: the elevation of the high point of a vertical curve.

Output data

Xo = 142.3448
Yo = 336.8362

Example problem #3/given data:

1. Xo = 142.3448
2. G2 = -4.67%
3. L = 400.00

Find: the starting Grade (G1).

Output data

G2 = -4.67%

Example problem #4/given data:

G1 = 2.58% G2 = -4.67%
L = 400.00 Ec = 335.00

Find: the location of the high point (Xo).
Xo = Horizontal distance between the PVC and the high point.

Output data

Xo = 142.3448
Yo = 336.8362

Example problem #5/given data:

Xo = 142.3448 Yo = 336.8362 G1 = 2.58%

Find: the elevation at the PVC

Output data

Ec = 335.00

VCSN

This program is used to solve an unknown parameter when a certain point in the Vertical Curve is held. This is similar to the **XOEQ** program except that the high or low point location and elevation are not part of the input data.

Required input data:

1. Xp = Horizontal location of any point with respect to the PVC.
2. Yp = Elevation of point (at Xp).
3. G1 = Beginning grade (negative if sloping from a higher to lower elevation).
4. G2 = Ending grade (negative if sloping from higher to lower elevation).
5. L = Length of the Vertical Curve
6. Ec = Elevation of the PVC.

Output data:
Results are tagged and displayed in the stack.

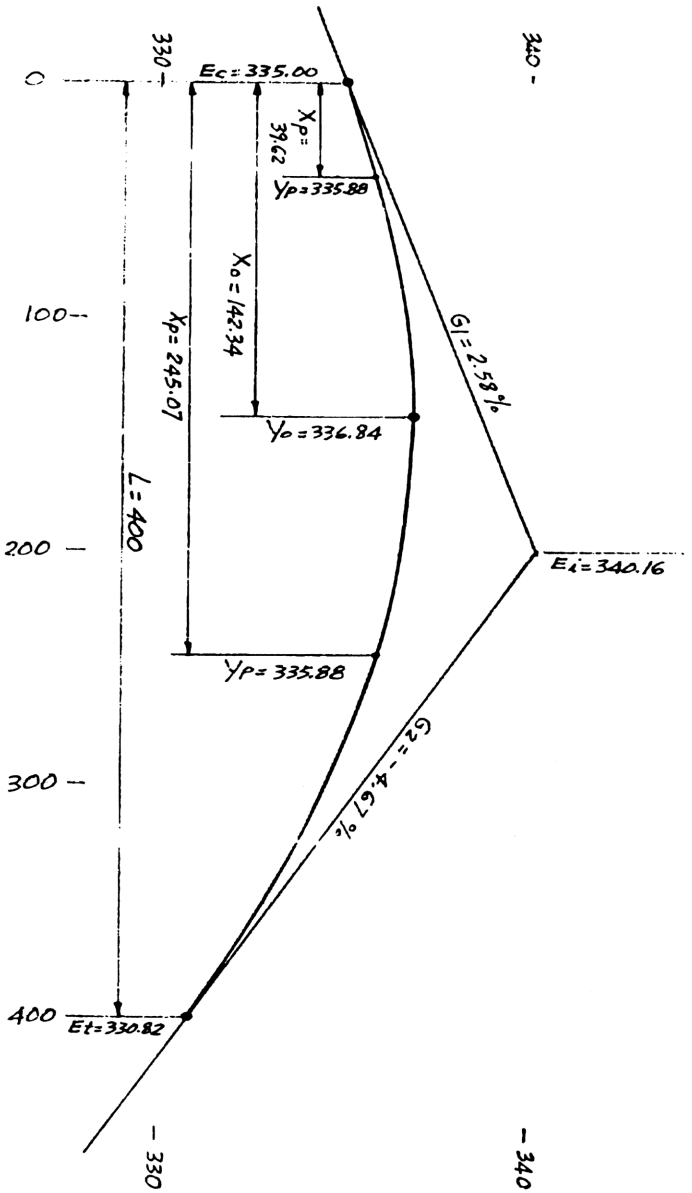
Running the VCSN program

Press [VCSN]. Enter data as prompted by the display(s).

Example problem #1/given data:
Starting Grade (G1) = 2.58%
Ending Grade (G2) = -4.67%
Length of V.C. = 400.00
Elevation at PVC (Ec)= 335.00

Find: the location of a point (Xp); its elevation in the V.C. is 335.88.

Figure 17.1: VCSN program



Output data

(Output as displayed in the stack; explanations are added)

12 Xp: 39.62	1st location
11 Xp: 245.07	2nd location
10 Yp: 335.88	Elev. of any point
9 G1 (%): 2.58	Starting Grade
8 G2 (%): -4.67%	Ending Grade
7 L: 400.00	Length of V.C.
6 Ec: 335.00	PVC Elevation
5 Ei: 340.16	PVI Elevation
4 Et: 330.82	PVT Elevation
3 Xo: 142.34	Location of high point
2 Yo: 336.84	Elevation of high point
1 Xp: 245.07	2nd location

Except for the highest point, any other point on the vertical curve can always occur in 2 places. In this example problem, elevation 335.88 is located 39.62 ft. and 245.07 ft. from the PVC.



Note that the location and elevation of the high or low point is included in the output display

Example problem #2/given data:
Horizontal distance of a point fr. PVC (Xp) = 39.62
Elevation of the given Point (Yp) = 335.88
Starting Grade (G1) = 2.58%
Ending Grade (G2) = -4.67%
PVC Elevation (Ec) = 335.00

Find: the length of the vertical curve (L).

Output data

11 Xp: 39.62	Dist from PVC of a point
10 Yp: 335.88	Elevation of any point
9 G1 (%): 2.58	Starting grade
8 G2 (%): -4.67	Ending grade
7 L: 400.00	Length of V.C.
6 Ec: 335.00	PVC elevation
5 Ei: 340.16	PVI elevation
4 Et: 330.82	PVT elevation
3 Xo: 142.41*	Location of high point
2 Yo: 336.84	Elevation of high point
1 L: 400.00	Length of V.C.

* Xo should equal 142.34 (as in problem #1). The discrepancy is due to the rounding off of the horizontal distance Xp = 39.62. If Xp were carried to 5 decimal places (Xp = 39.62333), Xo would have a value of 142.34, rather than 142.41 as shown above.

CHAPTER 18

TNGL

Triangle solutions

This program will solve any of 5 triangle configurations shown below when 3 of the 6 parameters are known.

3 known interior angles may not be used in this formula.

S and A denote the known sides or angles, respectively:

1. SSS: 3 sides, entered in any order.
2. AAS: 2 angles and 1 side opposite either angle. Input must be in the form →A A→S; the arrow means that the first given angle and the given side are directly opposite each other.
3. SAS: 2 sides and 1 angle opposite an unknown third side.
4. SSA: 2 sides and 1 angle opposite either side. Input must be in the form →S S→A; the arrow means that the first given side and the given angle are directly opposite each other.
5. ASA: 2 angles and 1 side opposite an unknown third angle.

Required input data:
Except for the use of 3 angles, any combination of angles and sides are valid.

Output data:
Output data are listed in the stack and labeled as follows:

1. a, b, & c are the sides arranged in numerical order.
2. A, B, & C are the interior angles directly opposite sides a, b, & c, respectively.
3. Area of the triangle.

Running the TNGL program

Press the [TNGL] soft key.
Or type **TNGL** on the command line and press [ENTER].

The program will show the following display:

```
Select No.    (1) = SSS
              (2) = AAS
              (3) = SAS
              (4) = SSA
              (5) = ASA
```

Enter the appropriate code number that corresponds to the given 3-parameter combination of angles and sides you wish to use.

The display will next show an input prompt of angles and sides, corresponding to the code you entered, above.

Enter the values of the 3 known parameters in the same sequence as shown by the input prompt.

The arrow symbol before angles (→A) and sides (→S) indicates that they are directly opposite each other.

For example, if you entered code 2 (to solve for AAS), display would prompt you to enter the following data:

→A=? A=? →S=?

Enter the values of the 3 known parameters, separated by a space (the [SPC] key) and press [ENTER].

The display will show the results.

We'll try a few examples.

Example problem #1/given data:
S1 = 125.69
S2 = 233.27
S3 = 205.44

When 3 sides of a triangle are known, they can be entered in any order.

Press [TNGL]. When prompted for a code, key in **1** and press [ENTER].

The display will then prompt:
S1=? S2=? S3=?

Key in: **125.69 [SPC] 233.27 [SPC] 205.44 [ENTER]**

The output displays are automatically arranged in numerical order (as shown below).

Output data

7	a	:	125.6900
6	A	:	32° 30' 52.73"
5	b	:	205.4400
4	B	:	61° 28' 12.05"
3	c	:	233.2700
2	C	:	86° 00' 55.22"
1	AREA:		12879.6672

Example problem #2/given data:
2 angles and 1 side opposite the first angle are known –
Angle 1 = 36°29'55"
Angle 2 = 41°33'14"
S1 = 176.38

Angle 1 is directly opposite S1.

Press [TRNG]. When prompted to select a solution type, key in **2** and press [ENTER].

The display will prompt:
→A=? A=? →S=?

Key in: **36.2955 [SPC] 41.3314 [SPC] 176.38 [ENTER]**

Output data

7	a	:	176.3800
6	A	:	36° 29' 55.00
5	b	:	196.6988
4	B	:	41° 33' 14.00
3	c	:	290.1114
2	C	:	101° 56' 51.00
1	AREA:		16971.0974

User Notes

CHAPTER 19

AREA

Programs for computing areas

ARAD

This program computes the area of a closed figure whose corners are defined by a series of horizontal angles and distances. Depending on the accuracy requirement, a transit-stadia or Theodolite-EDM combination maybe used to read field angles and distances. This program could be useful in obtaining the area of an irregular figure such as a pond, an open pit mine, or a contaminated area.

Fieldwork consists of selecting a random and arbitrary Backsight, then taking horizontal angle and distance readings around the figure's perimeter.

Required input data:
Any number of horizontal angle distance pairs defining the outline of a closed figure. These pairs are entered continously, separated by a space. The [ENTER] key is pressed after the last input data is entered.

Output data:
Area in square feet or meters, depending on which unit was used for distance.

Running the ARAD program

Example problem:
The following are the field notes gathered by a survey crew to find the area of an existing Water Detention Pond.

No.	Horizontal Angles	Stadia Dist (ft.)
1	10° 25'	101.33
2	28° 30'	145.69
3	48° 18'	148.98
4	55° 46'	267.25
5	71° 33'	251.37
6	82° 44'	187.44
7	95° 36'	128.75
8	45° 27'	31.88

☞ The backsight point is arbitrarily selected.

Find: Area of the pond.

Press [ARAD]. Or type **ARAD** and press [ENTER].

The display will prompt you with the following:
AREA By ANGLE & DIST:
ANGLE=? DIST.=?
(Repeat for ea. pt.)

Key in: **10.25 {SPC] 101.33 [SPC] 28.30 [SPC] 145.69 [SPC] 48.18 [SPC] 148.98 [SPC] 55.46 [SPC] 267.25 [SPC] 71.33 [SPC] 251.37 [SPC] 82.44 [SPC] 187.44 [SPC] 95.36 [SPC] 128.75 [SPC] 45.27 [SPC] 31.88 [ENTER]**

Output data

Area = 22,421.69 sq. ft.

ACXS

This program computes an Area using Coordinates (Northing and Easting) or Elevation and offset data. It is applicable to any closed figure whose corners or angle breaks are defined by coordinates. It can also be applied to any cross section (Vertical or Otherwise) whose corners or grade breaks are defined by Elevation and Offset. Some examples of Vertical Cross Section include a Roadway Cut or Fill and underground Tunnel Cuts.

Required input data:
Any number of north and east coordinates or elevation and offset pairs. The entry of these pairs can run either clockwise or counterclockwise.

Output data:
Area in square units, depending on the units used in the coordinates or elevation/offset data.

Running the ACXS program

Example problem:
Find the area of a piece of land, given the coordinates of its corners.

No.	North (ft)	East (ft)
1	5000	7000
2	5077	7066
3	5173	7070
4	4987	7255
5	5043	7052
6	4964	7117

Press [ACXS]. Or type **ACXS** and press [ENTER].

The display will prompt you to enter northings and eastings for each point. Key in data consecutively and separate each entry with a space.

Press [ENTER] to end data entry.



Coordinates or elevation/offset data may be entered either clockwise or counterclockwise around a figure.

Output data

Area = 17,129.50 sq. ft.

CHAPTER 20

RESECT

3-point resection

RSCC

This program computes the plane coordinates of a point occupied by the observer, by measuring 2 horizontal angles between 3 known and visible control points. It also computes all the sides and interior angles of the resulting quadrilateral.

Required input data:

1. N1 = Northing of the first point
2. E1 = Easting of the first point
3. N2 = Northing of the 2nd point
4. E2 = Easting of the 2nd point
5. N3 = Northing of the 3rd point
6. E3 = Easting of the 3rd point
7. ∠1 = Measured horizontal angle between the first or extreme left point and the 2nd or middle point in dd.mmss format
8. ∠ 2 = Measured horizontal angle between the middle point and the 3rd or extreme right point in dd.mmss format.

☞ Measured horizontal angles are entered in dd.mmss format. For example, 23°15' 08 is entered as 23.1508

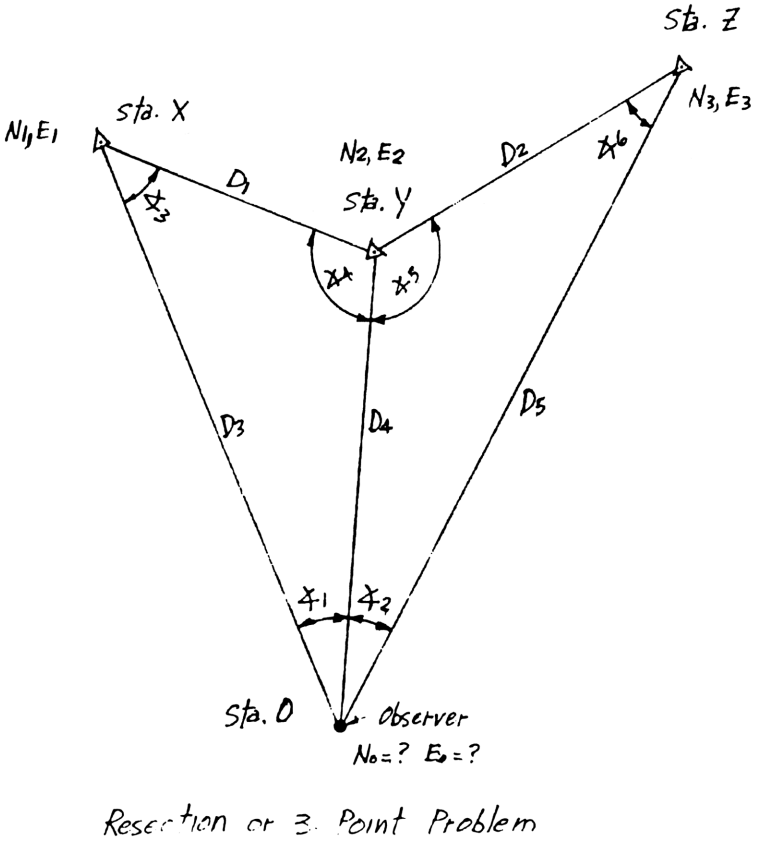
Output data:

All sides and interior angles as shown in Figure 20.1.

Figure 20.1: RSCC program

Example problem: coordinates of stations X, Y, and Z are known. ∠1 and ∠2 are measured horizontal angles at station 0.

Find: all labeled angles and distances as shown in the figure below:



Resection or 3 Point Problem

Running the RSCC program

Given data:

N1 = 5304.9746	E1 = 6833.9276
N2 = 5303.5927	E2 = 6968.3307
N3 = 5352.2889	E3 = 7201.1888
∠1 = 22°36' 54"	∠2 = 35° 41' 08"

Press [RSCC]. Or type **RSCC** and press [ENTER].

The display will prompt you with the following:

N1 =? E1 =? N2 =? E2 =?
N3 =? E3 =? ∠1 =? ∠2 =?

Key in: **5304.974 [SPC] 6833.9276 [SPC] 5303.5927 [SPC] 6968.3307 [SPC] 5352.2889 [SPC] 7201.1888 [SPC] 22.3654 [SPC] 35.4108 [ENTER]**

Output data

19 N1: 5304.9746
18 E1: 6833.9276
17 N2: 5303.5927
16 E2: 6968.3307
15 N3: 5352.2889
14 E3: 7201.1888
13 ∠1: 22.3654
12 ∠2: 35.4108
11 ∠3: 60.5026
10 ∠4: 96.3240
9 ∠5: 95.5123
8 ∠6: 48.2729
7 D1: 134.4102
6 D2: 237.8954
5 D3: 347.2601
4 D4: 305.2400
3 D5: 405.6900
2 No: 5000.0000
1 Eo: 7000.0001

☞
Units for coordinates and distance may be either English or metric.

BLTI

Finding the plane coordinates of 2 occupied stations by observing 2 known stations

This program computes the plane coordinates of 2 points randomly occupied by the observer from which a total of 4 horizontal angles are measured. When these 4 angles and the coordinates of the 2 control points are given, all the labeled interior angles and the labeled sides will be computed. For purposes of illustration and identification of various parameters used in this program, refer to the attached sketch (Figure 20.2).

This program differs from that of a 3-Point Resection, in that only 2 points are observed instead of 3. This could well happen in many instances when only 2 control points can be located in the field. Field setup consist of selecting 2 random points from which 2 horizontal angles are measured at each point.

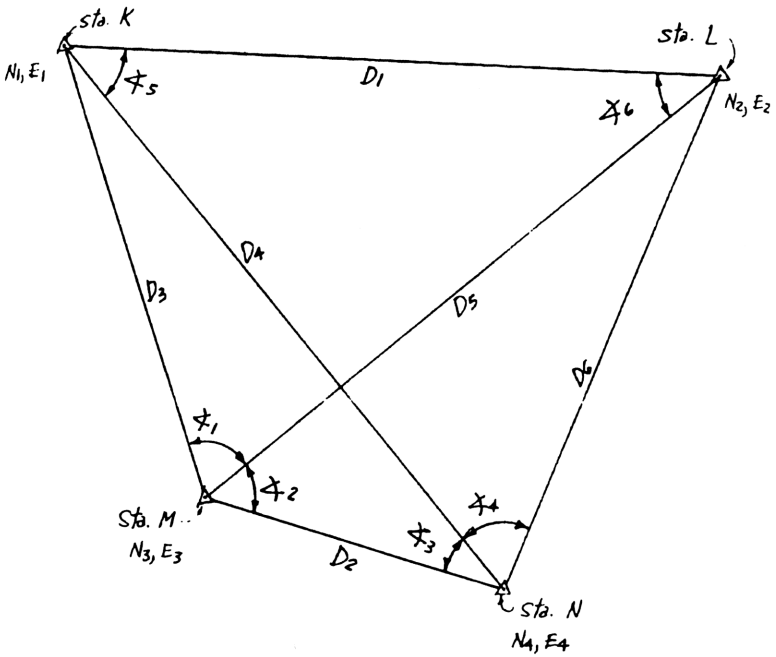
Required input data:

1. N1 = Northing of the first point
2. E1 = Easting of the first point
3. N2 = Northing of the 2nd point
4. E2 = Easting of the 2nd point
5. $\angle 1$, $\angle 2$, $\angle 3$, and $\angle 4$ = measured horizontal angles in degrees.minutes/seconds (dd.mmss) format.

Figure 20.2: BLTI program

Example problem: coordinates of stations K and L are known. ∠1 and ∠2 are measured horizontal angles at station M. ∠3 and ∠4 are measured horizontal angles from station N.

Find:
1) coordinates of stations M and N; and
2) all labeled angles and distances as shown in the figure below:



Running the BLTI program

Example problem/given data:
(Refer to Figure 20.2 for details)
N1 = 5000
E1 = 7000
N2 = 4736
E2 = 9033
∠1 = 79°14'02"
∠2 = 69°04'36"
∠3 = 18°15'56"
∠4 = 63°24'40"

Press [BLTI]. Or type **BLTI** and press [ENTER].

The display will prompt you with the following:
N1? E1? N2? E2?
∠1? ∠2? ∠3? ∠4?

Key in: **5000 [SPC] 7000 [SPC] 4736 [SPC] 9033 [SPC] 79.1402 [SPC] 69.0436 [SPC] 18.1556 [SPC] 63.2440 [ENTER]**

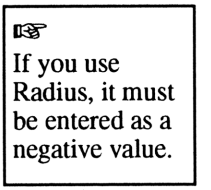
Output data

22 N1: 5000.000000
21 E1: 7000.000000
20 N2: 4736.000000
19 E2: 9033.000000
18: AZ1: 97.235595
17 D1: 2050.069511
16 ∠1: 79.140200
15 ∠2: 69.043600
14 ∠3: 18.155600
13 ∠4: 63.244000
12 ∠5: 50.323965
11 ∠6: 36.475235
10 D3: 1249.981432
9 D4: 2095.049597
8 D5: 1875.097393
7 D6: 1770.096385
6 AZ2: 129.403960
5 D2: 925.869494
4 N3: 3815.536143
3 E3: 7399.373200
2 N4: 3224.398234
1 E4: 8111.967257

CHCP

Constrained horizontal curve

This program computes the elements of a circular curve when it is forced to pass through a given point. The location of the point is given by an offset distance from either tangent and its distance from the intersection of the two tangents (P.I.). Either the Radius or the Interior Angle at the P.I. must be known.



Required input data:

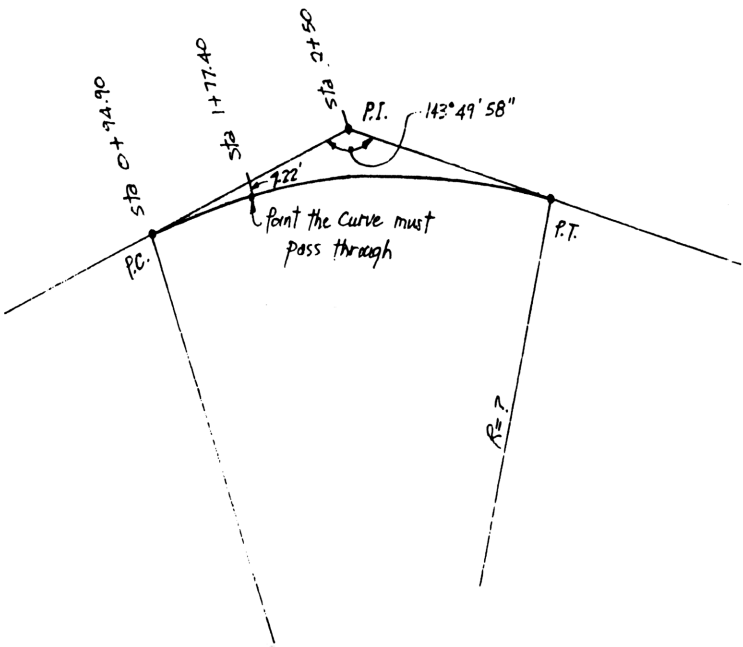
1. P.I. Station: station values are entered as a decimal number. For example, station 12 + 25.24 is entered as 1225.24.
2. Station of Point: same reference station as the P.I. Station.
3. Offset Distance of the Point from either Tangent.
4. Radius of Curve (enter as negative value) or Interior angle at the P.I. (enter in dd.mmss format). If the Radius is given, the program will solve for the P.I. angle and vice versa.

Output data:
Elements of the curve are tagged and displayed in the stack.

Figure 20.3: CHCP program

Example problem: a point is located by station and offset as shown in the figure below. The 2 tangents form a P.I. angle of 143°49'58".

Find: radius and other curve data so that the arc of the curve will pass through the given point.



Running the CHCP program

Example problem/given data:
(Refer to Figure 20.3, above)
P.I. Station = 2 + 50.00
Station of Point = 1 + 77.40
Offset distance of Point from Tangent = 7.22 ft.
Angle at P.I. = 143° 49' 58"

Find:
1. Radius of the curve that will pass through the given point.
2. All other curve parameters.

Press [CHCP]. Or type **CHCP** and press [ENTER].

The display will prompt you with the following:
HOR. CURVE PASSING
THRU A POINT
P.I. STA.=?

Key in: **250 [ENTER]**

The display will prompt:
STA. of POINT=?

Key in: **177.40 [ENTER]**

The display will prompt:
O/S DIST. OF PT.=?
(fr. either Tangent)

Key in: **7.22 [ENTER]**

The display will prompt:
-RADIUS=? (Neg.)
OR
ANGLE @P.I.=? (d.ms)

Key in: **143.4958 [ENTER]**

Output data

CHORD:	294.8848
TAN:	155.1038
DEG. C:	12.0344
ARC:	299.8382
DELTA:	36.1002
RADIUS:	475.0009
∠ @ P.I.:	143.4958

CURV.

This program is used to solve all the elements of a Circular Curve when any 2 of the 8 parameters are known. For example, if the Tangent and Middle Ordinate are given, the program will solve for the Radius, Delta, Arc, Chord, External, Degree of Curve, plus the areas of the sector, segment, and fillet.

Any 2-parameter combination except the Radius and Degree of Curve can be used as input. If a Degree of Curve by Chord definition is desired, Flag 8 must be set prior to running the program; otherwise, the program will always assume a degree of curve by Arc definition. The 2 values of the 2 known parameters must be mathematically consistent; otherwise, the program will not execute.

Required input data/format:
Any 2-parameter combination except the Radius and Degree of Curve can be valid input.

Enter data using one alpha character (representing the first letter of the name of the variable), a space, then the given value.

For example, if the Tangent (T) = 256.38 and Middle Ordinate (M) = 53.69, the correct input format is:

T [SPC] 256.38 [SPC] M [SPC] 53.69 [ENTER]

8 input parameters:

R	Radius
D	Delta
A	Arc
C	Chord
T	Tangent
E	External
M	Middle Ordinate
G	Degree of Curve

Output data:
Output data are displayed in the stack to include all the given and computed parameters plus the areas of the sector, segment, and fillet.

Example problem/given data:
Tangent (T) = 182.715644
Chord (C) = 357.270197

Find: all curve parameters.

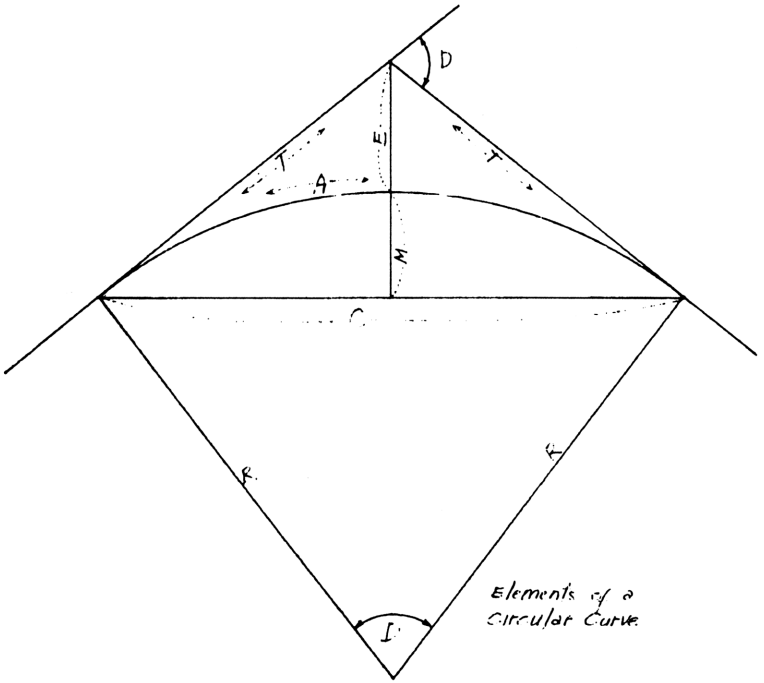
Press [CURV.]. Or type **CURV.** and press [ENTER].

The display will prompt you with the following:
R D A C T E M G
SELECT ANY 2 ABOVE &
THEIR GIVEN VALUES

Key in: **T [SPC] 182.715644 [SPC] C [SPC] 357.270197 [ENTER]**

☞
Wait several seconds for the results to appear.

Figure 20.4: CURV. program



Elements of a circular curve

Output data

FIL:	2327.9343	Area of Fillet
SEG:	4531.5329	Area of Segment
SEC:	152980.3677	Area of Sector
M.O.:	18.9829	Middle Ordinate
EXT:	19.4165	External
DEG:	6.4426	Degree of Curve
CHORD:	357.2702	
TAN:	182.7156	
ARC:	359.9538	
DELTA:	24.1548	
RADIUS:	850.0000	

APPENDIX a

n

Manning roughness coefficients

	Manning's *n* range [1]
I. Closed conduits:	
A. Concrete pipe	0.011–0.013
B. Corrugated-metal pipe or pipe-arch:	
1. 2⅔ by ½-in. corrugation (riveted pipe): [2]	
a. Plain or fully coated	0.024
b. Paved invert (range values are for 25 and 50 percent of circumference paved):	
(1) Flow full depth	0.021–0.018
(2) Flow 0.8 depth	0.021–0.016
(3) Flow 0.6 depth	0.019–0.013
2. 6 by 2-in. corrugation (field bolted)	0.03
C. Vitrified clay pipe	0.012–0.014
D. Cast-iron pipe, uncoated	0.013
E. Steel pipe	0.009–0.011
F. Brick	0.014–0.017
G. Monolithic concrete:	
1. Wood forms, rough	0.015–0.017
2. Wood forms, smooth	0.012–0.014
3. Steel forms	0.012–0.013
H. Cemented rubble masonry walls:	
1. Concrete floor and top	0.017–0.022
2. Natural floor	0.019–0.025
I. Laminated treated wood	0.015–0.017
J. Vitrified clay liner plates	0.015
II. Open channels, lined [4] (straight alinement): [5]	
A. Concrete, with surfaces as indicated:	
1. Formed, no finish	0.013–0.017
2. Trowel finish	0.012–0.014
3. Float finish	0.013–0.015
4. Float finish, some gravel on bottom	0.015–0.017
5. Gunite, good section	0.016–0.019
6. Gunite, wavy section	0.018–0.022
B. Concrete, bottom float finished, sides as indicated:	
1. Dressed stone in mortar	0.015–0.017
2. Random stone in mortar	0.017–0.020
3. Cement rubble masonry	0.020–0.025
4. Cement rubble masonry, plastered	0.016–0.020
5. Dry rubble (riprap)	0.020–0.030
C. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017–0.020
2. Random stone in mortar	0.020–0.023
3. Dry rubble (riprap)	0.023–0.033
D. Brick	0.014–0.017
E. Asphalt:	
1. Smooth	0.013
2. Rough	0.016
F. Wood, planed, clean	0.011–0.013
G. Concrete-lined excavated rock:	
1. Good section	0.017–0.020
2. Irregular section	0.022–0.027

III. Open channels, excavated [4] (straight alinement,[5] natural lining):	
A. Earth, uniform section:	
1. Clean, recently completed	0.016–0.018
2. Clean, after weathering	0.018–0.020
3. With short grass, few weeds	0.022–0.027
4. In gravelly soil, uniform section, clean	0.022–0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022–0.025
2. Grass, some weeds	0.025–0.030
3. Dense weeds or aquatic plants in deep channels	0.030–0.035
4. Sides clean, gravel bottom	0.025–0.030
5. Sides clean, cobble bottom	0.030–0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028–0.033
2. Light brush on banks	0.035–0.050
D. Rock:	
1. Based on design section	0.035
2. Based on actual mean section:	
a. Smooth and uniform	0.035–0.040
b. Jagged and irregular	0.040–0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08–0.12
2. Clean bottom, brush on sides	0.05–0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07–0.11
4. Dense brush, high stage	0.10–0.14

IV. Highway channels and swales with maintained vegetation [6] (values shown are for velocities of 2 and 6 f.p.s.):	Manning's *n* range [1]
A. Depth of flow up to 0.7 foot:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.07–0.045
b. Length 4–6 inches	0.09–0.05
2. Good stand, any grass:	
a. Length about 12 inches	0.18–0.09
b. Length about 24 inches	0.30–0.15
3. Fair stand, any grass:	
a. Length about 12 inches	0.14–0.08
b. Length about 24 inches	0.25–0.13
B. Depth of flow 0.7–1.5 feet:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.05–0.035
b. Length 4 to 6 inches	0.06–0.04
2. Good stand, any grass:	
a. Length about 12 inches	0.12–0.07
b. Length about 24 inches	0.20–0.10
3. Fair stand, any grass:	
a. Length about 12 inches	0.10–0.06
b. Length about 24 inches	0.17–0.09

V. Street and expressway gutters:	
A. Concrete gutter, troweled finish	0.012
B. Asphalt pavement:	
1. Smooth texture	0.013
2. Rough texture	0.016
C. Concrete gutter with asphalt pavement:	
1. Smooth	0.013
2. Rough	0.015
D. Concrete pavement:	
1. Float finish	0.014
2. Broom finish	0.016
E. For gutters with small slope, where sediment may accumulate, increase above values of n by	*0.002*
VI. Natural stream channels:[9]	
A. Minor streams [9] (surface width at flood stage less than 100 ft.):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030–0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035–0.05
c. Some weeds, light brush on banks	0.035–0.05
d. Some weeds, heavy brush on banks	0.05–0.07
e. Some weeds, dense willows on banks	0.06–0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	*0.01–0.02*
2. Irregular sections, with pools, slight channel meander; increase values given in 1a–e about	*0.01–0.02*
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04–0.05
b. Bottom of cobbles, with large boulders	0.05–0.07
B. Flood plains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030–0.035
b. High grass	0.035–0.05
2. Cultivated areas:	
a. No crop	0.03–0.04
b. Mature row crops	0.035–0.045
c. Mature field crops	0.04–0.05
3. Heavy weeds, scattered brush	0.05–0.07
4. Light brush and trees: [10]	
a. Winter	0.05–0.06
b. Summer	0.06–0.08
5. Medium to dense brush: [10]	
a. Winter	0.07–0.11
b. Summer	0.10–0.16
6. Dense willows, summer, not bent over by current	0.15–0.20
7. Cleared land with tree stumps, 100–150 per acre:	
a. No sprouts	0.04–0.05
b. With heavy growth of sprouts	0.06–0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10–0.12
b. Flood depth reaches branches	0.12–0.16
C. Major streams (surface width at flood stage more than 100 ft.): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited [9] if possible. The value of n for larger streams of most regular section, with no boulders or brush, may be in the range of	0.028–0.033

User Notes

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