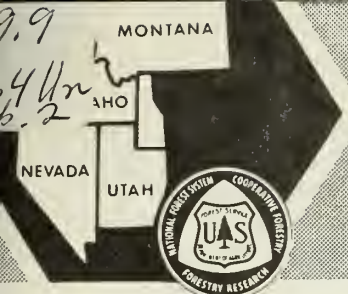


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# Research Note

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## FIRE CONTAINMENT EQUATIONS FOR POCKET CALCULATORS

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### ABSTRACT

*Presents simplified equations for solving the fire containment problem. Equations can be used on a programmable pocket calculator to derive the burned area, given forward rate of spread, initial area, fire shape length/width ratio, and control-line construction rate. Equations can also be used to find the line construction rate needed to hold the burned area to a fixed value, knowing the other variables listed. Potential uses seen for this capability are preliminary fire control planning and as a dispatching aid. Copies of a program for the Texas Instruments Model 59 calculator<sup>2</sup> are available on request.*

KEYWORDS: Fire containment, fire control, fire suppression, planning, dispatching, calculator program

Prefire planning and initial attack dispatching are fire management activities that require the solution to the classical fire containment problem: How much containment capability is needed? The question can be phrased in a variety of ways and answered in many ways. Often there are additional considerations that modify or even override the answer to the strictly-limited question, but it is still necessary to estimate potential fire sizes and potential requirements for fire suppression capabilities (Barrows 1951).

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<sup>2</sup>The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Concern over rising costs of wildland fire suppression has stimulated more intensive planning for fire control.<sup>3</sup> The computer program FOCUS (Storey 1972) was designed to test fire control plans and force dispositions for the purpose of increasing efficiency and reducing costs. This program uses tables of numbers that give the final area and perimeter of an easily controlled fire in terms of its initial area, length/width ratio, and ratio of control line construction rate to forward rate of spread (Bratten 1978).

For preliminary planning work and as a ready aid for dispatcher use, a simplified mechanized process for solving the fire containment problem may be useful. This note presents simple equations that can be used on a programmable pocket calculator for this purpose. The structure of an appropriate program for such application is given. This structure has been used to program a Texas Instrument Model 59 calculator to solve the equations presented here.

### SIMPLIFYING ASSUMPTIONS

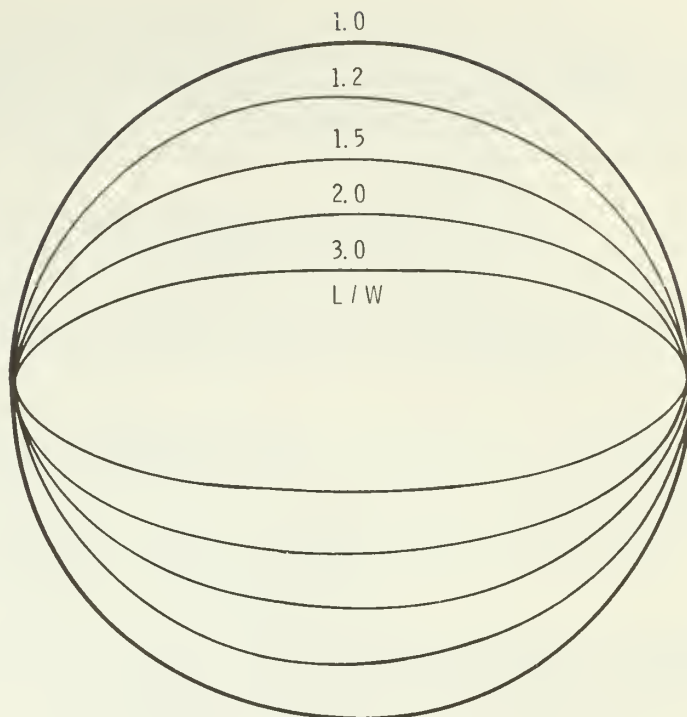
In its general (real-life) form, the mathematical problem of calculating the time required to construct a control line around a spreading fire, working at the fire edge, is intractably complicated. By making a series of simplifying assumptions, the problem can be reduced to one that can be solved. The applicability of the results must then be judged according to how closely the real situation conforms to the idealized model of it. So that the reader may make such judgment, the assumptions used in setting up the mathematical problem are spelled out below:

1. The unconstrained spread of the fire would not change its shape. That is, while the fire may spread at different rates in different directions, its growth would resemble the enlargement of a photograph.
2. The rate of spread of the fire is constant over the time that control line construction takes place. In practical terms this implies that the fire is contained within one burning period and that the fuels, topography, and weather remain essentially the same from the time work starts until it is finished.
3. The shape of the free-burning fire is that of an ellipse, with the point of origin at a focus. Of course it need not be exactly an ellipse, but an elliptical shape must roughly describe the location of the fire edge. Note that an ellipse with a length/width ratio of unity is a circle, so this case is included. See figure 1 for ellipses of various length/width (L/W) ratios.
4. The rate of line construction is constant. Of course this is never exactly correct, but the analysis depends on treating the rate as a constant. By using different, constant, values in example calculations, one can explore how sensitive the results are to the validity of this assumption in each case considered.
5. Work proceeds simultaneously on both sides of the fire at an equal pace. That is, the line-construction force is split into two equal parts (in terms of line construction rates) and they separate at the point of attack--either the head or the rear of the fire--and work around the flanks to meet at the opposite end.
6. The containment line is constructed at the edge of the fire. No indirect containment tactics are handled in this simplified analysis, so this constraint indirectly limits the intensity level of fires that can be analyzed; only fires of low and moderate intensity permit direct suppression (Albini 1976).

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<sup>3</sup>"Fire management analysis for forest planning," National Fire Management Planning Task Force, USDA For. Serv. Working Draft No. 1; May 1979 (to be revised). Authors: James F. Mann, Richard A. Henry, Richard A. Chase, Randall J. Van Gelder.

Figure 1.--Ellipses of various length/width (L/W) ratios.



The last constraint is imposed simply to limit the scope of the cases considered. Indirect attack tactics have been successfully treated (Albini and others 1978) so the methodology could be extended if interest warrants it. That is, we could fit curves to numerical results obtained using a well-placed barrier before the head of the fire as done by Albini and others (1978).

7. An implicit assumption here is that the containment or suppression work is 100 percent effective. That is, the fire does not spread beyond the control line once constructed.

#### METHODOLOGY

The problem described above, with the simplifying assumptions outlined, was formulated mathematically and reduced to the numerical evaluation of two integrals (Albini and others 1978). The exact expressions to be computed are:

$$P/2R(\theta_o) = \int_{\theta_o}^{\theta_o + \pi} G(\theta) F(\theta) d\theta \quad (1)$$

$$A/R^2(\theta_o) = \int_{\theta_o}^{\theta_o + \pi} F^2(\theta) d\theta \quad (2)$$

where

P = the final perimeter of the burned area (= the total length of control line constructed)

A = the burned area

$R(\theta_o)$  = the distance from the fire's point of origin to the point on its edge where control line construction started, designated by the angle  $\theta_o$ .



The function  $F$  describes the shape of the final burned area in radial coordinates,<sup>4</sup> and the product  $GF$  is the derivative of perimeter length with respect to the angle  $\theta$ . The size and shape of the free-burning fire is described in radial coordinates, with origin at the point of origin of the fire, by the function  $r(\theta, t)$ , where

- $r(\theta, t)$  = distance from the point of origin to the fire edge at time  $t$  in the direction  $\theta$   
 $\theta$  = an angle measured from the direction of the maximum rate of spread ( $\theta = 0$  toward the head of the fire), counterclockwise  
 $t$  = time since start of the fire.

In terms of the function  $r$ , its time derivative  $\dot{r}$ , its derivative with respect to the angle  $r'$ , and rate of control line construction on each flank,  $V_L$ , the function  $F$  can be written as

$$F(\theta) = \exp \left( \int_{\theta_0}^{\theta} f(\theta') d\theta' \right) \quad (3)$$

where

$$f = \frac{\dot{r}/V_L + (r'/r)(1 + (r'/r)^2 - (\dot{r}/V_L)^2)^{1/2}}{-(r'/r)(\dot{r}/V_L) + (1 + (r'/r)^2 - (\dot{r}/V_L)^2)^{1/2}}. \quad (4)$$

Because of simplifying assumptions 1, 2, and 4, the function  $f$  is independent of time. Likewise, function  $G(\theta)$  is time-independent:

$$G = (1 + (r'/r)^2) / (-(r'/r)(\dot{r}/V_L) + (1 + (r'/r)^2 - (\dot{r}/V_L)^2)^{1/2}). \quad (5)$$

By assumption 3 above the outline of the free-burning fire can be expressed as

$$r(\theta) = r(0)(1 - \epsilon)/(1 - \epsilon \cos \theta) \quad (6)$$

where  $r(0)$ , the distance from the point of origin to the head of the fire is given by

$$r(0) = V_F t \quad (7)$$

and  $V_F$  is the forward rate of spread. The factor  $\epsilon$  in equation 6 is the eccentricity of the elliptical fire outline. It is related to the length/width ratio,  $L/W$ , by the formula

$$\epsilon = ((L/W)^2 - 1)^{1/2} / (L/W). \quad (8)$$

If control line construction starts at the head of the fire,  $\theta_0$  is zero; if at the rear,  $\theta_0$  is  $\pi$ :

$$R(\theta_0) = \begin{cases} r(0), & \theta_0 = 0 \\ r(0)(1 - \epsilon)/(1 + \epsilon), & \theta_0 = \pi \end{cases} \quad (9)$$

The value of  $r(0)$  can be related to the area of the fire at the time line construction begins,  $A_0$ , and the length/width ratio:

$$r(0) = (1 + \epsilon)((L/W)A_0/\pi)^{1/2}. \quad (10)$$

<sup>4</sup>The interested reader should consult Albini and others (1978) for the development of equations 1-5. These equations are given here only for completeness of this presentation.

## APPROXIMATE FORMS

The equations above were programmed for calculation on the CDC7600 computer at Lawrence Berkeley Laboratories' facility on the University of California campus at Berkeley. The results, expressed in the dimensionless forms of equations 1 and 2, were tabulated against the ratios  $V_F/V_L$  and  $L/W$ . The tabular entries were then fitted by simple functional forms.

Holding  $L/W$  constant, nonlinear regressions yielded functions of  $V_F/V_L$ . Keeping the functional forms constant allowed the tabulation of the regression coefficients in terms of the fire shape parameter  $L/W$ . These tables were, in turn, fitted to simple forms by regressions. The expressions resulting from this sequence are listed in the equation summary below.

The approximate forms for elliptical fire shapes are accurate to within about 5 percent for all length/width ratios in the range 1.2 to 3.0 inclusive. Outside this range the expressions begin to deviate rapidly from "exact" results. The upper limit of 3.0 is probably not overly restrictive, because fires with greater eccentricity than this will probably not be contained on initial attack or within one burning period (recall assumptions 1 and 2 above). This is so because usually only very rapidly spreading fires will have large length/width ratios.

Because the fire shape used here is an ellipse and the point of origin of the fire is at a focus of the ellipse, a length/width ratio of 3.0 represents a fire spreading very much more rapidly in the forward direction than in the backing direction. The graph in figure 2 shows how the length/width ratio varies with the ratio of forward to backing rates of spread.<sup>5</sup> From this figure one can see that a fire with length/width ratio exceeding 3.0 would probably escape initial attack. Figure 3 shows the variation of length/width ratio with windspeed, based on Hal Anderson's double-ellipse formulas for wind-driven fire shapes (Albini 1976, erratum). This graph indicates that the windspeed at 20-foot height must exceed 20 mi/h before a length/width ratio of 3 is exceeded.

To extend the lower limit ( $L/W = 1.2$ ), exact results for a circular fire shape are used. When the unconstrained fire grows as a circle, functions  $f$  (equation 4) and  $G$  (equation 5) become constants and equations 1 and 2 are simple to evaluate. These results are listed in the summary of equations. Whenever the length/width ratio of an elliptical fire shape is less than 1.2, the circular fire shape results can be used to obtain approximate results.

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<sup>5</sup>The spread rate ratio is the ratio of distance from the focus of origin to the forward and backward edges of the ellipse.

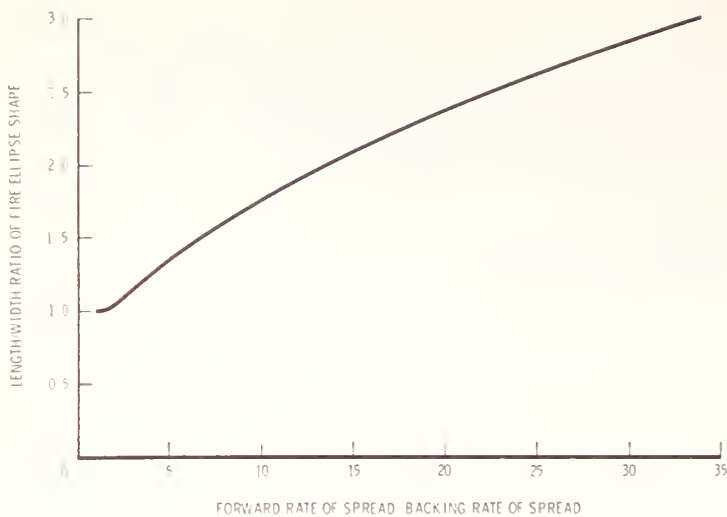


Figure 2.--Variation of length/width ratio of elliptical fire shapes with the ratio of forward rate of spread to backing rate of spread.

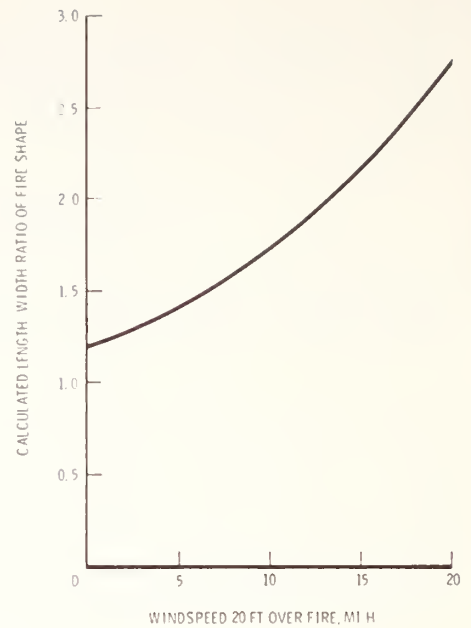


Figure 3.--Calculated length/width ratios for fire shapes, based on Hal Anderson's double-ellipse equations.

#### SUMMARY OF EQUATIONS FOR FIRE CONTAINMENT

##### Symbols

$A_0$  = area of fire at the time containment work begins

$r(0)$  = distance from point of origin to head of fire when containment work begins

$L/W$  = length/width ratio of elliptical shape of free-burning fire

$V_F$  = forward rate of spread of free-burning fire

$V_L$  = rate of construction of control line on each flank

$A_B$  = final area of contained fire

$P$  = perimeter of burned area (= length of control line built)

$\Delta t$  = elapsed time to contain the fire

##### All Cases

$$r(0) = (1 + \epsilon) \left( (L/W) A_0 / \pi \right)^{1/2}$$

$$\epsilon = \left( (L/W)^2 - 1 \right)^{1/2} / (L/W)$$

$$\Delta t = P / (2V_L)$$



Case A. Work Starts at Head of Fire ( $1.2 \leq L/W \leq 3.0$ )

$$P/A_B^{1/2} = 3.52 + 0.044(L/W)^{2.4}$$

$$A_B^{1/2}/r(0) = \begin{cases} A_{11} + A_{12}(V_F/V_L)^{A_{13}}, & 0 \leq V_F/V_L \leq 0.95 \\ A_{21} + A_{22}\left(-\frac{1}{3} \ln(1 - V_F/V_L)\right)^{A_{23}}, & 0.95 < V_F/V_L < 1 \end{cases}$$

$$A_{11} = (2.341 - 3.126 \exp(-0.6284 L/W))^{-1}$$

$$A_{12} = (4.799(L/W)^{0.774} - 5.047)^{-1}$$

$$A_{13} = (1.02 - 1.62 \exp(-0.82 L/W))^{-1}$$

$$A_{21} = 0.45 + 2/(L/W)^3$$

$$A_{22} = 0.55(L/W - 1) - 2/(L/W)^3$$

$$A_{23} = 0.091 + 1.76/(L/W)^2$$

Case B. Work Starts at Back of Fire ( $1.2 \leq L/W \leq 3.0$ )

$$r(0)/A_B^{1/2} = B_{11} + B_{12}(V_F/V_L)^{B_{13}}$$

$$P/2r(0) = (B_{21}/(1.0 - V_F/V_L))^{B_{22}}$$

$$B_{11} = 0.825 + 0.925(\ln(L/W))^{1.01}$$

$$B_{12} = 5.1 - 5.96(L/W)^{0.1234}$$

$$B_{13} = -0.813 + 1.972(\ln(L/W))^{0.0925}$$

$$B_{21} = 1.112 + 3.4 \exp(-1.5L/W)$$

$$B_{22} = (0.988 - 2.46 \exp(-2.35L/W))^{-1}$$

Case C. Circular Fire Shape ( $1 \leq L/W < 1.2$ )

$$A_B/A_O = (\exp(Z) - 1)/Z$$

$$P/2r(0) = (\exp(Z/2) - 1)(V_F/V_L)$$

$$Z = 2\pi/((V_F/V_L)^2 - 1)^{1/2}$$

The equations given in the summary can be inverted to express the rate of line construction required ( $V_L$ ) to keep the burned area ( $A_B$ ) to a specified value. In the pocket calculator program structure shown below, this option is selectable.

In the circular fire case, the equation for  $A_B/A_O$  in terms of  $Z$  can be solved for  $Z$  using the iteration:

$$Z_1 = 2 \ln (A_B/A_O) \quad (11)$$

$$Z_{n+1} = (1 + (Z_n - 1)\exp(Z_n))/(\exp(Z_n) - A_B/A_O). \quad (12)$$

That is, use equation (11) to calculate a first estimate ( $Z_1$ ) for  $Z$ , and use equation (12) to calculate successively better approximations  $Z_2$ ,  $Z_3$ , etc., using the last estimate ( $Z_n$ ) to generate the next one ( $Z_{n+1}$ ). Repeating equation (12) six times gives convergence of  $Z$  to within one percent for  $A_B/A_O$  of 1,000. The iteration is strongly convergent.

Note that all the equations given in the summary are in dimensionless form. That is, the burned area is always divided by the initial area or appears as the square root divided by  $r(0)$ ;  $V_F$  and  $V_L$  always appear in ratio, etc. This was done for the convenience of the user, so that any system of units could be used. While the choice of units is up to the user, the user is reminded that internal consistency demands that the square of the unit of length be the unit of area. So if one chooses to express rate of spread and line construction rate in chains per hour, the unit of area (initial area and burned area) is squared chains. In this case it would be necessary to multiply areas measured in acres by a factor of 10 to convert them to squared chains. If the rate units are feet per minute (or per second or per hour) the area units are square feet, etc.

The conversion factor desired can be included in the program for a pocket calculator; this was done for a version programmed at the Northern Forest Fire Laboratory. In this version (see appendix), the units are assumed to be chains per hour and acres, the most common American forestry units, so a factor of 10 was programmed to multiply area entries to convert them to squared chains internally. For display, calculated areas are converted to acres. In the list of symbols shown in the appendix, the initial area in squared chains is denoted by  $A_O^*$  while the same area in acres is called  $A_O$ . The asterisk implies the same conversion for burned area,  $A_B$ .

#### CALCULATOR PROGRAM STRUCTURE

The equations listed in the summary can be solved using a programmable pocket calculator. Exhibits 1 and 2 show appropriate program structures for the elliptical and circular fire shapes, respectively. These structures have been used to program the Texas Instruments Model 59 calculator. The combined cases A and B fit within the storage capability of that calculator, and required two magnetic-strip cards to record. Case C is much more compact, but could not be combined with either case A or B, so was recorded separately. Copies of these programs on magnetic strips are available from the authors at the Northern Forest Fire Laboratory. See the appendix for program listings and instructions for using them.

## OPERATING STEPS, ELLIPTICAL FIRE SHAPE PROGRAM

1. Select case: A = head attack; B = rear attack
2. Select option: A' = compute line construction rate; B' = compute burned area
3. Input  $V_F$
4. Input  $A_O$
5.  $\begin{cases} \text{A': Input } A_B \text{ (stop occurs if } A_B \leq A_O) \\ \text{-or-} \\ \text{B': Input } V_L \text{ (stop occurs if } V_L \leq V_F) \end{cases}$
6. Input L/W (stop occurs if out of range)

### Computation Sequence

1. Test:  $1.2 \leq L/W \leq 3.0$  (stop out of range)
2. Calculate:  $\epsilon, r(0)$
3. Case A. Calculate and store  $A_{ij}$  coefficients

Option A'. Test:  $A_B/A_O > 1.0$  (stop out of range)

Test:  $A_B^{1/2}/r(0) < A_{21} + A_{22}$  (choose equation for  $V_L$ )

Calculate:  $V_L, P, \Delta t$

Option B'. Test:  $V_F/V_L > 1.0$  (stop out of range)

Test:  $V_F/V_L \leq 0.95$  (choose equation for  $V_L$ )

Calculate:  $A_B, P, \Delta t$

Case B. Calculate and store  $B_{ij}$  coefficients

Option A'. Test:  $A_B/A_O > 1.0$  (stop out of range)

Calculate:  $V_L, P, \Delta t$

Option B'. Test:  $V_F/V_L < 1.0$  (stop out of range)

Calculate:  $A_B, P, \Delta t$

4. Display results

Option A'.  $V_L, P, \Delta t$

Option B'.  $A_B, P, \Delta t$

Exhibit 1.--Pocket calculator program structure and operating steps for solving the fire containment problem for elliptical fire shapes.

## OPERATING STEPS, CIRCULAR FIRE SHAPE PROGRAM

1. Select option: A' = compute line construction rate; B' = compute burned area.
2. Input  $V_F$
3. Input  $A_O$
4.  $\begin{cases} \text{A': Input } A_B \text{ (stop occurs if } A_B \leq A_O) \\ \text{-or-} \\ \text{B': Input } V_L \text{ (stop occurs if } V_L \leq V_F) \end{cases}$

### Computation Sequence

1. Option A'. Test:  $A_B/A_O > 1.0$  (stop out of range)

Calculate:  $Z, A_B, P, \Delta t$

- Option B'. Test:  $V_F/V_L < 1.0$  (stop out of range)

Calculate:  $Z, V_L, P, \Delta t$

2. Display results:

Option A'.  $V_L, P, \Delta t$

Option B'.  $A_B, P, \Delta t$

Exhibit 2.--Pocket calculator program structure and operating steps for solving the fire containment problem for circular fire shapes.

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APPENDIX: OPERATING PROCEDURE FOR SOLVING FIRE CONTAINMENT PROBLEMS  
ON THE TI-59 CALCULATOR

I. Preliminaries

1. Turn calculator on.
2. Press:  $\boxed{2}$   $\boxed{2nd}$   $\boxed{Op}$   $\boxed{1}$   $\boxed{7}$  .

II. Selection of program

1. Press:  $\boxed{2nd}$   $\boxed{CP}$   $\boxed{INV}$   $\boxed{2nd}$   $\boxed{fix}$  .
2. Select set of cards to be used (see fig. 1 to help you select the right value for L/W).
  - a. If  $L/W \geq 1.2$ , use elliptical program, a set of 2 cards with sides 1 through 4.
  - b. If  $L/W < 1.2$ , use circular program, a single card with sides 1 and 2.
3. Press:  $\boxed{1}$  .
4. Feed into lower slot side 1 of program strip of option chosen (circular or elliptical). The motor will start and stop automatically. A 1. should appear in the display after the strip is read. If the display flashes, press  $\boxed{CLR}$  and go back to step 3.
5. Press:  $\boxed{2}$  .
6. Feed in side 2 of program strip. (Keep printed side up, just start at the other end.) A 2. should appear in the display after the strip is read. If the display flashes, press  $\boxed{CLR}$  and go back to step 5.
7. (OMIT STEPS 7-10 FOR CIRCULAR OPTION.) Press:  $\boxed{3}$  .
8. Feed in side 3 similarly. The number 3. should appear in the display. If the display flashes, go back to step 7.
9. Press:  $\boxed{4}$  .
10. Feed in side 4 as above. When the number 4. appears in the display, you are ready to solve the problem. If the display flashes, press  $\boxed{CLR}$  and go back to step 9.

III. (OMIT PART III FOR CIRCULAR OPTION.)

Select mode of attack on fire

1. If containment work is to begin at the *head* of the fire, press  $\boxed{A}$  .
2. If containment work is to begin at the *rear* of the fire, press  $\boxed{B}$  .

Each time a problem is solved, one *must* select either A or B. If  $\boxed{A}$  or  $\boxed{B}$  is pressed in the circular option, a flashing display will result. Press  $\boxed{CLR}$  and proceed.

IV. Choose type of problem to be solved.

1. To calculate line building rate required to hold burned area to a set acreage, press  $\boxed{2nd}$   $\boxed{A'}$  .
2. To calculate burned area when fire is contained with a set line building rate, press  $\boxed{2nd}$   $\boxed{B'}$  .

Each time a problem is solved, one *must* select either A' or B'.

A' Selected

1. Input forward rate of spread of fire in chains per hour. Press number keys (include decimal point if needed) and value will appear in the display. If an error is made, press  $\boxed{CE}$  and try again. When the desired number appears in the display, press  $\boxed{R/S}$  .

2. Input size of fire when containment work begins, in acres. When the desired number appears in the display, press  $\boxed{R/S}$ .
3. Input burned area target, in acres; press  $\boxed{R/S}$ . This value must be greater than the initial size or the display will flash 9's--go back to IV.
4. (OMIT STEP 4 IN CIRCULAR OPTION.) Input the length/width ratio of the fire shape at the time containment work begins. This number must be at least 1.2 and no more than 3.0. Press  $\boxed{R/S}$ . If  $L/W$  is outside the allowable range, display will flash 9's--go back to IV. If  $1 \leq L/W < 1.2$ , display will flash 1--go back to II and use circular option.
5. A flickering "C" should now appear in the display. If it does not, an error has occurred. Go back to III.
6. Calculation will cease with a number in the display. This number indicates the line-building rate (chains per hour) required on each flank of the fire. The total line-building rate capability, then, must be twice this number. Record this value for reference and then press  $\boxed{R/S}$ .
7. The number in the display indicates perimeter of the burned area (in chains) which is the same as the total length of control line constructed. Record this number for reference and then press  $\boxed{R/S}$ .
8. The number in the display indicates the time (in hours) that it will take to contain the fire. This completes the problem. To do another problem under the same option, go back to step III. To change options, go to part II.

#### B' Selected

1. Input forward rate of spread of fire in chains per hour. Press number keys (include decimal point if needed) and value will appear in display. If an error is made, press  $\boxed{CE}$  and try again. When desired number appears in the display, press  $\boxed{R/S}$ .
2. Input size of fire when containment work begins, in acres. When the desired number appears in the display, press  $\boxed{R/S}$ .
3. Input line-building rate capability (chains per hour) assigned equally to each flank of the fire. Press  $\boxed{R/S}$ . This must be more than the forward rate of spread or the display will flash 9's--go back to IV.
4. (OMIT STEP 4 IN CIRCULAR OPTION.) Input the length/width ratio of the fire shape at the time containment work begins. This number must be at least 1.2 and no more than 3.0. Press  $\boxed{R/S}$ . If  $L/W$  is outside the allowable range, display will flash 9's--go back to IV. If  $1.0 \leq L/W < 1.2$ , display will flash 1--go back to II and use circular option.
5. A flickering "C" should now appear in the display. If it does not, an error has occurred. Go back to III.
6. Calculation will cease with a number in the display. This number is the burned area, in acres, when the fire is contained. Record this value for reference and then press  $\boxed{R/S}$ .
7. The number in the display now is the perimeter of the burned area, which is the same as the total length of control line constructed, in chains. Record this number for reference and then press  $\boxed{R/S}$ .
8. The number in the display now will be the time, in hours, that it will take to contain the fire. This completes the problem. To do another problem under the same option, go back to step III. To change options, go to part II.



## Condensed Instruction Steps

I. Press **2** **2nd** **Op** **1** **7** .

II. Press **2nd** **CP** **INV** **2nd** **Fix** .

Load: Press **1** , feed side 1, display 1. (flashing display: **CLR** try again)  
Press **2** , feed side 2, display 2. (flashing display: **CLR** try again)  
Etc.

III. Mode of attack--head: **A** } OMIT FOR CIRCULAR OPTION--Flashing display, **CLR** ,  
Mode of attack--rear: **B** } continue

IV. Calculate line building rate: **2nd** **A'**  
Calculate burned area: **2nd** **B'**

### Option A'

#### Input

1. Forward rate of spread (ch/h), **R/S**
2. Initial fire size (acres), **R/S**
3. Burned area target (acres), **R/S**
4. Length/width ratio (1.2 - 3), **R/S**

#### Output

5. Line building rate per flank (ch/h): **R/S**
6. Total length of line (ch): **R/S**
7. Containment time (hours)

#### Error Indications

- (3) Flashing 9's--number too small--go to IV
- (4) a. Flashing 9's--number out of range--go to IV  
b. Flashing 1--wrong option--go to II and use circular option

### Option B'

#### Input

1. Forward rate of spread (ch/h), **R/S**
2. Initial fire size (acres), **R/S**
3. Line building rate per flank (ch/h), **R/S**
4. Length/width ratio (1.2 - 3) **R/S**

#### Output

5. Burned area (acres): **R/S**
6. Total length of line (ch): **R/S**
7. Containment time (hours)

#### Error Indications

- (3) Flashing 9's--number too small--go to IV
- (4) a. Flashing 9's--number out of range--go to IV  
b. Flashing 1--wrong option--go to II and use circular option

### Worked Examples

1. Suppose a fire has a size of 2 acres, a forward rate of spread of 15 chains per hour, and a length/width ratio of 2.5 when line construction begins. Assuming attack at the head of the fire, what line construction capability is required to contain the fire at 4 acres?

| <u>Step</u> | <u>Procedure</u>                                   | <u>Enter</u> | <u>Display should be</u>             | <u>Press</u>  | <u>Display changes to</u> |
|-------------|--|--------------|--------------------------------------|---|---------------------------|
| 1.1         | Turn calculator on                                 |              |                                      |   |                           |
| 1.2         | Partition program memory                           |              |                                      | <b>2</b> <b>2nd</b> <b>Op</b> <b>1</b> <b>7</b>       | 799.19                    |
| 1I.1        | Clear memory; prepare decimal format               |              |                                      | <b>2nd</b> <b>CP</b> <b>INV</b> <b>2nd</b> <b>Fix</b> | ignore                    |
| 1I.2        | Select elliptical program                          |              |                                      |   |                           |
| 1I.3        | Prepare to read side 1                             | 1            | 1                                    |   |                           |
| 1I.4        | Insert program side 1                              |              | (motor starts & stops automatically) |   | 1.                        |
| 1I.5        | Prepare to read side 2                             | 2            | 2                                    |   |                           |
| 1I.6        | Insert program side 2                              |              | (motor starts & stops automatically) |   | 2.                        |
| 1I.7        | Prepare to read side 3                             | 3            | 3                                    |   |                           |
| 1I.8        | Insert program side 3                              |              | (motor starts & stops automatically) |   | 3.                        |
| 1I.9        | Prepare to read side 4                             | 4            | 4                                    |   |                           |
| 1I.10       | Insert program side 4                              |              | (motor starts & stops automatically) |   | 4.                        |
| III.1       | Select head attack                                 |              |                                      | <b>A</b>  | ignore                    |
| 1V.1        | Select calculation of line building rate           |              |                                      | <b>2nd</b> <b>A'</b>                                  | ignore                    |
| A'.1        | Enter rate of spread                               | 15           | 15                                   | <b>R/S</b>  | 15.                       |
| A'.2        | Enter size when fire containment begins            | 2            | 2                                    | <b>R/S</b>  | 2.                        |
| A'.3        | Enter burned area target                           | 4            | 4                                    | <b>R/S</b>  | 4.                        |
| A'.4        | Enter length/width ratio                           | 2.5          | 2.5                                  | <b>R/S</b>  | flickering C              |
| A'.6        | Record line construction rate on each flank (ch/h) |              |                                      |   | 15.5 ←                    |
| A'.7        | Record perimeter of                                |              | 15.5                                 | <b>R/S</b>  | 24.8 ←                    |
| A'.8        | Record time required to contain fire (hours)       |              | 24.8                                 | <b>R/S</b>  | 0.8 ←                     |

Output: 15.5 = line construction rate on each flank (ch/h)  
 24.8 = perimeter of burned area (ch)  
 0.8 = time required to contain fire (hours)

2. Suppose that the size of a fire is 2 acres when containment begins and that the forward spread rate is 15 chains per hour. If the length/width ratio is 1 and line can be constructed at a rate of 25 chains per hour on each flank, what is the burned area when the fire is contained?

| <u>Step</u> | <u>Enter</u> | <u>Press</u>  | <u>Display</u> |
|-------------|--------------|---|----------------|
| II          |              | <b>2nd</b> <b>CP</b> <b>INV</b> <b>2nd</b> <b>fix</b> | ignore         |
|             | 1            | (insert side 1)                                       | 1.             |
|             | 2            | (insert side 2)                                       | 2.             |
| IV          |              | <b>2nd</b> <b>8'</b>                                  | ignore         |
|             | 15           | <b>R/S</b>  | 15.            |
|             | 2            | <b>R/S</b>  | 2.             |
|             | 25           | <b>R/S</b>  | 46.8 ←         |
|             |              | <b>R/S</b>  | 80.3 ←         |
|             |              | <b>R/S</b>  | 1.6 ←          |

Output: 46.8 = burned area (acres)  
80.3 = perimeter of burned area (ch)  
1.6 = time required to contain fire (hours)

### Storage Registers

| <u>Register number</u> | <u>Elliptical shape</u> | <u>Circular shape</u> |
|------------------------|-------------------------|-----------------------|
| 00                     | $V_F$                   | $V_F$                 |
| 01                     | $A_O$                   | $A_O$                 |
| 02                     | $A_B$                   | $A_B$                 |
| 03                     | $L/W$                   | $L/W$                 |
| 04                     | $V_L$                   | $V_L$                 |
| 05                     | $P$                     | $P$                   |
| 06                     | $\Delta t$              | $\Delta t$            |
| 07                     | $A_{11}, B_{11}$        |                       |
| 08                     | $A_{12}, B_{12}$        |                       |
| 09                     | $A_{13}, B_{13}$        |                       |
| 10                     | $B_{22}$                |                       |
| 11                     | $B_{23}$                |                       |
| 12                     | $A_O^*$                 | $A_O^*$               |
| 13                     | $A_B^*$                 | $A_B^*$               |
| 14                     | $V_F/V_L$               | $V_F/V_L$             |
| 15                     | $A_{21}$                |                       |
| 16                     | $A_{22}$                |                       |
| 17                     | $A_{23}$                |                       |
| 18                     | $r(0)$                  | $r(0)$                |
| 19                     |                         | $Z$                   |

ELLIPTICAL  
FIRE SHAPE

|     |    |      |     |    |      |     |    |     |     |    |      |     |    |     |     |    |      |
|-----|----|------|-----|----|------|-----|----|-----|-----|----|------|-----|----|-----|-----|----|------|
| 000 | 76 | LBL  | 082 | 77 | GE   | 168 | 93 | .   | 254 | 85 | +    | 340 | 93 | .   | 426 | 22 | INV  |
| 001 | 11 | A    | 083 | 52 | EE   | 169 | 00 | 0   | 255 | 01 | 1    | 341 | 04 | 4   | 427 | 45 | YX   |
| 002 | 22 | INV  | 084 | 01 | 1    | 170 | 02 | 2   | 256 | 54 | )    | 342 | 65 | X   | 428 | 43 | RCL  |
| 003 | 58 | FIN  | 085 | 93 | .    | 171 | 54 | )   | 257 | 34 | FX   | 343 | 93 | .   | 429 | 17 | 17   |
| 004 | 22 | INV  | 086 | 02 | 2    | 172 | 35 | 1/X | 258 | 85 | +    | 344 | 00 | 0   | 430 | 54 | )    |
| 005 | 82 | STF  | 087 | 32 | X/IT | 173 | 42 | STD | 259 | 01 | 1    | 345 | 04 | 4   | 431 | 22 | INV  |
| 006 | 01 | 01   | 088 | 43 | RCL  | 174 | 09 | 09  | 260 | 54 | )    | 346 | 04 | 4   | 432 | 23 | LNK  |
| 007 | 22 | INV  | 089 | 03 | 03   | 175 | 53 | (   | 261 | 65 | X    | 347 | 85 | +   | 433 | 54 | )    |
| 008 | 82 | STF  | 090 | 22 | INV  | 176 | 53 | (   | 262 | 53 | (    | 348 | 03 | 3   | 434 | 54 | )    |
| 009 | 03 | 02   | 091 | 77 | GE   | 177 | 43 | RCL | 263 | 43 | RCL  | 349 | 93 | .   | 435 | 95 | =    |
| 010 | 47 | CMS  | 092 | 44 | SUM  | 178 | 03 | 03  | 264 | 03 | 03   | 350 | 05 | 5   | 436 | 42 | STD  |
| 011 | 91 | R/S  | 093 | 53 | (    | 179 | 45 | )   | 265 | 65 | X    | 351 | 02 | 2   | 437 | 04 | 04   |
| 012 | 76 | LBL  | 094 | 53 | (    | 180 | 03 | 3   | 266 | 43 | RCL  | 352 | 54 | )   | 438 | 61 | GTD  |
| 013 | 11 | B    | 095 | 43 | PCL  | 181 | 54 | )   | 267 | 13 | 12   | 353 | 65 | .   | 439 | 23 | LNK  |
| 014 | 22 | INV  | 096 | 03 | 03   | 182 | 15 | 1/X | 268 | 55 | -    | 354 | 43 | RCL | 440 | 76 | LBL  |
| 015 | 58 | FIN  | 097 | 65 | .    | 183 | 65 | .   | 269 | 83 | 4    | 355 | 13 | 13  | 441 | 22 | INV  |
| 016 | 11 | INV  | 098 | 93 | .    | 184 | 03 | 2   | 270 | 54 | )    | 356 | 34 | FX  | 442 | 43 | RCL  |
| 017 | 82 | STF  | 099 | 06 | 6    | 185 | 54 | .   | 271 | 34 | FX   | 357 | 95 | =   | 443 | 00 | 00   |
| 018 | 01 | 02   | 100 | 02 | 2    | 186 | 42 | STD | 272 | 95 | =    | 358 | 42 | STD | 444 | 55 | +    |
| 019 | 82 | STF  | 101 | 03 | 8    | 187 | 15 | 19  | 273 | 43 | STD  | 359 | 05 | 05  | 445 | 43 | RCL  |
| 020 | 01 | 01   | 102 | 04 | 4    | 188 | 65 | +   | 274 | 18 | 13   | 360 | 76 | LBL | 446 | 04 | 04   |
| 021 | 47 | CMS  | 103 | 54 | +    | 189 | 93 | +   | 275 | 83 | IFF  | 361 | 35 | 1/X | 447 | 95 | =    |
| 022 | 91 | R/S  | 104 | 94 | +    | 190 | 04 | 4   | 276 | 01 | 02   | 362 | 43 | RCL | 448 | 43 | STD  |
| 023 | 76 | LBL  | 105 | 01 | INV  | 191 | 15 | 5   | 277 | 31 | INV  | 363 | 05 | 05  | 449 | 14 | 14   |
| 024 | 11 | B    | 106 | 11 | LNK  | 192 | 45 | =   | 278 | 83 | IFF  | 364 | 55 | -   | 450 | 87 | IFF  |
| 025 | 22 | INV  | 107 | 65 | .    | 193 | 43 | STD | 279 | 01 | 01   | 365 | 02 | 2   | 451 | 01 | 01   |
| 026 | 82 | STF  | 108 | 07 | 1    | 194 | 15 | 15  | 280 | 43 | STD  | 366 | 55 | -   | 452 | 40 | STD  |
| 027 | 01 | 01   | 109 | 01 | 1    | 195 | 43 | RCL | 281 | 43 | RCL  | 367 | 43 | RCL | 453 | 03 | X/IT |
| 028 | 47 | CMS  | 110 | 01 | 1    | 196 | 15 | 15  | 282 | 18 | 18   | 368 | 04 | 04  | 454 | 93 | .    |
| 029 | 91 | R/S  | 111 | 01 | 1    | 197 | 93 | +   | 283 | 83 | IFF  | 369 | 95 | =   | 455 | 09 | 9    |
| 030 | 76 | LBL  | 112 | 06 | 6    | 198 | 55 | +   | 284 | 83 | IFF  | 370 | 42 | STD | 456 | 05 | 5    |
| 031 | 11 | B    | 113 | 06 | 6    | 199 | 53 | +   | 285 | 43 | RCL  | 371 | 06 | 06  | 457 | 38 | INV  |
| 032 | 22 | INV  | 114 | 05 | 5    | 200 | 3  | 3   | 286 | 13 | 13   | 372 | 58 | FIN | 458 | 77 | GE   |
| 033 | 58 | FIN  | 115 | 02 | 2    | 201 | 06 | 6   | 287 | 34 | FX   | 373 | 01 | 01  | 459 | 43 | RCL  |
| 034 | 11 | B    | 116 | 93 | .    | 202 | 05 | 5   | 288 | 45 | =    | 374 | 87 | IFF | 460 | 53 | +    |
| 035 | 22 | INV  | 117 | 01 | 1    | 203 | 55 | -   | 289 | 73 | X/IT | 375 | 03 | 03  | 461 | 53 | +    |
| 036 | 82 | STF  | 118 | 04 | 4    | 204 | 53 | .   | 290 | 43 | RCL  | 376 | 55 | -   | 462 | 43 | RCL  |
| 037 | 01 | 01   | 119 | 01 | 1    | 205 | 43 | RCL | 291 | 13 | 15   | 377 | 43 | RCL | 463 | 14 | 14   |
| 038 | 47 | CMS  | 120 | 54 | +    | 206 | 07 | 03  | 292 | 65 | +    | 378 | 04 | 04  | 464 | 45 | YX   |
| 039 | 91 | R/S  | 121 | 05 | 5    | 207 | 75 | -   | 293 | 43 | RCL  | 379 | 91 | P/S | 465 | 43 | RCL  |
| 040 | 76 | LBL  | 122 | 43 | STD  | 208 | 01 | 1   | 294 | 15 | 16   | 380 | 43 | RCL | 466 | 09 | 09   |
| 041 | 11 | B    | 123 | 07 | 7    | 209 | 54 | +   | 295 | 45 | =    | 381 | 05 | 05  | 467 | 65 | X    |
| 042 | 22 | INV  | 124 | 53 | .    | 210 | 54 | +   | 296 | 01 | INV  | 382 | 91 | P/S | 468 | 43 | RCL  |
| 043 | 58 | FIN  | 125 | 43 | RCL  | 211 | 45 | =   | 297 | 43 | GE   | 383 | 43 | RCL | 469 | 08 | 08   |
| 044 | 11 | B    | 126 | 01 | 03   | 212 | 43 | STD | 298 | 13 | 13   | 384 | 06 | 06  | 470 | 85 | +    |
| 045 | 82 | STF  | 127 | 45 | .    | 213 | 15 | 16  | 299 | 76 | LBL  | 385 | 91 | P/S | 471 | 43 | RCL  |
| 046 | 01 | 01   | 128 | 07 | 7    | 214 | 43 | RCL | 300 | 43 | X/IT | 386 | 76 | LBL | 472 | 07 | 07   |
| 047 | 47 | CMS  | 129 | 07 | 7    | 215 | 03 | 03  | 301 | 53 | (    | 387 | 53 | (   | 473 | 54 | +    |
| 048 | 91 | R/S  | 130 | 07 | 7    | 216 | 53 | 12  | 302 | 53 | (    | 388 | 43 | RCL | 474 | 65 | X    |
| 049 | 76 | LBL  | 131 | 04 | 4    | 217 | 15 | 15  | 303 | 53 | .    | 389 | 00 | 03  | 475 | 43 | RCL  |
| 050 | 11 | B    | 132 | 05 | 5    | 218 | 65 | +   | 304 | 43 | RCL  | 390 | 91 | P/S | 476 | 16 | 18   |
| 051 | 22 | INV  | 133 | 04 | 4    | 219 | 01 | 1   | 305 | 13 | 13   | 391 | 43 | RCL | 477 | 54 | +    |
| 052 | 58 | FIN  | 134 | 93 | .    | 220 | 91 | .   | 306 | 34 | FX   | 392 | 05 | 05  | 478 | 33 | X2   |
| 053 | 11 | B    | 135 | 07 | 7    | 221 | 07 | 7   | 307 | 55 | -    | 393 | 91 | P/S | 479 | 42 | STD  |
| 054 | 82 | STF  | 136 | 09 | 9    | 222 | 06 | 6   | 308 | 43 | RCL  | 394 | 43 | RCL | 480 | 13 | 13   |
| 055 | 01 | 01   | 137 | 09 | 9    | 223 | 85 | +   | 309 | 18 | 18   | 395 | 06 | 06  | 481 | 55 | +    |
| 056 | 47 | CMS  | 138 | 75 | -    | 224 | 93 | .   | 310 | 75 | -    | 396 | 91 | P/S | 482 | 01 | 1    |
| 057 | 91 | R/S  | 139 | 05 | 5    | 225 | 00 | 0   | 311 | 43 | RCL  | 397 | 76 | LBL | 483 | 00 | 0    |
| 058 | 76 | LBL  | 140 | 93 | .    | 226 | 09 | 9   | 312 | 07 | 07   | 398 | 33 | X2  | 484 | 95 | =    |
| 059 | 11 | B    | 141 | 00 | 0    | 227 | 01 | 1   | 313 | 54 | )    | 399 | 43 | RCL | 485 | 42 | STD  |
| 060 | 22 | INV  | 142 | 04 | 4    | 228 | 95 | =   | 314 | 55 | +    | 400 | 00 | 00  | 486 | 02 | 02   |
| 061 | 58 | FIN  | 143 | 07 | 7    | 229 | 42 | STD | 315 | 43 | RCL  | 401 | 55 | +   | 487 | 61 | GTD  |
| 062 | 11 | B    | 144 | 54 | )    | 230 | 17 | 17  | 316 | 08 | 08   | 402 | 53 | (   | 488 | 23 | LNK  |
| 063 | 82 | STF  | 145 | 35 | 1/X  | 231 | 43 | RCL | 317 | 54 | )    | 403 | 01 | 1   | 489 | 76 | LBL  |
| 064 | 01 | 01   | 146 | 42 | STD  | 232 | 01 | 01  | 318 | 22 | INV  | 404 | 75 | -   | 490 | 43 | RCL  |
| 065 | 47 | CMS  | 147 | 08 | 08   | 233 | 65 | X   | 319 | 45 | YX   | 405 | 53 | (   | 491 | 53 | (    |
| 066 | 91 | R/S  | 148 | 53 | (    | 234 | 01 | 1   | 320 | 43 | RCL  | 406 | 53 | (   | 492 | 53 | (    |
| 067 | 76 | LBL  | 149 | 53 | (    | 235 | 00 | 0   | 321 | 09 | 09   | 407 | 03 | 3   | 493 | 53 | (    |
| 068 | 11 | B    | 150 | 43 | RCL  | 236 | 95 | =   | 322 | 54 | +    | 408 | 94 | +/+ | 494 | 53 | (    |
| 069 | 22 | INV  | 151 | 03 | 03   | 237 | 42 | STD | 323 | 35 | 1/X  | 409 | 65 | X   | 495 | 01 | 1    |
| 070 | 58 | FIN  | 152 | 65 | X    | 238 | 12 | 12  | 324 | 65 | X    | 410 | 53 | (   | 496 | 75 | -    |
| 071 | 11 | B    | 153 | 93 | .    | 239 | 43 | RCL | 325 | 43 | RCL  | 411 | 53 | (   | 497 | 43 | RCL  |
| 072 | 82 | STF  | 154 | 08 | 8    | 240 | 02 | 02  | 326 | 00 | 00   | 412 | 43 | RCL | 498 | 14 | 14   |
| 073 | 01 | 01   | 155 | 02 | 2    | 241 | 65 | X   | 327 | 95 | =    | 413 | 13 | 13  | 499 | 54 | +    |
| 074 | 47 | CMS  | 156 | 94 | +/+  | 242 | 01 | 1   | 328 | 42 | STD  | 414 | 34 | FX  | 500 | 23 | LNK  |
| 075 | 91 | R/S  | 157 | 54 | )    | 243 | 00 | 0   | 329 | 04 | 04   | 415 | 55 | +   | 501 | 55 | +    |
| 076 | 76 | LBL  | 158 | 22 | INV  | 244 | 95 | =   | 330 | 87 | IFF  | 416 | 43 | RCL | 502 | 03 | 3    |
| 077 | 11 | B    | 159 | 23 | LNK  | 245 | 42 | STD | 331 | 01 | 01   | 417 | 18 | 18  | 503 | 94 | +/+  |
| 078 | 22 | INV  | 160 | 65 | X    | 246 | 13 | 13  | 332 | 45 | YX   | 418 | 75 | -   | 504 | 54 | )    |
| 079 | 58 | FIN  | 161 | 01 | 1    | 247 | 53 | (   | 333 | 76 | LBL  | 419 | 43 | RCL | 505 | 45 | YX   |
| 080 | 11 | B    | 162 | 93 | .    | 248 | 53 | (   | 334 | 23 | LNK  | 420 | 15 | 15  | 506 | 43 | RCL  |
| 081 | 82 | STF  | 163 | 06 | 6    | 249 | 43 | RCL | 335 | 53 | (    | 421 | 54 | +   | 507 | 17 | 17   |
|     | 52 | EE   | 164 | 02 | 2    | 250 | 03 | 03  | 336 | 43 | RCL  | 422 | 55 | +   | 508 | 65 | X    |
|     | 32 | X/IT | 165 | 94 | +/+  | 251 | 33 | X2  | 337 | 03 | 03   | 423 | 43 | RCL | 509 | 43 | RCL  |
|     | 03 | 3    | 166 | 85 | +    | 252 | 35 | 1/X | 338 | 45 | YX   | 424 | 16 | 16  | 510 | 16 | 16   |
|     | 22 | INV  | 167 | 01 | 1    | 253 | 94 | +/+ | 339 | 02 | 2    | 425 | 54 | )   | 511 | 85 | +    |

|     |    |     |     |    |     |     |    |     |     |    |     |     |    |     |     |    |     |
|-----|----|-----|-----|----|-----|-----|----|-----|-----|----|-----|-----|----|-----|-----|----|-----|
| 512 | 43 | RCL | 598 | 43 | RCL | 684 | 45 | YX  | 016 | 01 | 01  | 102 | 19 | 19  | 188 | 55 | +   |
| 513 | 15 | 15  | 599 | 03 | 03  | 685 | 53 | (   | 017 | 91 | R/S | 103 | 22 | INV | 189 | 43 | RCL |
| 514 | 54 | )   | 600 | 65 | x   | 686 | 43 | RCL | 018 | 42 | STD | 104 | 23 | LNK | 190 | 04 | 04  |
| 515 | 65 | x   | 601 | 01 | 1   | 687 | 15 | 15  | 019 | 02 | 02  | 105 | 65 | x   | 191 | 95 | =   |
| 516 | 43 | RCL | 602 | 93 | .   | 688 | 55 | -   | 020 | 22 | INV | 106 | 53 | (   | 192 | 42 | STD |
| 517 | 18 | 18  | 603 | 05 | 5   | 689 | 53 | (   | 021 | 77 | GE  | 107 | 43 | RCL | 193 | 06 | 06  |
| 518 | 54 | )   | 604 | 94 | +/- | 690 | 01 | 1   | 022 | 52 | EE  | 108 | 19 | 19  | 194 | 87 | IFF |
| 519 | 33 | YX  | 605 | 54 | +   | 691 | 75 | -   | 023 | 67 | EO  | 109 | 75 | -   | 195 | 01 | 01  |
| 520 | 42 | STD | 606 | 22 | INV | 692 | 43 | RCL | 024 | 52 | EE  | 110 | 01 | 1   | 196 | 54 | )   |
| 521 | 13 | 13  | 607 | 23 | LNK | 693 | 14 | 14  | 025 | 61 | GTO | 111 | 54 | +   | 197 | 58 | FIX |
| 522 | 55 | +   | 608 | 65 | x   | 694 | 54 | )   | 026 | 24 | CE  | 112 | 85 | +   | 198 | 01 | 01  |
| 523 | 01 | 1   | 609 | 03 | 3   | 695 | 54 | )   | 027 | 76 | LBL | 113 | 01 | 1   | 199 | 43 | RCL |
| 524 | 00 | 0   | 610 | 93 | .   | 696 | 45 | YX  | 028 | 17 | B*  | 114 | 54 | +   | 200 | 04 | 04  |
| 525 | 95 | =   | 611 | 04 | 4   | 697 | 43 | RCL | 029 | 22 | INV | 115 | 55 | -   | 201 | 91 | R/S |
| 526 | 42 | STD | 612 | 85 | +   | 698 | 16 | 16  | 030 | 58 | FIX | 116 | 53 | (   | 202 | 43 | RCL |
| 527 | 02 | 02  | 613 | 01 | 1   | 699 | 65 | )   | 031 | 86 | STF | 117 | 43 | RCL | 203 | 05 | 05  |
| 528 | 61 | GTO | 614 | 93 | .   | 700 | 02 | 2   | 032 | 01 | 01  | 118 | 19 | 19  | 204 | 91 | R/S |
| 529 | 21 | LNK | 615 | 01 | 1   | 701 | 65 | -   | 033 | 47 | CMS | 119 | 22 | INV | 205 | 43 | RCL |
| 530 | 76 | LBL | 616 | 01 | 1   | 702 | 43 | RCL | 034 | 91 | R/S | 120 | 23 | LNK | 206 | 06 | 06  |
| 531 | 42 | STD | 617 | 02 | 2   | 703 | 15 | 18  | 035 | 43 | STD | 121 | 75 | -   | 207 | 91 | R/S |
| 532 | 43 | RCL | 618 | 95 | =   | 704 | 95 | =   | 036 | 00 | 00  | 122 | 53 | +   | 208 | 76 | LBL |
| 533 | 01 | 03  | 619 | 43 | STD | 705 | 42 | STD | 037 | 32 | XIT | 123 | 43 | RCL | 209 | 54 | )   |
| 534 | 23 | LNK | 620 | 15 | 15  | 706 | 05 | 05  | 038 | 42 | RCL | 124 | 13 | 13  | 210 | 58 | FIX |
| 535 | 45 | YX  | 621 | 53 | )   | 707 | 67 | STD | 039 | 00 | 00  | 125 | 55 | -   | 211 | 01 | 01  |
| 536 | 01 | 1   | 622 | 50 | -   | 708 | 15 | 18  | 040 | 91 | R/S | 126 | 43 | RCL | 212 | 43 | RCL |
| 537 | 93 | .   | 623 | 42 | RCL | 709 | 54 | +   | 041 | 42 | STD | 127 | 12 | 12  | 213 | 02 | 02  |
| 538 | 06 | 01  | 624 | 01 | 03  | 710 | 54 | +   | 042 | 01 | 01  | 128 | 54 | +   | 214 | 91 | R/S |
| 539 | 01 | 1   | 625 | 65 | x   | 711 | 53 | -   | 043 | 91 | R/S | 129 | 54 | +   | 215 | 43 | RCL |
| 540 | 65 | x   | 626 | 01 | 2   | 712 | 43 | RCL | 044 | 43 | STD | 130 | 95 | =   | 216 | 05 | 05  |
| 541 | 93 | .   | 627 | 31 | 3   | 713 | 13 | 18  | 045 | 04 | 04  | 131 | 42 | STD | 217 | 91 | R/S |
| 542 | 05 | 9   | 628 | 01 | 3   | 714 | 55 | -   | 046 | 22 | INV | 132 | 19 | 19  | 218 | 43 | RCL |
| 543 | 02 | 2   | 629 | 05 | 5   | 715 | 58 | +   | 047 | 77 | GE  | 133 | 97 | DSZ | 219 | 06 | 06  |
| 544 | 05 | 5   | 630 | 91 | +   | 716 | 43 | RCL | 048 | 52 | EE  | 134 | 06 | 06  | 220 | 91 | R/S |
| 545 | 85 | +   | 631 | 92 | +   | 717 | 14 | 14  | 049 | 67 | EO  | 135 | 32 | INV | 221 | 76 | LBL |
| 546 | 53 | .   | 632 | 01 | 3   | 718 | 42 | STD | 050 | 52 | EE  | 136 | 53 | +   | 222 | 34 | FX  |
| 547 | 06 | 8   | 633 | 01 | 3   | 719 | 42 | RCL | 051 | 76 | LBL | 137 | 53 | +   | 223 | 53 | +   |
| 548 | 07 | 1   | 634 | 65 | x   | 720 | 04 | 09  | 052 | 34 | CE  | 138 | 02 | 3   | 224 | 53 | +   |
| 549 | 05 | 5   | 635 | 00 | 2   | 721 | 65 | x   | 053 | 43 | RCL | 139 | 65 | -   | 225 | 43 | RCL |
| 550 | 95 | =   | 636 | 31 | 3   | 722 | 42 | RCL | 054 | 01 | 01  | 140 | 89 | +   | 226 | 04 | 04  |
| 551 | 42 | STD | 637 | 04 | 2   | 723 | 03 | 08  | 055 | 65 | x   | 141 | 55 | -   | 227 | 55 | -   |
| 552 | 07 | 07  | 638 | 06 | 6   | 724 | 15 | +   | 056 | 01 | 1   | 142 | 43 | RCL | 228 | 43 | RCL |
| 553 | 47 | RCL | 639 | 94 | +   | 725 | 47 | RCL | 057 | 00 | 0   | 143 | 19 | 19  | 229 | 00 | 00  |
| 554 | 03 | 03  | 640 | 85 | +   | 726 | 07 | 07  | 058 | 95 | =   | 144 | 54 | +   | 230 | 54 | )   |
| 555 | 45 | YX  | 641 | 91 | +   | 727 | 53 | +   | 059 | 42 | STD | 145 | 32 | INV | 231 | 33 | YX  |
| 556 | 91 | +   | 642 | 01 | 4   | 728 | 74 | +   | 060 | 12 | 12  | 146 | 85 | +   | 232 | 75 | -   |
| 557 | 01 | 1   | 643 | 08 | 3   | 729 | 21 | 2   | 061 | 42 | RCL | 147 | 01 | 1   | 233 | 01 | 1   |
| 558 | 03 | 2   | 644 | 00 | 8   | 730 | 42 | STD | 062 | 02 | 02  | 148 | 54 | +   | 234 | 54 | +   |
| 559 | 01 | 3   | 645 | 53 | 1   | 731 | 13 | 13  | 063 | 65 | x   | 149 | 34 | FX  | 235 | 34 | FX  |
| 560 | 04 | 4   | 646 | 33 | 1   | 732 | 65 | x   | 064 | 01 | 1   | 150 | 65 | -   | 236 | 35 | 1/X |
| 561 | 65 | x   | 647 | 42 | STD | 733 | 01 | 1   | 065 | 00 | 0   | 151 | 43 | RCL | 237 | 65 | x   |
| 562 | 05 | 5   | 648 | 16 | 16  | 734 | 01 | 0   | 066 | 95 | =   | 152 | 00 | 00  | 238 | 02 | 2   |
| 563 | 93 | .   | 649 | 07 | IFF | 735 | 95 | =   | 067 | 42 | STD | 153 | 95 | =   | 239 | 65 | x   |
| 564 | 09 | 9   | 650 | 01 | 02  | 736 | 42 | STD | 068 | 13 | 13  | 154 | 42 | STD | 240 | 89 | +   |
| 565 | 06 | 6   | 651 | 54 | 00  | 737 | 02 | 02  | 069 | 53 | +   | 155 | 04 | 04  | 241 | 95 | =   |
| 566 | 94 | +   | 652 | 50 | 2   | 738 | 61 | STD | 070 | 43 | RCL | 156 | 76 | LBL | 242 | 42 | STD |
| 567 | 85 | +   | 653 | 51 | +   | 739 | 45 | YX  | 071 | 12 | 12  | 157 | 23 | LNK | 243 | 19 | 19  |
| 568 | 05 | 5   | 654 | 53 | +   | 740 | 76 | LBL | 072 | 55 | +   | 158 | 53 | +   | 244 | 53 | +   |
| 569 | 93 | .   | 655 | 43 | RCL | 741 | 52 | EE  | 073 | 89 | +   | 159 | 53 | +   | 245 | 43 | RCL |
| 570 | 01 | 1   | 656 | 18 | 18  | 742 | 00 | 0   | 074 | 54 | +   | 160 | 43 | RCL | 246 | 19 | 19  |
| 571 | 95 | =   | 657 | 55 | +   | 743 | 35 | 1/X | 075 | 34 | FX  | 161 | 19 | 19  | 247 | 22 | INV |
| 572 | 42 | STD | 658 | 43 | RCL | 744 | 91 | R/S | 076 | 95 | =   | 162 | 55 | -   | 248 | 23 | LNK |
| 573 | 06 | 08  | 659 | 13 | 13  | 745 | 76 | LBL | 077 | 42 | STD | 163 | 02 | 2   | 249 | 75 | -   |
| 574 | 43 | RCL | 660 | 34 | FX  | 746 | 44 | SUM | 078 | 12 | 18  | 164 | 54 | +   | 250 | 01 | 1   |
| 575 | 03 | 03  | 661 | 75 | -   | 747 | 01 | 1   | 079 | 87 | IFF | 165 | 22 | INV | 251 | 54 | +   |
| 576 | 23 | LNK | 662 | 43 | RCL | 748 | 94 | +   | 080 | 01 | 01  | 166 | 23 | LNK | 252 | 55 | +   |
| 577 | 45 | YX  | 663 | 07 | 07  | 749 | 34 | FX  | 081 | 34 | FX  | 167 | 75 | -   | 253 | 43 | RCL |
| 578 | 95 | .   | 664 | 54 | +   | 750 | 91 | R/S | 082 | 53 | +   | 168 | 01 | 1   | 254 | 19 | 19  |
| 579 | 00 | 0   | 665 | 55 | +   |     |    |     | 083 | 43 | RCL | 169 | 54 | +   | 255 | 65 | x   |
| 580 | 09 | 9   | 666 | 43 | RCL |     |    |     | 084 | 13 | 13  | 170 | 65 | x   | 256 | 43 | RCL |
| 581 | 02 | 2   | 667 | 08 | 08  |     |    |     | 085 | 55 | -   | 171 | 43 | RCL | 257 | 12 | 12  |
| 582 | 05 | 5   | 668 | 54 | +   |     |    |     | 086 | 43 | RCL | 172 | 04 | 04  | 258 | 95 | =   |
| 583 | 65 | x   | 669 | 22 | INV |     |    |     | 087 | 12 | 12  | 173 | 55 | -   | 259 | 42 | STD |
| 584 | 01 | 1   | 670 | 45 | YX  |     |    |     | 088 | 54 | +   | 174 | 43 | RCL | 260 | 13 | 13  |
| 585 | 93 | .   | 671 | 43 | RCL |     |    |     | 089 | 23 | LNK | 175 | 00 | 00  | 261 | 55 | +   |
| 586 | 09 | 9   | 672 | 09 | 09  |     |    |     | 090 | 65 | x   | 176 | 65 | x   | 262 | 01 | 1   |
| 587 | 07 | 7   | 673 | 54 | +   |     |    |     | 091 | 02 | 2   | 177 | 02 | 2   | 263 | 00 | 0   |
| 588 | 02 | 2   | 674 | 42 | STD |     |    |     | 092 | 95 | =   | 178 | 65 | x   | 264 | 95 | =   |
| 589 | 75 | -   | 675 | 14 | 14  |     |    |     | 093 | 42 | STD | 179 | 43 | RCL | 265 | 42 | STD |
| 590 | 93 | .   | 676 | 35 | 1/X |     |    |     | 094 | 19 | 19  | 180 | 18 | 18  | 266 | 02 | 02  |
| 591 | 08 | 8   | 677 | 65 | x   |     |    |     | 095 | 06 | 6   | 181 | 95 | =   | 267 | 61 | GTO |
| 592 | 01 | 1   | 678 | 43 | RCL |     |    |     | 096 | 42 | STD | 182 | 42 | STD | 268 | 23 | LNK |
| 593 | 03 | 3   | 679 | 00 | 00  |     |    |     | 097 | 06 | 06  | 183 | 05 | 05  | 269 | 76 | LBL |
| 594 | 95 | =   | 680 | 95 | =   |     |    |     | 098 | 76 | LBL | 184 | 43 | RCL | 270 | 52 | EE  |
| 595 | 42 | STD | 681 | 42 | STD |     |    |     | 099 | 22 | INV | 185 | 05 | 05  | 271 | 00 | 0   |
| 596 | 09 | 09  | 682 | 04 | 04  |     |    |     | 100 | 53 | +   | 186 | 55 | +   | 272 | 35 | 1/X |
| 597 | 53 | (   | 683 | 76 | LBL |     |    |     | 101 | 43 | RCL | 187 | 02 | 2   | 273 | 91 | R/S |







The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 273 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

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