United States
Department of
Agriculture

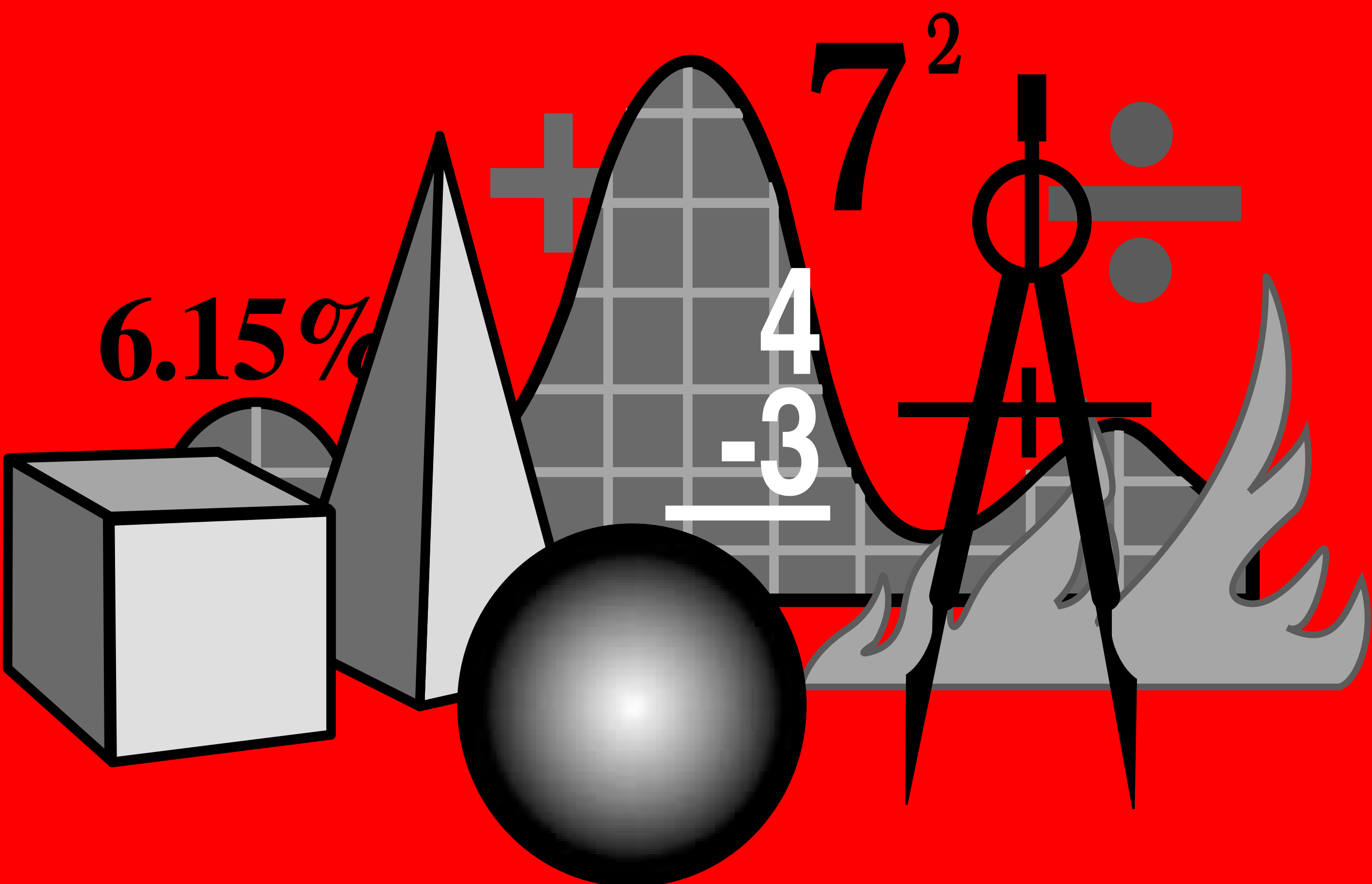
Forest Service

**Technology &
Development
Program**

5100—Fire Mgmt
May 2000
0051 1802—SDTDC
Revised July 2002

Firefighter Math

Self-Paced Math Course



ACKNOWLEDGMENTS

This self-paced math course is the result of the efforts of many Forest Service employees, contractors, and retired personnel, with special thanks to:

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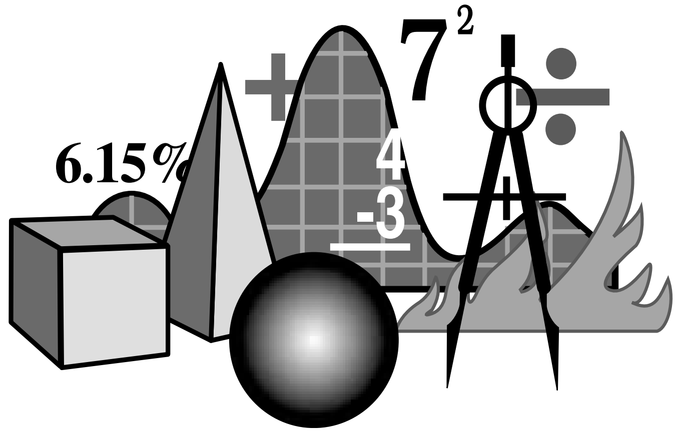

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May 2000
Revised July 2002

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Introduction and Scope

This self-paced math course is designed to prepare professional wildland firefighters for math-based training courses required for advancement to positions of greater responsibility. Consequently, the Forest Service will be able to more fully utilize the skills of more employees. Course content was developed from S244, S290, S390, and other training courses that require math.

A Mentor's Guide (see appendix A) outlines how a mentor can address students' questions and provide motivation for working to effectively complete the course. The guide also provides a problem-solving strategy for the student.

Chapters 1, 2, and 3 are a review for some students. Other students will begin this self-paced math course in chapter 4. Each math concept is developed by a text description with a graphic illustration and a sample problem with a detailed solution. In addition, exercise problems support each math concept. Appendix B, Developmental Units is a review of basic math skills. Appendix C supplies answers to these excercises. Appendix D is a final exam.

Steps to Success

Before starting this self-paced math course, select a mentor to serve as a resource and motivator. Provide your mentor with the information in appendix A. As a student, you also have a responsibility to ensure your success. Read the description for each math concept, follow the sample problems, study the illustrations, and work the exercise problems. If you have difficulty grasping a math concept, reread the description and review the sample problem thoroughly. If it still isn't clear, talk with your mentor. Typically, mentors can cite real life examples and descriptions. Follow these steps to success, to be well prepared for the final exam and for subsequent math-based training courses.

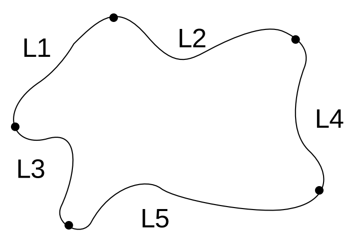
Some basic equipment is required to complete this math course. You will need a protractor, ruler, pencils, an engineer's ruler divided into tenths of an inch, a basic scientific calculator equipped with buttons labeled Tangent or Tan, $\sqrt{x}$, x^2, and a transparency of a Modified Acreage Grid (see chapter 5).

The material in chapter 1 describes how to determine perimeter, fractions, ratios, percentages, and area of burn.

[Note: To review basic math skills, see appendix B.]

1.1 Perimeter of Burn The **perimeter** is the distance around the fire or along the handline. Perimeter is determined by adding the lengths of the various lines that enclose the black area of a fire. The perimeter of a fire is often approximated by assembling a combination of known shapes and lines, since fires often burn in unusual shapes, such as fingers.

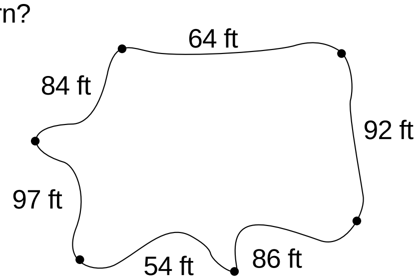
P = Perimeter = sum of the lengths of the sides
L = Length of a side



P = L1 + L2 + L3 + L4 + L5

The perimeter of this burn is L1 + L2 + L3 + L4 + L5.

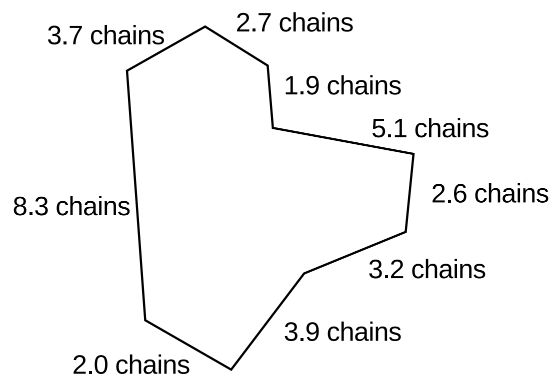
Example 1—The first fire of the season burns in approximately the following shape. What is the perimeter of the burn?



Add all the lengths of the sides.
P = 64 ft + 92 ft + 86 ft + 54 ft + 97 ft + 84 ft = 477 ft

The perimeter of the burn is 477 feet.

Example 2—The Division Supervisor (DIVS) is given the shape of the spot fire as illustrated below. What is the perimeter of this spot fire as measured in chains (66-foot units)? (A chain is the basic unit for measuring distances in fire-control work.)



Perimeter = Adding the lengths of all the sides.
P = (3.7 + 2.7 + 1.9 + 5.1 + 2.6 + 3.2 + 3.9 + 2.0 + 8.3) chains
P = 33.4 chains

The perimeter of the spot fire is 33.4 chains.

Note: When adding or subtracting the same units, such as chains, the numbers can be grouped together with parentheses, as above.

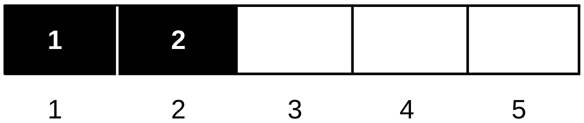
1.2 Fractions **Bits and Pieces —**Fractions are used often, such as when adding leftover pails of foam or when mixing gas and oil for chain saw fuel. Fractions allow the use of parts of a number or combinations of parts and whole numbers, such as 1/2, 1-2/3, or 12/16. The remainder found in long division can be changed to a fraction. Like whole numbers, fractions can be added, subtracted, divided, and multiplied. The common acceptable form for writing fractions in fire service adds a dash "-" between a whole number and a fraction, such as 1-1/2.

See appendix B for treatment of decimals.

A fraction consists of a **numerator (top number)** and a **denominator (bottom number)**.

$$\frac{\text{Numerator}}{\text{Denominator}} = \frac{\text{Number of Parts}}{\text{Number of Parts in a Whole}}$$

Example 3—What fraction is shaded? What fraction is not shaded?



The box is divided into five parts. Two of those five parts are shaded. The shaded fraction represents 2/5.

So, 2/5 of the figure is shaded.

Three of the five parts are not shaded. The unshaded fraction represents 3/5.

So, 3/5 of the figure is not shaded.

Fractions can also describe whole numbers or a whole number with a remainder (fraction). For example, a whole number can be written as: 4/2 = 2 8/4 = 2 32/16 = 2.

The whole number 1 can be written as:

1/1 = 1 3/3 = 1 6/6 = 1 7/7 = 1

Fractions larger than 1 have a larger number on top.

4/3 8/5 6/4 3/2

1.3 Simplifying Fractions Simplifying a fraction is writing a number in its most basic form. Sometimes fractions involve very large numbers in both the numerator (top number) and in the denominator (bottom number). As a general rule, it is easier to work with simpler fractions. So, always simplify.

Always Simplify. There are three basic rules, A, B, and C, for simplifying fractions.

Rule A *Any number written over 1 is that number. 6/1 = 6.*

Example 4—Simplify: 7/1

7/1 = 7

Rule B *A fraction can be simplified if the top and bottom numbers can both be divided by the same number, without leaving a remainder.* 6/3 $= \frac{(6 \div 3)}{(3 \div 3)} = \frac{2}{1} = 2$

Example 5—Simplify 14/16.

Step 1. Begin by checking whether both the top and bottom numbers can be divided by 2, 3, 5, 7, 9, 11, 13, or 17. In firefighter math, checking 2, 3, and 5 is usually all that is required.

$\frac{14 \div 2}{16 \div 2} = \frac{7}{8}$ Both the top and bottom numbers can be divided by 2.

Step 2. Repeat step 1 until no further division is possible. This will give the simplest form of the fraction.

$\frac{7}{8}$ This is the simplest form of the fraction, since there is no number by which both the top and bottom can be divided without leaving a remainder.

Therefore, 14/16 simplified is 7/8.

Example 6—Simplify 7/16.

Step 1. Divide the top and bottom number by the same number. There isn't a number that goes into both top and bottom numbers.

Therefore, 7/16 simplified is 7/16.

Example 7—Simplify 21/16

Rule C *If the top number is larger than the bottom number, and neither number can be divided by the same number, divide the top number by the bottom number.*

Divide the top number by the bottom number.
21 ÷ 16

```
     1
16 ) 21
    -16
      5
```

Long division provides the whole number—1.

The remainder makes up part of the fraction. To make the fraction, put the remainder over the denominator—5/16.

Therefore, 21/16 simplified is the whole number plus the remainder—1-5/16.

Example 8—Simplify 8/1.

Remember that "any number over 1 equals that number," so 8/1 = 8.

Therefore, 8/1 = 8.

Example 9—Simplify 18/24.

Step 1. Check to see whether the top and bottom numbers can be divided by 2.

$\frac{18 \div 2}{24 \div 2} = \frac{9}{12}$ Yes, both 18 and 24 can be divided by 2.

Step 2. Repeat Step 1. The top can't be divided by 2. Check to see whether both numbers can be divided by 3.

$\frac{9 \div 3}{12 \div 3} = \frac{3}{4}$ Yes, both the top and bottom numbers can be divided by 3. No further division is possible.

18/24 simplified is 3/4

Example 10—Simplify 5/2.

Step 1. Check to see whether division of both the top and bottom by 2, 3, or 5 is possible. The answer is No.

The top number is larger than the bottom number.

Step 2. Divide the top number by the bottom number.

```
    2
2 ) 5
  - 4
    1
```

The answer to this division problem is 2 remainder (R) 1. The whole number is 2, and the remainder is 1.

Step 3. The remainder 1 goes over the original denominator 2, turning the remainder into a fraction.

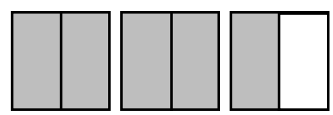
R = $\frac{1}{2}$ ← remainder / ← original denominator

Add the whole number 2, with remainder 1/2 to get 2-1/2.

5/2 = 2-1/2 = 2.5

See appendix B for treatment of decimals.

The solution can be shown graphically.



The shaded area is 2-1/2 = 5/2. The unshaded area is 1/2 = 1/2.

1.4 Multiplying Fractions **Multiply Straight Across**—A whole number and a fraction, or two or more fractions, can be multiplied together. Whole numbers and fractions must be changed to all fractions, with no whole numbers, in order to multiply.

Step 1. Multiply the tops (numerators) by each other.

Step 2. Multiply the bottoms (denominators) by each other.

Example 11—Multiply 3 x 1/4.

$3 \times \frac{1}{4} = \frac{3}{1} \times \frac{1}{4} = \frac{3 \times 1}{1 \times 4} = \frac{3}{4}$

Step 1. Multiply straight across the top. 3 x 1 = 3

Step 2. Multiply straight across the bottom. 1 x 4 = 4

Step 3. Can 3/4 be simplified? No.

3 x 1/4 = 3/4

Example 12—Multiply. $\frac{5}{7} \times \frac{8}{4}$

Step 1. Multiply straight across the top. 5 x 8 = 40

Step 2. Multiply straight across the bottom. 7 x 4 = 28

$$\frac{5}{7} \times \frac{8}{4} = \frac{5 \times 8}{7 \times 4} = \frac{40}{28}$$

Step 3. Simplify the fraction. 40/28

$$\frac{40 \div 2}{28 \div 2} = \frac{20}{14} = \frac{20 \div 2}{14 \div 2} = \frac{10}{7}$$

The top number is larger than the bottom number, so divide.

10 ÷ 7 = 1 R 3 = 1-3/7

5/7 x 8/4 = 1-3/7

1.5 Dividing Fractions

Flip the second fraction and then multiply across. Division of fractions involves using the **reciprocal** (flipped form) of the second fraction. The reciprocal of a number is such that the product of a number and its reciprocal is 1. To get the reciprocal, simply interchange (flip) the numerator and the denominator. 1/3 becomes 3/1, 4/5 becomes 5/4, and so on. After the second fraction has been flipped, the division problem turns into a multiplication problem, and the numerators and denominators are multiplied straight across.

Example 13—Divide. $\frac{1}{2} \div \frac{2}{3}$

Step 1. Flip the second fraction. 2/3 becomes 3/2.

$$\frac{1}{2} \div \frac{2}{3} = \frac{1}{2} \times \frac{3}{2}$$

Step 2. Multiply. $\frac{1}{2} \times \frac{3}{2} = \frac{1 \times 3}{2 \times 2} = \frac{3}{4}$

Step 3. Can 3/4 be simplified? No.

1/2 ÷ 2/3 = 3/4

Example 14—Divide. $\frac{2}{5} \div \frac{3}{4}$

Step 1. Flip the second fraction. Then 3/4 becomes 4/3.

$$\frac{2}{5} \div \frac{3}{4} = \frac{2}{5} \times \frac{4}{3}$$

Step 2. Multiply across both top and bottom.

$$\frac{2}{5} \times \frac{4}{3} = \frac{2 \times 4}{5 \times 3} = \frac{8}{15}$$

Step 3. Can 8/15 be simplified? No.

2/5 ÷ 3/4 = 8/15

1.6 Adding Fractions

Fractions must have a common denominator (the bottom numbers must be the same) before being added and simplified.

Example 15—Add and simplify. 1/4 + 1/4

Step 1. Are the denominators the same? Yes.

Step 2. Add the numerators (top numbers), and put them over the common denominator.

$$\frac{1}{4} + \frac{1}{4} = \frac{1+1}{4} = \frac{2}{4}$$

Step 3. Can 2/4 be simplified? Yes, both numbers are divisible by 2.

$$\frac{2 \div 2}{4 \div 2} = \frac{1}{2}$$

1/4 + 1/4 = 1/2

Example 16—Add and simplify. 1/2 + 1/4

Step 1. Are the denominators the same? No.

Step 2. Is one of the denominators a multiple of the other? Yes.

Step 3. Find a common denominator.

$\frac{1}{2} + \frac{1}{4}$ 2 is a multiple of 4, so change $\frac{1}{2}$ to $\frac{?}{4}$

2 x 2 = 4 so multiply both the top and bottom by 2.

$\frac{1 \times 2}{2 \times 2} = \frac{2}{4}$ So, $\frac{1}{2} = \frac{2}{4}$

Step 4. Substitute 2/4 for 1/2 and add, $\frac{1}{4} + \frac{2}{4} = \frac{3}{4}$

Step 5. Can 3/4 be simplified? No.

1/4 + 1/2 = 3/4

Example 17—Add and simplify. $\frac{1}{4} + \frac{1}{3}$

Step 1. Are the denominators the same? No.

Step 2. Is one of the denominators a multiple of the other? No. Multiply the denominators to find a common denominator.

4 x 3 = 12 The new denominator is 12.

Step 3. Expand (opposite of simplify) both fractions to have a denominator of 12.

$\frac{1 \times 3}{4 \times 3} = \frac{3}{12}$ $\frac{1 \times 4}{3 \times 4} = \frac{4}{12}$

Step 4. Add and simplify.

$\frac{3}{12} + \frac{4}{12} = \frac{7}{12}$ Can 7/12 be simplified? No.

$$\boxed{\frac{1}{4} + \frac{1}{3} = \frac{7}{12}}$$

Adding Multiple Fractions

The same process applies when adding multiple fractions. Add all fractions with like denominators. Then add fractions with denominators that are multiples of the other denominators. Then find common denominators for the remaining fractions. Add and simplify.

Example 18—Add and simplify.

$\frac{2}{3} + \frac{3}{4} + \frac{5}{8} + \frac{1}{5} + \frac{1}{8} + \frac{2}{4} + \frac{1}{3}$

Add all fractions with like denominators and simplify.

$\frac{2}{3} + \frac{1}{3} = \frac{3}{3} = 1$ $\frac{3}{4} + \frac{2}{4} = \frac{5}{4}$ $\frac{5}{8} + \frac{1}{8} = \frac{6}{8} = \frac{3}{4}$

$\frac{1}{5} + 1 + \frac{5}{4} + \frac{3}{4} = \frac{1}{5} + 1 + \frac{5+3}{4} = \frac{1}{5} + 1 + \frac{8}{4} =$

$\frac{1}{5} + 1 + 2 = \frac{1}{5} + 3 =$ 3-1/5

Can 3-1/5 be simplified further? No.

$$\boxed{\frac{2}{3} + \frac{3}{4} + \frac{5}{8} + \frac{1}{5} + \frac{1}{8} + \frac{2}{4} + \frac{1}{3} = 3\text{-}1/5}$$

1.7 Subtracting Fractions Fractions must have a common denominator (the bottom numbers must be the same) before being subtracted.

Example 19—Subtract and simplify. 2-1/2 – 2/3

First, both the numbers must be put in fraction form. Earlier in this chapter, it was shown that 2-1/2 = 5/2. See example 10. 5/2 – 2/3

Step 1. Subtract fractions with like denominators. There are none.

Step 2. Subtract fractions with denominators that are multiples of the other denominators. There are none.

Step 3. Find a common denominator by multiplying the denominators by each other. 3 x 2 = 6 The common denominator is 6.

Step 4. Expand (opposite of simplify) both fractions to have a denominator of 6.

$\frac{5 \times 3}{2 \times 3} = \frac{15}{6}$ $\frac{2 \times 2}{3 \times 2} = \frac{4}{6}$

Step 5. Subtract.

$\frac{15}{6} - \frac{4}{6} = \frac{11}{6}$

Step 6. Simplify. Can 11/6 be simplified? Yes.

Since the top number is larger than the bottom number, the fraction can be simplified to a whole number with a fraction remainder.

$\frac{11}{6} - \frac{6}{6} = \frac{5}{6}$ It is simplified to 1-5/6. Can this be simplified further? No.

$\frac{5}{2} - \frac{2}{3} = 1\text{-}5/6$

1.8 Ratios A ratio is a proportional relationship of one value to another, e.g., the ratio of gas to oil in chain saw mix. Ratios can be written either as a fraction, 1/2, or in ratio notation, 1:2. The value of a ratio is the division of the first number by the second number.

$1{:}40 = \frac{1}{40}$ This ratio is read as “1 to forty.”

For example, the fraction 1/30 may be written as the ratio 1:30.

Example 20—The Mara Bella District has 6 engines. The Baldy District has 5 engines. What is the ratio of engines on the Mara Bella versus the Baldy District?

The ratio of engines on the Mara Bella versus Baldy District is 6:5 or 6/5.

Percentage—A percentage is another way of describing a ratio with respect to 100. Percent (%), means how many out of a hundred (per hundred).

Example 21a—Write four notations for 56.8%.

56.8% = 56.8 out of 100
56.8% = 56.8/100
56.8% = 56.8:100
56.8% = 0.568

Performing the calculation above results in moving the decimal two places to the left because there are two zeros in 100.

56.8% = 56.8/100 = 0.568

Divisions or Multiples of 10—Dividing by a factor of 10, 100, 1,000, etc., moves the decimal place to the left by the number of zeros in the factor. For example, when dividing by 100, count two zeros and move the decimal two places to the left—3/100 = .03. Multiplying by multiples of 10, 100, 1,000, etc., moves the decimal place to the right by the number of zeros in the multiple.

Divide by a factor of 10.

$\frac{3}{10} = .3$ $\frac{3}{100} = .03$ $\frac{3}{1000} = .003$

← Division, move decimal places to the left.

Multiply by a factor of 10.

3 x 10 = 30	.03 x 10 = .3
3 x 100 = 300	.03 x 100 = 3
3 x 1000 = 3000	.03 x 1000 = 30

Multiplication, move decimal places to the right. →

Example 21b—Write the following as a decimal. 35.4%

Remember, percent means how much out of 100.
35.4% ÷ 100% = ?
There are two zeros in 100, so move the decimal point two places to the left.

35.4% = 35.4 /100 = 0.354

Just the opposite happens when multiplying by 100 percent.

Example 21c—Change 0.75 to a percentage and multiply by 100 percent.

There are two zeros in 100. Move the decimal point two places to the right.

0.75 x 100% = 75%

Example 22—Write as a percentage. 0.509
0.509 x 100% = ?

There are two zeros in 100, so move the decimal point two places to the right.
0.509 x 100% = 50.9%

0.509 = 50.9%

When solving a more complex percentage problem, write the problem down in words and numbers.

Example 23—The chain saw gas/oil mix is 30 parts gas to 1 part oil. Chain saw oil comes in 2-pint cans. How much gas is added to 2 pints of oil for a 1:30 oil:gas mixture?

The ratio of 1:30 means that for every 1 part of oil, there must be 30 parts of gas. There are 2 pints of oil.

The amount of gas needed will be 30 times 2.
30 x 2 = 60 pints

Sixty pints of gas are needed for a 1:30 oil:gas mixture that contains 2 pints of oil.

Example 24—Sabrina has a 2-1/2-gallon container. She is going to fill it with a 40:1 gas to oil mixture. How much of each does she need to put into the container?

Step 1. The total of the gas and the oil mixture is 40 + 1 = 41 parts.

Step 2. Divide the 2-1/2-gallon container into 41 parts, using a calculator.

$$\frac{\text{2-1/2 gallons}}{41} = \frac{2.5}{41} = 0.06 \text{ gallons}$$

Step 3. The gas has 40 of these parts.
0.06 gallons x 40 = 2.44 gallons

Step 4. The oil has 1 part.
0.06 gallons x 1 = 0.06 gallons

She needs 2.44 gallons of gas and 0.06 gallons of oil.

Notice that the total amount of gas and oil adds up to 2.5 gallons. 2.44 + 0.06 = 2.5 = 2-1/2

See chapter 2, for converting 0.06 gallons of oil to a more useful term, such as cups or pints.

Example 25—When the crew leaves for a fire, they have a full tank of foam agent. This tank holds a total of 5 gallons. When they return to the station, they find only 1 gallon. What percentage of the foam was used? What percentage is left?

(Hint: the percentage used + the percentage left should equal 100 percent)

Step 1. Find how much foam was used.
5 gallons total – 1 gallon of foam left = 4 gallons of foam used

Step 2. Find the percentage of foam used. Since 4 of the total 5 gallons were used, the fraction becomes 4/5.

Step 3. Perform the division to obtain a decimal.

$$\begin{array}{r} 0.8 \\ 5.0\overline{)\,4.0\,0} \\ -\underline{4.0\,0} \\ 0 \end{array}$$

To convert the decimal to a percentage, multiply by 100 percent.
0.8 x 100% = 80.0%

The crew used 80.0% of the foam.

<u>Step 4.</u> To find the percentage left in the tank, subtract the percentage used from 100 percent.
100% – 80% = 20%
Or, divide the number of gallons of foam left by the total number of gallons of foam. 1/5 = 0.2
Multiply by 100 percent. 0.2 x 100% = 20%

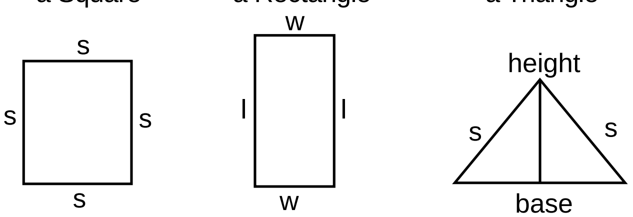
The crew had 20% of the foam left.

1.9 Area of Burn Another common use of math is the use of multiplication to determine areas. Area is the amount of surface covered within a given perimeter. "A" is the symbol used for area. Area is useful in determining burnout acreage. Area is always in square units: square feet (ft^2), square yards (yd^2), etc.

When a number is "squared," it has an exponent of 2. The number being squared is called the base number. The exponent represents the number of times the base number is multiplied by itself. For further explanation of exponents, see appendix B.8.

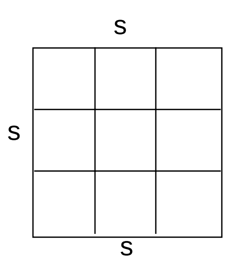
A square, rectangle, and triangle are shown in the following figures, with their formulas for area and perimeter.

Area of a Square | Area of a Rectangle | Area of a Triangle



A = s x s | A = l x w | A = 1/2 base x height
P = 4s | P = 2l + 2w | P = s + s + base

Example 26—Find the area of the square below.



The equation to find the area of a square is Area = s x s.

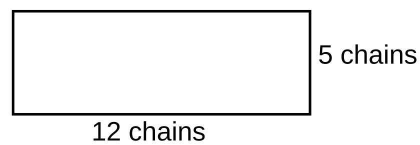
A = 3 chains x 3 chains = 9 square chains or 9 chains squared or 9 ch^2

Count the units to see that there are 9 square units in the square.

The area of the square is 9 square chains.

Note that chains x chains = chains squared, or square chains, or ch^2.

Example 27—Find the area of the rectangle below.

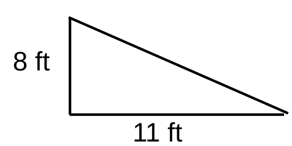


To find the area, use Area = length x width.

A = 5 ch x 12 ch = 60 square chains

The area of the above rectangle is 60 square chains.

Example 28—Find the area of the triangle below. To find the area, use Area = 1/2 x base x height.



The base in this case is b = 11 ft. The height is h = 8 ft.

Area = 1/2 x b x h

$$\text{Area} = \frac{1}{2} \times \frac{11\text{ ft}}{1} \times \frac{8\text{ ft}}{1}$$

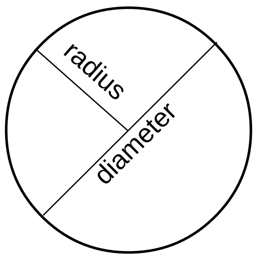
Multiplying across the top and bottom gives: $\text{Area} = \frac{88\text{ ft}^2}{2}$

Simplify. The top and bottom can be divided by 2.

$$\text{Area} = \frac{88 \text{ ft}^2/2}{2/2} = \frac{44 \text{ ft}^2}{1} = 44 \text{ ft}^2$$

The area of the triangle is 44 ft^2.

Circles—Most calculations involving circles, use π (spelled pi, pronounced pie). $\pi = 3.14$ Always use π when determining circumference, area, and volume of a circle.



The diameter (d) of a circle is a line passing through the center of a circle with endpoints on the circle. A diameter measures the distance across a circle passing through the center. The radius (r) is a line segment from the center of a circle to a point on the circle. A radius measures the distance from the center of a circle to the circle itself. Consequently, the radius is half of the diameter.

radius = 1/2 x diameter, abbreviated $r = 1/2\ d$
$(2)r = 1/2\ d(2)$ multiply both sides by 2 to get
2 radius = diameter, abbreviated $2r = d$

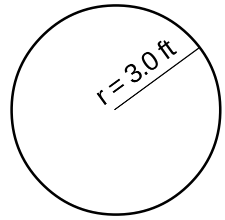
The circumference (C) of a circle is the distance around it. In other words, it is the perimeter of the circle. The circumference of a circle is found by multiplying the diameter of the circle by π. $\pi = 3.14$

Circumference = π x diameter
$C = d \times \pi = \pi d$
Or, using the radius instead of the diameter,
$C = 2r \times \pi = 2\pi r$

Finally, the area of a circle is given by: $A = \pi \times r \times r$
$A = \pi \times r^2$

Or, using the diameter: $A = \pi \times d/2 \times d/2$
$A = \pi \times (d/2)^2$
$A = \pi d^2/4$

Example 29—Find the area and circumference of the circle.



Use the formula: $A = \pi \times r \times r$
The radius is given as 3.0 feet.

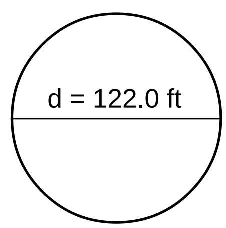
$A = 3.14 \times 3.0 \text{ ft} \times 3.0 \text{ ft} = 28.26 \text{ ft}^2$

The area of the circle is 28.3 ft^2.

Calculating the circumference with the known radius, $C = 2\pi r$
$C = 2 \times 3.14 \times 3.0 \text{ ft} = 18.8 \text{ ft}$

The circumference of the circle is 18.8 feet.

Example 30—There was a spot fire early in the fire season in the general shape of a circle. What was the circumference of the fire? What was the area of the spot fire?



The circumference is found from $C = \pi d$.

The diameter is given as $d = 122.0$ ft.
$C = 122.0 \text{ ft} \times \pi$
$C = 122.0 \text{ ft} \times 3.14 = 383.1 \text{ ft}$

The circumference of the spot fire is 383 feet.

The area of a circle equals πr^2. Area of circle = $\pi \times r \times r$
From this equation, the radius is required. The radius is 1/2 the diameter, which is given as 122.0 ft.

$r = d/2$
$r = 122.0 \text{ ft} / 2$
$r = 61.0 \text{ ft}$

The area of the burn is $A = \pi \times r \times r$

$A = \pi \times 61.0 \text{ ft} \times 61.0 \text{ ft}$
$A = 3.14 \times 61.0 \text{ ft} \times 61.0 \text{ ft} = 11{,}683.9 \text{ ft}^2$

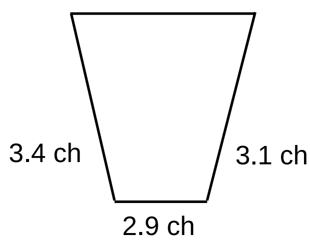
The area of the spot fire is 11,684 ft^2.

In chapter 2, area will be converted to acres.

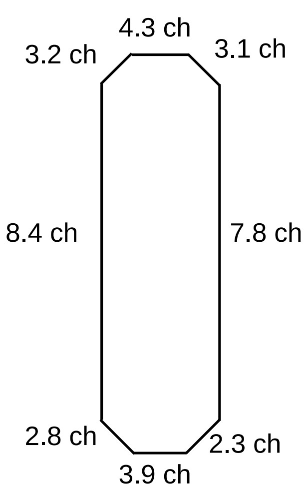
EXERCISES

P = Perimeter **L = Length** **P = L + L + L**

Problem 1. A hotshot crew constructs a handline to contain a fire. See the diagram of the handline below. How many chains of handline did the crew put in?

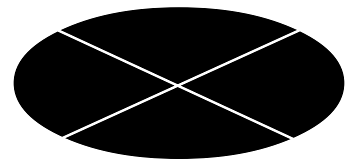


Problem 2. Find the perimeter of the fire below.

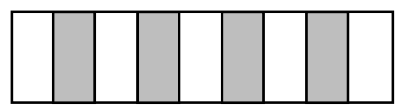


Problems 3, 4, & 5.
What fraction is shaded?
What fraction is not shaded?
What is the total amount of shaded and unshaded area?

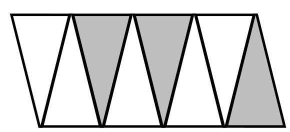
Problem 3.



Problem 4.



Problem 5.



Simplify.

Problem 6. 4/4

Problem 7. 22/1

Problem 8. 3/11

Problem 9. 6/10

Simplify.

Problem 10. 84/90

Problem 11. 18/24

Problem 12. 8/36

Problem 13. 15/9

Problem 14. 4/3

Problem 15. 6/4

Multiply and simplify.

Problem 16. $5 \times \frac{2}{3}$

Problem 17. $9 \times \frac{2}{5}$

Problem 18. $\frac{4}{7} \times \frac{3}{9}$

Problem 19. $\frac{8}{13} \times \frac{11}{19}$

Problem 20. $\frac{3}{5} \times \frac{4}{7}$

Find the reciprocal.

Problem 21. $\frac{5}{9}$

Problem 22. $\frac{5}{32}$

Problem 23. 5

Problem 24. $\frac{1}{2}$

Divide and simplify.

Problem 25. $\frac{5}{7} \div \frac{9}{12}$

Problem 26. $\frac{8}{13} \div \frac{11}{50}$

Problem 27. $\frac{4}{5} \div \frac{2}{3}$

Problem 28. $\frac{5}{8} \div 2$

Problem 29. $\frac{3}{4} \div \frac{1}{5}$

Add and simplify.

Problem 30. $\frac{1}{6} + \frac{7}{18}$

Problem 31. $\frac{2}{9} + \frac{5}{6}$

Problem 32. $\frac{7}{10} + \frac{2}{21} + \frac{1}{7}$

Problem 33. $\frac{2}{5} + \frac{11}{10} + \frac{7}{15}$

Problem 34. $\frac{1}{2} + 2$

Subtract and simplify.

Problem 35. $\frac{9}{10} - \frac{4}{100}$

Problem 36. $\frac{4}{5} - \frac{2}{3}$

Problem 37. $\frac{5}{12} - \frac{5}{16}$

Problem 38. $3\text{-}1/3 - \frac{5}{6}$

Problem 39. Raul's crew is composed of 13 men and 5 women. What is the ratio of men to women? What is the ratio of women to men? Convert this to a percentage. What is the ratio of men to the total crew? What is the ratio of women to the total crew?

Convert to a percentage.

Problem 40. 5/50

Problem 41. 0.194

Problem 42. 1 to 3

Problem 43. 4 : 5

Problem 44. 3 to 4

Convert to a decimal.

Problem 45. 21.7%

Problem 46. 61.0%

Problem 47. 50/100

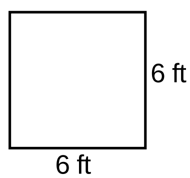
Problem 48. 43/1000

Problem 49. Rick worked in unit supply at fire camp. There were a total of 56 tools. Ten were shovels, 33 were pulaskis, and 13 were mcLeods. What percentage were shovels?

A = area
s = side
l = length
w = width
b = base
h = height
P = perimeter

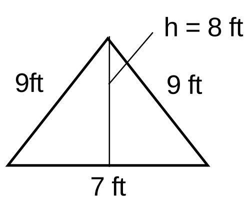
Find the area and perimeter of each figure.

Problem 50.

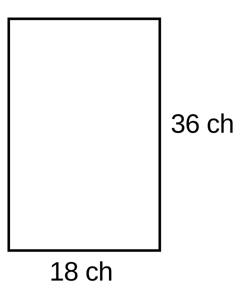


Problem 51.

Problem 52.

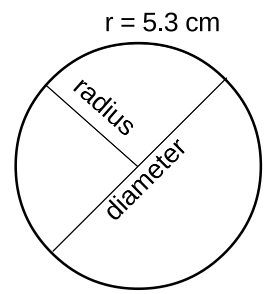


Problem 53.



d = diameter
r = radius
diameter = 2 radius
1/2 diameter = radius
C = circumference
π = 3.14

Problem 54. Find the area and circumference of the circle.



Problem 55. A spot fire burns in the shape of a circle. The diameter of the circle is 268 feet. What is the perimeter (circumference) and the area of the fire?

Problem 56. Pizza Galore has two 7-inch pizzas for $9.99 or one 14-inch pizza for $9.99. Which is a better deal (has more surface area)?

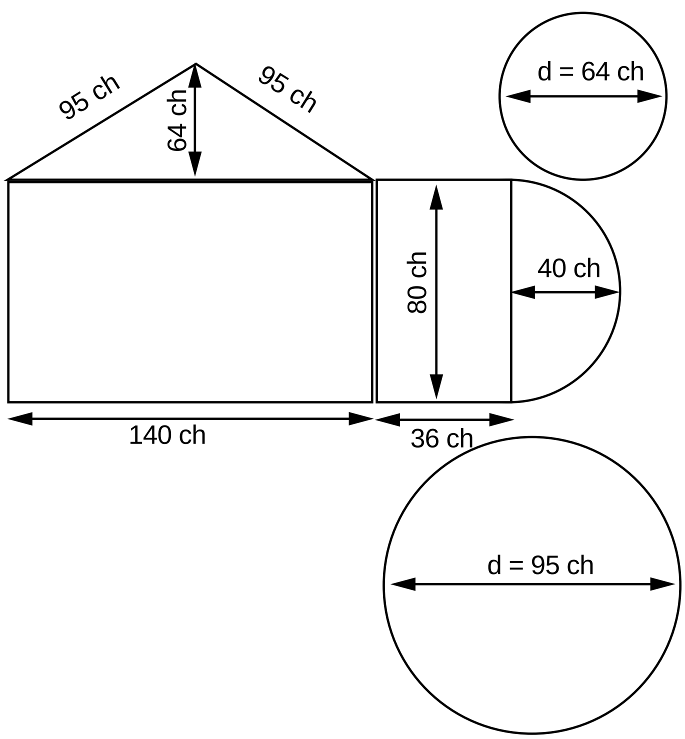
CHAPTER PROBLEM

The main wind-driven fire burned up the mountainside for a distance of 140 chains, by a width of 80 chains. The burn was the approximate shape of a rectangle with some fingers. One of the fingers burnt in the shape of a triangle with a height of 64 chains and two sides of 95 chains each. The second finger could be broken into a semicircle with a radius of 40 chains and a rectangle with a width of 36 chains. Two of the larger spot fires had a diameter of 95 chains and 64 chains each. The spot fires were in the approximate shape of circles.

What is the perimeter of the main fire?
What is the total area of the three fires?

On the main fire, 50 chains of the perimeter of line were constructed by hand crews, and the rest were constructed by dozers.

How many chains of dozer line were constructed?
What percentage of line was constructed by dozers, and what percentage was constructed by hand crews?



Use the blank problem-solving worksheet found on page 261. For the solution, see page 163.

Chapter 2 describes converting units of measure, using conversion factors, and a unit cancellation table. Conversion tables of typical units in fire service are included as reference material.

2.1 Unit Conversion and Conversion Factors

A unit conversion is an equal exchange of value involving different units. Often measurements are given in one set of units, such as feet; but are needed in different units, such as chains. A conversion factor enables feet to be changed to chains as an equal exchange. Problem solving in units that are familiar to fire staff is crucial to sound planning. Making a mistake with units can be very costly.

A Conversion Factor is a number used to change one set of units to another, by multiplying or dividing. When a conversion is necessary, the appropriate conversion factor/equal value must be used. For example, to convert inches to feet, the appropriate conversion value is 12 inches equal 1 foot. To convert minutes to hours, the appropriate conversion value is 60 minutes equal 1 hour.

Setting up a **Unit Cancellation Table** helps keep units straight, even for the most seasoned professional firefighter. This is particularly important when more than one unit conversion is necessary to obtain the desired unit. A cancellation table is developed by using known units, conversion factors, and the fact that anything ÷ anything = 1. Line up the units so all the units cancel, except for the unit desired. To cancel a unit, the same unit must be in the numerator and in the denominator. This will become 1. Multiply straight across. Divide the top number by the bottom number. This will give the answer desired in the desired units.

Answers should be presented with the appropriate number of significant digits. For significant digits and rounding up, see appendix B.7, Using Decimals.

Example 1—Gretchen has \$5 and wants to play arcade games. She exchanges her \$5 for quarters. How many quarters did she receive?

Note: For this to be an equal exchange/conversion, Gretchen must end up with the same amount of money with which she started.

Step 1. The appropriate conversion factor is:
4 quarters = 1 dollar.

Step 2. Set up the unit cancellation table so all units except the desired unit will cancel when converting 5 dollars to quarters. Dollars is given, so that will go in the numerator. The conversion needs to be set up so the dollars will cancel. To cancel, dollars must be in the denominator.

$$\begin{array}{|l|c|l} 5\ \cancel{\text{dollars}} & 4\ \text{quarters} & = 20\ \text{quarters} \\ \hline & 1\ \cancel{\text{dollar}} & \end{array}$$

Notice that the dollar units on the top and bottom cancel, leaving quarters as the only unit.

Gretchen will receive 20 quarters for 5 dollars.

Example 2—Monique has 10 dimes. If she traded them in for quarters, how many quarters would she get?

Step 1. The appropriate conversion factors are:
4 quarters = 1 dollar, 10 dimes = 1 dollar

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, quarters.

$$\begin{array}{|l|c|c|l} \cancel{10\ \text{dimes}} & \cancel{1\ \text{dollar}} & 4\ \text{quarters} & = 4\ \text{quarters} \\ \hline & \cancel{10\ \text{dimes}} & \cancel{1\ \text{dollar}} & \end{array}$$

Notice that the dime units on the top and bottom cancel as well as the dollars, leaving quarters as the only unit.

Monique will get 4 quarters for 10 dimes.

Example 3—Ralph wants to know how many seconds are in 3 hours and 36 minutes.

Step 1. Change 3 hours and 36 minutes to the same units. This can be in terms of hours or minutes. Using minutes is easier because the time value will need to be in minutes.

The appropriate conversion factor is: 1 hour = 60 minutes.

3 ~~hr~~	60 min	= 3 x 60 = 180 minutes
	1 ~~hr~~	

3 hours and 36 minutes = 180 minutes plus 36 minutes = 216 minutes

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, seconds.

The appropriate conversion factor is:
1 minute = 60 seconds.

216 ~~min~~	60 sec	= 216 x 60 = 12,960 seconds
	1 ~~min~~	

> There are 12,960 seconds in 3 hours 36 minutes.

Notice that the hour units on the top and bottom cancel as well as the minutes, leaving seconds as the only unit.

Example 4—How many pints are in a 5-gallon pail? How many cups are in a 5-gallon pail?

Step 1. Find the appropriate conversion factors in conversion table 2.1 at the end of this chapter.
1 gallon = 4 quarts, 1 quart = 2 pints, 1 pint = 2 cups

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, pints.

5 ~~gallons~~	4 ~~quarts~~	2 pints	= 40 pints
	1 ~~gallon~~	1 ~~quart~~	

> There are 40 pints in 5 gallons.

40 ~~pints~~	2 cups	= 80 cups
	1 ~~pint~~	

> There are 80 cups in 5 gallons.

Example 5—Javier constructed 2,678 feet of dozer line. How many chains of dozer line did he construct?

Step 1. Find the appropriate conversion factor in table 2.1.
1 chain = 66 feet

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, chains.

2,678 ~~feet~~	1 chain	= 40.6 chains, which
	66 ~~feet~~	is 41 chains, rounded-up

> Javier constructed 41 chains of dozer line.

Notice that table 2.2 has two conversions for each set of units. When setting up the table, it is not important which conversion factor is used. What is important is that the appropriate units cancel.

Example 6—Repeat example 5 using the other conversion factor presented in table 2.2.

Step 1. The appropriate conversion factor is 0.0152 chains per foot.

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, chains.

2,678 ~~feet~~	0.0152 chains	= 40.7 chains = 41 chains
	1 ~~foot~~	

Example 7—Ludka's crew has been out on the Marre Fire for 2 weeks and 2 days. How many hours have they been there?

Step 1. Find the appropriate conversion factors.
1 week = 7 days, 1 day = 24 hours

First, 2 weeks and 2 days will have to be changed to the same units. It doesn't matter whether days or weeks are used so long as the same units are used.

Step 2. Set up the cancellation table to convert 2 weeks to days.

$$\begin{array}{|c|c|} 2\ \cancel{\text{week}} & 7\ \text{days} \\ \hline & 1\ \cancel{\text{week}} \end{array} = 14\ \text{days}$$

Since they were out 2 weeks and 2 days, add the 2 days.
14 days + 2 days = 16 days

Continuing,

$$\begin{array}{|c|c|} 16\ \cancel{\text{days}} & 24\ \text{hours} \\ \hline & 1\ \cancel{\text{day}} \end{array} = 384\ \text{hours}$$

Ludka's crew has been out on the fire for 384 hours.

Example 8a—Nina fills a backpack pump bag with 5 gallons of water. How much weight in water has she added to her pack?

Step 1. Find the appropriate conversion factor in table 2.1.
1 gallon = 8.3 pounds

Step 2. Set up the cancellation table so all units will cancel except the desired unit, pounds.

$$\begin{array}{|c|c|} 5\ \cancel{\text{gallons}} & 8.3\ \text{pounds} \\ \hline & 1\ \cancel{\text{gallon}} \end{array} = 41.5\ \text{pounds} = 42\ \text{pounds}$$

Nina has added 42 pounds to her pack.

Example 8b—Nina wants a 0.5 percent foam solution for a 5-gallon backpack trombone pump. How much volume of foam concentrate will Nina add to the 5-gallon bag for a 0.5 percent foam solution?

Set up the problem. Percent means per 100. See chapter 1.8.

$$\begin{array}{|c|c|} 5\ \text{gal} & 0.5\ \cancel{\%} \\ \hline & 100\ \cancel{\%} \end{array} = 0.025\ \text{gallons}$$

Nina does not have the correct beaker to accurately measure out 0.025 gallons. She usually measures the foam concentrate with a cup. Convert the gallon value to an equal amount in cups.

Step 1. Find the appropriate conversion factors in table 2.1.
1 gallon = 4 quarts, 1 quart = 2 pints, 1 pint = 2 cups

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, cups.

$$\begin{array}{|c|c|c|c|} 0.025\ \cancel{\text{gallons}} & 4\ \cancel{\text{quarts}} & 2\ \cancel{\text{pints}} & 2\ \text{cups} \\ \hline & 1\ \cancel{\text{gallon}} & 1\ \cancel{\text{quart}} & 1\ \cancel{\text{pint}} \end{array} = 0.4\ \text{cups}$$

Nina will add 0.4 cup foam concentrate to the 5-gallon backpack bag for a 0.5 percent foam solution.

Example 8c—If Nina puts 1/2 cup of foam concentrate into 5 gallons of water in a backpack bag, what percent of the foam solution is foam concentrate? What percent of the foam solution is water?

Step 1. The water and foam concentrate must be converted to the same units. Convert the 0.5 cup to gallons.
1 gallon = 4 quarts, 1 quart = 2 pints, 1 pint = 2 cups

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, gallons.

$$\begin{array}{|c|c|c|c|} 0.5\ \cancel{\text{cups}} & 1\ \cancel{\text{pint}} & 1\ \cancel{\text{quart}} & 1\ \text{gallon} \\ \hline & 2\ \cancel{\text{cups}} & 2\ \cancel{\text{pints}} & 4\ \cancel{\text{quarts}} \end{array} = 0.03\ \text{gallons}$$

Step 3. The total of water and foam concentrate is
5 gallons + 0.03 gallons = 5.03 gallons.

Step 4. The percentage of foam in the solution is the amount of foam divided by the total amount of solution, times 100 percent.

$$\begin{array}{|c|c|} 0.03\ \cancel{\text{gal}} & 100\% \\ \hline & 5.03\ \cancel{\text{gal}} \end{array} = 0.6\%$$

Nina added 0.5 cup foam concentrate to the 5-gallon backpack bag and has 0.6 percent foam concentrate in the foam solution.

Step 5. The percentages add up to 100.
100% – 0.6% = 99.4% of the solution is water

Nina added 0.5 cup foam concentrate to the 5-gallon backpack bag and has 99.4 percent water in the foam solution.

Example 9—A fire burned an area of 112,684 ft^2. How many acres are in 112,684 ft^2?

Step 1. Find the appropriate conversion factor in table 2.1.
43,560 ft^2 = 1 acre.

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, acres.

$$\frac{112{,}684\ \cancel{ft^2}}{} \left|\ \frac{1\ \text{acre}}{43{,}560\ \cancel{ft^2}}\right| = 2.6\ \text{acres} = 3\ \text{acres}$$

112,684 ft^2 equals 3 acres

Example 10—A fire burned an area of 550 square chains. How many acres were burned?

Step 1. Find the appropriate conversion factor in table 2.1.
10 square chains = 1 acre.

Step 2. Set up the cancellation table so all units will cancel except the desired unit, acres.

$$\frac{550\ \cancel{\text{square chains}}}{} \left|\ \frac{1\ \text{acre}}{10\ \cancel{\text{square chains}}}\right| = 55\ \text{acres}$$

550 square chains equals 55 acres

Example 11—Convert 22 °C to °F.

Step 1. Use the Fahrenheit to Celsius temperature conversion equation. See table 2.2.

$$°F = (°C \times \frac{9}{5}) + 32$$

Step 2. Set up the problem.
°F = (22 °C x 9/5) + 32

Step 3. Solve the problem. Always work inside the parentheses first. See appendix B.9 for order of operation.

$$(22\ °C \times \frac{9}{5}) + 32 = 39.5 + 32$$

39.5 + 32 = 71.5 = 72 °F

Example 12—The chain saw gas/oil mix is 33 parts gas to 1 part oil. The head swamper carries four sig bottles. Sig gas bottles hold 1 liter. The chain saw gas tank holds 1.2 pints. How much gas and oil will be mixed for a 33:1 gas/oil mix ratio to fill four sig bottles and the gas tank?

Step 1. The ratio tells us that for every 1 part of oil, there must be 33 parts of gas for a total of 34 parts.
33 + 1 = 34 parts

Step 2. Find the total amount of desired gas/oil mix.

4 sig bottles x 1.0 liter = 4.0 liters + gas tank holding 1.2 pints Change to common units. 4.0 liters + 1.2 pints

Step 3. Set up the cancellation table so all units will cancel except the desired unit, pints.

$$\frac{4.0\ \cancel{\text{liter}}}{} \left|\ \frac{2.114\ \text{pint}}{1.0\ \cancel{\text{liter}}}\right| = 8.5\ \text{pints}$$

8.5 pints + 1.2 pints = 9.7 pints

Step 4. 9.7 divided by 34 parts will give the amount of each part. 9.7/34 = 0.3 pint

There are 33 parts of gas. 33 x 0.3 = 9.9 pints of gas
There is 1 part of oil. 1 x 0.3 = 0.3 pints of oil

9.9 pints of gas and 0.3 pints of oil are needed for a 1:33 oil:gas mixture with a volume of 10.2 pints

Note that the sum of the two is 10.2 pints.
9.9 + 0.3 = 10.2 pints

Table 2.1—Summarized Conversion Table

Linear Measure

1 foot	=	12 inches
1 foot	=	0.3048 meter
1 mile	=	5,280 feet
1 chain	=	66 feet
1 mile	=	80 chains

Area Measure

1 acre	=	10 square chains = ch^2
1 acre	=	43,560 square feet = ft^2
1 acre	=	4,046 square meters = m^2
1 square mile	=	640 acres

Volume Measure

1 pint	=	2 cups
1 quart	=	2 pints
4 quarts	=	1 gallon
1 liter	=	2.11 pints
1 liter	=	0.2642 gallons
1 cubic foot = ft^3	=	7.4805 gallons
1 gallon	=	0.003485 cubic meters = m^3
1 gallon	=	0.13346 cubic feet = ft^3
1 gallon	=	231 cubic inches = in^3
1 cubic foot = ft^3	=	1,728 cubic inches = in^3

Time Measure

1 minute	=	60 seconds
1 hour	=	60 minutes
1 day	=	24 hours
1 week	=	7 days
1 year	=	12 months

Force Measure

1 kilogram	=	2.205 pounds
1 kg m/s^2	=	0.2248 pounds
1 slug ft/s^2	=	1 pound

Pressure Measure

1 psi	=	2.036 in Hg at 32 °F
1 atm	=	14.7 psi
1 psi	=	2.304 ft of water

Weight

1 gallon of water	=	8.34 pounds
1 cubic foot of water	=	62.4 pounds

Table 2.2—Approximate Metric System Conversion Factors

To Change	To	Multiply by	To Change	To	Multiply by
feet	chains	0.0152	chains	feet	66.0
feet	meters	0.305	meters	feet	3.280
yards	meters	0.914	meters	yards	1.094
miles	kilometers	1.609	kilometers	miles	0.621
square feet	square meters	0.093	square meters	square feet	10.764
square yards	square meters	0.836	square meters	square yards	1.196
square miles	sq. kilometers	2.590	sq. kilometers	square miles	0.386
acres	sq. hectometers	0.405	sq. hectometers	acres	2.471
cubic feet	cubic meters	0.028	cubic meters	cubic feet	35.315
cubic yards	cubic meters	0.765	cubic meters	cubic yards	1.308
fluid ounces	milliliters	29,573.0	milliliters	fluid ounces	0.034
pints	liters	0.473	liters	pints	2.114
quarts	liters	0.946	liters	quarts	1.057
gallons	liters	3.785	liters	gallons	0.264
ounces	grams	28.349	grams	ounces	0.035
pounds	kilograms	0.454	kilograms	pounds	2.205
short tons	metric tons	0.907	metric tons	short tons	1.102
pound-feet	Newton-meters	1.365	ounce-inches	Newton-meters	0.007062
pound-inch	Newton-meters	0.11375			

Example of use of this conversion table:

To change **feet** to **chains—**Multiply **feet** by **0.0152**

To change 124 feet to chains—Multiply feet by 0.0152

124 feet x 0.0152 = 1.88 chains = 1.9 chains

Temperature Conversion of Units

°F = °Fahrenheit to °C = °Celsius

°F = (°C x 9/5) + 32

°C = °Celsius to °F = °Fahrenheit

°C = 5/9 x (°F – 32)

Table 2.3—Metric System and Equivalents

The purpose for including the following metric system equivalents and approximate conversion factors is to meet the requirements of Public Law 100-418. This law requires each Federal agency to use the metric system of measurement by Fiscal Year 1992 in procurements, grants, and other business related activities.

Linear Measure	Liquid Measure
1 centimeter = 10 millimeters = 0.39 inch	1 centiliter = 10 milliliters = 0.34 fl. ounce
1 decimeter = 10 centimeters = 3.94 inches	1 deciliter = 10 centiliters = 3.38 fl. ounces
1 meter = 10 decimeters = 39.37 inches	1 liter = 10 deciliters = 33.82 fl. ounces
1 decameter = 10 meters = 32.8 feet	1 deciliter = 10 liters = 2.64 gallons
1 hectometer = 10 decameters = 328.08 feet	1 hectoliter = 10 deciliters = 26.42 gallons
1 kilometer = 10 hectometers = 3,280.8 feet	1 kiloliter = 10 hectoliters = 264.18 gallons

Weights	Area Measure
1 centigram = 10 milligrams = 0.15 grain	1 sq. centimeter = 100 sq. millimeters = 0.155 sq. inch
1 decigram = 10 centigrams = 1.54 grains	1 sq. decimeter = 100 sq. centimeters = 15.5 sq.inches
1 gram = 10 decigrams = 0.035 ounce	1 sq. meter (centare) = 100 sq. decimeters = 10.76 sq. feet
1 decagram = 10 grams = 0.35 ounce	1 sq. decameter (are) = 100 sq. meters = 1,076.4 sq. feet
1 hectogram = 10 decagrams = 3.52 ounces	1 sq. hectometer (hectare) = 100 sq. decameters = 2.47 acres
1 kilogram = 10 hectograms = 2.2 pounds	1 sq. kilometer = 100 sq. hectometers = 0.386 sq. mile
1 quintal = 100 kilograms = 220.46 pounds	
1 metric ton = 10 quintals = 1.1 short tons	

Cubic Measure

1 cu. centimeter = 1000 cu. millimeters = 0.06 cu. inches

1 cu. decimeter = 1000 cu. centimeters = 61.02 cu. inches

1 cu. meter = 1000 cu. decimeters = 35.31 cu. feet

EXERCISES

Problem 1. How many quarters can Kim get for 15 dimes?

Problem 2. How many minutes are there in 24 hours?

Problem 3. How many seconds are there in 24 hours?

Problem 4. How many gallons are in 10 pints?

Problem 5. Dennis carries three canteens. Each holds 1 quart. How many pints is Dennis carrying in all? How many cups? What is the total weight of the water that Dennis is carrying?

Problem 6. Mark walks out 120 chains. How many miles has he walked? How many feet has he walked?

Problem 7. Ricardo mapped out a burn with a perimeter of 6 miles. What is the perimeter of the burn in chains? In feet?

Problem 8. Mona was constructing handline for 5 hours. How many minutes was she on the line? How many seconds?

Problem 9. How many acres are in 78 square miles?

Problem 10. Isaac determines that the last fire he was on burned 89 acres. How many square chains were burned?

Problem 11. It is 99 degrees Fahrenheit outside. What is the temperature in degrees Celsius? See table 2.2.

See appendix B.9 for order of operation.
See section 1.8 for treatment of percentages.

The material in chapter 3 describes hydraulic concepts regarding the use of water in wildland firefighting. These include determining weight of water, a description of factors related to friction loss, and a review of basic drafting guidelines, volume, pump pressure calculations, and flow rate. Instructions for estimating in the field and a round-off table are also provided.

The correct terminology is important in hydraulics. The unit for pressure that is used in hydraulics is pounds per square inch, “psi.” This is often confused or replaced with “pounds,” which is a unit for weight. Making this exchange is incorrect and causes much confusion; therefore, it is crucial that the correct terminology be used for both pressure (pounds per square inch) and weight (pounds).

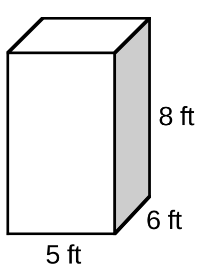
3.1 Volume or Capacity

Volume is used by firefighters to determine “How much water is left in the tank and at 15 gallons per minute (gpm), how many more minutes before the tank is empty?” Volume is used to indicate the capacity of a tank or container.

Volume of a rectangular tank—The volume of a rectangular container is determined by multiplying the length (l) by the width (w) by the height (h).

Volume = length x width x height
V = l x w x h

Example 1—Determine the volume of the tank in gallons.



<u>Step 1.</u> Use the equation for determining the volume of a rectangle. V = l x w x h

<u>Step 2.</u> Identify the length, width, and height.
l = 5 ft, w = 6 ft, h = 8 ft

<u>Step 3.</u> Set up the problem and solve.
V = 5ft x 6ft x 8ft = (5 x 6 x 8) (ft x ft x ft) = 240 ft^3

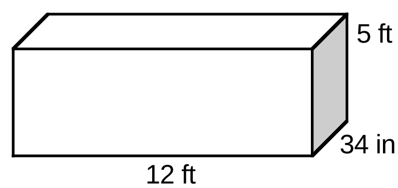
<u>Step 4.</u> Determine the appropriate conversion factor.
1 cubic foot = 7.4805 gallons

<u>Step 5.</u> Set up the cancellation table so all units will cancel, except the desired unit, gallons.

$$240\,\cancel{ft^3} \times \frac{7.48 \text{ gallons}}{1\,\cancel{ft^3}} = 1{,}795 \text{ gallons}$$

The volume of the tank of water is 240 cubic feet or 1,795 gallons.

Example 2—The water tank on a newly designed engine is 34 inches wide, 5 feet high, and 12 feet long. What is the capacity of the water tank in cubic feet? In gallons?



<u>Step 1</u>. Use the equation for determining the volume of a rectangle.
V = l x w x h

<u>Step 2</u>. Identify the length, width, and height.
l = 12 ft, w = 34 in, h = 5 ft

<u>Step 3.</u> Convert all the measurements to the same units, feet.

$$34\,\cancel{\text{inches}} \times \frac{1 \text{ foot}}{12\,\cancel{\text{inches}}} = 2.83 \text{ feet}$$

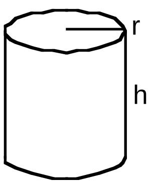
<u>Step 4.</u> Set up the problem, and solve for volume.
V = 2.83 ft x 5 ft x 12 ft = 170 ft^3

Step 5. Set up the cancellation table so all units will cancel, except the desired unit, gallons.

$$\left|\begin{array}{c|c} 170\ \cancel{ft^3} & 7.48\ gal \\ \hline & 1\ \cancel{ft^3} \end{array}\right| = 1{,}272 \text{ gallons}$$

The capacity of the new tank is 170 cubic feet or 1,272 gallons.

Volume of a cylinder—The volume of a cylinder is found by multiplying the area of the base times the height, "h." The base of a cylinder is a circle, $A = \pi \times r^2$, where π = 3.14. See chapter 1.9.



Volume = π x radius x radius x height

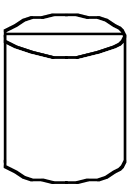
$V = \pi \times r \times r \times h$

$V = \pi \times r^2 \times h$

Example 3—A cylindrical tank of foam concentrate is 5 feet tall. Tank diameter is 2.5 feet. What is the capacity, in gallons, of the tank?

Step 1. Use the equation for determining the volume of a cylinder.
$V = \pi \times r^2 \times h$

Step 2. Draw a sketch. Label the height and diameter.



π = 3.14 r = 1/2 d = 1/2 x 2.5 ft = 1.25 ft h = 5 ft

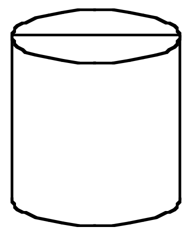
Step 3. Set up the problem and solve.
$V = 3.14 \times (1.25\ ft)^2 \times 5\ ft = 24.5\ ft^3$

Step 4. Set up the cancellation table so all units will cancel, except the desired unit, gallons.

$$\left|\begin{array}{c|c} 24.5\ \cancel{ft^3} & 7.48\ gal \\ \hline & 1\ \cancel{ft^3} \end{array}\right| = 183.3 \text{ gallons}$$

Tank capacity is 183.3 gallons.

Example 4—Carla is filling the cylindrical tank below with a pump. She's pumping at a rate of 13 gallons per minute (gpm). How long will it take to fill the tank?



Step 1. Use the equation for determining the volume of a cylinder. $V = \pi \times r^2 \times h$

Step 2. Identify the radius and height.
π = 3.14 r = 1/2 d = 8ft/2 = 4 ft h = 10 ft

Step 3. Set up the problem, and solve for volume.
$V = 3.14 \times (4\ ft)^2 \times 10\ ft = 502.4\ ft^3$

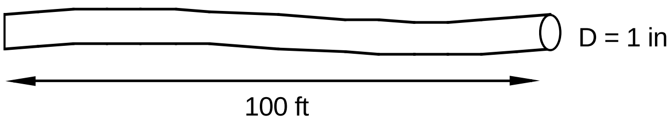
Step 4. Set up the cancellation table so all units will cancel, except the desired unit, hours.

$$\left|\begin{array}{c|c|c|c} 502.4\ \cancel{ft^3} & 7.48\ \cancel{gal} & \cancel{min} & h \\ \hline & 1\ \cancel{ft^3} & 13\ \cancel{gal} & 60\ \cancel{min} \end{array}\right| = 4.82 \text{ hours}$$

It will take Carla about 5 hours to fill the tank.

3.2 Volume of Water in Hose The volume of hose is also important in firefighting. The hose diameter is usually given in inches, with length in feet.

Example 5—A 100-foot length of 1-inch diameter hose is charged with water. How many gallons of water are in that length of hose?



Step 1. Use the equation for determining the volume of a cylinder. $V = \pi \times r^2 \times h$

Step 2. Identify the radius and height.
$\pi = 3.14$ $r = 1/2\ d = 1\text{ in}/2 = 0.5\text{ in}$ $h = 100\text{ ft}$

Step 3. Convert all measurements to the same units. Convert the 100-foot hose length to inches.

$$\text{Hose length} = \frac{100\ \cancel{\text{ft}}}{} \times \frac{12\text{ in}}{1\ \cancel{\text{ft}}} = 1{,}200\text{ in}$$

Step 4. Set up the problem and solve.
$V = 3.14 \times 0.5\text{ in} \times 0.5\text{ in} \times 1{,}200\text{ in} = 942\text{ in}^3$

Step 5. Set up the cancellation table so all units will cancel, except the desired unit, gallons.

$$\frac{942\ \cancel{\text{in}^3}}{} \times \frac{1\ \cancel{\text{ft}^3}}{1{,}725\ \cancel{\text{in}^3}} \times \frac{7.48\text{ gal}}{1\ \cancel{\text{ft}^3}} = 4\text{ gallons}$$

The capacity of a 100-foot length of 1-inch diameter hose is 4 gallons.

Estimating in the Field—Rounding makes numbers easier to use. Sometimes estimations or approximations are useful, such as for planning sessions in the field, especially when without a calculator. For example, table 3.1 indicates that 1-1/2 inch x 100 feet of hose length holds 9.2 gallons of fluid. In the field, the conversion value can be rounded to 9 gallons when doing rough estimations/calculations. These rounded values are easier to remember.

Example 6—Sherman is out on a fire. His crew has a trunk line of 6 lengths of 100-foot, 1-1/2 inch hose. He needs to estimate the volume of water in this trunk line. What is a good estimate?

Step 1. Find the appropriate conversion/estimation in table 3.1. Commit these rounded values to memory.

The exact tables indicate that a single 100-foot length of 1-1/2-inch hose holds 9.2 gallons of water from table 3.1. Use the rounded value of 9 gallons per 100-foot length of 1-1/2-inch hose.

Step 2. Set up the table. This may or may not need to be done on paper. Typical rough estimations involve only one multiplication or division step, and usually this math can be done in your head.

$$\frac{6\ \cancel{\text{lengths}}}{} \times \frac{9.0\text{ gallons}}{1\ \cancel{\text{length}}} = 54\text{ gallons}$$

Sherman has used 54 gallons of water to charge the hose lay.

Sherman now knows that he has about 54 gallons of water in his hose lay. The exact value would have been 6 x 9.2 = 55.2 gallons. This shows that the rounded number is easier to use, since multiplying whole numbers is simpler than multiplying decimals.

In example 6, the number was rounded down from 9.2 to 9.0. If it would have been rounded up from 9.2 to 10.0, the solution would have been 6 x 10 = 60 gallons. By performing the calculations using whole numbers, both higher and lower than the actual value, a margin is created. This margin allows for an upper and lower limit. It is therefore safe to say that the actual value is between 54 gallons (6 x 9) and 60 gallons (6 x 10).

Determining Weights and Volumes of Water—Table 3.1 shows the volumes of water in specific hose lengths, along with the weight of 1 gallon of water. The weight of 1 gallon of water is 8.3 pounds (**1 gallon = 8.3 pounds**). With this, the weight of water can be calculated in a certain length of hose or volume of water by multiplying by 8 pounds per gallon (rounded value).

Example 7—The tank on a Model 62 Engine is filled with 500 gallons of water. How much weight does the water add to the weight of the engine?

Step 1. Find the appropriate estimation in table 3.1.
1 gallon = 8 pounds (lb)

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, pounds.

$$\begin{array}{|c|c|} 500\ \cancel{\text{gallons}} & 8\ \text{pounds} \\ \hline & 1\ \cancel{\text{gallon}} \end{array} = 4{,}000\ \text{pounds}$$

Water in the tank adds 4,000 pounds to the weight of the engine.

Example 8—Two 100-foot lengths of 1-1/2-inch cotton-synthetic hose weigh about 54 pounds total when dry. How much will the same hose weigh when fully charged?

Step 1. Find the appropriate estimation in table 3.1. The volume capacity of one 1-1/2-inch ID x 100-foot hose length = 9 gallons. For two lengths of hose, there are two times 9 gallons.

$$\begin{array}{|c|c|} 2\ \cancel{\text{lengths}} & 9\ \text{gallons} \\ \hline & 1\ \cancel{\text{length}} \end{array} = 18\ \text{gallons}$$

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, pounds.

$$\begin{array}{|c|c|} 18\ \cancel{\text{gallons}} & 8\ \text{pounds} \\ \hline & 1\ \cancel{\text{gallon}} \end{array} = 144\ \text{pounds}$$

Step 3. Add the dry weight of the hose to the weight of the water.
54 lb + 144 lb = 198 lb

Two fully charged 1-1/2-inch ID x 100-foot hose lengths weigh 198 pounds.

Example 9—An engine company is pumping a progressive hose lay with 1-inch laterals every 100 feet. At 800 feet up from the engine, the trunk line breaks, and firefighters replace it, but they forget to shut off the gated wye valve above the broken hose. As a result, they accidentally drain ten 100-foot lengths of 1-1/2-inch hose and ten 100-foot lengths of 1-inch hose. How much water above the break was lost due to this mistake?

Step 1. Find the appropriate estimation in table 3.1 for the volume of water in both 1-inch and 1-1/2-inch lengths of hose.

Each 1-1/2-inch ID x 100-foot hose length holds 9 gallons.
Each 1-inch ID x 100-foot hose length holds 4 gallons.

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, gallons, for each length of hose.

Ten lengths of 1-1/2-inch ID x 100-foot hose

$$\begin{array}{|c|c|} 10\ \cancel{\text{lengths}} & 9\ \text{gallons} \\ \hline & 1\ \cancel{\text{length}} \end{array} = 90\ \text{gallons}$$

Ten lengths of 1-inch ID x 100-foot hose

$$\begin{array}{|c|c|} 10\ \cancel{\text{lengths}} & 4\ \text{gallons} \\ \hline & 1\ \cancel{\text{length}} \end{array} = 40\ \text{gallons}$$

Step 3. Add these together to find the amount of water lost. 90 gallons + 40 gallons = 130 gallons

Firefighters lost 130 gallons of water.

3.3 Friction Loss in Fire Hose Friction loss is the resulting resistance as water (fluid) moves along the inside wall of either hose, pipe, or hose fittings.

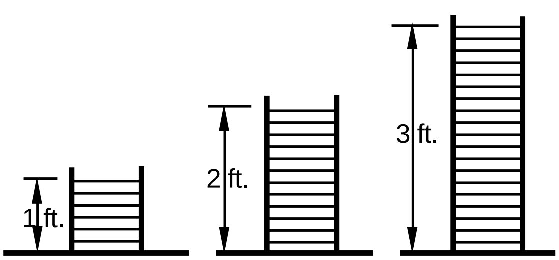
Points to Remember

- Friction loss increases as flow (gpm) increases.
- Total friction loss varies with length—the greater the length, the higher the friction loss.

- Friction losses on reeled hose average about 21 percent more than for straight hose lays.
- Friction loss is nearly independent of pressure.
- Friction loss varies with type, lining, weave, quality, and age of hose.
- Friction loss increases four times for each reduction of diameter by one half.

The pressure at which the pump is working must be increased or decreased to compensate for the head loss or gain along with the friction losses, in order to produce the desired nozzle pressure.

3.4 Calculating Engine Pump Pressures In order to achieve a desired nozzle pressure (DNP), a few considerations must be taken into account. First, head loss (HL) and head gain (HG) must be noted. Water head is the height of the water column due to imposing pressure. The head pressure is positive (gain) if the hose lay is downhill because the force of gravity is helping push the water down, consequently increasing the pressure. The head pressure is negative (loss) if the hose lay is uphill, since the force of gravity is pulling the water down, when it needs to be pumped up. Table 3.1 indicates that 1 foot of water head produces 0.5 pounds per square inch of pressure. On that same note, 1 pound per square inch can produce 2 feet of water head (lift). For every foot uphill or downhill, there is a change of 0.5 pounds per square inch of pressure. Note that this is the height of the hose (elevation) and not the length of the hose. See figure 3.1.



Actual	0.434 psi	0.868 psi	1.302 psi
Rounded	0.5 psi	1.0 psi	1.5 psi
Difference due to rounding	0.066 psi	0.132 psi	0.198 psi

Figure 3.1—Water Pressure vs Height—These figures show the pressure on a square inch cross section caused by the height of water above it. Note that as the column's height doubles, so does the pressure. Both exact and rounded field application values are given.

The second consideration involves friction losses (FL). As a field rule, the pressure in a line is reduced by 5 pounds per square inch for each appliance added to the line. For example, a hose lay with five wye valves will result in a 25 pounds per square inch pressure loss due to the friction introduced by these fittings. This is an approximation used for calculations and is not precisely what occurs in the field. See table 3.3 for friction loss in forestry hose.

Calculating Desired Nozzle and Pump Pressures—Engine and nozzle pressures are calculated as follows:
DNP = Desired Nozzle Pressure
EP = Engine Pressure
HG = Head Gain
HL = Head Loss
FL = Friction Loss

Desired Nozzle Pressure =
Engine (Pump) Pressure ± Head Gain/Head Loss
Friction Loss:
DNP = EP ± HG/HL – FL

When calculating **desired nozzle pressure** in a **downhill** hose lay, **add** the head pressure. In **uphill** hose lays, **subtract** the head pressure. The calculations vary to account for the work of gravity.

In terms of engine pressure: EP = DNP + HL/-HG + FL
When calculating **engine pressure** in **downhill** hose lays, **subtract** the head pressure; in **uphill** hose lays, **add** the head pressure.

The head pressure is in terms of loss or gain. Because the pump and the nozzle are at opposite ends of the hose, head pressure that is positive at the pump, will be negative at the nozzle and vice versa. See figure 3.1. It is crucial that the sign of the head pressure be correct. If the hose lay is uphill, the head pressure is negative, and if it is downhill, the head pressure is positive. Careful attention must be paid to the second equation above, when the signs are switched.

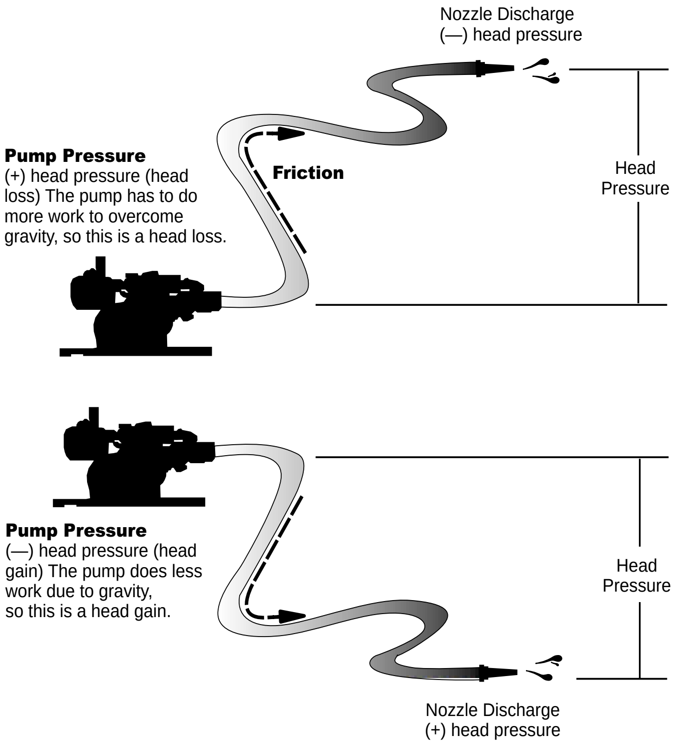
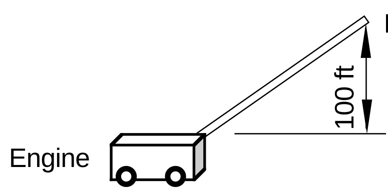


Figure 3.2—Pump pressure with head gain and head loss.

Example 10—Kevin is fighting a fire and needs the nozzle pressure to be 100 pounds per square inch. He is 100 feet above the engine. What pump pressure does he need?



There is a head loss due to the height of the nozzle.

<u>Step 1.</u> Find the appropriate estimation in table 3.1 for the pressure change caused by each vertical foot of water head.

1 ft head = 0.5 psi head pressure

<u>Step 2.</u> Set up the cancellation table so all units will cancel, except the desired unit, psi. Since the nozzle is uphill, the head pressure is considered a head loss and is negative.

$$\frac{100\,\cancel{\text{ft}}}{} \cdot \frac{0.5\text{ psi}}{1\,\cancel{\text{ft}}} = 50\text{ psi}$$

HL = –50 psi

<u>Step 3.</u> Calculate the friction loss.
There is no friction loss due to appliances in the line.
FL = 0

<u>Step 4.</u> Use the equation for the engine pressure.

EP = DNP ± HL/HG + FL

<u>Step 5.</u> Identify the desired nozzle pressure, the head loss, and the friction loss.
DNP = 100 psi, HL = –50 psi, FL = 0

<u>Step 6.</u> Set up the problem and solve. See appendix B for subtracting negative numbers.

EP = 100 psi – (–50 psi) + 0
EP = 150 psi

The engine pressure would have to be 150 pounds per square inch to obtain a nozzle pressure of 100 pounds per square inch.

Estimating Values—As mentioned earlier, it is often necessary to round numbers either up or down to make calculations easier. When precise calculation is not possible because there is no paper, pen, or calculator, rounded estimations are helpful. In the field, rounding does not greatly affect the results. Actually, it is helpful to round numbers to take outside disturbances of any kind into account. For example, rounding the pressure caused by water head up from 0.434 to 0.5 takes any additional friction that might be caused by the hose itself into account.

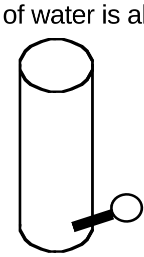
Looking back at example 10 where there is a 100-foot vertical height of water in the hose, using the exact value of 0.434 pounds per square inch per foot would give a 43 pounds per square inch head loss. This is 7 pounds per square inch less than what was calculated earlier. By rounding up to 0.5 from 0.434, friction and head losses due to the hose itself are taken into account, and no additional calculation is needed. So, for future calculations, the 0.5 pounds per square inch head loss will be used. This not only eases calculations, but is a more realistic field application.

For hose longer than 100 feet, friction loss in the hose should be considered. Friction loss of 100-foot, 1-inch hose, all synthetic, and at 15 gallons per minute, is typically 4 to 9 pounds per square inch. Friction loss of 100-foot, 1-inch hose, cotton-synthetic, and at 15 gallons per minute, is typically 3 to 6 pounds per square inch. And friction loss for 1.5-inch hose at 15 gallons per minute is typically 1 pound per square inch for 100 feet. See table 3.3.

Estimations and rounding are applied to example 10.

Exact value	43 psi
Field use value (rounded)	50 psi
Difference	+7 psi

Example 11—A pressure gauge attached to a standpipe system shows a pressure of 64 pounds per square inch. What head (height) of water is above this gauge?



Step 1. Find the appropriate estimation in table 3.1.
1 psi = 2 ft

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, feet.

$\left| \frac{64\ \cancel{psi}}{} \middle| \frac{2\ ft}{1\ \cancel{psi}} \right|$ = 128 ft of water

There are 128 feet of water above the gauge.

Example 12—A progressive hose lay has six gated wye valves along the length of the trunk line. The nozzle outlet is 200 feet below the engine. The desired nozzle pressure of the trunk line is 100 pounds per square inch. At what pressure does the engine need to perform?

Step 1. Find the appropriate conversion/estimation in table 3.1 for the pressure caused by 1 foot of water head.
1 ft = 0.5 psi

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, psi. There is a head gain due to the hose lay being downhill.

HG = $\left| \frac{200\ \cancel{ft}}{} \middle| \frac{0.5\ psi}{1\ \cancel{ft}} \right|$ = 100 psi

Step 3. Set up the cancellation table so all units will cancel, except the desired unit, psi, to calculate the friction loss due to the fittings. Guidelines indicate a 5 pounds per square inch loss per fitting.

FL = $\left| \frac{6\ \cancel{fittings}}{} \middle| \frac{5\ psi}{1\ \cancel{fitting}} \right|$ = 30 psi

Step 4. Use the equation for the engine pressure.
EP = DNP $\pm$ HG/HL +FL

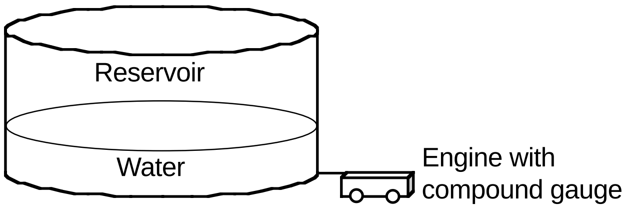
Step 5. Identify the DNP, the HG, and the FL.
DNP = 100 psi, HG = 100 psi, FL = 30 psi

Step 6. Set up the problem and solve.
EP = 100 psi – 100 psi + 30 psi

The engine pressure needs to be 30 pounds per square inch for a desired nozzle pressure of 100 pounds per square inch in this hose lay.

Water Levels—Knowing that 1 pound per square inch of pressure can lift water vertically 2 feet, the water level of certain volumes of water (cisterns or tanks) can also be calculated.

Example 13—An engine's compound gauge is connected at the base of a 100-foot tall reservoir tank, and the gauge reads 35 pounds per square inch. How high is the water level in the reservoir?



<u>Step 1.</u> Find the appropriate conversion/estimation in table 3.1 for the height of water that creates 1 pound per square inch of pressure. 1 psi = 2 ft of water head

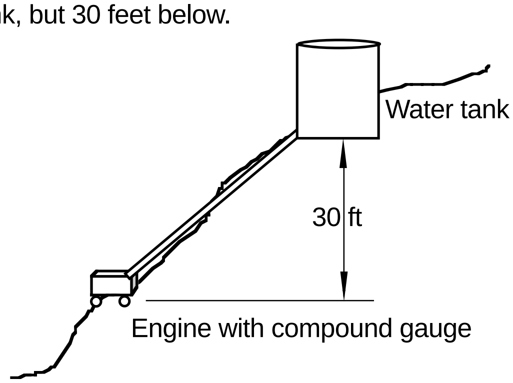
<u>Step 2.</u> Set up the cancellation table so all units will cancel, except the desired unit, feet, to calculate the height of water that creates the 35 pounds per square inch of pressure above the gauge.

$$\begin{array}{|c|c|} 35\ \cancel{\text{psi}} & 2\text{ ft} \\ \hline & 1\ \cancel{\text{psi}} \end{array} = 70\text{ ft height of water}$$

The water level is 70 feet above the gauge.

Example 14—Harvey has parked his engine 30 feet below the base of a nearby water tank. He connects his engine's compound gauge to the water line coming from the tank and obtains a reading of 40 pounds per square inch. How high is the water level in the tank?

In this problem, the pressure is not read at the base of the tank, but 30 feet below.



<u>Step 1.</u> Find the appropriate conversion/estimation in table 3.1 for the height of water that creates 1 pound per square inch of pressure. 1 psi = 2 ft

<u>Step 2.</u> Set up the cancellation table so all units will cancel, except the desired unit, feet, to calculate the height of the water level that creates the 40 pounds per square inch pressure reading.

$$\begin{array}{|c|c|} 40\ \cancel{\text{psi}} & 2\text{ ft} \\ \hline & 1\ \cancel{\text{psi}} \end{array} = 80\text{ ft}$$

The water level is 80 feet above Harvey's gauge.

<u>Step 3.</u> Determine the height of the water in the tank. Subtract the 30 feet between the gauge and the base of the tank.

80 ft – 30 ft = 50 ft

The height of the water in the tank is 50 feet.

Size and Shape versus Pressure—Notice that the diameter of the tank does not affect the pressure. A column of water 100 feet high creates the same amount of pressure in a 2-foot diameter tank as it does in a 20-foot diameter tank. Imagine that diameter did affect the pressure in a certain height of water: Would people be able to swim in the ocean or would the pressure of such a large body of water crush them, compared to a small swimming pool of the same depth? The answer is no, the pressure is the same if the height is the same, no matter how wide or what shape. See figure 3.3.

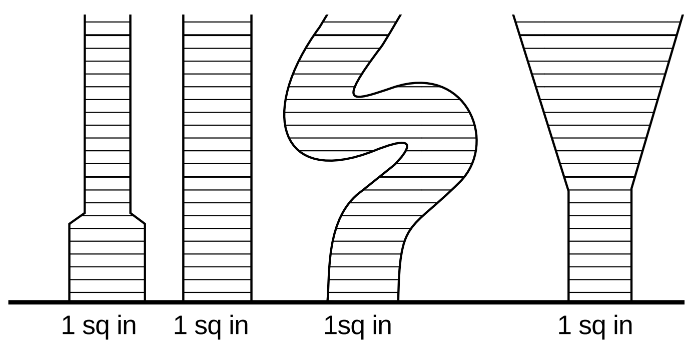


Figure 3.3—Different shapes, same pressure.

3.5 Drafting Guidelines

When drafting water from a pond or stream, it is important to know the difference in elevation between the pump and the water source. When drafting water, the air at atmospheric pressure is removed from the hose line, creating a vacuum (negative pressure) within the pump chamber. The atmospheric pressure (weight of air) on the water's surface forces the water up through the suction hose to the pump.

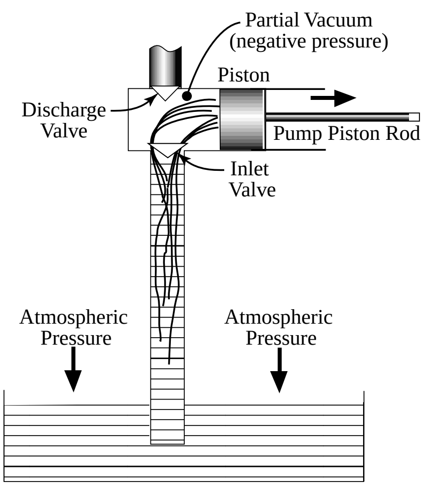


Figure 3.4—Drafting diagram.

The maximum height to which an engine or pump can lift water is determined by the atmospheric pressure. At sea level the atmosphere exerts an average pressure of 14.7 pounds per square inch. Atmospheric pressure will vary due to changes in the weather. However, these changes tend to even themselves out, and the average pressure will tend to go back toward 14.7 pounds per squre inch. That is why it is safe to use this value of 14.7 pounds per squre inch as a constant for calculations.

Example 15—What would be the maximum height of water that a pressure of 14.7 pounds per square inch would be capable of sustaining?

Step 1. Find the appropriate conversion in table 3.1.
1 psi = 2.304 ft

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, feet, to calculate the lift created by 14.7 pounds per square inch.

14.7 ~~psi~~	2.304 ft lift	= 33.9 feet
	1 ~~psi~~	

This is the exact value using the conversion 1 pound per square inch = 2.304 feet.

This pressure (atmospheric pressure) is capable of sustaining a column of water 33.9 feet in height.

If a pump could produce a perfect vacuum, the maximum height to which it could lift water at sea level would be 33.9 feet. This is the maximum theoretical lift, but no pump built can produce a perfect vacuum. A fire engine in fairly good condition can lift water two thirds of the theoretical lift, 2/3 x 33.9 = 22.5 feet. This is called the maximum attainable lift. With an increase in elevation above sea level, atmospheric pressure decreases, thus reducing the vertical distance from the water source where drafting can be done effectively.

For every 1,000 feet of change in elevation, there is a loss of 1 foot in suction or lift and a 0.5 pounds per square inch decrease in atmospheric pressure.

Example 16—An engine can lift water 22.5 feet at sea level. The same engine is driven to a fire at an elevation of 2,000 feet above sea level. What lift is it capable of producing at this elevation?

Step 1. Use the conversion given for elevation change.
1-ft loss = 1,000-ft elevation change

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, feet, to calculate the loss in lift for a 2,000-foot elevation.

2,000 ~~ft~~	1 ft (loss)	= 2 ft lift will be lost
	1,000 ~~ft~~ (elevation)	

Step 3. Subtract this value from the number of feet that can be lifted at sea level.
22.5 ft – 2 ft = 20.5 ft

This pump can lift 20.5 feet of water at a 2,000-foot elevation.

Example 17—Larry is 16 feet above his water source, at an elevation of 4,000 feet. Will Larry still be able to draft water?

Step 1. Find the appropriate conversion/estimation in table 3.1 to calculate the decrease in possible lift. At sea level, attainable lift is 22.5 feet.

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, feet (loss), to calculate the loss in lift. Due to the elevation, the sustainable lift decreases by:
1,000-foot increase in elevation = 1-foot loss

4,000 ~~ft~~	1 ft (loss)	= 4-ft loss in lift
	1,000 ~~ft~~ (elev.)	

Step 3. Calculate the adjusted attainable lift. The maximum attainable lift would now be:
attainable lift – decrease due to elevation = adjusted attainable lift 22.5 ft – 4 ft = 18.5 ft

Step 4. Determine whether drafting is still possible.
attainable lift = 18.5 ft Larry would still be able to draft water up to a vertical distance of 18.5 feet, he desires to lift at least 16 ft.

The difference is 18.5 feet – 16 feet = 2.5 feet above Larry's current location.

Yes, Larry is able to draft 16 feet above his water source.

3.6 Flow Rates Flow rates describe the speed at which water is flowing. They are described in gallons per minute (gpm). The following test is a simple way to see this.

Use a large drum with a marked level to indicate a premeasured 50-gallon volume. Begin filling the drum with a hose and at the instant that the water begins to fill the tank, start timing how long it takes with a precise stop watch (preferably to 1/100 of a minute). When the water level reaches the marked line, take the hose away, and stop timing. To calculate the flow rate of the water through the hose, divide the total volume by the total time it took to reach that volume. Suppose it took 3.55 minutes.

50 gallons per 3.55 minutes (50/3.55)
50 ÷ 3.55 = 14.08
Flow rate = 14.08 gpm

If the stop watch has only seconds and minutes, the seconds can be converted into fractions (parts) of minutes. There are 60 seconds in 1 minute.

Example 18—If it took 3 minutes and 40 seconds to fill the bucket, how many minutes did it take?

Step 1. Set up the cancellation table so all units will cancel, except the desired unit, minutes. There are 60 seconds in 1 minute.

40 ~~seconds~~	1 minute	= 0.67 minutes
	60 ~~seconds~~	

Step 2. Add the minutes together.
3 minutes + 0.67 minutes = 3.67 minutes.

It took 3.67 minutes to fill the bucket.

Table 3.1—Water Handling Unit Estimations

Description **ID = Inner Diameter**	**Rounded Values** Used in Field Estimations **GOOD TO MEMORIZE** **Volume (Capacity)**	U.S. Measure **Volume (Capacity)**
One hose length		
1-1/2-in ID x 100 ft	9 gal	9.2 gal
1-in ID x 100 ft	4 gal	4.1 gal
3/4-in ID x 50 ft	1 gal	1.2 gal
5/8-in ID x 50 ft	1 gal	0.8 gal

	Weight	**Weight**
1 gal of water at 20 °C	8 lb	8.3 lb

	Pressure	**Pressure**
1 ft of water head (1 in^2 column of water)	0.5 psi	0.434 psi
1 psi	2 ft of water head	2.304 ft of water head
Atmospheric pressure	15 psi @ sea level	14.7 psi @ sea level
1,000 ft increase in elevation	0.5 psi decrease in atmospheric pressure	0.5 psi decrease in atmospheric pressure

	Draft (lift)	**Draft (lift)**
1 in of mercury	1 ft	1.134 ft
1,000 ft increase in elevation	1 ft loss	1 ft loss
Maximum theoretical lift	34 ft	33.9 ft
Maximum attainable lift with new pump	29 ft *	29.4 ft
Maximum practical attainable lift	22 ft	22.4 ft

* Pump lift varies with pump efficiency, which decreases proportionately to the hours of use.

Table 3.2—Comparative Diameters and Weights (100-foot lengths) of Coupled Fire Hose

Type of Hose	FS SPEC	Jacket	ID (in)	Factory Proof Pressure (psi)	Burst Pressure (psi)	Max Dry Weight (lb)	Water (gal)	Weight Water (lb)	Max Total Weight (lb)
Garden, synthetic jacket, lined (50 ft only)	Item purchase description	Single	5/8	300	550	1.7	0.8	6.6	8.4
High pressure, reel (50 ft only)	5100-185	———	3/4	1,200	2,400	28.4	1.2	10	38.4
Cotton-synthetic jacket, lined	5100-186	Single	1	450	900	22.4	4.1	34	56.4
Synthetic jacket, lined	5100-187	Single	1	450	900	9.4	4.1	34	43.4
Cotton-synthetic jacket, lined	5100-186	Single	1-1/2	450	900	26.9	9.2	77	103.9
Synthetic jacket, lined	5100-187	Single	1-1/2	450	900	15.9	9.2	77	92.9
Cotton-synthetic jacket, rubber lined (light tube) (50 ft only)	None	Double	2-1/2	———	———	60 to 162	25.5	213	273 to 375

Table 3.3—Friction Loss of Forestry Hose

Friction loss comparison of the forestry hose and hose on the Forest Service qualified products lists for 5100-186 and 5100-187 in units of pounds per square inch per 100 feet.

Flow	5/8-in GH	3/4-in straight hardline	3/4-in reeled hardline	1-in Cotton-synthetic—186			1-in All-synthetic—187				1-in Hotline
				Imperial	Niedner	National	Mercedes	Imperial	National	Niedner	
gpm	psi/ 100 ft	psi/ 100 ft	psi/ 100 ft	v 100 ft	psi/ 100 ft	psi/ 100 ft	psi/ 100 ft	psi/ 100 ft	psi/ 100 ft	psi/ 100 ft	psi/ 100 ft
5	6	5	6	1	1	1	1	0	1	1	2
10	23	13	17	2	3	3	3	2	4	3	4
15	45	27	34	5	3	6	5	4	8	9	9
20	78	42	53	8	10	10	7	8	16	18	16
25	92	62	79	12	14	17	11	12	25	29	24
30	~	86	109	18	19	24	14	18	35	42	34
35	~	91	115	22	25	28	20	24	48	57	49
40	~	~	~	28	33	37	22	31	61	75	59
45	~	~	~	35	41	46	24	39	77	~	73
50	~	~	~	42	50	55	29	48	86	~	80
60	~	~	~	60	68	73	41	64	~	~	~
70	~	~	~	65	~	~	55	~	~	~	~
80	~	~	~	~	~	~	~	~	~	~	~
90	~	~	~	~	~	~	~	~	~	~	~
100	~	~	~	~	~	~	~	~	~	~	~

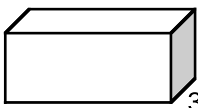
Friction loss (pounds per square inch per 100 feet) in hose comparison

Flow	1-1/2-in Cotton-synthetic—186		1-1/2-in All synthetic—187				1-1/2-in hotline	1-3/4-in hotline
	Imperial	National	Mercedes	Imperial	National	Niedner		
gpm	psi/100 ft	psi/100 ft	psi/100 ft	psi/100 ft	psi/100 ft	psi/100 ft	psi/100 ft	psi/100 ft
5	0	0	0	0	1	0	0	0
10	1	0	0	0	1	1	0	0
15	1	1	1	1	1	1	1	0
20	2	1	2	1	2	2	2	0
25	3	2	2	2	3	3	3	2
30	3	3	2	3	4	5	5	2
35	4	4	4	4	5	7	6	2
40	5	5	4	5	7	8	8	2
45	6	7	6	6	8	11	10	3
50	8	8	6	7	11	13	12	3
60	9	12	7	9	16	20	18	5
70	12	17	9	12	21	26	24	6
80	16	22	12	15	23	33	31	8
90	20	27	15	19	30	42	39	11
100	25	29	19	24	32	52	~	14

EXERCISES

V = Volume
L = Length
w = Width
h = Height

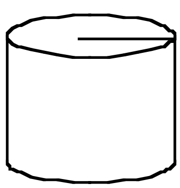
Problem 1. Find the volume, in gallons, of the tank below.



Problem 2. Diego is filling a rectangular water tank with the following dimensions: length = 10 ft, height = 8 ft, and width = 48 in. How many gallons of water can he put in the tank?

V = Volume
h = height of cylinder
r = radius of the circular base

Problem 3. How much water can the tank hold?



Problem 4. Kate is in charge of filling her engine tank. The tank is 6.2 ft wide, 4.5 ft tall, and 18.2 ft long. What volume of water can she put into the tank to fill it?

See chapter 1.9 for diameter and radius.
See table 2.3 for conversion factor.

Problem 5. A cylindrical canteen is 9 inches high and has a 4.5-inch diameter. What volume of water can the canteen hold in gallons?

See table 2.1.

Problem 6. How many cubic inches of water are held in a fully charged 1-1/2-inch diameter hose length of 100 feet? Does this value agree with the water handling units in table 3.1?

Problem 7. What volume of water is held in a 15-inch length of 5/8-inch diameter hose?

Problem 8. There are 4 gallons of water in tank A. Estimate how much weight 4 gallons of water would add to the tank.

Problem 9. Estimate the volume of water, in gallons, that is in 8 lengths of 5/8-inch 50-foot mop-up hose in the hose lay? Use the long method from table 2.1 and the short method using table 3.1.

Problem 10. Determine the weight of water in a 6-foot length of 2-inch diameter piping.

Problem 11. Determine the weight of water in a rectangular tank 3 feet wide, 4 feet high, and 7 feet long.

Problem 12. Determine the weight of the water in a 150-foot length of hose with a 1-inch diameter.

Problem 13. Eric weighs his backpack pump when it is empty. It weighs 6.5 pounds. He fills it with 5 gallons of water. How much weight has he added to his pack?

Problem 14. Daniel is filling helicopter tanks with his engine at a helibase. A helicopter with an empty 360-gallon tank lands, and the pilot tells Daniel to fill the tank three-quarters full of water. How many gallons must he fill? How much weight has Daniel added to the helicopter?

Problem 15. Jacob reads the pressure gauge on his engine and finds the pressure to be 60 pounds per square inch. What height of water is there in the hose lay above his engine's pump?

Problem 16. What is the pressure Victor needs at the pump if his nozzle is 120 feet above the pump, he has 6 fittings in the line, and he wants a nozzle pressure of 100 pounds per square inch?

Problem 17. Carlos deployed a hose lay of 400 feet of 1-1/2-inch Forest Service cotton-synthetic hose with 3 fittings. What is the friction loss using field application approximations at a nozzle flow of 50 gallons per minute?

Problem 18. Ralph is pumping water from a pond to a fire 230 feet below. He has a hose lay of 600 feet of 1-1/2-inch hose with 5 fittings. The pump pressure is 20 pounds per square inch. What is his nozzle pressure?

Problem 19. Joe lays 400 feet of 1-1/2-inch hose down a slope 100 feet below the pump. He has three brass fittings in the hose. What pump pressure will he need to produce 100 pounds per square inch nozzle pressure?

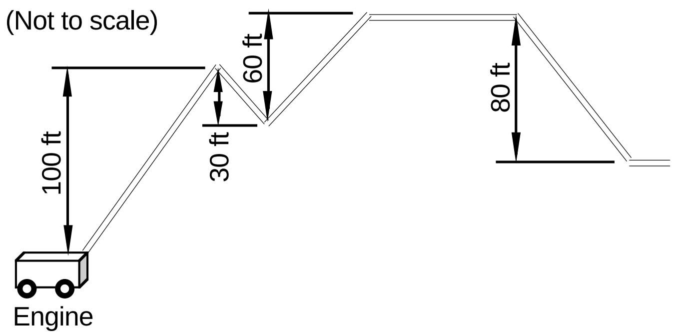
Problem 20. At sea level the engine can lift water 22.5 feet. What lift will the engine be able to produce at an elevation of 5,000 feet?

Problem 21. A 15-gallon tank is emptied through a release valve. From the instant the valve is opened to the instant the tank finishes draining, the time is recorded as 3.45 minutes. What is the flow rate through the valve?

CHAPTER PROBLEM

The following hose lay is in place. A nozzle pressure of 100 pounds per square inch is needed. What must the engine pump pressure be? There are fittings at each bend in the line (five in total).

(Not to scale)



The material in chapter 4 describes concepts of measuring: flame length and height, angles, degrees, and slopes. Reading clinometers and graphs and pacing out a chain are also covered.

4.1 Flame Length

Flame length is the distance measured from the average flame tip to the middle of the flaming zone at the base of the fire. It is measured on a slant when the flames are tilted due to effects of wind and slope. Flame length is an indicator of fireline intensity.

4.2 Flame Height

Flame height is the average height of flames as measured vertically ↕, up and down. It may be less than flame length if the flames are angled in the horizontal direction ↔, backward and forward. See figure 4.1.

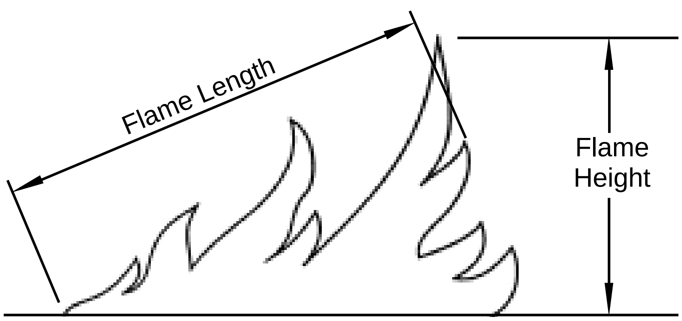
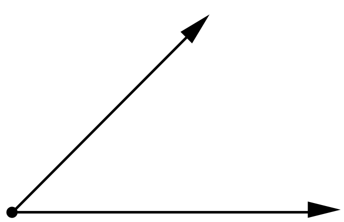


Figure 4.1—An approximation can be made by comparing the flame height to an object of known dimensions, such as a fencepost, firefighter, or pole.

4.3 Angles

Angles are formed when two or more lines come together at a point. The amount an angle opens is measured in degrees with a protractor. See example 1.

The symbol for angle is "∠."
This angle measures 45°.



Firefighters use angles everyday. Some common ways that angles are used are:

- Determining position with a compass or on a map.
- Calculating the slope of an incline in order to determine whether a dozer can drive safely up it.

4.4 Degrees and Protractor

Degrees are the unit of measure used for angles, just as feet are used to measure distance. There are 360° in a full circle. The symbol for degrees is " ° ."

A protractor is used for measuring angles. See figure 4.2. A protractor is a half or full circle measuring device, marked in degrees along the outer edge, with a straight line running from 0° to 180°. There is also a small hole in the center of the protractor. To use a protractor—

1. Place the hole of the protractor over the point of the angle where the lines meet.
2. Make sure one side of the angle is on the zero line.
3. Read the degrees off the protractor where the line of the other side is or mark a point along the edge at the appropriate angle measurement.

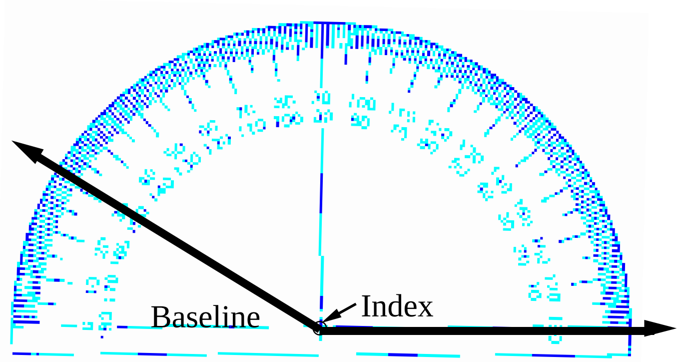
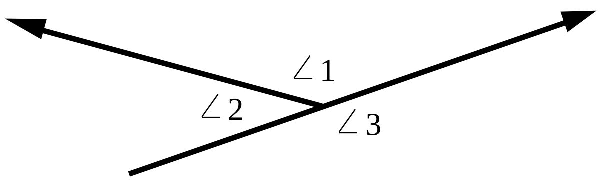


Figure 4.2—Protractor.

Example 1—a) Measure angles 1, 2, and 3. b) Add angles 1 and 2. How does that compare to the value for angle 3? Why? c) Add angles 1, 2, and 3. What is significant about the sum of these angles? Does this make sense?



Step 1. Place the hole (index point) of a protractor on the point where the lines meet.

Step 2. Place the zero line of the protractor on the edge of the angle.

Step 3. Read the degrees off the protractor where the other line is (extend the line if necessary).

a) Measure angles 1, 2, and 3.

$\angle 1 = 146°$, $\angle 2 = 34°$, $\angle 3 = 180°$

b) How does the sum of angles 1 and 2 compare to angle 3?

The sum of angles 1 and 2 is 180 degrees. Angle 3 also equals 180 degrees.

Angle 3 is a straight line, so it follows that the sum of angles 1 and 2, 180°, is also a straight line.

c) Add angles 1, 2, and 3.

The sum of angles 1, 2, and 3 are 360 degrees.

d) There are 360 degrees in a circle.

e) Yes, because the sum of angles 1, 2, and 3 is an angle that goes full circle.

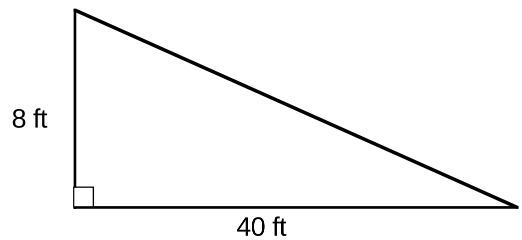
4.5 Slope Slope refers to the angle of the lay of the land. Slope can be upward or downward. Slope is described as rise over run. Where the rise is the vertical ↕ (up and down) distance and the run is the horizontal (back and forth) ↔ distance.

Slope $= \dfrac{\text{rise}}{\text{run}}$

Slope Percent—Slope percent is the amount of rise, vertical distance, as compared (in terms of percentage) to the run, horizontal distance. Percentage means per 100. Therefore, to find slope percent, multiply the slope by 100.

Slope Percent $= \dfrac{\text{(rise)}}{\text{(run)}} \times 100$

Example 2—Find the slope percent.



Slope percent $= \dfrac{8 \text{ feet}}{40 \text{ feet}} \times 100 = 20\%$

The slope percent is 20 percent.

Calculating Horizontal Distance from Slope and Vertical Distance.

If the slope and the vertical distance (rise) are known, then the horizontal distance (run) can be calculated. The slope percent equation can be rearranged to provide the equation for the horizontal distance.

Slope percent $= \dfrac{\text{rise}}{\text{run}} \times 100$

Rearrange terms:

Multiply both sides by "run."

$\text{run} \times \text{slope }\% = \dfrac{\text{rise}}{\text{run}} \times 100 \times \text{run}$

Divide both sides by "slope percent."

$\dfrac{\text{run} \times \text{slope }\%}{\text{slope }\%} = \dfrac{(\text{rise} \times 100)}{\text{slope }\%}$

$\text{run} = \dfrac{(\text{rise} \times 100)}{\text{slope }\%} = \text{horizontal distance}$

Example 3—A hill has a slope of 8 percent. The height of the hill is 15 feet. What is the horizontal distance?

horizontal distance = run = $\frac{\text{(rise x 100)}}{\text{slope \%}}$

Step 1. Enter the given values into the equation.

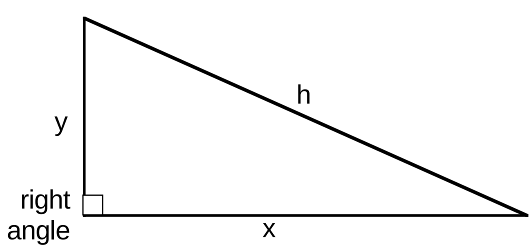
Step 2. Solve.

$$\text{run} = \frac{(15 \text{ ft} \times 100)}{8} = \frac{1500 \text{ ft}}{8} = 188 \text{ ft}$$

The hill has a horizontal distance of 188 feet.

Calculating Slope Distance from Horizontal and Vertical Distance, using a basic scientific calculator with a square root (√x) function.

Slope Distance—Slope distance (h) is the length of a slope. Slope distance can be calculated when the vertical height (y) and the horizontal distance (x) of a right angle are known. There is a right angle if the vertical and horizontal distances are "true" to the vertical and horizontal, respectively. See the following figure.



Use the equation: $h^2 = x^2 + y^2$

where h = slope distance
x = horizontal distance
y = vertical distance

$h = \sqrt{(x^2 + y^2)}$

slope distance =
$\sqrt{[(\text{horizontal distance})^2 + (\text{vertical distance})^2]}$

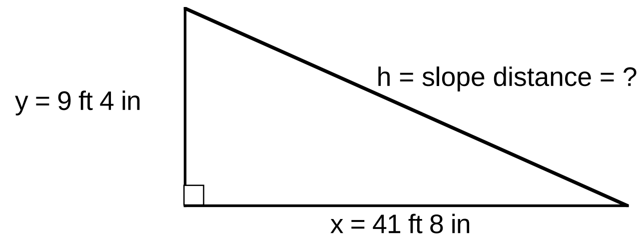
Rearranging terms: $x = \sqrt{(h^2 - y^2)}$

horizontal distance =
$\sqrt{[(\text{slope distance})^2 - (\text{vertical distance})^2]}$

Rearranging terms: $y = \sqrt{(h^2 - x^2)}$

vertical distance =
$\sqrt{[(\text{slope distance})^2 - (\text{horizontal distance})^2]}$

Example 4—Calculate the slope distance.



$h = \sqrt{(x^2 + y^2)}$

slope distance =
$\sqrt{[(\text{horizontal distance})^2 + (\text{vertical distance})^2]}$

Step 1. Change all the values to the same units. Change to feet. Conversion factor is 12 inches = 1 foot.

x = horizontal distance = 41 ft 8 in

$41 \text{ ft} + \left| \frac{8\,\cancel{\text{in}}}{} \middle| \frac{1 \text{ ft}}{12\,\cancel{\text{in}}} \right| = 41.66 \text{ ft}$ (round to 41.7 ft)

y = vertical distance = 9 ft 4 in

$9 \text{ ft} + \left| \frac{4\,\cancel{\text{in}}}{} \middle| \frac{1 \text{ ft}}{12\,\cancel{\text{in}}} \right| = 9.33 \text{ ft}$ (round to 9.3 ft)

Step 2. Plug in values and solve.

$h = \sqrt{(x^2 + y^2)}$

$h = \sqrt{[(41.7 \text{ ft} \times 41.7 \text{ ft}) + (9.3 \text{ ft} \times 9.3 \text{ ft})]}$
$= \sqrt{[(1738.9 \text{ ft}^2 + 86.5 \text{ft}^2)]}$

$h = \sqrt{(1825 \text{ ft}^2)} = 42.7 \text{ ft}$

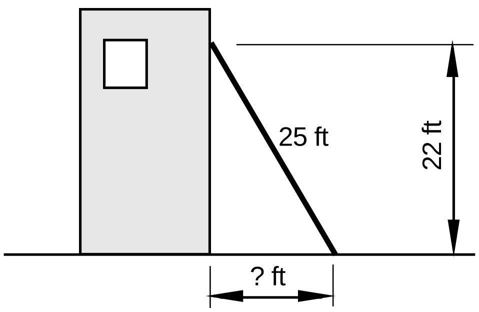
Use a scientific calculator with a square root √x key. Enter 1,825 and then press the √x key. Instructions may vary with different calculators.

In feet and inches?
h = 42 ft + 0.7 x 12 in = 42 ft 8 in
See appendix B.8

h = slope distance = 42.7 ft or 42 ft 8 in

Example 5—A 25 foot ladder is placed against the side of a lookout tower. The top of the ladder is 22 feet from the ground. What is the distance from the base of the ladder to the building?

Step 1. Draw a diagram.



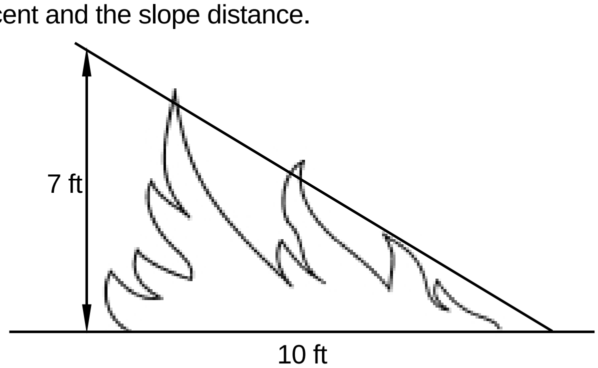
vertical distance = y = 22 ft
horizontal distance = x = ?
Slope distance = h = 25 ft

Step 2. Use the equation for horizontal distance.
$x = \sqrt{(h^2 - y^2)}$
horizontal distance =
$\sqrt{[(\text{slope distance})^2 - (\text{vertical distance})^2]}$

Step 3. Plug in the values and solve.
$x = \sqrt{[(25 \text{ ft} \times 25 \text{ ft}) - (22 \text{ ft} \times 22 \text{ ft})]}$
$x = \sqrt{[(625 \text{ ft}^2 - 484 \text{ ft}^2)]} = \sqrt{[(141 \text{ ft}^2)]}$
x = horizontal distance = 11.9 ft (round up to 12 ft.)

The base of the ladder is 12 feet from the building.

Example 6—A fire is burning and the flames reach a height of 7 feet vertically, in a 10-foot span. Find the slope percent and the slope distance.



$$\text{Slope \%} = \frac{\text{rise}}{\text{run}} = \frac{7 \text{ feet}}{10 \text{ feet}} \times 100 = 70\%$$

The slope percent of the flames is 70 percent.

$h = \sqrt{(x^2 + y^2)}$
slope distance =
$\sqrt{[(\text{horizontal distance})^2 + (\text{vertical distance})^2]}$
$h = \sqrt{[(10 \text{ ft} \times 10 \text{ ft}) + (7 \text{ ft} \times 7 \text{ ft})]} = \sqrt{(149 \text{ ft}^2)}$
h = 12.2 ft (round to 12 feet)

The slope distance of the flame front is 12 feet.

The slope can also be determined from topographic maps. See chapter 5.

Slope Angle from Slope Percent—The angle of the slope is the amount of deviation from flat in terms of degrees. The slope angle can be calculated from the slope percent by the use of a basic scientific calculator with trigonometric functions. Slope percent is change in vertical distance divided by the change in horizontal distance. This ratio is the tangent ratio for angles.

Calculating the inverse tangent, also called arc tan, of the slope percent in decimal form, gives the slope angle.

inv tan of the slope percent (in decimal) = Slope angle

Example 7—The slope percent is 60 percent. What is the slope angle?

Step 1. Change 60 percent to decimal form. Sixty percent means 60 out of 100. It can also be written 60/100 = 0.60. *See chapter 1.8.*

inv tan of the slope percent (in decimal) = slope angle
inv tan of 0.6 = slope angle

Step 2. Enter .6 into the calculator.

Step 3. Push the inverse, inv, or 2nd button, then the tan button to get $\tan^{-1}$. The calculator will show the slope angle.

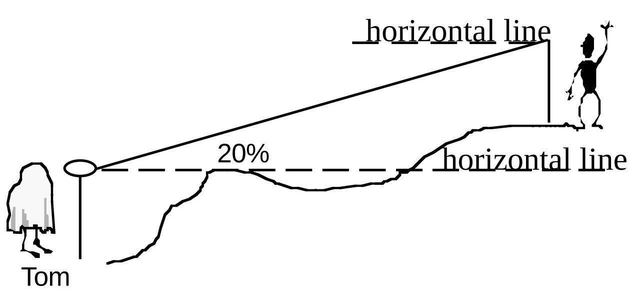
slope angle = 31°

Instructions may vary with different scientific calculators.

Using a Clinometer—A clinometer measures slope angle or percent slope. It is used to measure the vertical angle between two points in terms of degrees, or percent slope as measured from horizontal. Sighting a clinometer is as follows:

- Open both eyes in order to sight the object and read the scale.
- There are two scales in the viewfinder—percent slope scale on the right margin and slope angle on the left margin. The vertical angle is in degrees. Verify which scale is being read.
- Sight the clinometer from eye level to the object or to a distant point that is also at about eye level. Read the scales for percent slope or degree of slope.
- In uneven terrain, place the clinometer on a pole at eye level and read to the distant point on another pole of the same height. This provides a more accurate reading.

Example 8—Tom has a clinometer on a 5.0-foot pole. He sights another 5.0-foot pole that is 24.0 feet away (horizontal distance). He gets a reading of 20.0 slope percent. What are the slope and vertical distances?



Step 1. Read the slope percent at 20 percent or the angle as 11.3 degrees.

Step 2. Use the slope percent formula to calculate the vertical distance.

$$0.2 = \frac{\text{vertical distance}}{\text{horizontal distance}} = \frac{\text{vertical distance}}{24.0\text{ ft}}$$

vertical distance = 24.0 feet x 0.2 = 4.8 feet

Step 3. Use the slope distance formula to calculate the slope distance.

Slope distance =
√[(24.0 ft x 24.0 ft) + (4.8 ft x 4.8 ft)] = 24.5 ft

The vertical distance is 4.8 feet and the slope distance is 24.5 feet.

4.6 Chain, Pace, Walking a Chain A chain is equal to 66 feet and is the basic unit for measuring distances in fire-control work. There are 80 chains in 1 mile.

A **pace** is the distance on level ground between the heel of one foot and the heel of the same foot, where it next touches the ground while walking normally (two normal steps). As everyone's pace differs, it is important to determine one's pace length.

Walking a chain or chaining—To walk a chain, measure several chains on level ground with a steel tape, marking each chain with a stake. Walking normally from one stake to the other, count the paces. Divide by the number of chains that were measured off to get the number of paces per chain. A person's pace will change depending on whether pacing is uphill or downhill. Therefore, the number of paces per chain will need to be recalculated as above.

Example 9—Victor marks off 3 chains or 198 feet (66 feet x 3 = 198 feet). He walks the distance in 36 paces. How many paces per chain is this? What is the length of each pace?

$$\frac{36\text{ paces}}{3\text{ chains}} = \frac{12\text{ paces}}{\text{chain}}$$

Victor walks 12 paces per chain.

$$\left|\ \frac{1\ \cancel{\text{chain}}}{12\ \text{paces}}\ \right|\ \frac{66\ \text{feet}}{\cancel{\text{chain}}}\ \Big| = \frac{66\ \text{feet}}{12\ \text{paces}} = \frac{5\text{-}1/2\ \text{feet}}{\text{pace}}$$

The length of Victor’s pace is 5-1/2 feet.

4.7 Graphs Graphing is a method of showing the relationship between two or more sets of data by means of a chart or sketch. Trends in performance data are easier to identify with a graph than a data table.

Use cross section or graphing paper when drawing line graphs. Paper can be purchased or drawn. Draw by marking off 6 inches x 6 inches, and add vertical and horizontal lines every 1/4 inch.

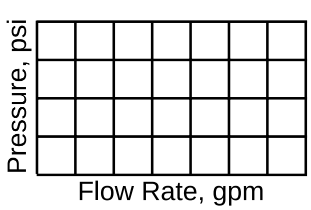
- Values of units are chosen for each axis that will permit the graph to fit conveniently on the paper.
- The units are marked off on the vertical and horizontal axes.
- Points are plotted in relation to the two axes from the table of information.
- Finally, the points are connected with a straight line or curve.

Example 10—Draw a graph for pump performance showing the relationship between pressure (psi) and flow (gpm). Use the following table of pump performance data values.

Pump Performance Values

psi	50	75	100	125	150	175	200	225	250	275	295
gpm	79	77	75	69.5	63	56.5	51	46	40.5	29.5	0

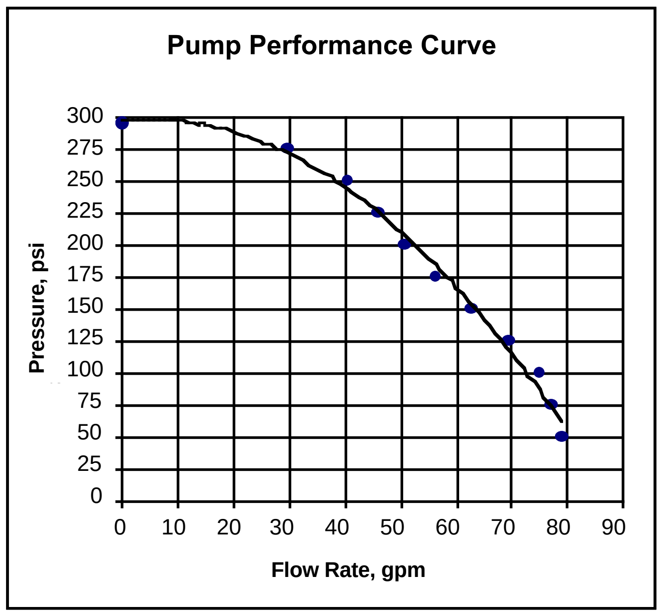
Step 1. Pump performance charts are typically drawn with the flow on the horizontal axis and pressure on the vertical axis. Label the horizontal axis as flow in gallons per minute. Label the vertical axis as pressure in pounds per square inch.



Step 2. Mark the horizontal axis from 0 to 90 in even increments. Mark the vertical axis from 0 to 300 in even increments of 25 pounds per square inch, as the data was collected in increments of 25 pounds per square inch.

Step 3. Plot each data set by finding the pressure value on the vertical axis and then the flow value on the horizontal axis. Mark/plot a point where the two values meet. Continue plotting points for all data sets.

Step 4. Run a curved line through the points. Not all the points will be on the curve, some of the points will lie above the line and some below. Special statistical calculations are used to determine how far off the curve a data point can be and still be meaningful. Typically, if the point is off the curve enough to affect the shape of the curve, the data set should be rerun.



Approximate Values from a Graph—A curve can be used to find approximate values for data in between the data sets collected. The curve can also be used to show performance trends. For example, this curve shows that as pressure is decreasing, the flow rate increases proportionally throughout the range of performance. This is a typical pump performance curve.

Example 11—Using the graph in example 10, find the indicated flow rate at a pressure of 263 pounds per square inch.

<u>Step 1.</u> Approximate the location of 263 pounds per square inch on the pressure axis. This will be halfway between 275 and 250 pounds per square inch.

<u>Step 2.</u> Move horizontally until the curved line is met.

<u>Step 3.</u> Move vertically from the curved line to the flow rate axis. Read or approximate the flow rate.

The flow rate is 35 gallons per minute at a pressure of 263 pounds per square inch.

Determining Slope of Curve from a Graph—The slope of the line can be determined from the plot by using the slope formula.

slope = rise/run

Example 12—Find the slope of the line drawn on the previous page from 50 to 150 pounds per square inch. Since the line drawn is a curve, the slope will change with each section of line.

The pressure varies from 50 to 150 pounds per square inch as the flow rate varies from about 79 to 63 gallons per minute.

Pressure, pounds per square inch, is on the vertical axis, so it is the rise.
Flow rate, gallons per minute, is on the horizontal axis, so it is the run.

$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{(150 - 50)\text{ psi}}{(63 - 79)\text{ gpm}} = \frac{100\text{ psi}}{-16\text{ gpm}} = -6\text{ psi/gpm}$$

The negative slope indicates that the slope is decreasing.

The slope of the above line graph is –6 pounds per square inch per gallons per minute.

Reading Distance from a Map Table—Maps are generally broken into grids and labeled on the vertical and horizontal axes for ease of locating places or numbers. If the vertical and horizontal values are known, the value on the graph can be obtained by finding where the two lines intersect (cross).

Example 13—Use the mileage chart below to find the distance between Tampa, FL, and Albuquerque, NM.

Mileage Chart, miles

	Los Angeles, CA	Portland, OR	Albuquerque, NM	Denver, CO	Tampa, FL	Fargo, ND
Los Angeles, CA	0	967	804	1,023	2,549	1,839
Portland, OR	967	0	1,366	1,236	3,064	1,494
Albuquerque, NM	804	1,366	0	439	1,760	1,272
Denver, CO	1,023	1,236	439	0	1,874	875

<u>Step 1.</u> Locate Tampa on the horizontal axis. Draw a vertical line through these grids.

<u>Step 2.</u> Locate Albuquerque on the horizontal axis. Draw a horizontal line across these grids.

<u>Step 3.</u> Read the mileage amount where the two lines cross.

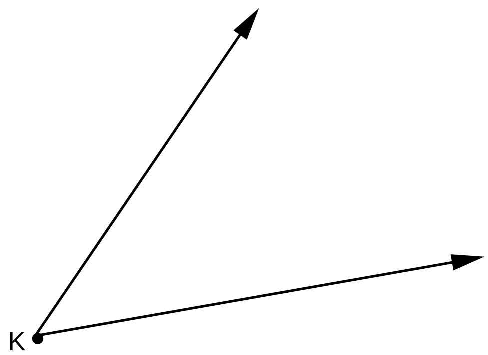
Mileage Chart, miles

	Los Angeles, CA	Portland, OR	Albuquerque, NM	Denver, CO	Tampa, FL	Fargo, ND
Los Angeles, CA	0	967	804	1,023	2,549	1,839
Portland, OR	967	0	1,366	1,236	3,064	1,494
Albuquerque, NM	804	1,366	0	439	1,760	1,272
Denver, CO	1,023	1,236	439	0	1,874	875

The distance between Tampa and Albuquerque is 1,760 miles.

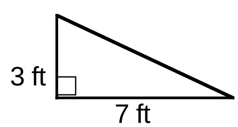
EXERCISES

Problem 1. Measure the angle.

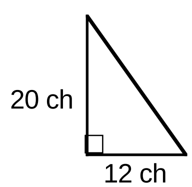


Find the slope percent for problems 2 and 3.

Problem 2.



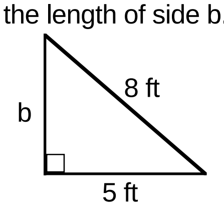
Problem 3.



Problem 4. A hill has a slope of 9 percent. The vertical distance is 5 chains. What is the horizontal distance?

Problem 5. A hill has a slope of 60 percent. The horizontal distance is 80 chains. What is the vertical distance?

Problem 6. Find the length of side b.



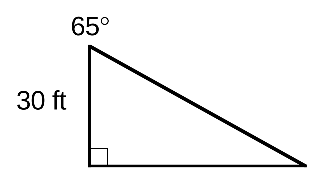
Problem 7. Raul spots a fire. He sees that the flames reach to the top of the shrubs. From this he determines that the flame height is 7 feet. The span of the fire is 9 feet. What is the flame length?

Problem 8. Find tan A = 0. 3.

Problem 9. Find tan 40°.

Problem 10. Sergio calculates the slope percent and finds it to be 35 percent. What is the measure of the angle?

Problem 11. Find the horizontal distance and the slope distance of the figure below.



Problem 12. Juanita is holding a 5-foot pole at the base of a hill. John is holding a 5-foot pole at the top of the hill. Juanita reads the clinometer and gets a 40 percent slope. The horizontal distance between John and Juanita is 30 feet. Find the slope distance and the vertical distance.

Problem 13. Mario is going to a fire. He has determined that his pace is 13 paces per chain. The distance to the fire is 20 chains on level ground. How many paces will Mario have to take to get to the fire?

Problem 14. Julie is determining her pace length. She has marked off 2 chains on level ground. It takes her 22 paces to walk the 2-chain distance. How many paces does she walk per chain?

Problem 15. Billy Joe's pace is 12 paces per chain. He is measuring the distance to a fire from a stream. He takes 480 paces. How many chains is it to the fire from the stream?

Problem 16. The following table shows the relationship between depth and pressure upon bodies submerged in water. Draw a line graph using this information. On the horizontal axis, represent depth in feet. On the vertical axis, represent pressure in pounds per square foot. Find the slope of the line.

Pressure (psft)	Depth (ft)
123	2
250	4
375	6
500	8
625	10
750	12
1,250	20
1,875	30

Problem 17. From the line graph in problem 16, read the pressure at 25 feet.

Problem 18. The fireline intensity readings, in British thermal units per foot per second for the first 10 days of the fire were as follows:

Day	Btu/ft/s
1	120
2	140
3	160
4	180
5	200
6	190
7	170
8	140
9	130
10	100

Draw a line graph using this information.

Problem 19. What is the slope of the line graph in problem 18 as it is increasing? On what day does the intensity of the fire peak? On what days is the intensity of the fire 130 British thermal units per foot per second?

Problem 20. Find the value that is in grid 3B.

D	9	4	0	3	25
C	1	8	42	8	16
B	5	6	22	2	33
A	6	5	15	7	14
	1	2	3	4	5

Problem 21. Using the mileage chart in example 13, find the distance between Denver, CO, and Portland, OR.

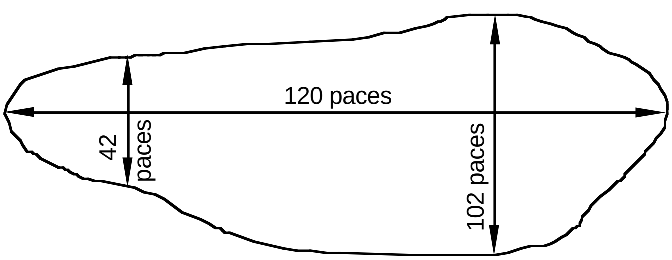
The material in chapter 5 describes calculating area and perimeter of a burn, fire spread distance, and effective windspeed. How to read and use a map scale, convert map to ground distances, and use topographic maps are described in detail.

5.1 Burn Area and Perimeter Determining perimeter and burn area after a fire is often necessary. Average dimensions for a sketch can be obtained by pacing or walking around and through the burn. This is especially useful for small fires. Global Positioning Systems (GPS) are used for larger fires to determine their shape, area, and perimeter.

Example 1—John sketched the following burn shape in his firefighter's notebook. Use this information to determine acreage. John's pace is 12 paces per chain.

Use the equation for determining the area of a rectangle.

area of rectangle = length x width



<u>Step 1.</u> Set up the cancellation table so all units will cancel, except the desired unit, chains.

$$\text{Width 1} = \left|\begin{array}{l|l} 102\ \cancel{\text{paces}} & \text{chain} \\ \hline & 12\ \cancel{\text{paces}} \end{array}\right| = 8.5 \text{ chains}$$

$$\text{Width 2} = \left|\begin{array}{l|l} 42\ \cancel{\text{paces}} & \text{chain} \\ \hline & 12\ \cancel{\text{paces}} \end{array}\right| = 3.5 \text{ chains}$$

$$\text{Length} = \left|\begin{array}{l|l} 120\ \cancel{\text{paces}} & \text{chain} \\ \hline & 12\ \cancel{\text{paces}} \end{array}\right| = 10 \text{ chains}$$

<u>Step 2.</u> Take the average of the two widths.

$$\text{The average width} = \frac{8.5 \text{ chain} + 3.5 \text{ chains}}{2} = 6 \text{ chains}$$

<u>Step 3.</u> Use the equation for determining the area of a rectangle.

area of rectangle = length x average width

Area = 10 chains x 6 chains = 60 square chains

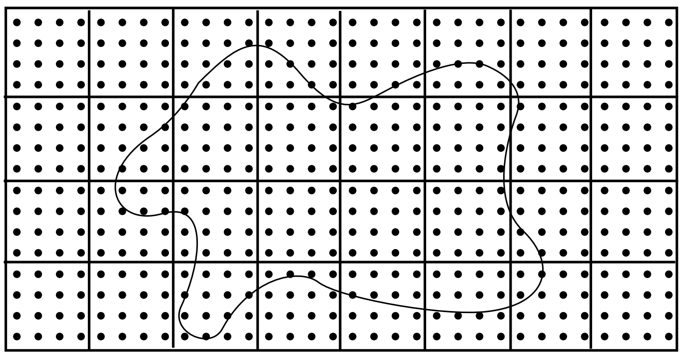
<u>Step 4.</u> Set up the cancellation table so all units will cancel, except the desired unit, acres.

$$\left|\begin{array}{l|l} 60\ \cancel{\text{square chains}} & 1 \text{ acre} \\ \hline & 10\ \cancel{\text{square chains}} \end{array}\right| = 6 \text{ acres}$$

The area of the fire is 6 acres.

Acreage Grid—A clear acetate/plastic dot acreage grid can be placed over the mapped sketch of a burn area. It is important that the plastic grid overlay and burn map have the same scale. Burn area is determined by counting the number of dots inside the sketch of the burn. For dots that are on the border of the burn sketch, count every other dot. Multiply the number of dots counted by the dot conversion factor. This is typically indicated on the bottom of the plastic overlay. See figure 5.1.

Example 2—The U.S. Geological Survey (USGS) produces a series of standard maps to various scales. The 7.5 minute map series has a 1:24,000 scale. One inch on a 7.5 minute map represents 2,000 feet on the ground. See chapter 6, Latitude and Longitude, for more information. Janie sketched out a burn area in the following shape on a 7.5 minute USGS quadrangle map. Use the acreage grid overlay to determine the area of the fire.



Step 1. Count the number of dots within the shape. Count every other dot for dots on the borderline. There are 181 dots.

Step 2. Read the overlay scale to obtain the dot-grid conversion of 2.500 acres per dot. See figure 5.1.

Step 3. Set up the cancellation table so all units will cancel, except the desired unit, acres.

$$\text{Area} = \frac{181\ \cancel{\text{dots}}}{} \,\Big|\, \frac{2.500\ \text{acres}}{\cancel{\text{dot}}} = 453\ \text{acres}$$

The area of the above figure is about 453 acres.

5.2 Map Scale The map scale is printed in the map legend. It is given as a ratio of inches on the map corresponding to inches, feet, or miles on the ground. Some common map scale units are listed in figure 5.2. For example, a map scale indicating a ratio of 1:24,000 (in/in), means that for every 1 inch on the map, 24,000 inches have been covered on the ground. Ground distances on maps are usually given in feet or miles.

Example 3—Convert the map scale of 1:24,000 (in/in) to (in/ft).

Step 1. Set up the cancellation table so all units will cancel, except the desired unit, ft/in.

$$\frac{24{,}000\ \cancel{\text{inches}}}{\text{inch}} \,\Big|\, \frac{1\ \text{foot}}{12\ \cancel{\text{inches}}} = \frac{2{,}000\ \text{feet}}{\text{inch}}$$

On the map 1 inch is equal to 2,000 feet on the ground, 1:2,000 (in/ft).

Example 4—Convert the 1:2,000 (in/ft) to (in/mile).

Step 1. Set up the cancellation table so all units will cancel, except the desired unit, miles/inch.

$$\frac{2{,}000\ \cancel{\text{feet}}}{\text{inch}} \,\Big|\, \frac{1\ \text{mile}}{5{,}280\ \cancel{\text{feet}}} = \frac{0.4\ \text{miles}}{\text{inch}}$$

On the map 1 inch is equal to 0.4 miles.

Example 5a—Between two points there is a map distance of 6 inches. The map scale is 1:24,000 (in/in). What is the ground distance in feet?

Step 1. Set up the cancellation table so all units will cancel, except the desired unit, feet.

$$\frac{24{,}000\ \cancel{\text{inches}}}{1\ \cancel{\text{inch}}} \,\Big|\, \frac{1\ \text{foot}}{12\ \cancel{\text{inches}}} \,\Big|\, \frac{6\ \cancel{\text{inches}}}{} = 12{,}000\ \text{feet}$$

The ground distance is 12,000 feet.

Example 5b—Find the ground distance in chains, miles, and inches.

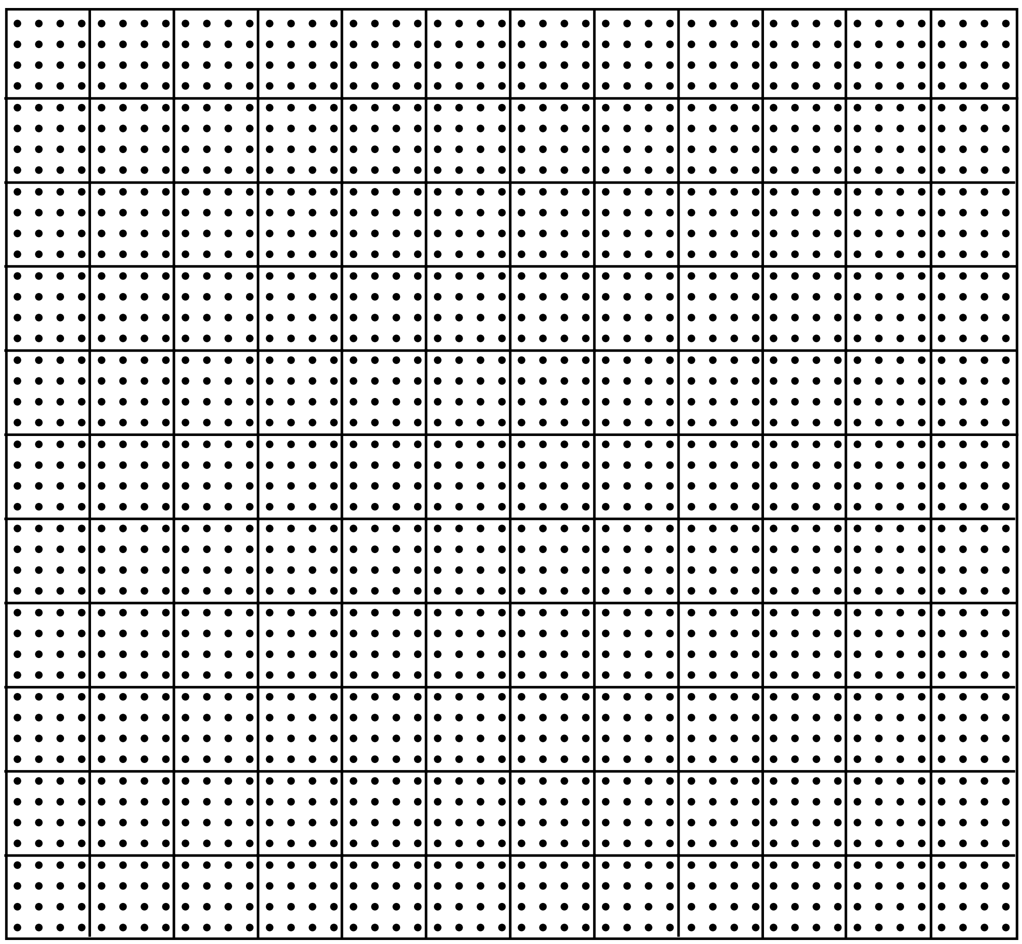
Step 1. Set up the cancellation table so all units will cancel, except the desired unit, chains.

$$\frac{12{,}000\ \cancel{\text{feet}}}{} \,\Big|\, \frac{1\ \text{chain}}{66\ \cancel{\text{feet}}} = 182\ \text{chains}$$

12,000 feet = 182 chains

Modified Acreage Grid (Transparency)

- Place the acreage grid transparency over the area to be measured.
- Count dots inside the sketched area. Count every other dot when dots fall on the boundary line.
- Multiply the total number of dots by the conversion factor on the map scale to determine the total acreage.



Map Scales and Equivalents

Scale	Inches per mile	Acres per square inch	Conversion factor that each dot equals
1:20,000	3.168	63.769	1.736 Acres
1:24,000	2.640	91.827	2.500 Acres
1:62,500	1.014	622.449	16.946 Acres
1:63,360	1.000	640.000	17.424 Acres

Figure 5.1—Acreage Grid Overlay, Map Scales, and Equivalents.

Step 2. Set up the cancellation table so all units will cancel, except the desired unit, miles.

$$\frac{12{,}000\ \cancel{\text{feet}}}{} \left| \frac{1\ \text{mile}}{5{,}280\ \cancel{\text{feet}}} \right| = 2.3\ \text{miles}$$

Step 3. Set up the cancellation table so all units will cancel, except the desired unit, inches.

$$\frac{12{,}000\ \cancel{\text{feet}}}{} \left| \frac{12\ \text{inches}}{1\ \cancel{\text{foot}}} \right| = 144{,}000\ \text{inches}$$

12,000 feet = 182 chains = 2.3 miles = 144,000 inches

Occasionally, a map may not provide a scale. The scale can be calculated by knowing the distance between two points on the map, and measuring the distance on the map. Also, if a map has section lines, the distance between section lines is typically 1 mile.

Example 6—The distance between point A and B is 6 inches on the map. The known ground distance is 3,600 feet. What is the scale in units of inches/foot?

$$\text{map scale} = \frac{\text{known distance}}{\text{measured distance}} = \frac{3{,}600\ \text{feet}}{6\ \text{inches}} = \frac{600\ \text{feet}}{\text{inch}}$$

The map scale is 1:600 inches/foot.

Example 7—Use the map scale in example 6. The known ground distance between points B and C is 1/2 mile. How many inches is this on the map?

$$\text{map scale} = \frac{\text{known distance}}{\text{measured distance}}$$

Rearrange terms by multiplying each side by the measured distance and dividing each side by the map scale.

$$\text{measured distance} = \frac{\text{known distance}}{\text{map scale}}$$

Step 1. Set up the cancellation table so all units will cancel, except the desired unit, feet.

$$\frac{1/2\ \cancel{\text{mile}}}{} \left| \frac{5{,}280\ \text{feet}}{1\ \cancel{\text{mile}}} \right. = 2{,}640\ \text{feet}$$

Step 2. Use the map scale from example 6 to find the map distance.

$$\text{measured distance} = \frac{\text{known distance}}{\text{map scale}}$$

$$\text{measured distance} = \frac{2{,}640\ \cancel{\text{feet}}}{} \left| \frac{1\ \text{inch}}{600\ \cancel{\text{feet}}} \right| = 4.4\ \text{inches}$$

On the ground one-half mile is the same as 4.4 inches on the map.

Map Scale Conversion Factors

Map Scales

Scale	Representative Fraction	Map in/mi	Map in/ch	Map ft/in
1:253,440	253.44	0.25	0.0031	21,120
1:126,720	126.72	0.50	0.0063	10,560
1:63,360	63.36	1.00	0.0125	5,280
1:62,500	62.50	1.01	0.0127	5,208
1:31,680	31.68	2	0.025	2,640
1:24,000	24.00	2.64	0.033	2,000
1:21,120	21.12	3	0.038	1,760
1:15,840	15.84	4	0.05	1,320
1:7,920	7.92	8	0.1	660

Figure 5.2—Map Scale Conversion Factors.

5.3 Spread Distance

Spread distance (SD) is the forward distance a fire spreads in a given amount of time. SD can be calculated from rate of spread (ROS) and projected time (PT).

Spread Distance = Rate of Spread x Projected Time

SD = ROS x PT

Example 8—What is the spread distance, in feet, for a fire that has a rate of spread of 6 chains per hour for a 3-hour time span?

<u>Step 1.</u> Use the equation for determining the spread distance.

$$SD = ROS \times PT = \left| \begin{array}{c|c} \frac{6 \text{ chains}}{\cancel{\text{hour}}} & 3\ \cancel{\text{hours}} \end{array} \right| = 18 \text{ chains}$$

<u>Step 2.</u> The answer needs to be in feet. Set up the cancellation table so all units will cancel, except the desired unit, feet.

$$\left| \begin{array}{c|c} 18\ \cancel{\text{chains}} & \frac{66 \text{ feet}}{1\ \cancel{\text{chain}}} \end{array} \right| = 1{,}188 \text{ feet}$$

The spread distance is 1,188 feet.

Example 9—Using example 8, find the map distance of the fire spread. The map scale is 1:31,680 (inch/inch).

<u>Step 1.</u> Convert inch/inch to feet/inch. Set up the cancellation table so all units will cancel, except the desired unit, feet/inch.

$$\left| \begin{array}{c|c} \frac{31{,}680\ \cancel{\text{inches}}}{\text{inch}} & \frac{1 \text{ foot}}{12\ \cancel{\text{inches}}} \end{array} \right| = 2{,}640 \text{ feet/inch}$$

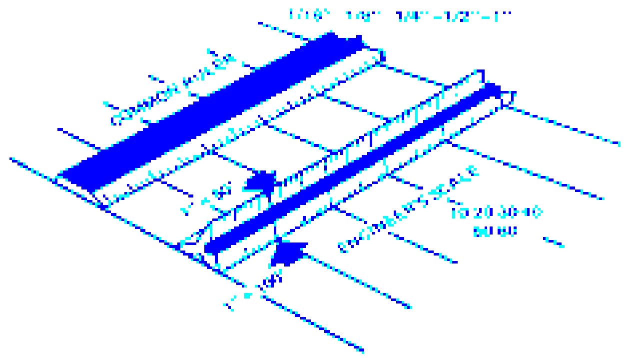
<u>Step 2.</u> Convert the ground spread distance to a map spread distance.

$$\left| \begin{array}{c|c} 1{,}188\ \cancel{\text{feet}} & \frac{1 \text{ inch}}{2{,}640\ \cancel{\text{feet}}} \end{array} \right| = 0.45 \text{ inch}$$

The map distance is 0.45 inches.

Note on Forward Rate of Spread—The shape of a fire is dependent on slope and effective windspeed. The higher the windspeed and percent of slope, the longer, more cigar-shaped the burn area. Consequently, safety dictates that firefighters be positioned at the flanks (sides) or back of a fire. A firefighter should never be uphill (at the head) of a fire where the rate of spread is the fastest. See the Standard Fire Orders (F-I-R-E-O-R-D-E-R-S) in the Fireline Handbook, PMS 410-1 or NFES 0065.

Using a Scaled Ruler for Measurements—When drawing or measuring distances, a scaled ruler is sometimes necessary for direct measurements. A scaled ruler, or engineer's ruler, has 1-inch increments subdivided into 1/10-inch increments, convenient for ground measurements. Ground measurements are usually given in fractions of multiples of 10. For example for 3.7 inches, where 1 inch equals 100 feet, then each tenth will equal 10 feet. Consequently, 3.7 inches equals 370 feet.



Basic Measurements

Map Spread Worksheet —All data collected and calculated in examples 8, 9, and 10 can be put into a map spread worksheet.

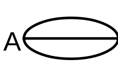
Example 10—Using a ruler scaled in 1/10 inch or 0.1 inch increments, draw a sketch of the burn in example 9. The effective windspeed is 3 miles/hour. Complete the map spread worksheet. See the steps below and figures 5.3 and 5.4.

<u>Step 1.</u> Draw a line of 0.5 inches from point A up the slope to point B.

A————B

<u>Step 2.</u> See the fire shapes in figure 5.3 to determine how wide to make the ellipse.

<u>Step 3.</u> Draw an ellipse around the line drawn.

AB

Fire Shapes Are Dependent on Effective Windspeeds

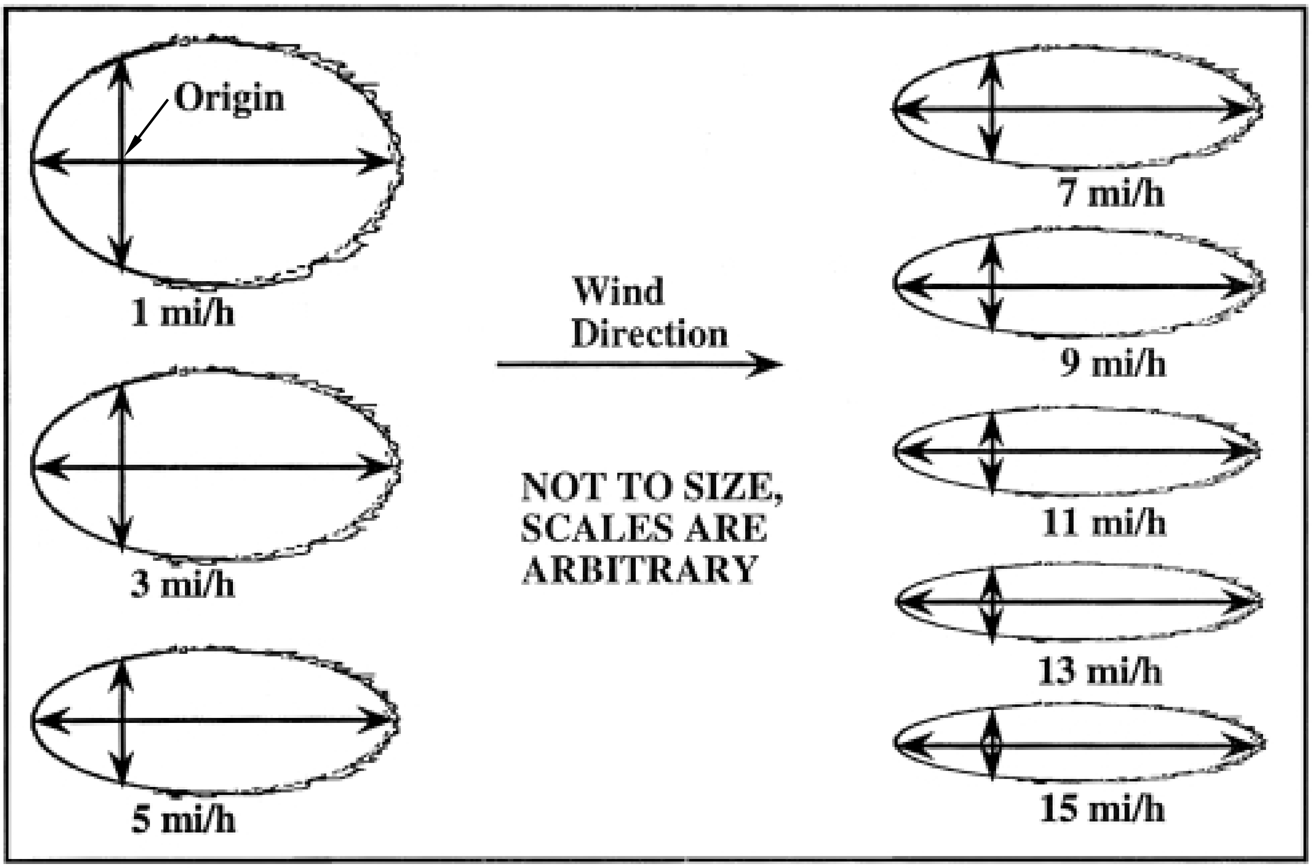


Figure 5.3—Fire shape.

Map Spread Worksheet

Line	Input			
0	PP	Projection point	______	______
1	ROS	Rate of spread, ch/h	______	______
2	PT	Projection time, h	______	______
3	SDCH	Spread distance, ch (line 1 x line 2)	______	______
4	SDFT	Spread distance, ft (line 3 x 66 ft/ch)	______	______
5	SCL	Map scale	______	______
6	CF	Conversion factor, ft/in (see map scale conversion)	______	______
	Output			
1	MD	Map spread distance, in (line 4 divided by line 6)	______	______

Figure 5.4—Map spread worksheet.

Map Spread Worksheet

Line	Input			
0	PP	Projection point	A	
1	ROS	Rate of spread, ch/h	6	Given
2	PT	Projection time, h	3	Given
3	SDCH	Spread distance, ch	18	From example 8
4	SDFT	Spread distance, ft	1,188	From example 8
5	SCL	Map scale	1:31,680	From example 9
6	CF	Conversion factor, ft/in	2,640	From example 9
	Output			
	MD	Map spread distance, in	.45	From example 9

When completing the map spread worksheet, notice that the projection point is line zero. Line 1 begins with the rate of spread.

Fire Area/Size Worksheet

Line	Input		
0	PP	Projection point	______
1	ROS	Rate of spread, ch/h	______
2	EWS	Effective windspeed, mi/h	______
3	PT	Projection time, h	______
4	SD	Spread distance, ch	______
	Output		
	PER	Perimeter, ch	______
	AC	Area, ac	______

5.4 Perimeter and Area Estimation Charts The perimeter and area of a fire can be determined by using estimation charts. See figures 5.5 and 5.6. The spread distance in chains and the effective windspeed in miles per hour are needed. A fire area/size worksheet is provided in figure 5.7 to be filled out with the data collected.

Effective Windspeed—Effective windspeed is the midflame windspeed, corrected for the effects of slope on fire spread.

Example 11—Using the perimeter estimation chart. A fire starts at point A. Given the following values, determine the fire perimeter.

rate of spread = 5 ch/h, projection time = 3 h,
effective windspeed = 10 mi/h

Step 1. Use the equation for determining the spread distance.
SD = ROS x PT
15 chains = 5ch/h x 3 h

Step 2. See figure 5.5, perimeter estimation chart. Look for a spread distance of 15 chains on the vertical axis. Go across horizontally.

Step 3. Look for an effective windspeed of 10 miles/hour on the horizontal axis, which is between 9 miles/hour and 11 miles/hour. Go down vertically.

Step 4. Where the two lines intersect, read the number. In this case there are two numbers.
34 chains and 33 ch

Step 5. Take an average of the two values.

$$\frac{34.0 \text{ chains} + 33.0 \text{ chains}}{2} = 33.5 \text{ chains}$$

The perimeter of the fire is 33.5 chains.

Example 12—Using the area estimation chart. Determine the area of the fire in example 11. Complete the fire area/size worksheet following. The spread distance is the same, 15 chains.

Step 1. Reference the area estimation chart for a spread distance of 15 chains. Go across horizontally.

Step 2. Look for an effective windspeed of 10 miles/hour, which is between 9 miles/hour and 11 miles/hour. Go down vertically and read the numbers from the two windspeeds.
4.9 acres and 5.7 acres

Step 4. Take an average of the two values.

$$\frac{4.9 \text{ acres} + 5.7 \text{ acres}}{2} = 5.3 \text{ acres}$$

The area of the fire is 5.3 acres.

Spread Distance (Chains)	Effective Windspeed, miles/hour 1	3	5	7	9	11	13	15	17	19
	Chains									
1	4	3	2	2	2	2	2	2	2	2
2	7	6	5	5	5	4	4	4	4	4
3	11	8	7	7	7	7	6	6	6	6
4	14	11	10	9	9	9	9	9	8	8
5	18	14	12	12	11	11	11	11	11	10
6	21	17	15	14	14	13	13	13	13	13
7	25	19	17	16	16	15	15	15	15	15
8	28	22	20	19	18	18	17	17	17	17
9	21	25	22	21	20	20	19	19	19	19
10	35	28	25	23	23	22	22	21	21	21
11	39	30	27	26	25	24	24	23	23	23
12	43	33	30	28	27	26	26	26	25	25
13	46	36	32	30	29	29	28	28	27	27
14	50	39	335	33	32	31	30	30	30	29
15	53	41	37	35	34	33	32	32	32	31
16	57	44	40	37	36	35	35	34	34	34
17	60	47	42	40	38	37	37	36	36	36
18	64	50	45	42	41	40	39	38	38	38
19	67	52	47	44	43	42	41	41	40	40
20	71	55	50	47	45	44	43	43	42	42
21	74	58	52	49	47	46	45	45	44	44
22	78	61	55	51	50	48	48	47	46	46
23	82	64	57	54	52	51	50	49	49	48
24	85	66	60	56	54	53	52	51	51	50
25	89	69	62	59	56	55	54	53	53	52
26	92	72	65	61	59	57	56	55	55	54
28	99	77	70	66	63	62	61	60	59	59
30	106	83	74	70	68	66	65	64	63	63
32	113	88	79	75	72	70	69	68	68	67
34	121	94	84	80	77	75	73	73	72	71
36	128	99	89	84	81	79	78	77	76	75
38	135	105	94	89	86	84	82	81	80	80
40	142	110	99	94	90	88	86	85	84	84
42	149	116	104	98	95	92	91	90	89	88
44	156	122	109	103	99	97	95	94	93	92
46	163	127	114	108	104	101	99	9a8	97	96
48	170	133	119	112	108	106	104	102	101	101
50	177	138	124	117	113	110	108	107	106	105
52	184	144	129	122	117	114	112	111	110	109
54	191	149	143	126	122	119	117	115	114	113
56	199	155	139	131	126	123	121	119	118	117
58	206	160	144	136	131	128	125	124	122	122
60	213	166	149	140	135	132	130	128	127	126
62	220	171	154	145	140	136	134	132	131	130
64	227	177	159	150	144	141	138	137	135	134
66	234	182	164	154	149	145	143	141	139	138
68	241	188	169	159	153	150	147	145	144	142

Figure 5.5—Perimeter estimation for point source fires (1).

Spread Distance (Chains)	Effective Windspeed, miles/hour 1	3	5	7	9	11	13	15	17	19
	Chains									
70	248	193	174	164	158	154	151	149	148	147
72	255	199	179	169	162	158	156	154	152	151
74	262	204	184	173	167	163	160	158	156	155
76	269	210	189	178	171	167	164	162	160	159
78	277	215	194	183	176	172	169	166	165	163
80	284	221	199	187	180	176	173	171	169	168
82	291	227	204	192	185	180	177	175	173	172
84	298	232	209	197	189	185	182	179	177	176
86	305	238	214	201	194	189	186	183	182	180
88	312	243	219	206	198	194	190	188	186	184
90	319	249	223	211	203	198	194	192	190	189
92	326	254	228	215	207	202	199	196	194	193
94	333	260	233	220	212	207	203	200	199	197
96	340	265	238	225	217	211	207	205	203	201
98	347	271	243	229	221	216	212	209	207	205
100	355	276	248	234	226	220	216	213	211	210
105	372	290	261	246	237	231	227	224	222	220
110	390	304	273	257	248	242	238	235	232	230
115	408	318	286	269	259	253	249	245	243	241
120	425	331	298	281	271	264	259	256	253	251
125	443	345	310	293	282	275	270	267	254	262
130	461	359	323	304	293	286	281	277	275	272
135	479	373	335	316	304	297	292	288	285	283
140	496	387	348	328	316	308	303	299	296	293
145	514	401	360	339	327	319	313	309	306	304
150	532	414	372	351	338	330	324	320	317	314
155	550	428	385	363	350	341	335	331	327	325
160	567	442	397	374	361	352	346	341	338	335
165	585	456	410	386	372	363	357	352	348	346
170	603	470	422	398	383	374	367	363	359	356
175	620	483	435	410	395	385	378	373	370	367
180	638	497	447	421	406	396	389	384	380	377
185	656	511	459	433	417	407	400	395	391	388
190	674	525	472	445	429	418	411	405	401	398
195	691	539	484	456	440	429	421	416	412	409
200	709	552	497	468	451	440	432	427	422	419
210	744	580	521	491	474	462	454	448	443	440
220	780	608	546	515	496	484	475	469	465	461
230	815	635	571	538	519	506	497	491	486	482
240	851	663	596	562	541	528	519	512	507	503
250	886	691	621	585	564	550	540	533	528	524
260	922	718	646	608	586	572	562	555	549	545
270	957	746	670	632	609	594	583	576	570	566
280	993	773	695	655	631	616	605	597	591	587
290	1,028	801	720	679	654	638	627	619	612	608
300	1,064	829	745	702	677	660	648	640	634	629

Figure 5.5—Perimeter estimation for point source fires (2).

Spread Distance (Chains)	Effective Windspeed, miles/hour 1	3	5	7	9	11	13	15	17	19
	Acres									
1	.1	.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
2	.4	.2	.2	.1	.1	.1	.1	.1	.1	.1
3	.9	.5	.3	.3	.2	.2	.2	.2	.1	.1
4	1.6	.9	.6	.5	.4	.3	.3	.3	.2	.2
5	2.5	1.4	1.0	.8	.6	.5	.5	.4	.4	.3
6	3.5	1.9	1.4	1.1	.9	.8	.7	.6	.5	.5
7	4.8	2.7	1.9	1.5	1.2	1.1	.9	.8	.7	.7
8	6.3	3.5	2.5	2.0	1.6	1.4	1.2	1.1	1.0	.9
9	8.0	4.4	3.1	2.5	2.1	1.8	1.5	1.4	1.2	1.1
10	9.8	5.4	3.9	3.1	2.5	2.2	1.9	1.7	1.5	1.4
11	11.9	6.6	4.7	3.7	3.1	2.6	2.3	2.0	1.8	1.7
12	14.1	7.8	5.6	4.4	3.7	3.1	2.7	2.4	2.2	2.0
13	16.6	9.2	6.6	5.2	4.3	3.7	3.2	2.9	2.6	2.3
14	19.2	10.6	7.6	6.0	5.0	4.3	3.7	3.3	3.0	2.7
15	22.1	12.2	8.7	6.9	5.7	4.9	4.3	3.8	3.4	3.1
16	25.1	13.9	9.9	7.8	6.5	5.6	4.9	4.3	3.9	3.6
17	28.4	15.7	11.2	8.8	7.3	6.3	5.5	4.9	4.4	4.0
18	31.8	17.5	12.6	9.9	8.2	7.0	6.2	5.5	4.9	4.5
19	35.4	19.6	14.0	11.1	9.2	7.8	6.9	6.1	5.5	5.0
20	39.3	21.7	15.5	12.2	10.2	8.7	7.6	6.8	6.1	5.5
21	43.3	23.9	17.1	13.5	11.2	9.6	8.4	7.5	6.7	6.1
22	47.5	26.2	18.8	14.8	12.3	10.5	9.2	8.2	7.4	6.7
23	52	29	21	16	13	11	10	8.9	8.1	7.3
24	57	31	22	18	15	13	11	9.7	8.8	8.0
25	61	34	24	19	16	14	12	10.6	9.5	8.7
26	66	37	26	21	17	15	13	11.4	10.3	9.4
28	77	42	30	24	20	17	15	13	12	11
30	88	49	35	28	23	20	17	15	14	12
32	101	55	40	31	26	22	19	17	16	14
34	113	63	45	35	29	25	22	20	18	16
36	127	70	50	40	33	28	25	22	20	18
38	142	78	56	44	37	31	27	24	22	20
40	157	87	62	49	41	35	30	27	24	22

Figure 5.6—Area estimation for point source fires.

The following values are from examples 11 and 12.

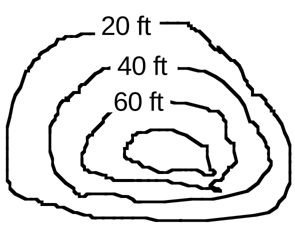
Line	Input		
0	PP	Projection point	A
1	ROS	Rate of spread, ch/h	5
2	EWS	Effective windspeed, mi/h	10
3	PT	Projection time, h	3
4	SD	Spread distance, ch	15
	Output		
	PER	Perimeter, ch	33.5
	AC	Area, ac	5.3

Figure 5.7—Fire Area/Size Worksheet.

5.5 Contour Lines and Intervals A contour line is an imaginary line on a topographic map, indicating ground elevation or depression. A contour interval is the vertical distance or difference in elevation between contour lines. Index contours are bold or thicker lines that appear at every fifth contour line.

If the numbers associated with specific contour lines are increasing, there is a peak. If the numbers associated with the contour lines are decreasing, there is a depression in the ground. See figure 5.9. As a contour approaches a stream or drainage area, the contour lines turn upstream. See figure 5.8. They then cross the stream and turn back along the opposite bank of the stream forming a "v." A rounded contour indicates a flatter or wider drainage or spur. Contour lines are smallest on ridge tops. Sharp contour points indicate pointed ridges. See figure 5.8.

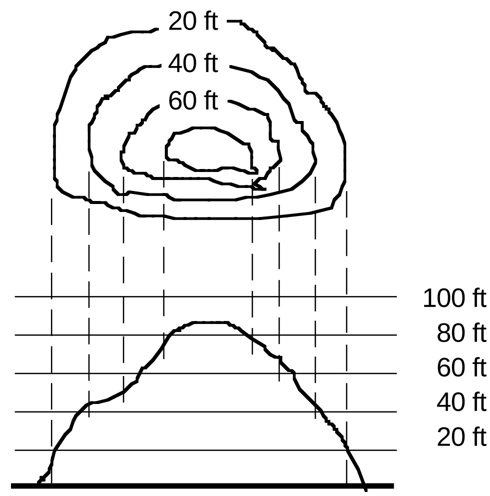
Example 13—What is the vertical distance between the contour lines?



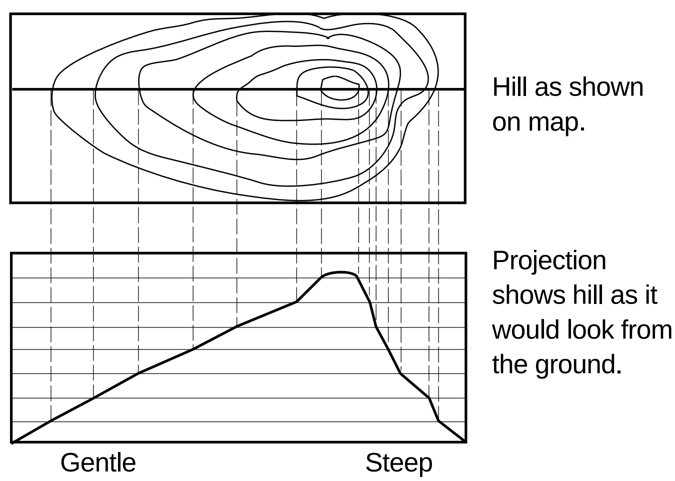
Step 1. Pick two contour lines that are next to each other and find the difference in associated numbers.
40 feet – 20 feet = 20 feet

The contour lines in this figure are equally spaced. This means the hill has a uniform slope. From the contour map, a profile can be drawn.

Example 14—Draw a profile showing the elevations of the contour. *Note: The intervals are increasing, therefore, this is a hill. The peak is normally considered to be located at half the interval distance.*



Widely separated contour lines indicate a gentle slope. Contour lines that are very close together indicate a steep slope.



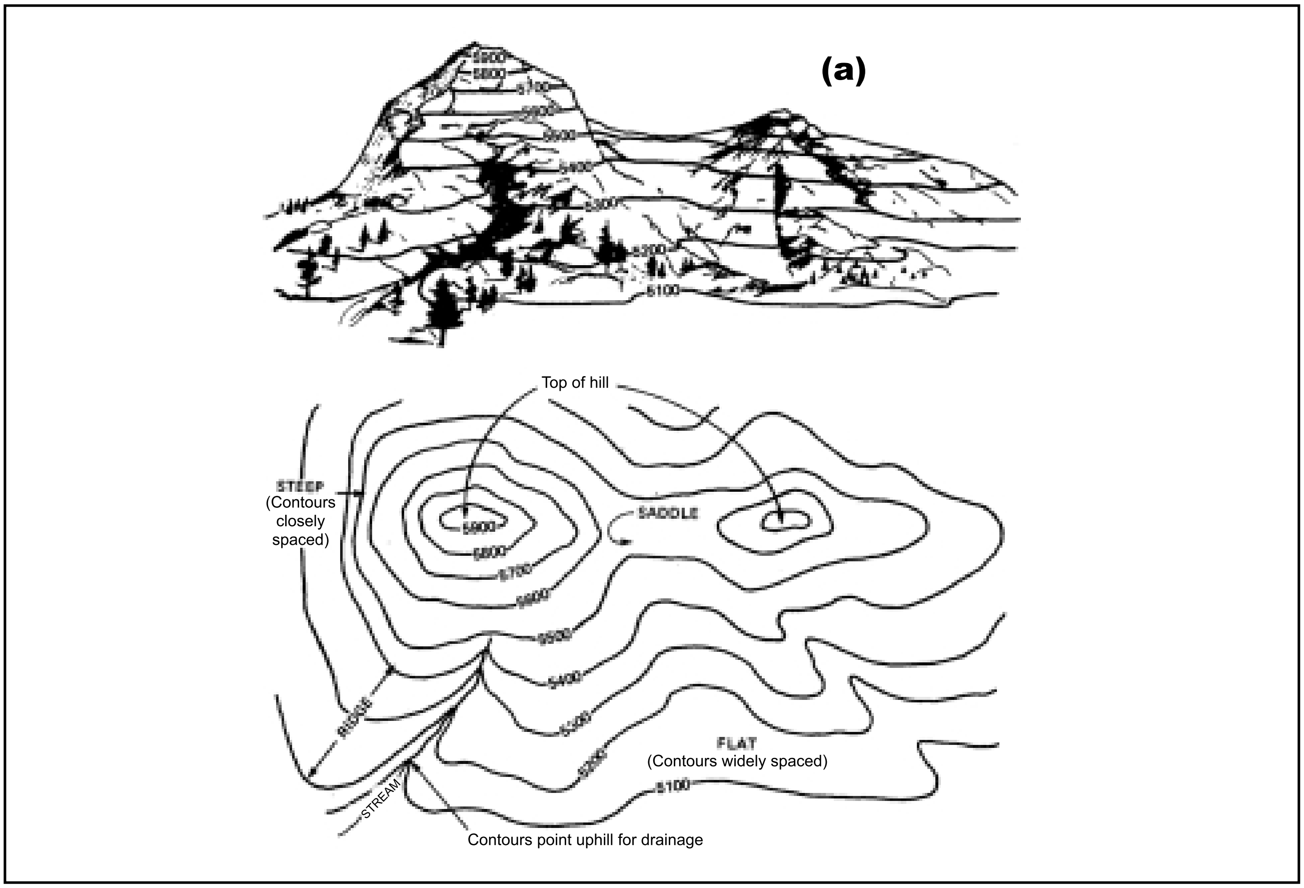


Figure 5.8—(a) Illustrates various topographic features. (b) Notice how a mountain saddle, a ridge, a stream, a steep area, and a flat area are shown with contour lines.

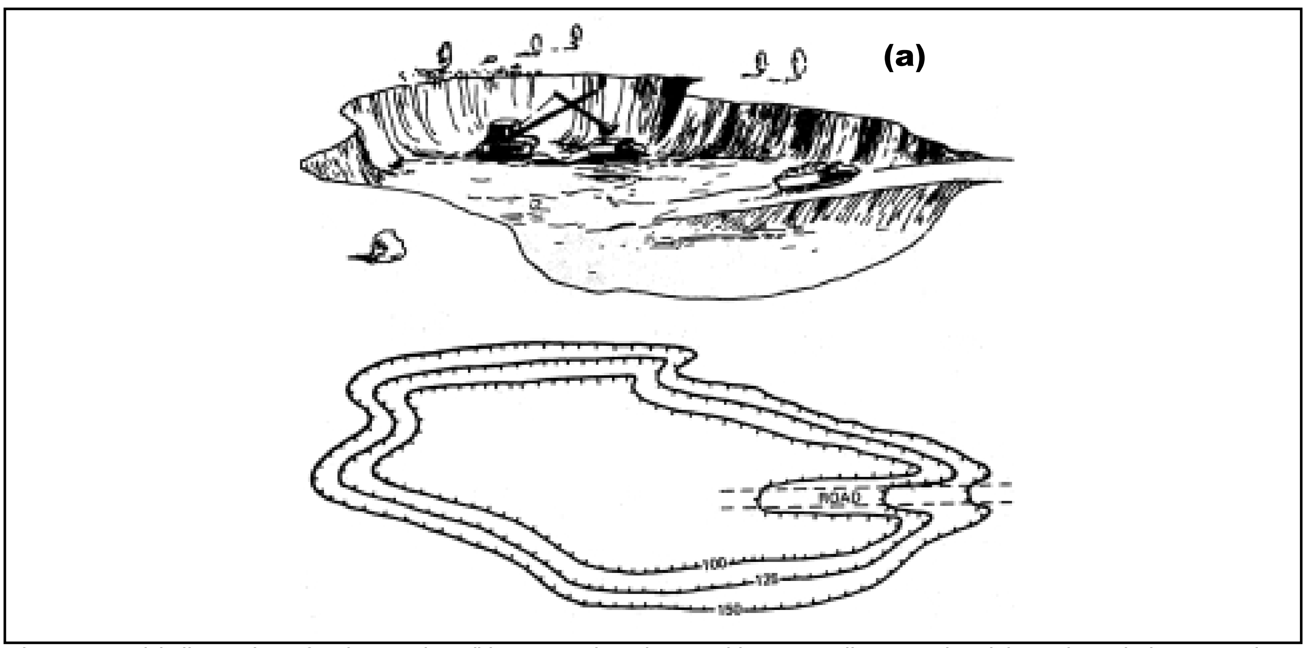
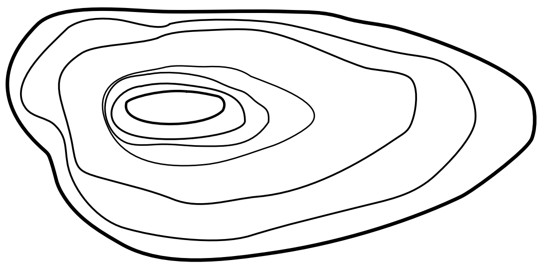


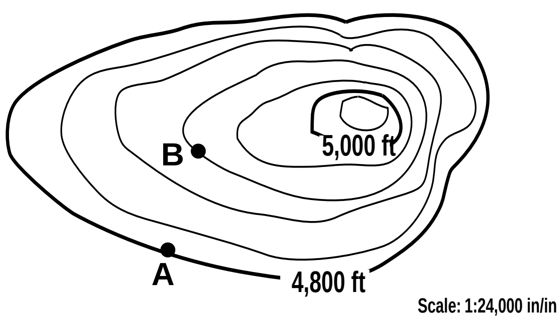
Figure 5.9—(a) Illustration of a depression. (b) Depression shown with contour lines. Notice tick marks pointing toward lower elevation.

Example 15—Is the following figure steeper at the top of the hill or at the bottom?



The contour lines are closer together at the top, which indicates a steeper slope at the top.

Example 16—In this topographic map, the contour interval is not indicated. Use the index contour lines to find the contour interval. Find the rise in elevation, the vertical distance, between points A and B.



<u>Step 1.</u> Find the vertical distance between two index contour lines.

5,000 ft – 4,800 ft = 200 ft

<u>Step 2.</u> There are five contour lines from one index contour line to the next. Consequently, divide by 5.

$\frac{200 \text{ ft}}{5}$ = 40 ft between each contour line

The contour interval is 40 feet.

<u>Step 3.</u> Find the change in elevation between points A and B.

Count the number of contour lines from point A to B and multiply by the contour interval.

There are three lines. The contour interval is 40 feet.
40 ft x 3 = 120 ft

The rise in elevation from point A to B is 120 feet.

Slope Percent from Topographic Map—The horizontal distance between points A and B can be measured with a scaled ruler and used to determine the slope percent.
slope percent = rise/run x 100

Example 17—What is the slope percent in example 16?

slope percent = rise/run x 100.

For this computation, the rise, vertical ground distance, run, and horizontal ground distance are needed.

<u>Step 1.</u> Measure the horizontal map distance between points A and B to get the vertical ground distance.
The horizontal map distance measured 0.5 inches.

<u>Step 2.</u> Use the appropriate conversion factor to convert the horizontal map distance to horizontal ground distance.
0.5 in x 24,000 in/in = 12,000 in

<u>Step 3.</u> The desired unit is feet. Set up the cancellation table so all units will cancel, except the desired unit, feet.

horizontal ground distance =

$$\begin{array}{|c|c|} 12{,}000\ \cancel{\text{in}} & 1\ \text{ft} \\ \hline & 12\ \cancel{\text{in}} \end{array} = 1{,}000 \text{ ft}$$

<u>Step 4.</u> Use the slope percent equation and solve. The rise in elevation is 120 feet.

slope percent = rise/run x 100

$$\text{slope percent} = \frac{120\ \cancel{\text{ft}}}{1{,}000\ \cancel{\text{ft}}} \times 100 = 12\%$$

Slope Worksheet—Use the information from example 17 and complete the slope worksheet. Line 1 starts with the contour interval, not the projection point. See figure 5.10.

Slope Worksheet

Line	Input		
0	PP	Projection point	_____
1	CON INT	Contour interval, ft	_____
2	SLC	Map scale	_____
3	CF	Conversion factor, ft/in	_____
4	# INTVLS	# of contour intervals	_____
5	RISE	Rise in elevation, ft	_____
6	MD	Map distance, in (between points)	_____
7	HZGD	Horizontal ground distance, ft	_____
	Output		
1	SLP %	Slope, %	_____

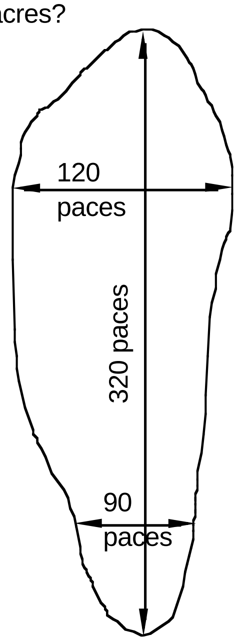
Slope Worksheet

Line	Input		
0	PP	Projection point	A—B
1	CON INT	Contour interval, ft	40
2	SLC	Map scale	1:24,000
3	CF	Conversion factor, ft/in	2,000
4	# INTVLS	# of contour intervals	3
5	RISE	Rise in elevation, ft	120
6	MD	Map distance, in (between points)	0.5
7	HZGD	Horizontal ground distance, ft	1,000
	Output		
1	SLP %	Slope, %	12

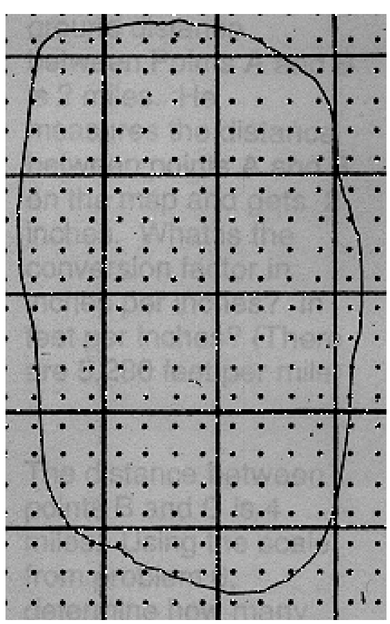
Figure 5.10—Slope Worksheet.

EXERCISES

Problem 1. Sheryl walked out the following dimensions in a burn site. Her pace is 11 paces per chain. What is the area of the fire in acres?



Problem 2. Karen sketched the following burn shape on a 7.5 minute USGS quadrangle map. Use the plastic dot acreage grid to determine the area of the fire.



Problem 3. The legend on the map shows the scale at 1: 63,000 (inch/inch). Convert this scale to feet per inch. One inch on the map equals how many feet, ground distance?

Problem 4. Using the scale from problem 3, determine the ground distance, in feet, for a map distance of 4 inches.

Problem 5. Convert the distance from problem 4 into chains.

Problem 6. Juan is using a map that does not have a scale. He knows the ground distance between points A and B is 2 miles. He measures the distance between points A and B on the map and gets 2 inches. What is the conversion factor in inches per inches? In feet per inches? There are 5,280 feet per mile.

Problem 7. The distance between points B and C is 4 miles. Using the scale from problem 6, determine how many inches this distance would be on the map.

Problem 8. There is a fire at point C on the map. The ROS is 12 chains/hour. The PT is 3 hours. What is the spread distance?

Problem 9. Using the fire above and a map scale of 1:21,120 (inch/inch), find the map distance.

Problem 10. Using the information from problems 8 and 9, fill out the map spread worksheet.

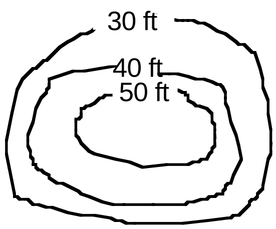
Problem 11. A fire that has a rate of spread of 10 chains/ hour. The effective windspeed is 14 miles/hour. What will be the perimeter and area of the fire in 2 hours?

Problem 12. Using an engineer's scale (tenth's ruler) draw a line the length of the fire burn in problem 9.

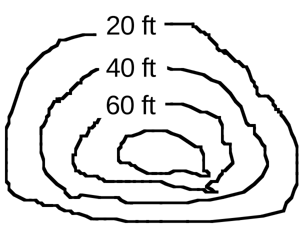
Problem 13. Use the fire shapes in figure 5.3 to draw the shape of the fire in problem 9. Use an effective windspeed of 5 miles per hour.

Problem 14. Use the information in problems 8 and 13 as well as in figures 5.5 and 5.6 to fill out the size worksheet.

Problem 15. What is the vertical distance between contour lines in the figure below?



Problem 16. Draw a profile showing the elevation of the contour below.



Problem 17. If the contour lines are close together, what kind of slope will it be, steep or gentle?

Problem 18. Write the elevation for each of the reference contour lines, using problem 25.

Problem 19. What is the rise in elevation between each contour line in problem 25?

Problem 20. What is the point C elevation in problem 25?

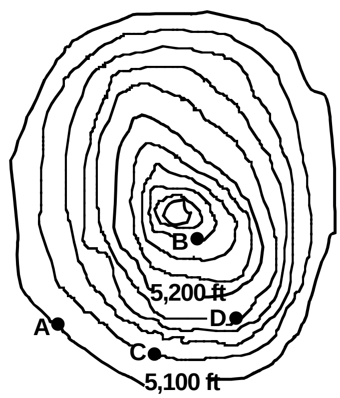
Problem 21. How many contour lines are between points A and B in problem 25?

Problem 22. What is the rise in elevation between points A and B?

Problem 23. What is the slope percent between points A and B?

Problem 24. Fill out the slope worksheet. See figure 5.10.

Problem 25. Calculate the slope for points C and D and put on the slope worksheet. Calculate the slope percent between points B and D.



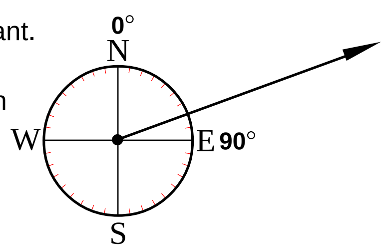
Scale 1:24,000 (in/in)

The material in chapter 6 describes finding current location by using bearing, azimuth reading, back azimuths, a compass, and a map; correcting for declination, intersection, resection, latitude, longitude, Global Positioning System, base, township, range, and section.

6.1 Bearing A bearing provides the primary direction, north or south, degree of angle, and then east or west designation. A line is described as heading north and deflected so many degrees toward the east or west. A bearing, therefore, will never have an angle over 90°.

Example 1—Julio starts off at point A and goes in the following direction. What is his bearing?

Julio is in the NE quadrant.
He is going north.
Count the degrees down from North, 70°.

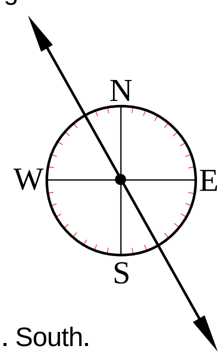


Julio's bearing is North70°East (N 70° E).

A straight line has two bearings. For example, the line above can be extended down into the SW quadrant.

Example 2—Jake is walking on the line in the sketch going southerly. What is his bearing?

He turns around and goes in the opposite direction along the same line. What would his bearing be?



Step 1. State the primary direction. South.

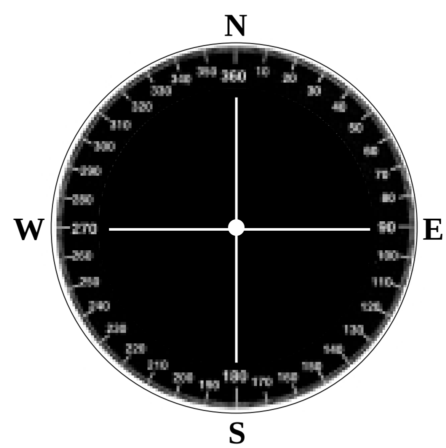
Step 2. Count the degrees from the primary direction. 30°

Step 3. State the direction the angle is deflected. East. South30°East

When Jake turns around, his bearing changes to North30°West.

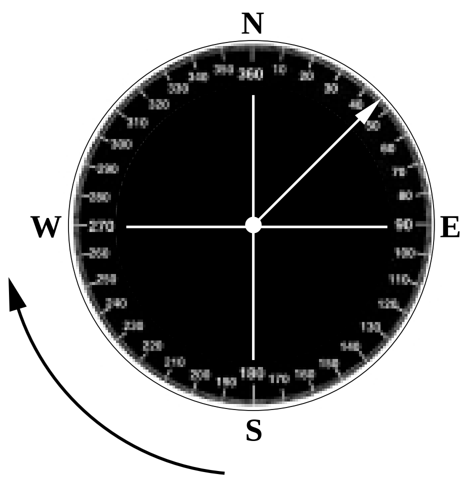
Note that the bearing letters N, S, E, W changed, but not the angle.

6.2 Azimuths An azimuth is the direction measured in degrees clockwise from north on an azimuth circle. An azimuth circle consists of 360 degrees. Ninety degrees as east, 180 degrees as south, 270 degrees as west, and 360 degrees and 0 degrees as north.



The word "bearing" is sometimes used interchangeably with azimuth to mean the direction (the degree reading) from one object to another. This is correct only in the first (NE) quadrant between 0° and 90°.

Example 3—What is the bearing and azimuth reading of the line?



The azimuth reading is 45° or the bearing is N 45° E.

Notice that the azimuth and bearing are both the same. This will only occur when the direction is in the NE or first quadrant.

Azimuths can also be read from the south. In the previous example, the azimuth reading is 225° from the south. The National Geodetic Survey of the National Oceanic and Atmospheric Administration (NOAA) (formerly the United States Coast and Geodetic Survey) always uses south as the zero direction.

In wildland fire service, the azimuth is always read from the north point.

Example 4—What are the azimuth readings for the two bearings in example 2?

Step 1. The SE quadrant has an azimuth reading of 150°.

Step 2. The NW quadrant has an azimuth reading of 330°.

6.3 Back Azimuth and Backsighting A back azimuth is a projection of the azimuth from the origin to the opposite side of the azimuth circle. Since there are 360 degrees in the azimuth circle, the opposite direction would be 180 degrees (half of 360 degrees) from the azimuth.

A back azimuth is calculated by adding 180° to the azimuth when the azimuth is less than 180°, or by subtracting 180° from the azimuth if it is more than 180°. For example: If the azimuth is 320°, the back azimuth would be 320° – 180° = 140°. If the azimuth is 30°, the back azimuth would be 180° + 30° = 210°.

Backsighting is a method of sighting, using an azimuth reading taken backwards. Backsighting uses the azimuth sight and turns it around to find the way back to the original starting point.

Example 5—Susan is at the lookout point and sights a fire at 100°. She starts out in the direction of the fire, but soon loses sight of the fire. Susan turns around and backsights to the lookout point. It is 260°. How many degrees off course is she? Which direction does Susan need to move to get back on course?

Step 1. The azimuth is more than 180°, so subtract 180° from the azimuth.
260° – 180° = 80°

Step 2. Subtract the calculated backsight reading from the original azimuth reading.
100° – 80° = 20°

Susan is 20 degrees off course.

Since the azimuth is less than the original, Susan needs to move to the left to make the back azimuth larger by 20°, or to 280°. When the lookout line of sight back azimuth of 280° is read, she can proceed along the line toward the fire.

Susan needs to move to the left by 20 degrees.

6.4 Compass A compass is an instrument used to determine direction in fire control work. An azimuth compass is graduated/marked with a full circle of 360 degrees. See figure 6.1. This is called an azimuth circle. Compass components include a magnetic needle which always points to magnetic north, a graduated circle for laying off angles from true north, and a sighting line for extending a line of sight while following a course of direction. The north end of the needle is marked with a small arrow.

Reading the compass and sighting:

- Always hold the compass level and firmly against the body to keep it still.
- Determine which direction is north by moving to get the north needle to the correct position, magnetic north.
- To determine the direction of an object, hold the compass and align the direction of the travel arrow with the object.
- Read the azimuth where the index line meets the 360° dial. Look along the sighting line and then, by raising the eyes, extend the line of sight.
- Take note of one or more objects, such as a tree or a rock, along the line of sight. Walk to the most distant object noted along the line of sight, and take another sight with the compass.

The compass direction can also be read off the map, by drawing a straight line between the initial point and the point of destination. Place the compass on the map so the orienting lines on the 360° dial point to north on the map. Read the compass on the map.

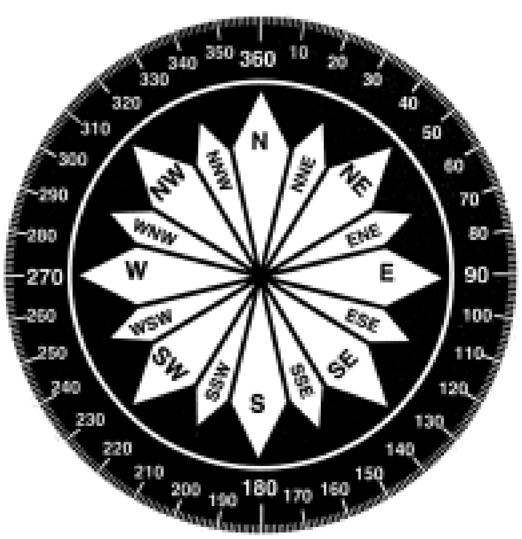


Figure 6.1—Compass rose.

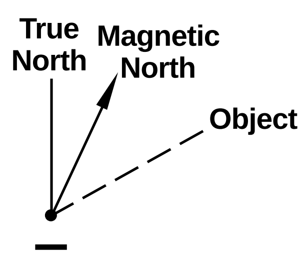
6.5 Declination The magnetic reference for the Earth is north regardless of whether you're traveling north or south. Magnetic declination, or declination, is the difference between the true north reading from the map and the magnetic north reading from the compass. When the compass is used in combination with a map, a correction must be made to allow for declination.

In North America, magnetic declination varies from 30 degrees East in Alaska to 20 degrees West in Labrador, ME. The degrees of declination for an area are usually located on the bottom margin of the map near the north arrow, or they can be looked up in a declination chart. See figure 6.2. The method for correcting for declination is as follows:

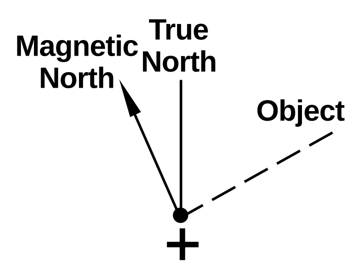
- for "Easterly Declination," subtract the declination from the true reading to obtain the magnetic reading. Magnetic = true – easterly declination

- For "Westerly Declination," add the declination to the true reading to obtain the magnetic reading. Magnetic = true + westerly declination

- An easy way to remember whether to add or subtract is "West is best and East is least." So for West declination, add to the true reading (West is best) and for East declination subtract from the true reading (East is least).



If the arrow *on the compass* is to the right of *true north*, or to the east, **subtract** the declination.

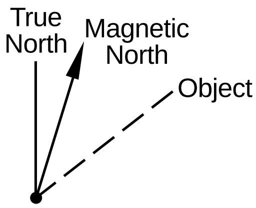


If the arrow *on the compass* is to the left of *true north*, or to the west, **add** the declination.

Example 6—Paloma is in San Jose, CA. The declination is 17°E. Paloma's compass reading from her current location to the mountain range to which she is traveling is 35°. What is her true reading?

Step 1. This is a declination of 17°E, an **easterly declination.**

Step 2. In this case, **add** the declination in order to go from the magnetic reading to the true reading.



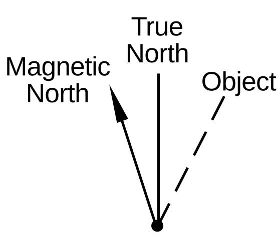
35°	magnetic reading
+ <u>17°E</u>	declination
52°	true reading

Paloma's true reading is 52 degrees.

Example 7—Sonia is in Augusta, ME. She had a compass reading, *magnetic north reading*, of 45°. What is her true reading *on a map*?

<u>Step 1.</u> Look up the declination for Augusta, ME, on the declination chart. Maine has a declination of 18°W.

<u>Step 2.</u> Becasue 18°W is a westerly declination, subtract the declination from the magnetic bearing to get the true reading.



45°	magnetic reading
– <u>18°W</u>	declination
27°	true reading

When going in the opposite direction and adjusting map readings for use with compass readings, do the opposite of the above for adding and subtracting the declination.

Sonia's true reading is 27 degrees.

Example 8—Roger looks at a map and takes an azimuth reading of 85°, true reading, off the map from where he is standing to the location of a tower. The declination for this area is 12°E. What is the magnetic reading?

<u>Step 1.</u> In order to find the magnetic reading by using a compass, subtract the easterly declination. Remember, "East is least."

85° – 12° = 73°

Example 9—Jim takes a compass reading of 35° from where he is standing to a lookout tower. The declination is 13° W. What is the true reading?

<u>Step 1.</u> There is a westerly declination. It is necessary to find the "true" reading, therefore, subtract the declination from the magnetic compass reading.

The true reading is 35° – 13° = 22°.

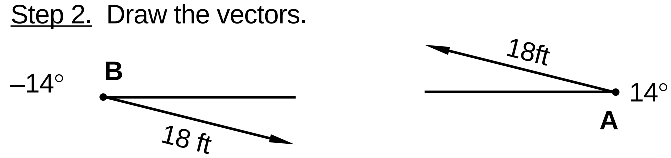
6.6 Vector A vector has magnitude (distance) and direction. When a clinometer is used to get the percent slope and the slope length is measured with a metal tape, the result is a vector.

Example 10—Linda is standing at point A. Joan is standing at point B. Joan reads the clinometer and gets 25 percent. They measure the slope length and get 18 feet. Draw the vector from point A and then again from point B.

<u>Step 1.</u> Convert the 25 percent to an angle with a calculator using inverse tan ($\tan^{-1}$).

tan A = .25 angle A = 14°

<u>Step 2.</u> Draw the vectors.



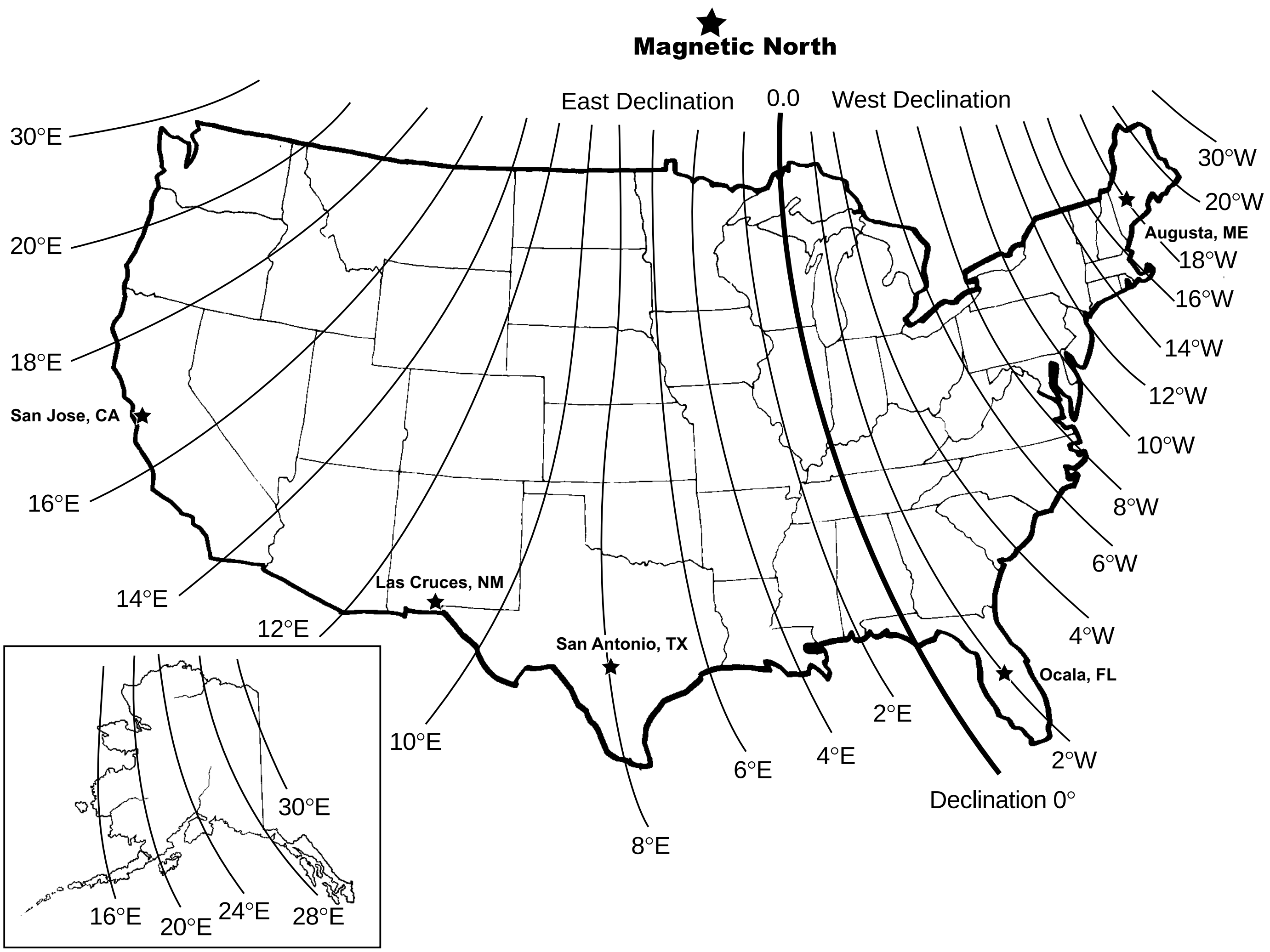
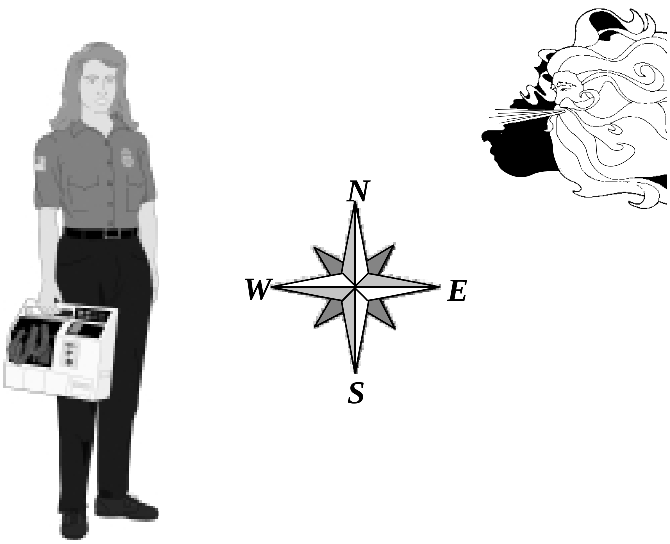


Figure 6.2—Map shows declination of the compass in North America.

Wind—Wind is the horizontal movement of air relative to the surface of the Earth. The wind direction is named by the direction from which the wind is blowing. If the wind is northerly, this means the wind is coming from the north. When the wind is blowing into your face, the wind would then be named from the direction one is facing. For example, Mandy is facing west and the wind is blowing into her face. The wind is said to be a westerly wind.

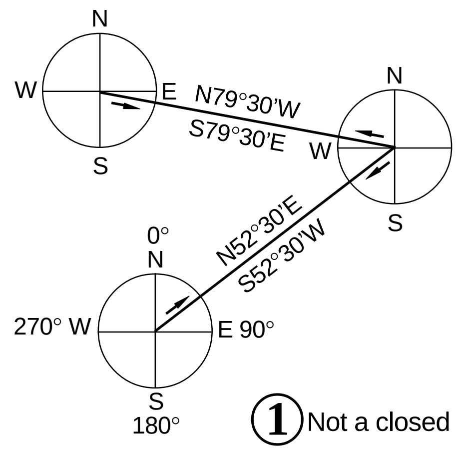
Example 11—Carol is facing east. The wind is blowing into her face. Describe the wind direction.



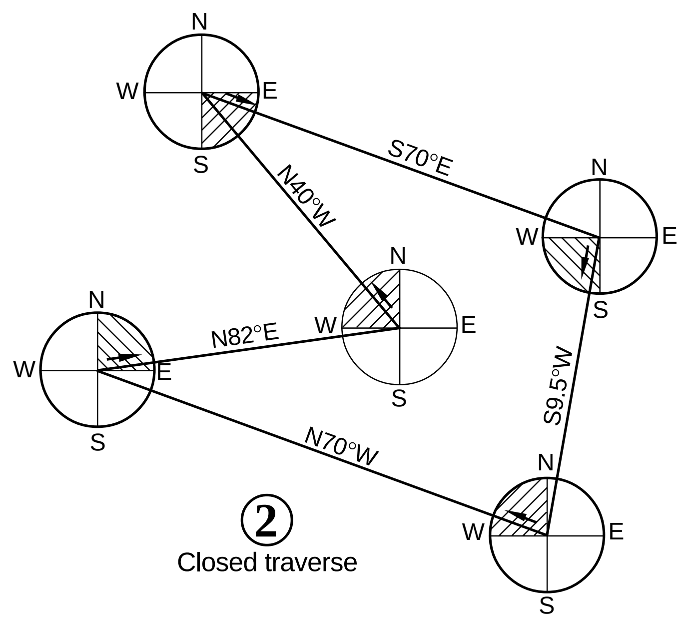
It is an east wind.

6.7 Closed Traverse A closed traverse can be used to show the shape of the perimeter of a fire. A closed traverse is a series of connected lines whose lengths and bearings are measured off these lines, also called sides, and enclose the entire burn area. When pacing continuously along the sides of a closed traverse, the finishing point will be the same as the starting location.

Note in the following sketch how the traverse is followed clockwise. If the direction was followed counterclockwise at any point, the bearing letters would change to their opposites but the numbers would not, as shown in number 1.



1 Not a closed traverse



2 Closed traverse

Example 12—Jeff paced the perimeter of the Zavala fire. His pace is 13 paces/chain. The declination for his current location is 14°E. The direction, distance, and travel for Jeff is as follows: Jeff begins at point 1 and goes N29°W for 27 paces; from point 2 he goes N1°W for 16-1/2 paces; from point 3 he goes N45°W for 24-1/2 paces; from point 4 he goes N22°E for 29-1/2 paces; from point 5 he goes S80°E for 22 paces; from point 6 he goes S28.5°E for 52-1/2 paces; from point 7 he goes S0.5°E for 10-1/4 paces back to the starting point, point 1.

Convert the bearings to magnetic readings. Adjust the magnetic readings to true north readings. Plot the closed traverse in feet using an engineer's tenth ruler and protractor.

Step 1. Convert paces into feet. Jeff's pace is 13 paces per chain.

$$\left|\frac{27\ \cancel{\text{paces}}}{}\right|\frac{\cancel{\text{chains}}}{13\ \cancel{\text{paces}}}\left|\frac{66\text{ feet}}{\cancel{\text{chain}}}\right| = 137\text{ feet}$$

Do this for each length.

Step 2. Convert the bearings to magnetic readings. The NW quadrant is between 270° and 360°.
360° – 42° = 318°

The SE quadrant is between 90° and 180°.
180° – 65° = 115°

The NE quadrant is already between 0° and 90° so those values are used as recorded.

The SW quadrant is between 180° and 270°.
180° + 21° = 201°

Step 3. Adjust each magnetic reading to a true reading.
318° + 14.5° = 332.5°

Closed Traverse

	Bearing	Mag.°	True°	Paces	Distance (ft)
Point 1	N29°W	299°	313°	27	137
Point 2	N1°W	271°	285°	16.5	83.8
Point 3	N45°W	315°	329°	24.5	124.4
Point 4	N22°E	22°	36°	29.5	149.8
Point 5	S80°E	100°	114°	22	111.7
Point 6	S28.5°E	151.5°	163.5°	52.5	266.5
Point 7	S0.5°E	179.5°	193.5°	10.25	52

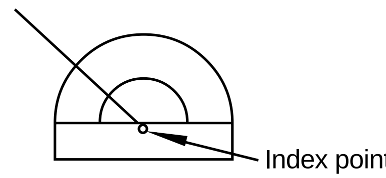
Step 4. Choose a scale. 1/10 inch = 10 feet

Step 5. Using a protractor (degrees) and an engineer's scale (tenth's ruler), plot the plan view of the traverse horizontal distance (feet) and the bearing (degrees) between points.

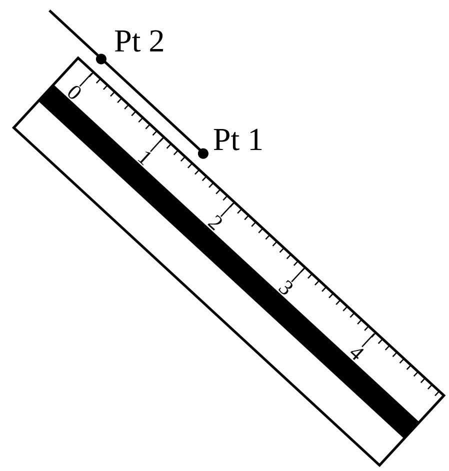
Step 5a. Set the protractor so the 0°/180° line is up (north) and on a north-south axis.

Step 5b. Put a point in the middle hole. This will be point 1.

Step 5c. Read 318° on the outer scale of the protractor. Put a dot to mark the point.



Step 5d. Draw a line from point 1 up to the dot that is 13-7/10 marks (each inch has 10 marks).



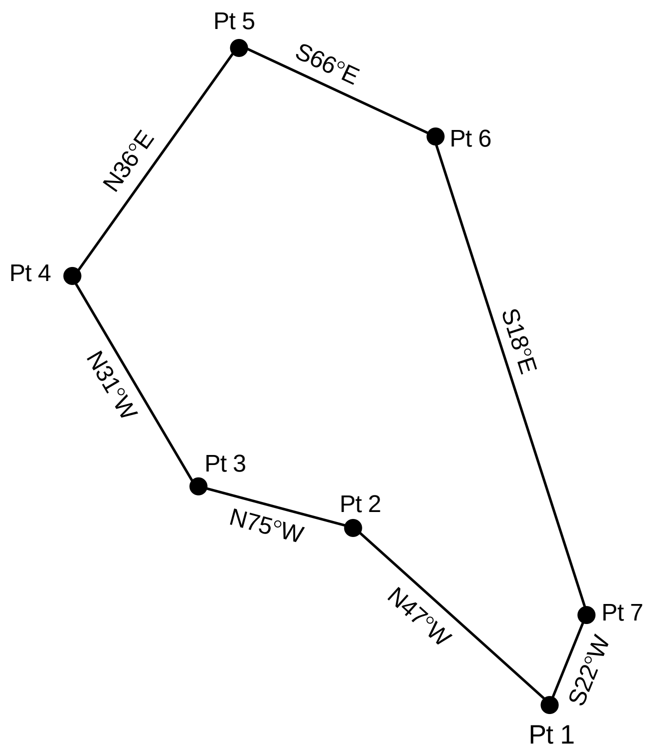
Step 5e. The end of this line will be point 2. Put the hole of the protractor on point 2. Follow steps 5b and 5c with the new values.

When plotting the values that are in the southern quadrants with a semicircle protractor, rotate the protractor so the 0°/180° line is down (facing south) and read the numbers on the inner scale. Continue with all the points. The end result should be a closed traverse as shown.

Step 5f. Convert true readings to bearings.

P1 to P2	=	313°	=	N47°W
P2 to P3	=	285°	=	N75°W
P3 to P4	=	329°	=	N31°W
P4 to P5	=	36°	=	N36°E
P5 to P6	=	114°	=	S66°E
P6 to P7	=	163.5°	=	S18°E
P7 to P1	=	193.5°	=	S22°W

Label the lines of the traverse with the corresponding bearings.



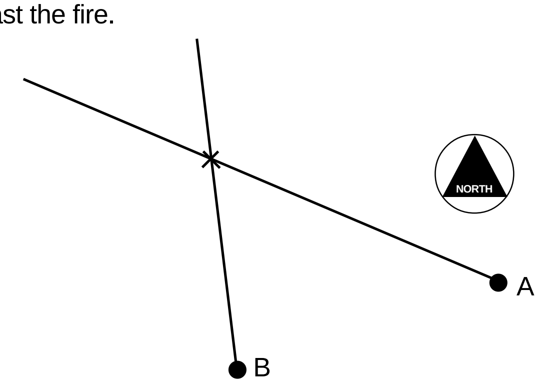
6.8 Intersection Intersection is a method of locating a point on a map by intersecting lines from two known landmarks on the ground. Intersection is one method fire lookouts use in determining the location of a fire. The procedure is:

1. From the first position, point 1, take a compass reading of the object or fire.
2. Adjust for declination.
3. With a compass or protractor, plot this azimuth on the map.
4. Draw a line from point 1 beyond the point of the object or fire.
5. Move down the road to a second position, or radio to the second person's location and get that azimuth reading. Repeat steps 2 through 4.
6. A third and maybe a fourth reading will help further describe the location.
7. The object or fire is located where the individual lines cross.

Example 13—Tom is at lookout tower A. He spots a fire and takes a compass reading. The magnetic azimuth is 277°. He radios to tower B, and John tells him his magnetic azimuth on the fire is 337°. Plot the lines to find the location of the fire. The tower points are marked below. The declination for the area is 16°E.

Step 1. Convert these magnetic azimuths to true azimuths by adjusting for declination.
277° + 16° = 293°
337° + 16° = 353°

Step 2. Draw the lines of the azimuth from each point well past the fire.



Step 3. Read where the two lines intersect, to get the location of the fire.

6.9 Resection Resection is a method of finding one's own location on a map by sighting two known landmarks. The procedure is as follows:

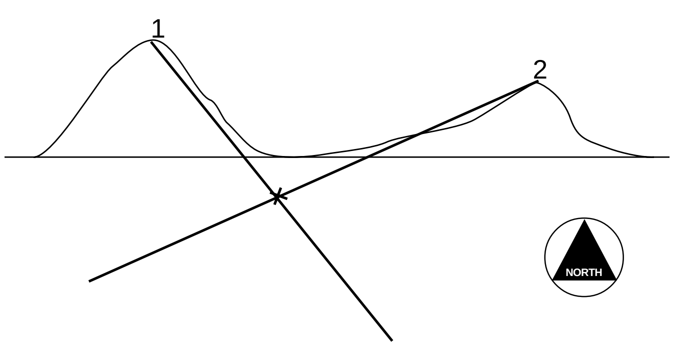
1. Find at least two landmarks on the map which can be identified on the ground. With a compass, measure an azimuth to each of the landmarks on the ground.
2. Adjust for declination.
3. Convert to back azimuths.
4. Using the two known landmarks on the map, draw the lines of the back azimuths until the lines cross.
5. The location is where the two lines cross.

Example 14—Mario is in the woods and is unsure of his current location. He sees two peaks in the distance and locates them on his map. He takes the azimuth reading of the first peak and gets 327°. He repeats this for the second peak and gets an azimuth reading of 83°. The declination for the area is 17°W. Find Mario's location on the map below.

<u>Step 1.</u> Convert the magnetic azimuths to true azimuths.
327° – 17° = 310°
83° – 17° = 66°

<u>Step 2.</u> Convert to back azimuths.
310° – 180° = 130°
66° + 180° = 246°

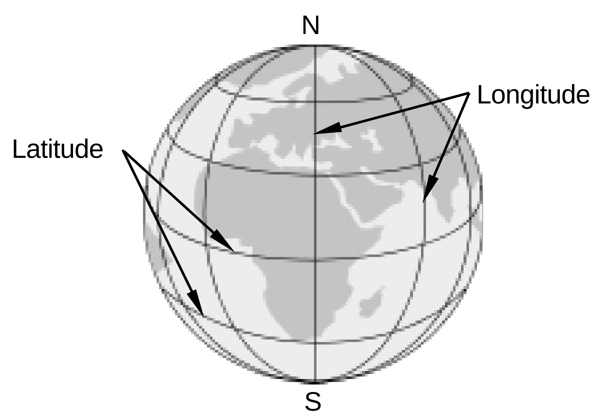
<u>Step 3.</u> From the two known landmarks on the map, draw the lines of the back azimuths until the lines intersect.



6.10 Latitude and Longitude Latitude and longitude are measuring lines used for locating places on the surface of the Earth. They are angular measurements, expressed as degrees of a circle. A full circle contains 360°, as shown in the azimuth circle. Each degree equals 60 minutes, and each minute equals 60 seconds. The symbol for minutes is (´) and for seconds is (˝).

Latitude lines (called parallels) circle the world in lines parallel with the equator, which lies halfway between the North and South poles. Latitude lines run east and west from 0° at the equator to 90° North or 90° South.

Longitude lines (called meridians) run north and south from pole to pole. Each line is identified by the number of degrees east or west from the starting point at Greenwich, England, (prime meridian) at 0°, to 180° East or West.



These angular measurements can be written in several ways. For example, 211 degrees, 22 minutes, and 30 seconds is written 211°22´30˝: with spaces—211 22 30; with a decimal after the degrees 211.2230; or with a decimal after the minutes 211 22.30. One degree of latitude equals about 69 miles. One minute is just over a mile, and one second is about 100 feet.

When adding or subtracting degrees, borrow the appropriate amount. For example, when borrowing 1 degree from 360°, change to 359°60´. To borrow 1 minute from 359°60´, change to 359°59´60˝.

Example 15— 320°25´32˝ – 210°50´41˝ =

1 9 60 4 60
320° 25´ 32˝
– 210° 50´ 41˝
109° 34´ 51˝

Step1. Subtract 1 from 2.
2 – 1 = 1

Step 2. Borrow 1 minute from the 5 for the seconds. There are 60 seconds in 1 minute.
60˝ + 30˝ = 90˝

Step 3. Subtract 4 from 9.
9 – 4 = 5

Step 4. Subtract 0 from 4.
4 – 0 = 4

Step 5. Borrow 1 degree from 20° for the minutes. There are 60 minutes in 1 degree.
60 + 20 = 80

Step 6. Subtract 5 from 8.
8 – 5 = 3

Step 7. Subtract 210 from 319.
319 – 210 = 109

109°34´51˝

Example 16— 142°54´43˝
+ 85°36´44˝
228°31´27˝

Step 1. Add the seconds. 43 + 44 = 87
Sixty seconds equal 1 minute.

Step 2. Since 87 is greater than 60, subtract 60 seconds from 87 seconds. Since 60 seconds equal 1 minute, add 1 minute to the minute column.
87 – 60 = 27 seconds

Step 3. Add the minutes.
54 + 36 + 1 (carried over from the seconds) = 91 minutes

Step 4. Since 91 is greater than 60, subtract 60 minutes from 91 minutes. Since 60 minutes equal 1 degree, add 1 to the degree column.
91 – 60 = 31 minutes

Step 5. Add the degrees.
142 + 85 + 1 (carried over from the minutes) = 228 degrees

228°31´27˝

Example 17—Name the range of latitude and longitude for the borders of Wyoming.

Step 1. Find Wyoming on a map.

Step 2. Locate the east and west borders of Wyoming. Longitude 111°W to 104°W. It is west of the Greenwich Longitude.

Step 3. Find the north and south borders of Wyoming. Latitude 41°N to 45°N. This is north of the equator.

6.11 Global Positioning System (GPS) with the Universal Transverse Mercator (UTM) Handheld GPS units are readily commercially available to easily convert latitude and longitude to metric or vice versa by use of the UTM. They vary in cost, with some units costing around $109. A UTM grid overlay is a method to determine current position. See figure 6.3. The UTM grid overlay provides for improved accuracy over use of the grid lines on a map. This grid overlay is placed on a map with the grid's edges parallel with the map grid lines. See figure 6.4. Read the Easting followed by the Northing.

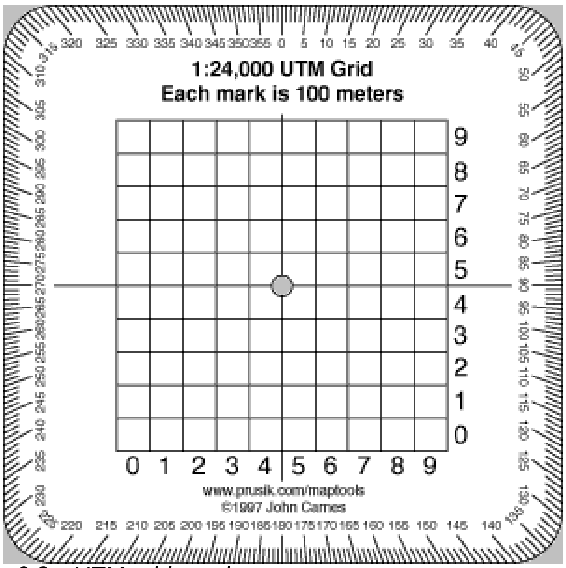


Figure 6.3—UTM grid overlay.

The "pocket sized" UTM grid overlay shown is available from Map Tools for $5 (www.maptools.com).

Example 18—Locate the star on the map to a precision of 100 m.

Figure 6.4—Grid overlay placed on a map.

Step 1. Read the 10,000 m and 1,000 m digits of the coordinate from the map.
59°E and 82°N

Step 2. Read the marks from the grid overlay.
7 and 1

The location of the star is 59.7°E 82.1°N.

6.12 Base, Township, Range, Sections, and Corners

Base and meridian lines are similar to latitude and longitude lines. Use geographic locations, such as prominent features of the area as reference points.

Townships are rectangular blocks of land about 6 miles square. Each square is layered on top and below the other. Townships are numbered according to their position north or south of the base line.

Ranges are columns of townships set side by side. They are numbered starting at the meridian which runs through the point of origin of each system. Ranges run east and west.

Sections—A township is further divided into 36 sections. Each section is about 1 square mile. Sections are numbered from the top right, or northeast section, then to the left, and down in an "S" formation. The section below is taken from T.2S., R.2E. Any township can be found by identifying the township number, then the range number, and finally the base and meridian system.

Corners—For more specific location, corners can be described as northeast, southeast, northwest, and southwest. There are corners within corners. For example, figure 6.5 indicates a lightning strike at the point labeled "X" in section 22. The lightning strike is located in the northwest corner of the northwest corner of section 22 of T.2S., R.2E. *The legal description of land begins with the smallest unit and ends with the largest unit.*

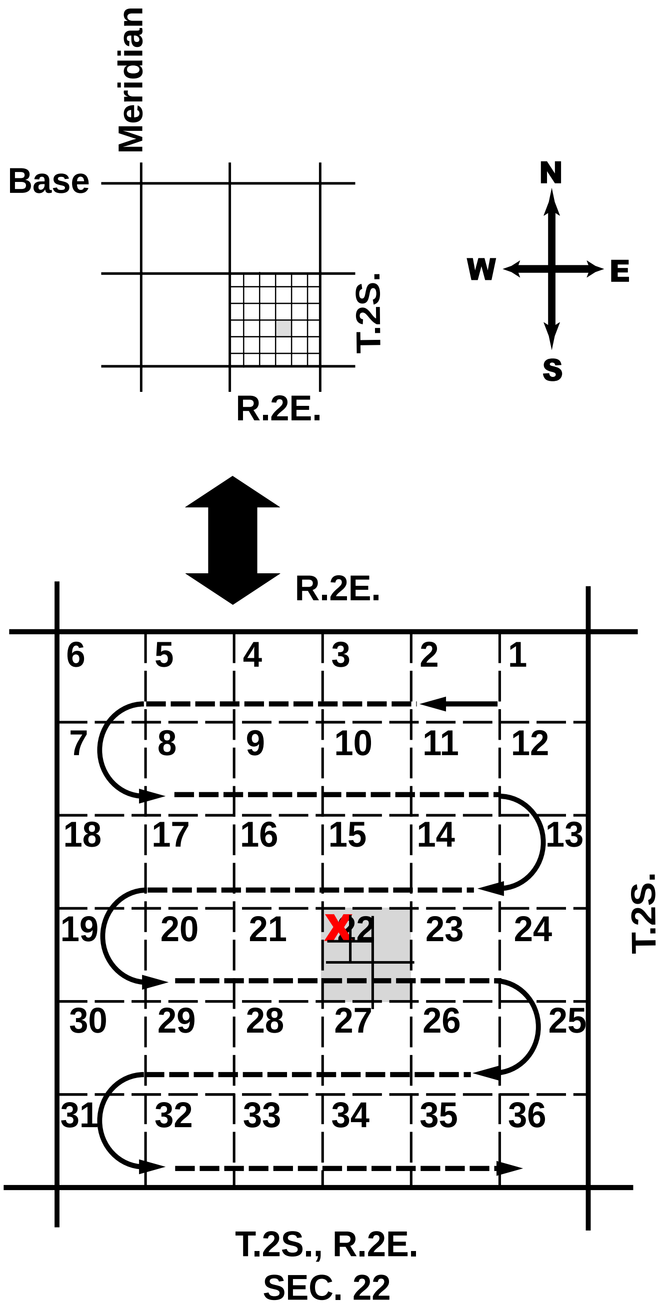


Figure 6.5

Section location description is written as T.2S., R.2E., M.D.M., which describes Township 2 South, Range 2 East, Mt. Diablo Meridian.

Example 19—What is the township, range, and section of the lightning strike labeled "X" in figure 6.5?

Step 1. Write the township.
T.2S.

Step 2. Write the range.
R.2E.

Step 3. Write the section.
22

Example 20—What would you tell the dispatcher is the exact location of the lightning strike using corners?

Step 1. Write the corners.
Northwest corner of the northwest corner

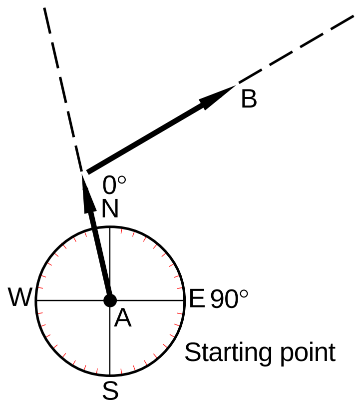
Step 2. Write the section.
22

Step 3. Write the township and range.
T.2S., R.2E.

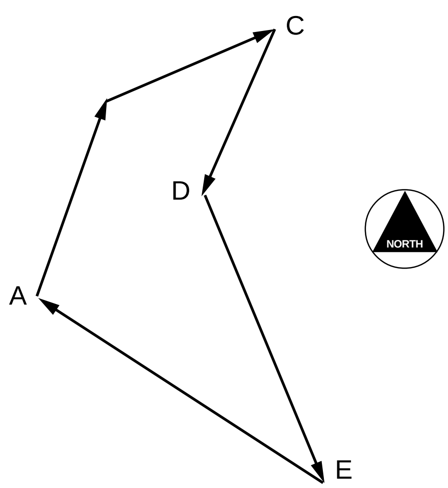
NW corner of the NW corner, Section 22, T.2S., R.2E.

EXERCISES

Problem 1. George is going to a fire. He has to walk around a steep rock formation in his path. The diagram below shows the path he walked. What are the bearings of each line he walked?



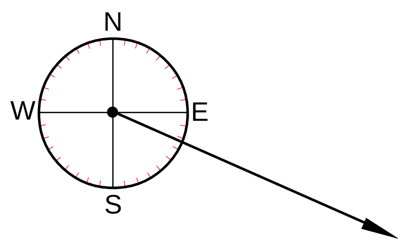
Problem 2. Jerry is pacing a fire. The final figure is sketched below. Find the compass bearing and distance between each line, starting at point A and following the direction of the arrows. Use an engineer's tenth ruler and protractor. Each 1/10 inch = 10 feet.



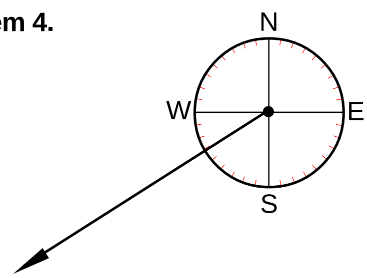
When the bearings are determined for all the lines surrounding a tract of land, and then the lines are followed continuously around the tract return to the starting point, what is this called? A closed traverse

In each diagram below, write the azimuth angle.

Problem 3.



Problem 4.



Problem 5. Determine the back azimuth for each of the forward azimuths in problems 3 and 4.

Problem 6. Mary sights a fire from a rock outcropping at 280 degrees. She starts out but loses sight of the fire. She backsights the rock outcropping and reads 130 degrees. How far off her mark is she? What direction does she have to move to get back on course?

Problem 7. Alan is in Ocala, FL. He takes a compass reading and gets 60°. Use the declination chart (see figure 6.2) to determine the declination for the area. What is his true azimuth reading?

Problem 8. Brenda is in Las Cruces, NM. She takes a compass reading and reads 230°. Find her true reading.

Problem 9. Fred is in San Antonio, TX. He reads his map and gets an azimuth reading of 150° from his present location to where he is headed. What is his magnetic reading?

Problem 10. Jane has a slope reading of 35 percent. The distance between points A and B, where the reading was taken, is 12 feet. Draw a vector from each point.

Problem 11. Bobby is standing on a ridge with the wind blowing in her face. She is facing N45°E. What is the wind direction and the wind vector?

Problem 12. Connie walked the perimeter of a fire. She radioed her bearings and distance to the Incident Commander. Below are the instructions. Convert each bearing into a magnetic reading, and then adjust each magnetic reading to a true magnetic reading by using a declination of 15°E. Convert the distance to feet, Connie's pace is 12 paces per chain. Then draw a scale model using an engineer's tenth ruler and a protractor. Be sure to write the scale used for the diagram.

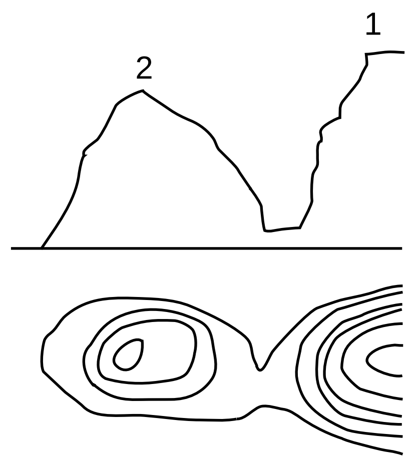
Instructions: Connie starts at point 1 and goes north 70° east (N70°E) for 25 paces; from point 2 she goes S54°E for 18 paces; from point 3 she goes S21°E for 19-1/2 paces, from point 4 she goes S84°W for 12-1/2 paces; from point 5 she goes S37°W for 28-1/2 paces; from point 6 she goes N49°W for 20 paces; from point 7 she goes N57°E for 20 paces; from point 8 she goes N49°W for 24-1/2 paces; from point 9 she goes N31°E for 5-1/2 paces. From her final location, record the bearing (degrees) and distance (feet) from the beginning point. If the error of closure on the closed traverse is greater than 15 feet, try plotting the traverse again.

Problem 13. Alix is on a ridge when he spots a fire. He takes a compass reading and gets 290°. He walks to another high point and takes another compass reading and gets 20°. The declination for the area is 17°E. Find his location in relation to the points below.

• Ridge

• High point

Problem 14. Jim is in the woods when he becomes confused on which direction to go. He can see two mountain ridges in the distance. He locates the two ridges on his map. He takes a compass reading to the first ridge of 40°. He takes a reading to the second ridge of 310°. The declination for the area is 14°W. Plot his location below.



Problem 15. Solve.

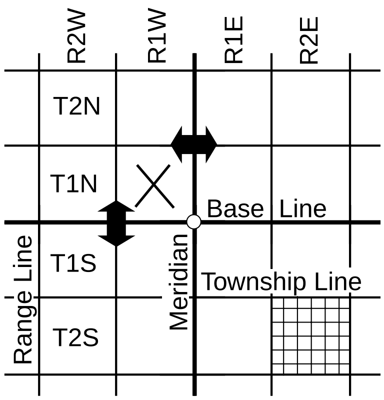
$$\begin{array}{r} 150°20'45'' \\ \underline{-\ 125°32'54''} \end{array}$$

Problem 16. Solve.

$$\begin{array}{r} 55°43'25'' \\ \underline{+\ 244°25'55''} \end{array}$$

Problem 17. Find the range of latitude and longitude of the borders of Arizona on a map.

Problem 18. Identify the location of the X.



Problem 19. What is the section location of square 8 in the section diagram in figure 6.5?

The material in chapter 7 describes weather factors that firefighters encounter in predicting fire behavior. These factors include dry and wet bulb temperatures, dew point, and relative humidity.

7.1 Dry Bulb Temperature Dry bulb temperature is the ambient temperature. It is measured in degrees, from a mercury thermometer with a scale of Fahrenheit or Celsius in an area away from direct sunlight.

7.2 Wet Bulb Temperature Wet bulb temperature is the lowest temperature to which the current air can be cooled. Cooling is achieved by evaporating water into air at a constant pressure. Wet bulb temperature is measured by a psychrometer. The greater the difference is between wet and dry bulb temperatures, the drier the air is.

7.3 Dew Point Dew point is the temperature to which air must be cooled to reach its saturation point. This must be done at a constant pressure and moisture content. A rising dew point indicates increasing moisture.

7.4 Relative Humidity Relative humidity is the amount of moisture in the air that is in the form of water vapor. Fully saturated air is fog. Relative humidity is always expressed as a percentage.

Once the dry and wet bulb temperatures have been measured, the dew point and relative humidity can be determined with the use of tables. See figure 7.1 for use at elevations between 501 and 1,900 feet above sea level.

Relative humidity will change with temperature, whereas the dew point will remain nearly the same. This fact can be used to determine the minimum relative humidity for the afternoon, using the predicted high temperature for the day and the observed dew point.

The average temperature change throughout the lower atmosphere over time and space is about 5.5 °F per 1,000 feet for dry weather. Average temperature varies with humidity.

Example 1—At an elevation of 1,800 feet on Mt. Tampico, the dry bulb temperature is 76 °F. The wet bulb temperature is 50 °F. What is the dew point temperature and the relative humidity?

Step 1. Select the proper table for the elevation in question. See figure 7.1.

Step 2. Find the wet bulb temperature of 50 °F at the top of the table, and then move down the column.

Step 3. Find the dry bulb temperature of 76 °F at the left side of the table, and then move horizontally to the right.

Step 4. Find the intersection of the wet bulb temperature column and dry bulb temperature row.

Step 5. Read the two numbers. The lower number in the block is the relative humidity; the upper number is the dew point temperature.

The dew point is 14 °F and the relative humidity is 9 percent.

Example 2—The wet bulb temperature is 55 °F and the dry bulb temperature is 68 °F. The expected high for the day is 90 °F. What will the relative humidity be when the temperature is 90 °F?

Step 1. Find the dew point. See figure 7.1. The dew point is 45 °F.

Step 2. Go to the dry bulb temperature of 90 °F, and move horizontally to the right until the block with the same dew point of 45 °F is found. On the chart only 44 °F and 47 °F are shown as the two closest dew points to 45 °F.

Step 3. Read the relative humidity from both squares. 20 and 22.

Step 4. Take an average of the two numbers.

$$\frac{20 + 22}{2} = \frac{42}{2} = 21$$

Relative humidity is 21percent
with a temperature of 90 °F.

Example 3—The observed temperature at 3,000 feet is 87 °F. What is the projected temperature at 5,000 feet?

Step 1. Find the change in elevation.
5,000 feet – 3,000 feet = 2,000 feet

Step 2. For every 1,000 foot gain in elevation there is a 5.5 °F temperature drop.

$$\left|\frac{2{,}000\,\cancel{\text{ft}}}{1{,}000\,\cancel{\text{ft}}}\right|\frac{5.5°}{}\Bigg| = 11°$$

$$\boxed{87\ °F – 11\ °F = 76\ °F}$$

For use at elevations between
501 and 1,900 feet above sea level

DP = Top number
RH = bottom number

Wet bulb temperatures (columns) / **Dry bulb temperatures** (rows)

	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
60	-50 1	-14 4	-1 8	+8 12	14 16	19 20	24 24	28 28	31 32	34 36	37 41	40 45	42 50	44 54	47 59	49 64	51 69	53 74	54 79	56 84	58 89	59 95	61 100			
62		-25 2	-6 6	+4 10	11 13	17 17	22 21	26 25	30 29	33 33	36 37	38 42	41 46	43 50	46 55	48 60	50 64	52 69	54 74	55 79	57 84	59 89	60 95	62 100		
63		-58	-14 4	-1 7	+8 11	14 15	20 19	24 22	28 26	31 30	34 34	37 38	40 43	42 47	45 51	47 56	49 60	51 65	53 70	55 74	57 79	58 84	60 89	61 95	63 100	
64			-27 2	-7 5	+4 9	11 12	17 16	22 20	26 24	30 27	33 31	36 35	39 39	41 43	44 48	46 52	48 56	50 61	52 65	54 70	56 75	58 80	59 85	61 90	62 95	64 100
65				-15 3	-1 7	+8 10	14 14	20 17	24 21	28 25	32 29	35 32	38 36	40 40	43 44	45 48	47 53	49 57	51 61	53 66	55 70	57 75	59 80	60 85	62 90	63 95
66				-28 2	-7 5	+4 8	11 12	17 15	22 19	26 22	30 26	33 30	36 33	39 37	42 41	44 45	46 49	49 53	51 58	53 62	54 66	56 71	58 76	60 80	61 85	63 90
67					-15 3	-1 6	+8 10	15 13	20 16	24 20	28 23	32 27	35 31	38 34	41 38	43 42	46 46	48 50	50 54	52 58	54 63	56 67	57 71	59 76	61 80	62 85
68					-29 2	-7 5	+4 8	12 11	18 14	22 18	27 21	30 24	34 28	37 32	40 35	42 39	45 43	47 47	49 51	51 55	53 59	55 63	57 67	59 72	60 76	62 81
69						-15 3	-1 6	+8 9	15 12	20 16	25 19	29 22	32 26	35 29	38 33	41 36	44 40	46 44	48 47	50 51	52 55	54 59	56 64	58 68	60 72	61 77
70						-29 1	-7 4	+4 7	12 10	18 14	23 17	27 20	31 23	34 27	37 30	40 34	43 37	45 41	47 44	50 48	52 52	54 56	55 60	57 64	59 68	61 72
71							-15 3	0 6	+9 9	15 12	21 15	25 18	29 21	33 24	36 28	39 31	42 34	44 38	46 42	49 45	51 49	53 53	55 57	57 60	58 65	60 69
72							-28 1	-6 4	+5 7	12 10	18 13	23 16	28 19	31 22	35 25	38 29	40 32	43 35	46 39	48 42	50 46	52 50	54 53	56 57	58 61	60 65
73								-14 3	0 5	+9 8	16 11	21 14	26 17	30 20	33 23	36 26	39 30	42 33	45 36	47 40	49 43	51 47	53 50	55 55	57 58	59 62
74								-27 1	-6 4	+5 7	13 10	19 12	24 15	28 18	32 21	35 24	38 27	41 30	44 34	46 37	48 40	51 44	53 47	55 51	57 54	58 58
75									-13 3	+1 5	10 8	16 11	22 13	26 16	30 19	34 22	37 25	40 28	43 31	45 35	48 38	50 41	52 44	54 48	56 51	58 55
76									-25 1	-5 4	+6 7	14 9	20 12	24 15	29 17	32 20	36 23	39 26	42 29	44 32	47 35	49 39	51 42	53 45	55 49	57 52
77									-57	-12 3	+2 5	10 8	17 10	22 13	27 16	31 18	34 21	38 24	41 27	43 30	46 33	48 36	50 39	53 43	55 46	57 49
78										-23 1	-4 4	+7 6	14 9	20 11	25 14	29 17	33 19	36 22	39 25	42 28	45 31	47 34	50 37	52 40	54 43	56 46
79										-48	-11 3	+3 5	11 8	18 10	23 13	28 15	32 18	35 20	38 23	41 26	44 29	46 32	49 35	51 38	53 41	55 44
80											-21 2	-2 4	+8 6	15 9	21 11	26 14	30 16	34 19	37 21	40 24	43 27	45 30	48 32	50 35	52 38	54 41
81											-40 1	-9 3	+4 5	12 7	19 10	24 12	28 15	32 17	36 20	39 22	42 25	45 28	47 30	49 33	52 36	54 39
82												-18 2	-1 4	+9 6	16 8	22 10	27 13	31 16	34 18	38 21	41 23	44 26	46 28	49 31	51 34	53 37
83												-34 1	-7 3	+5 5	13 7	20 9	25 12	29 14	33 17	36 19	40 21	43 24	45 27	48 29	50 32	52 35
84													-15 2	+1 4	10 6	17 8	23 10	27 13	32 15	35 17	38 20	41 22	44 25	47 27	49 30	52 33
85													-29 1	-5 3	+7 5	14 7	21 9	26 11	30 14	34 16	37 18	40 21	43 23	46 26	48 28	51 31
86														-12 2	+2 4	11 6	18 8	24 10	28 12	32 15	36 17	39 19	42 22	45 24	48 26	50 29
87														-24 1	-3 3	+8 5	16 7	22 9	27 11	31 13	35 16	38 18	41 20	44 22	47 25	49 27
88														-50	-10 2	+4 4	13 6	19 8	25 10	29 12	33 14	37 16	40 19	43 21	46 23	48 26
89															-19 1	-1 3	+10 5	17 7	23 9	28 11	32 13	36 15	39 17	42 19	45 22	48 24
90															-37	-7 2	+6 4	14 6	21 8	26 10	30 12	34 14	38 16	41 18	44 20	47 22

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
65	65 100																									
66	64 95	66 100																								
67	64 90	66 95	67 100																							
68	63 85	65 90	67 95	68 100																						
69	63 81	65 86	66 90	68 95	69 100																					
70	62 77	64 81	66 86	67 90	69 95	70 100																				
71	62 73	63 77	65 82	67 86	68 91	70 95	71 100																			
72	61 69	63 73	65 77	66 82	68 86	69 91	71 95	72 100																		
73	61 65	62 69	64 74	66 78	67 82	69 86	70 91	72 95	73 100																	
74	60 62	62 66	64 70	65 74	67 78	68 82	70 87	71 91	73 95	74 100																
75	60 59	61 62	63 66	65 70	66 74	68 78	69 82	71 87	72 91	74 95	75 100															
76	59 56	61 59	62 63	64 67	66 71	67 75	69 79	70 83	72 87	73 91	75 96	76 100														
77	58 53	60 56	62 60	64 63	65 67	67 71	68 75	70 79	71 83	73 87	74 91	76 96	77 100													
78	58 50	60 53	61 57	63 60	65 64	66 67	68 71	69 75	71 79	72 83	74 87	75 91	77 96	78 100												
79	57 47	59 50	61 54	63 57	64 61	66 64	67 68	69 72	71 75	72 79	73 83	75 87	76 91	78 96	79 100											
80	56 45	58 48	60 51	62 54	64 58	65 61	67 65	69 68	70 72	72 76	73 79	75 83	76 87	77 92	79 96	80 100										
81	56 42	58 45	60 48	61 51	63 55	65 58	67 62	68 65	70 69	71 72	73 76	74 80	76 84	77 88	78 92	80 96	81 100									
82	55 40	57 43	59 46	61 49	63 52	64 55	66 59	68 62	69 65	71 69	72 73	74 76	75 80	77 84	78 88	79 92	81 96	82 100								
83	54 38	56 40	58 43	60 46	62 49	64 53	66 56	67 59	69 62	70 66	72 69	73 73	75 76	76 80	78 84	79 88	80 92	82 96	83 100							
84	54 35	56 38	58 41	60 44	62 47	63 50	65 53	67 56	68 59	70 63	71 66	73 70	74 73	76 77	77 80	79 84	80 88	81 92	83 96	84 100						
85	53 33	55 36	57 39	59 42	61 45	63 47	65 50	66 54	68 57	69 60	71 63	73 66	74 70	76 73	77 77	78 81	80 84	81 88	82 92	84 96	85 100					
86	52 32	54 34	57 37	59 40	60 42	62 45	64 48	66 51	67 54	69 57	71 60	72 64	74 67	75 70	77 74	78 77	79 81	81 84	82 88	83 92	85 96	86 100				
87	52 30	54 32	56 35	58 37	60 40	62 43	64 46	65 49	67 51	69 54	70 58	72 61	73 64	75 67	76 70	78 74	79 77	80 81	82 85	83 88	84 92	86 96	87 100			
88	51 28	53 30	55 33	57 35	59 38	61 41	63 43	65 46	66 49	68 52	70 55	71 58	73 61	74 64	76 67	77 71	79 74	80 78	81 81	83 85	84 88	85 92	87 96	88 100		
89	50 26	52 29	55 31	57 34	59 36	61 39	62 41	64 44	66 47	68 50	69 52	71 55	72 58	74 61	76 65	77 68	78 71	80 74	81 78	83 81	84 85	85 88	86 92	88 96	89 100	
90	49 25	52 27	54 29	56 32	58 34	60 37	62 39	64 42	66 45	67 47	69 50	71 53	72 56	74 59	75 62	77 65	78 68	79 71	81 75	82 78	84 82	85 85	86 89	87 92	89 96	90 100

Ex1 Ex2

Figure 7.1—Relative humidity and dew point table, (Psychrometric.)

EXERCISES

Problem 1. Lupe is at an elevation of 1,000 feet. The dry bulb temperature is 80 °F. The wet bulb temperature is 52 °F. What is the relative humidity and the dew point?

Problem 2. What is the relative humidity if the wet bulb temperature is 47 °F and the dry bulb temperature is 64 °F?

Problem 3. Vivian is trying to determine what the minimum relative humidity will be at 1600 hours. She is at an elevation of 1,200 feet. The current dry bulb temperature is 67 °F. The wet bulb temperature is 56 °F. The predicted temperature for the afternoon is 80 °F.

The material in chapter 8 describes fuel models for fire behavior variables, including fine dead fuel moisture and live fuel moisture.

8.1 Fuel Models

A fuel model is a preliminary representation of vegetation characteristics used in analyzing fire behavior and planning. The models provide wildland firefighters with a common way of describing fuels in the area.

There are two sets of fuel models, a set designated with numbers for the Fire Behavior Prediction System (FBPS) and a set designated with letters for the National Fire Danger Rating System (NFDRS). Thirteen fuel models associated with fire behavior are described in this chapter. They are subdivided into the Grass, Shrub, Timber Litter, and Logging Slash Groups. These descriptions provide insight into various components of the fuel model that have the potential to carry the fire spread. Choosing appropriate fuel models requires experience and sound personal judgment. See figure 8.4.

The Grass Group—Fuel Models 1, 2, and 3

Fuel Model 1 (1-foot deep) Fire spread in Fuel Model 1 is governed by fine herbaceous fuels that are cured or nearly cured. Surface fires move rapidly through cured grass and associated material. Very little shrub or timber is present, generally in less than one-third of the area. Grasslands and savanna are represented, along with stubble, grass tundra, and grass shrub combinations that meet the above area constraint. Annual and perennial grasses are included in this fuel model.

Fuel Model 2 (1-foot deep) Fire spread in Fuel Model 2 is primarily through fine herbaceous fuels, either curing or dead. These are surface fires where the herbaceous material, besides litter and dead-down stemwood from the open shrub or timber overstory, contribute to the fire intensity. Open shrub lands, pine stands, or scrub oak stands that cover one-third to two-thirds of the area, generally fit this model. However, they may include clumps of fuels that generate higher fire intensities and may produce firebrands. Some pinyon-juniper may be in this model.

Fuel Model 3 (2.5-feet deep) Fires in this fuel are the most intense of the grass group and display high rates of spread under the influence of wind. Fire may be driven into the upper heights of a grass stand by wind and may cross over standing water. Stands are tall, averaging about 3 feet, but considerable variation may occur. Approximately one-third or more of the stand is considered dead or cured, maintaining the fire.

The Shrub Group—Fuel Models 4, 5, 6, and 7

Fuel Model 4 (6-feet deep) Fire intensity and fast spreading fires involving foliage and live and dead fine woody materials in the crowns of a nearly continuous secondary overstory characterize Fuel Model 4. Examples are stands of mature shrub 6-or-more-feet tall, such as California mixed chaparral, high pocosins along the east coast, pine barrens of New Jersey, or the closed jack pine stands of the north central States. Besides flammable foliage, there is dead woody material in the stand that significantly contributes to fire intensity. Heights of stands qualifying for this model vary with local conditions. There may also be a deep litter layer that compounds suppression efforts.

Fuel Model 5 (2-feet deep) Fire generally is carried in surface fuels composed of litter cast by shrubs and grasses, or forbs, in the understory. Fires generally lack intensity as surface fuel loads are light, shrubs are young with little dead material, and foliage contains little volatile material. Shrubs generally are not tall, but nearly cover the entire area. Examples are young green stands with little or no deadwood, such as laurel, vine maple, alder, or even chaparral, manzanita, or chamise. As shrub fuel moisture drops, consider using Fuel Model 6.

Fuel Model 6 (2.5-feet deep) Fires carry through the shrub layer where foliage is more flammable than Fuel Model 5, but require moderate winds, greater than 8 miles per hour, at midflame height. Fire will drop to the ground at low windspeeds or openings in the stand. Shrubs are older, but not as tall as shrub types of Model 4, nor do they contain as much fuel as Model 4. A broad range of shrub conditions are covered by this model. Typical examples include intermediate stands of chamise, chaparral, oak brush, low pocosin, Alaskan spruce taiga, and shrub tundra. Cured hardwood slash can be considered. Pinyon-juniper shrub-lands may fit, but may overpredict the rate of spread, except at high winds, for example 20 miles per hour at the 20-foot level.

Fuel Model 7 (2.5-feet deep) Fire burns through the surface and shrub strata equally. Fire can occur at higher dead fuel moisture contents due to the flammable nature of live foliage. Shrubs are generally 2 to 6 feet high. Examples are Palmetto-gallberry understory-pine overstory sites, low pocosins, and Alaska black spruce shrub combinations.

The Timber Litter Group—Fuel Models 8, 9, and 10

Fuel Model 8 (0.2-foot deep) Slow burning ground fires with low flame heights are common to this fuel model, although an occasional "jackpot," or heavy fuel concentration, may cause a flareup. Only under severe weather conditions do these fuels pose fire problems. Closed-canopy stands of short-needle conifers or hardwoods that have leafed out support fire in the compact litter layer. This layer is mainly needles, leaves, and some twigs, since little undergrowth is present in the stand. Representative conifer types are white pine, lodgepole pine, spruce, true firs, and larches.

Fuel Model 9 (0.2-foot deep) Fires run through surface litter faster than in Model 8 and have a higher flame height. Both long-needle conifer and hardwood stands, especially the oak hickory types, are typical. Fall fires in hardwoods are representative, but high winds will actually cause higher rates of spread than predicted because of spotting caused by rolling and blowing leaves. Closed stands of long-needled pine, such as ponderosa, Jeffrey, red pines, or southern pine plantations, are grouped in this model. Concentrations of dead-down woody materials will contribute to possible torching out of trees, spotting, and crowning activity.

Fuel Model 10 (1-foot deep) The fires in this model burn in surface and ground fuels with greater fire intensity than in other timber litter models. Dead-down fuels include greater quantities of 3-inch or larger limb wood, resulting from over-maturity or natural events that create a large load of dead material on the forest floor. Crowning out, spotting, and torching of individual trees are more frequent in this fuel situation, leading to potential fire control difficulties. Any forest type may be considered when heavy-down materials are present. Examples are insect-infested or diseased stands, wind-thrown stands, or over-mature situations with deadfall, cured light thinning, or partial-cut slash.

The Logging Slash Group—Fuel Models 11, 12, and 13

Fuel Model 11 (1-foot deep) Fires are fairly active in slash and herbaceous material intermixed with slash. Spacing of a rather light fuel load, shading from overstory, or aging of fine fuels can contribute to limiting fire potential. Light partial cuts or thinning operations in mixed conifer stands, hardwood stands, and southern pine harvests are considered representative. Clear cut operations generally produce more slash than represented here. The less than 3-inch material load is smaller than 12 tons per acre. The less than 3-inch material is represented by not more than 10 pieces, 4 inches in diameter, along a 50-foot transect.

Fuel Model 12 (2.3-feet deep) Rapidly spreading fires with high intensities capable of generating firebrands can occur. When fire starts, it is generally sustained until a fuel break or change in fuels is encountered. The visual impression of these stands is one dominated by slash, much of it less than 3 inches in diameter. These fuels total less than 35 tons per acre and seem well distributed. Heavily thinned conifer stands, clear cuts, and medium or heavy partial cuts are represented. The less than 3-inch material is represented by encountering 11 pieces, 6 inches in diameter, along a 50-foot transect.

Fuel Model 13 (3-feet deep) Fire is generally carried by a continuous layer of slash. Large quantities of greater than 3-inch material are present. Fires spread quickly through fine fuels, and the intensity builds up as large fuels start burning. Active flaming is sustained for long periods, and a wide variety of firebrands can be generated. Firebrands contribute to spotting problems as weather conditions become more severe. Clear cut and heavy partial cuts in mature and over-mature stands occur where the slash load is dominated by less-than-3-inch material. The total load may exceed 300 tons per acre, but the less-than-3-inch fuel is generally only 10 percent of the total load. Situations where slash still has “red” needles attached, but the total load is lighter, such as a Model 12, can be represented because of an earlier higher fire intensity and faster rate of spread.

8.2 Fuel Moisture Content Fuel moisture content is the amount of water in fuel, expressed as a percent of the oven-dry weight of that fuel. If no moisture was in a fuel, as if it was dried in an oven, the fuel moisture content would be zero. Fuel moisture content can be estimated in the field by using fuel moisture tables. Fuel moisture plays a significant role in determining how quickly a fire will spread.

Fine Dead Fuel Moisture—Dead fuel moisture in fuels ranges from about 2 to 30 percent. Fine dead fuel moisture fluctuates considerably over time due to environmental factors. Tables can provide acceptable estimates of 1-hour time-lag fine dead fuel moistures under a variety of conditions. To determine the adjusted fine dead fuel moisture (FDFM), add the reference fuel moisture (RFM) and the fuel moisture correction value (FMC). RFM and FMC values are obtained from tables referenced by analysis of specific conditions.

Reference Fuel Moisture, Table 8.1

To read a value for reference fuel moisture, the dry bulb temperature and relative humidity of the site must be known. Temperature range is on the left and humidity is on the top of the table. Once the appropriate range for both items is chosen, find where the temperature row and humidity column intersect. At the intersection, there is a RFM content percent. Note this number.

Dead Fuel Moisture Content Correction, Tables 8.2, 8.3, and 8.4

Three tables are used for correcting dead fuel moisture content, based on shaded or unshaded surface fuels, hour during the day, relative location, aspect, and percent slope. In addition, each table references different months of the year.

Table 8.2 provides the correction for the months of May, June, and July between the hours of 0800 and 1959. Table 8.3 is for the months of February, March, April, August, September, and October between the hours of 0800 and 1959. Table 8.4 is for the months of November, December, and January between the hours of 0800 and 1959. Notice that the time is given in military time. Military time is based on 24 hours, i.e., 2400 is midnight, 0100 is 1:00 a.m., 1200 is noon, and 1400 is 2:00 p.m.

Each table has a top section indexed for unshaded surface fuels by daytime hour and a bottom section for shaded surface fuels. Each section is further indexed by relative location, A for 1,000 to 2,000 feet above the site location, B for 1,000 to 2,000 feet below, and L for 0 to 1,000 feet above or below the site location.

Corrections for aspect and percent slope are presented on the left side of the table. Referencing the appropriate values, the intersection of the row and column will indicate the appropriate fuel moisture correction value.

Fine Dead Fuel Moisture Worksheet, Figure 8.1

All of the necessary data for the fine dead fuel moisture calculation is recorded in the Fine Dead Fuel Moisture Worksheet. The input values are all of the data that is used to compute the final answer or output value. This guides the process, and the addition is performed at the conclusion of the data collection.

Example 1—It is October 1, at 1300. Fuels are exposed to the sun on a west aspect. Readings from a belt weather kit taken 1,500 feet above the fire give a dry bulb temperature of 93 °F and a relative humidity of 17 percent. The slope is 45 percent. What is the fine dead fuel moisture content?

Step 1. Enter all the data values given into the worksheet. See figure 8.1.

Step 2. According to table 8.1 the reference fuel moisture (RFM) has an index of 2. Put the result on line 6 of the worksheet.

Table 8.1—Reference Fuel Moisture, Day (0800 to 1959) (Input Line 6)

Dry Bulb Temp (°F)	Relative Humidity (Percent)																				
	0 ▼ 4	5 ▼ 9	10 ▼ 14	15 ▼ 19	20 ▼ 24	25 ▼ 29	30 ▼ 34	35 ▼ 39	40 ▼ 44	45 ▼ 49	50 ▼ 54	55 ▼ 59	60 ▼ 64	65 ▼ 69	70 ▼ 74	75 ▼ 79	80 ▼ 84	85 ▼ 89	90 ▼ 94	95 ▼ 99	100
10-29	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
30-49	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
50-69	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
70-89	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
90-109	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
109+	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	12

Go to table 8.2, 8.3, or 8.4 for Fuel Moisture Content Corrections

Table 8.2—Dead Fuel Moisture Content Correctons Day (0800 to 1959) May, June, July (Input Line 13)

Aspect	% slope	0800>			1000>			1200>			1400>			1600>			1800>		
Unshaded—Less than 50% shading of surface fuels																			
		B	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**
N	0-30	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
	31+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
	31+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
	31+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
	31+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
Shaded—50% or more shading of surface fuels																			
N	all	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	all	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	all	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	all	4	5	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

Note: when using tables 8.2, 8.3, and 8.4: B = 1,000 to 2,000 feet below the site location
L = 0 to 1,000 feet above or below the site location
A = 1,000 to 2,000 feet above the site location

Table 8.3—Dead Fuel Moisture Content Corrections Day (0800 to 1959) February, March, April, August, September, October (Input Line 13)

Unshaded—Less than 50% shading of surface fuels																			
Aspect	% slope	0800>			1000>			1200>			1400>			1600>			1800>		
		B	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**
N	0-30	3	4	5	1	2	3	1	1	2	1	1	2	1	2	3	3	4	5
	31+	3	4	5	3	3	4	2	3	4	2	3	4	3	3	4	3	4	5
E	0-30	3	4	5	1	2	3	1	1	1	1	1	2	1	2	4	3	4	5
	31+	3	4	4	1	1	1	1	1	1	1	2	3	3	4	5	4	5	6
S	0-30	3	4	5	1	2	2	1	1	1	1	1	1	1	2	3	3	4	5
	31+	3	4	5	1	2	2	0	1	1	0	1	1	1	2	2	3	4	5
W	0-30	3	4	5	1	2	3	1	1	1	1	1	1	1	2	3	3	4	5
	31+	4	5	6	3	4	4	1	3	3	1	1	1	1	1	1	3	3	4
Shaded—50% or more shading of surface fuels																			
N	all	4	5	6	4	5	5	3	4	5	3	4	5	4	5	5	4	5	6
E	all	4	5	6	3	4	5	3	4	5	3	4	5	4	5	6	4	5	6
S	all	4	5	6	3	4	5	3	4	5	3	4	5	3	4	5	4	5	6
W	all	4	5	6	4	5	5	3	4	5	3	4	5	3	4	5	4	5	6

Note: when using tables 8.2, 8.3, and 8.4: *B = 1000 to 2000 feet below the site location*
L = 0 to 1000 feet above or below the site location
A = 1000 to 2000 feet above the site location

Table 8.4—Dead Fuel Moisture Content Corrections Day (0800 to 1959) November, December, January (Input Line 13)

Unshaded—Less than 50% shading of surface fuels																			
Aspect	% slope	0800>			1000>			1200>			1400>			1600>			1800>		
		B	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**
N	0-30	4	5	6	3	4	5	2	3	4	2	3	4	3	4	5	4	5	6
	31+	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	0-30	4	5	6	3	4	4	2	3	3	2	3	3	3	4	5	4	5	6
	31+	4	5	6	2	3	4	2	2	3	3	4	4	4	5	6	4	5	6
S	0-30	4	5	6	3	4	5	2	3	3	2	2	3	3	4	4	4	5	6
	31+	4	5	6	2	3	3	1	1	2	1	1	2	2	3	3	4	5	6
W	0-30	4	5	6	3	4	5	2	3	3	2	3	3	3	4	4	4	5	6
	31+	4	5	6	4	5	6	3	4	4	2	2	3	2	3	4	4	5	6
Shaded—50% or more shading of surface fuels																			
N	all	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
E	all	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
S	all	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
W	all	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6

Note: when using tables 8.2, 8.3, and 8.4: *B = 1,000 to 2,000 feet below the site location*
L = 0 to 1,000 feet above or below the site location
A = 1,000 to 2,000 feet above the site location

Table 8.5—Reference Fuel Moisture Night (2000 to 0759)

Dry Bulb Temp (°F)	Relative Humidity (Percent)																				
	0 ▼ 4	5 ▼ 9	10 ▼ 14	15 ▼ 19	20 ▼ 24	25 ▼ 29	30 ▼ 34	35 ▼ 39	40 ▼ 44	45 ▼ 49	50 ▼ 54	55 ▼ 59	60 ▼ 64	65 ▼ 69	70 ▼ 74	75 ▼ 79	80 ▼ 84	85 ▼ 89	90 ▼ 94	95 ▼ 99	100
10-29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
30-49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
50-69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	25+
70-89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
90-109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	25+
109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+

Table 8.6—Dead Fuel Moisture Content Correctons Night (2000 to 0759)

Aspect	2000>			2200>			0000>			0200>			0400>			0600>		
	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A	B	L	A
N + E	9	1	1	13	1	2	16	2	2	17	1	1	18	1	1	16	2	1
S + W	9	0	1	14	0	1	16	0	2	17	0	1	18	0	0	9	0	1

Note: B = 1,000 to 2,000 feet below the site location
L = 0 to 1,000 feet above or below the site location
A = 1,000 to 2,000 feet above the site location

Fine Dead Fuel Moisture Worksheet

Input				
0	Projection point	Ex 1	Prob 5	
1	Daytime calculation	D	D	D
2	Dry bulb temperature, °F		99	
3	Wet bulb temperature, °F			
4	Dew point, °F			
5	Relative humidity, %	17	12	
6	Reference fuel moisture (RFM), % (from table 1)	2	2	
7	Month	October	July	
8	Unshaded (U) or shaded (S) (Circle)	U/S	U/S	U/S
9	Time	1300	1500	
10	Elevation change (Circle) B = 1,000 to 2,000 feet below site L = ±1,000 feet of site location A = 1,000 to 2,000 feet above site	B/L/A	B/L/A	B/L/A
11	Aspect (N, E, S, W)	West	West	
12	Slope, %	45	42	
13	Fuel moisture correction (FMC), % (from table 2, 3, or 4)	3	0	
Output				
1	Fine dead fuel moisture (FDFM), % (line 6 + line 13)	5	2	

Figure 8.1—Fine dead fuel moisture worksheet.

Step 3. On table 8.3 a dead fuel moisture content correction (FMC) of 3 is read. Put the result on line 13 of the worksheet.

Step 4. Add these two together (RFM + FMC = FDFM), FDFM = 5. Put the answer in line 1 of the output on the worksheet.

8.3 Live Fuel Moisture Oven drying and weighing procedures can accurately determine live fuel moisture content, but fire considerations are usually satisfied with a good estimate. Live fuel moisture is estimated from figure 8.2, which provides moisture percentages for fuels at different stages of vegetative development.

Live Fuel Moisture

Stage of vegetative development	% Moisture content
Fresh foliage, annuals developing early in growing cycle	300
Maturing foliage, still developing with full turgor	200
Mature foliage, new growth complete and comparable to older perennial foliage	100
Entering dormancy, coloration starting, some leaves may have dropped from stem	50
Completely cured	Less than 30, treat as a dead fuel

Figure 8.2—Live fuel moisture approximations.

A method for calculating these percentages is governed by the following equation:

Moisture Content (MC) =

$$\frac{\text{Net Wet Weight} - \text{Net Dry Weight}}{\text{Net Dry Weight}} \times 100$$

8.4 Determining Fuel Size Fuels can be assumed to have a circular cross sectional area. Consequently, the diameter can be estimated from the cut section. See figure 8.3.

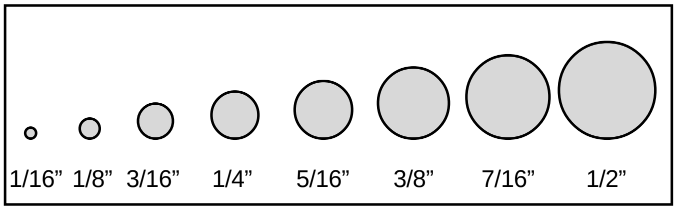


Figure 8.3—Diameter key.

Fuel Model	Fuel Loading 1-hour	10-hour	100-hour	Live	Approx. Fuel Bed Depth (ft)	Moist. of Ext. (%)	ROS (ch/h)	FL (ft)
Grass Group								
1	X				1.0	12	78	4
2	X	X	X	X	1.0	15	35	6
3	X				2.5	25	104	12
Shrub Group								
4	X	X	X	X	6.0	20	75	19
5	X	X		X	2.0	20	18	4
6	X	X	X		2.5	25	32	6
7	X	X	X	X	2.5	40	20	5
Timber Litter Group								
8	X	X	X		0.2	30	2	1
9	X	X	X		0.2	25	8	3
10	X	X	X	X	1.0	25	8	5
Logging Slash Group								
11	X	X	X		1.0	15	6	4
12	X	X	X		2.3	20	13	8
13	X	X	X		3.0	25	14	11

Figure 8.4—Fuel model size class key.

EXERCISES

Problem 1. What is the reference fuel moisture (RFM) at a temperature of 89 °F and a relative humidity of 23 percent?

Problem 2. What is the reference fuel moisture (RFM) at a temperature of 67 °F and a relative humidity of 67 percent?

Problem 3. What is the fuel moisture correction (FMC) for May 21, at 1330 with a south aspect and 19 percent slope in a clear unshaded area for elevations B, L, and A?

Problem 4. What is the fuel moisture correction (FMC) for August 12, at 0830 with a north aspect in cloudy skies (shaded fuel) on a 44° slope for elevations B, L, and A?

Problem 5. It is July 19, at 1500. Fuels are exposed to the sun on a west aspect. Readings from a belt weather kit taken 600 feet below the fire give a dry bulb temperature of 99 °F and a relative humidity of 12 percent. The slope is 42 percent. What is the fine dead fuel moisture (FDFM)? Input the data values on the fine dead fuel moisture worksheet (see figure 8.1).

The material in chapter 9 describes how to use surface fire behavior and spotting nomograms, fire characteristic and interpretation charts, probability of ignition charts, and associated worksheets. These charts, graphs, and worksheets easily capture known or calculated information to obtain surface fire behavior characteristics, such as effective windspeed, heat per unit area, rate of spread, and fireline intensity. Fire characteristics defined are flame length, spread distance, which is converted to a map spread distance, flame height, maximum spotting distance, rate of spread, and probability of ignition.

9.1 Surface Fire Behavior Nomograms Surface fire behavior can be determined by using a series of charts and graphs called nomograms. Variables of surface fire behavior include the effective windspeed, heat per unit area, rate of spread, and fireline intensity. A surface fire behavior nomogram is a set of four interconnected graphs that, when given a set of inputs, provides fire behavior characteristics as output values.

There are 26 surface fire behavior nomograms, consisting of nomograms for each of the 13 fuel models, at both low and high windspeeds. The range of values for low and high windspeed nomograms varies depending on the fuel type. Consequently, windspeed and fuel type will determine the correct nomogram to be used.

Nomograms consist of four graphs, positioned in four quadrants. The upper left quadrant contains dead fuel moisture in percentages and the live fuel (foliage) moisture in percentages. The upper right quadrant contains the flame length, rate of spread, fireline intensity, heat per unit area, live fuel moisture in percentages, and the dead fuel moisture in percentages. The lower left quadrant contains the midflame windspeed, percent slope, and the effective value of windspeed. The lower right quadrant contains the effective value of windspeed in miles per hour.

Overview

Nomograms provide essential fire behavior information. To organize this information, input and output values are recorded on a fire behavior worksheet. Before beginning work on the nomogram, the windspeed (usually obtained from a local weather report) must be used to compute the midflame windspeed. See chapter 9, section 2.

Midflame windspeed and slope are needed to determine the effective windspeed in the lower left quadrant of the nomogram. Effective windspeed determines the turning point in the lower right quadrant of the nomogram. Dead fuel moisture, if not given, must be determined. See chapter 8, section 2. Dead fuel moisture determines the turning point in the upper left quadrant and is the beginning of the final information line in the upper right quadrant. For live fuel moistures, a horizontal line is drawn across both upper quadrants connecting these two points. Rate of spread, flame length, fireline intensity, and heat per unit area are read from the intersection of the final information line and appropriate quadrant borders.

Begin the nomogram by establishing all the inputs around the nomogram, then draw the information line around the nomogram, using the inputs as turning points, and conclude by reading the outputs. The following steps are a guide on how to read a nomogram. It is important that the correct nomogram is chosen for the fuel model being studied. The input and output data can be recorded in a fire behavior worksheet.

Surface Fire Behavior Nomogram Input Values

1. Fuel model—Select one of the 13 fire behavior fuel models discussed in chapter 8.

2. Live and dead fuel moistures—Fuel moisture content is the water content of a fuel expressed as a percentage of the oven dry weight of the fuel. Both dead and live fuel moisture contents are used as inputs to the nomogram.

3. Midflame windspeed—Midflame windspeed is the windspeed within a wildland environment at about eye level, measured in miles per hour. See chapter 9, section 2.

4. Slope percent—Slope percent describes the steepness of the site. For wildland fire behavior calculations, slope is always expressed as a percentage rather than by degree. It is found on the lower left quadrant of the nomogram.

5. Effective windspeed—Effective windspeed combines the midflame windspeed and slope values into one input. It is found by using the nomogram, but is listed as an input because once it is determined, it is used as a turning point in the lower right quadrant.

Surface Fire Behavior Nomogram Output Values

1. Rate of spread—Rate of spread is the relative activity of a fire, expressed as a rate of advance of the head of the fire in chains per hour (ch/h).

2. Heat per unit area—Heat per unit area is the total amount of heat released per square foot during the passage of the fire front. It is expressed in British thermal units per square foot (Btu/ft^2).

3. Fireline intensity—Fireline intensity is the amount of heat released per linear foot of fire front per second. It is based on both rate of spread and heat per unit area of a fire and is expressed in British thermal units per foot per second (Btu/ft/s).

4. Flame length—Flame length is the distance between the flame tip and the midpoint of the flame depth at the base of the flame (in feet). Flame length is directly related to fireline intensity.

9.2 Midflame Windspeed (MFWS) Midflame windspeed is defined as the velocity of the winds, in miles per hour, taken at the mid-height of the flames. MFWS will directly affect the direction of movement of the flaming front. This is important in fire spread calculations.

The midflame windspeed is determined by use of the wind adjustment table, which is in terms of fuel overstory exposure and fuel model. See figures 9.2 and 9.4. Windspeed that is measured 20 feet above any fuel or obstruction is referred to as a 20-foot windspeed. It is usually measured by a weather station. The midflame windspeed is obtained by multiplying the 20-foot windspeed by the appropriate wind adjustment factor from figure 9.2. It is very important to know which fuel model and sheltering configuration is being studied, and whether a given windspeed is a 20-ft windspeed or an already adjusted midflame windspeed. All of this information can be entered in a wind adjustment worksheet. See figure 9.1.

Example 1—A fire is burning in a fully sheltered area of dense, or closed, stands described as Fuel Model 4. The local weather station reports the 20-ft windspeed is 15 miles per hour. What is the midflame windspeed? Show all work on the wind adjustment worksheet, figure 9.1.

Solution—Figure 9.2 describes wind reduction factors and is used to determine the appropriate correction factor.

<u>Step 1.</u> See figure 9.2. The correction factor is 0.1 for any fuel model under fully sheltered conditions with dense stands.

<u>Step 2.</u> To find the midflame windspeed, multiply the 20-foot windspeed by the adjustment factor.

midflame windspeed =
20-foot windspeed x adjustment factor

MFWS = 15 mi/h x 0.1 = 1.5 mi/h

Example 2—A 20-foot windspeed at the top of the ridge is reported to be 35 miles per hour, with fuel model 11 vegetation. What is the midflame windspeed? Show all work on the wind adjustment worksheet, figure 9.1.

<u>Step 1.</u> See figure 9.4. The top of a ridge is indicated to be unsheltered.

<u>Step 2.</u> From figure 9.2, the adjustment factor is 0.4.

<u>Step 3.</u> MFWS = 35 x 0.4 = 14 mi/h

Wind Adjustment Worksheet

			Example 1	Example2
	Input			
0	PP	Projection point		
1	20' W	20-ft windspeed, mi/h	15	35
2	Model #	Fuel model number (1-13)	4	11
3	Shltr	Wind sheltering 1 = Unsheltered 2 = Partially sheltered 3 = Fully sheltered, open 4 = Fully sheltered, closed	4	1
4	WAF	Wind adjustment factor (see figure 9.2)	0.1	0.4
	Output			
1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)	1.5	14

Figure 9.1—Wind adjustment worksheet.

Fuel Exposure	Fuel Model	Adjustment Factor
Unsheltered Fuels Fuel exposed directly to the wind. No or sparse overstory. Fuel beneath timber that has lost its foliage; fuel beneath timber near clearings or clearcuts; fuel on high ridges where trees offer little shelter from the wind.	4 13 1, 3, 5, 6, 11, 12 (2, 7)[1] (8, 9, 10)[2]	0.6 0.5 0.4 0.4 0.4 0.4
Partially Sheltered Fuels Fuel beneath patchy timber, where it is not well sheltered; fuel beneath standing timber at midslope or higher on a mountain with wind blowing directly at the slope.	All fuel models	0.3
Fully Sheltered Fuels Fuel sheltered beneath standing timber on flat or gentle slope or near base of a mountain with steep slopes.	All fuel models	Open stands 0.2 Dense stands 0.1

[1] Fuels usually partially sheltered
[2] Fuels usually fully sheltered

Figure 9.2—Wind reduction factors.

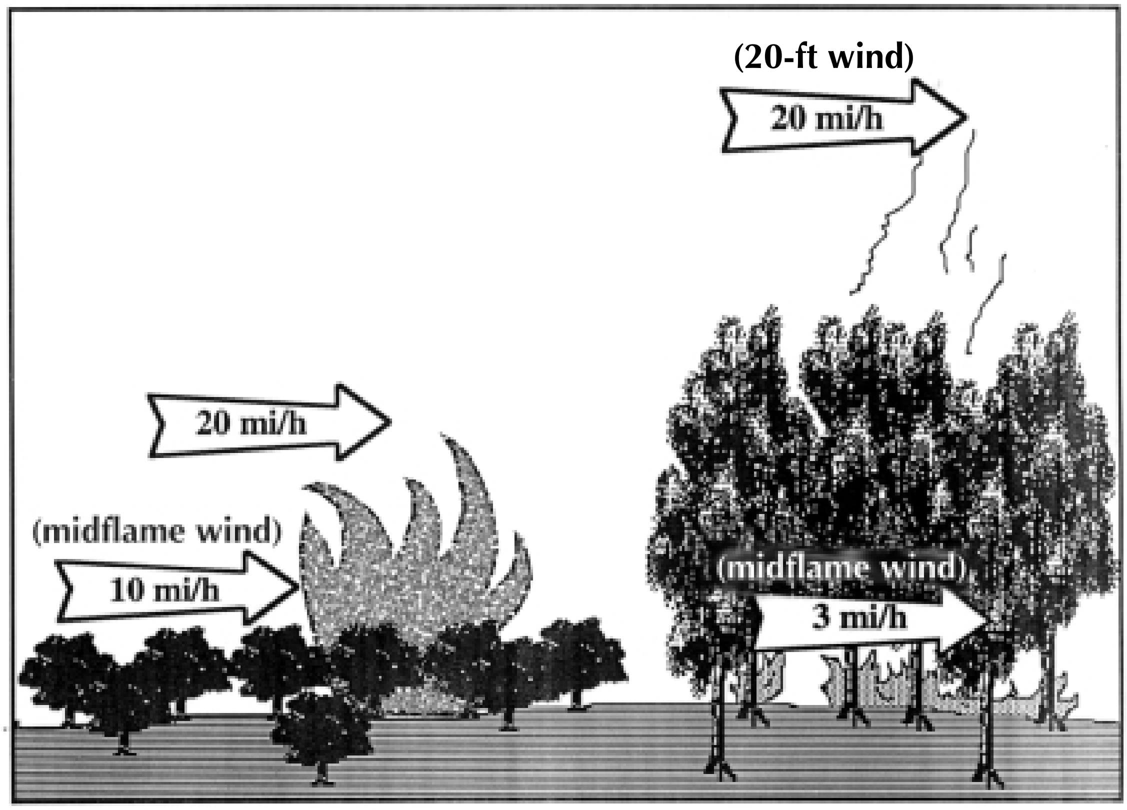


Figure 9.3—Midflame winds vs 20-foot winds.

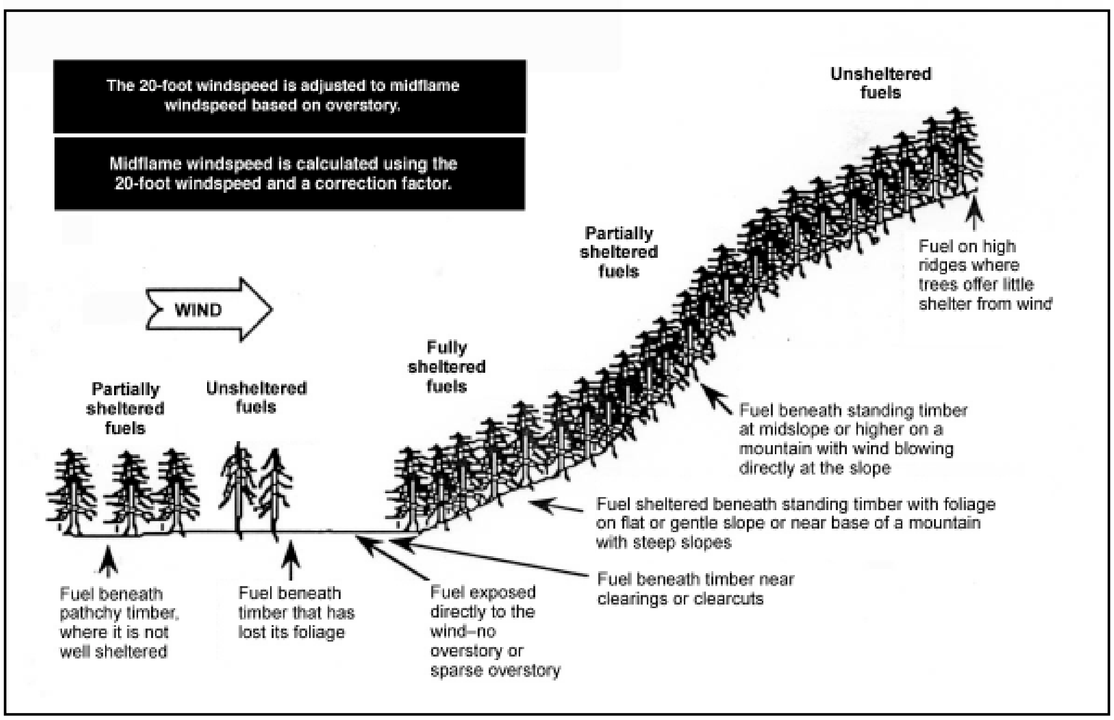


Figure 9.4—Fuel diagram.

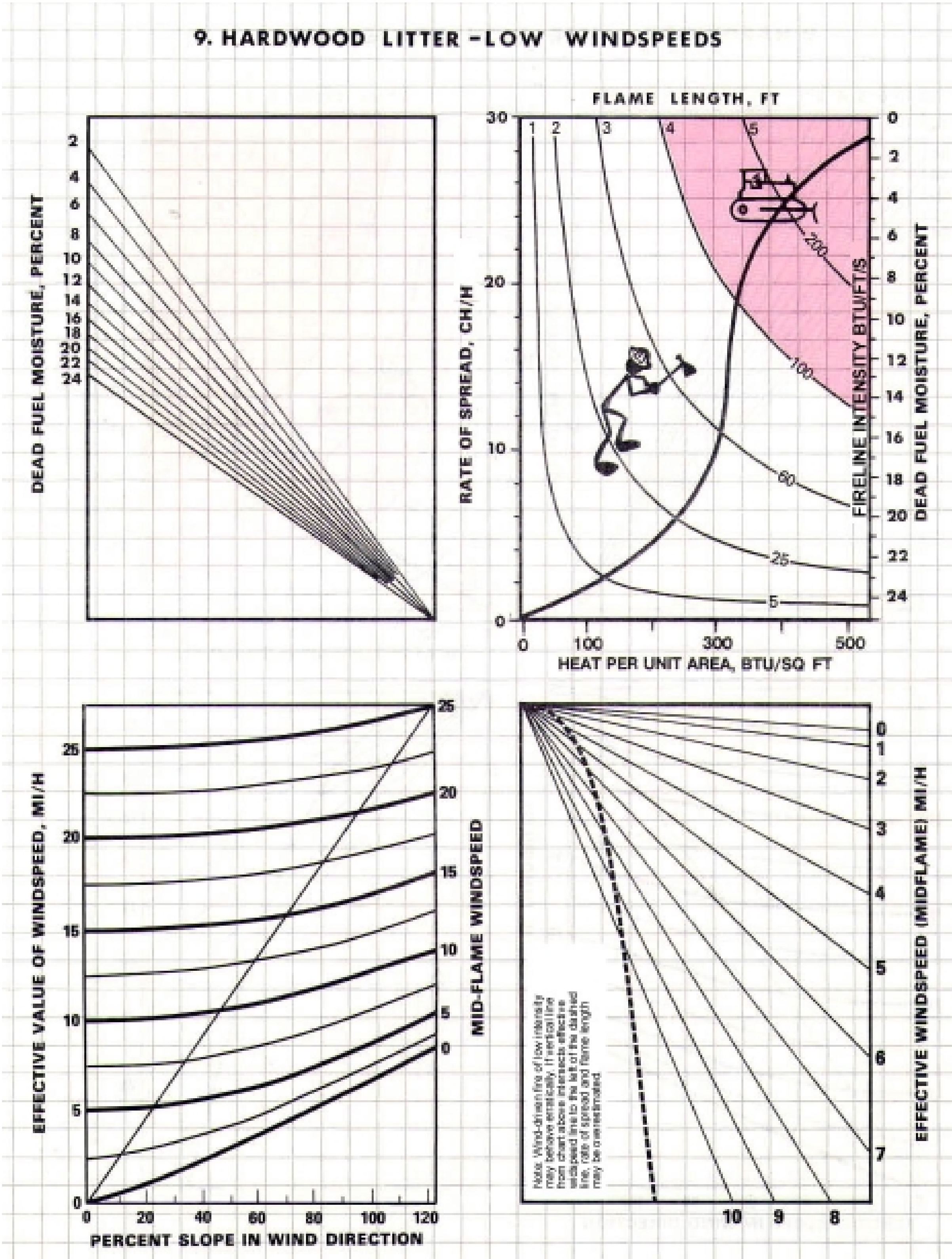


Figure 9.5—Nomogram – fuel model 9.

Name of fire ________________ Fire pred spec ____________________
Date ________________________ Time ______________________________
Proj period date _____________ Proj time from __________ to ________

Fire Behavior Worksheet

Input					
0	PP	Projection point	____	____	____
1	Model #	Fuel model number (1-13)	____	____	____
2	1H-FDFM	Fine dead fuel moisture, %	____	____	____
3	LFM	Live fuel moisture, %	____	____	____
4	MFWS	Midflame windspeed, mi/h	____	____	____
5	SLP	slope, %	____	____	____
6	EWS	Effective windspeed, mi/h	____	____	____
Output					
1	ROS	Rate of spread, ch/h	____	____	____
2	HA	Heat per unit area, Btu/ft^2	____	____	____
3	FLI	Fireline intensity, Btu/ft/s	____	____	____
4	FL	Flame length, ft	____	____	____
5	SD	Spread distance, ch	____	____	____
		Map spread distance, in	____	____	____
6	PER	Perimeter, ch	____	____	____
7	AC	Area, ac	____	____	____
8	SPOT	Max spotting distance, mi	____	____	____
		Map distance spot, in	____	____	____
9	PIG	Probability of ignition, %	____	____	____

Fine Dead Fuel Moisture/Probability of Ignition Worksheet

Input					
0	PP	Projection point	____	____	____
1	D	Daytime calculation	D	D	D
2	DB	Dry bulb temperature, °F	____	____	____
3	WB	Wet bulb temperature, °F	____	____	____
4	DP	Dew point, °F	____	____	____
5	RH	Relative humidity, %	____	____	____
6	RFM	Reference fuel moisture, % (table 2)	____	____	____
7	MO	Month	____	____	____
8	SH	Unshaded (U) or shaded (S)	U/S	U/S	U/S
9	T	Time	____	____	____
10	CH	Elevation change B = 1,000 ft to 2,000 ft below site L = ± 1,000 ft of site location A = 1,000 ft to 2,000 ft above site	B/L/A	B/L/A	B/L/A
11	ASP	Aspect, (N, S, E, W)	____	____	____
12	SLP	Slope, %	____	____	____
13	FMC	Fuel moisture correction, % (table 3, 4, or 5)	____	____	____
Output					
1	1H-FDFM	Fine dead fuel moisture, % (line 6 + line 13)	____	____	____
2	PIG	Probability of ignition, % (table 12)	____	____	____

Slope Worksheet

Input					
0	PP	Projection point	____	____	____
1	CON INT	Contour interval, ft	____	____	____
2	SLC	Map scale	____	____	____
3	CF	Conversion factor, ft/in	____	____	____
4	# INTVLS	Number of contour intervals	____	____	____
5	RISE	Rise in elevation	____	____	____
6	MD	Map distance, in (between points)	____	____	____
7	HZGD	Horizontal ground distance, ft	____	____	____
Output					
1	SLP%	Slope, %	____	____	____

Wind Adjustment Worksheet

Input					
0	PP	Projection point	____	____	____
1	20' W	20-ft windspeed, mi/h	____	____	____
2	MODEL #	Fuel model number (1-13)	____	____	____
3	SHLTR	Wind sheltering 1 = unsheltered 2 = partially sheltered 3 = fully sheltered, open 4 = fully sheltered, closed	____	____	____
4	WAF	Wind adjustment factor (table 7)	____	____	____
Output					
1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)	____	____	____

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Figure 9.6—Nomogram worksheet.

Example 3—A fire is spreading uphill in hardwood litter, fuel model 9, on a 55 percent slope. The midflame windspeed is 5 miles per hour. The wind is blowing uphill. The fine dead fuel moisture is 3 percent. Determine the rate of spread, flame length, fireline intensity, and heat per unit area.

The following nomograms and worksheet were used to solve example 3.
Figure 9.5—Nomogram—fuel model 9
Figure 9.6—Nomogram worksheet

Solution

Step 1. Determine nomogram input values.

a. Determine effective windspeed. In the lower left quadrant find the percent slope and draw a vertical line up. See figure 9.7.

b. Find the midflame windspeed on the right-hand side of the same quadrant. Follow the curved line down to the left until it intersects the line just made. If the midflame windspeed lies between the index values, make an approximation of the intersection.

c. From this intersection, draw a horizontal line to the left side of the lower left quadrant and read the effective windspeed (6 mi/h). Record the effective windspeed on the worksheet.

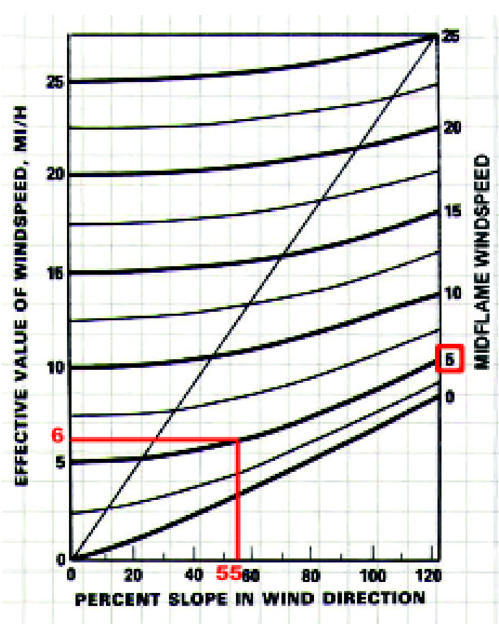

Figure 9.7—Nomogram–lower left quadrant.

Step 2. Using the lower right quadrant of the nomogram, see figure 9.8:

a. Locate the line along the right side, which represents the effective windspeed determined in step 1c, (in most cases a line will need to be drawn approximating the effective windspeed value, if it does not appear along the outside edge of the lower right quadrant). This line will be the turning point in the continuous information line drawn around the nomogram.

b. The line must always be located to the right of the dashed line. See the note on the graph. If the vertical line from the chart above intersects the effective windspeed line to the left of the dashed line, the rate of spread and flame length may be overestimated. When the vertical line is to the left of the dashed line, recheck the windspeed. This is typical when the low windspeed graph is being used, when the high windspeed nomogram may be more appropriate.

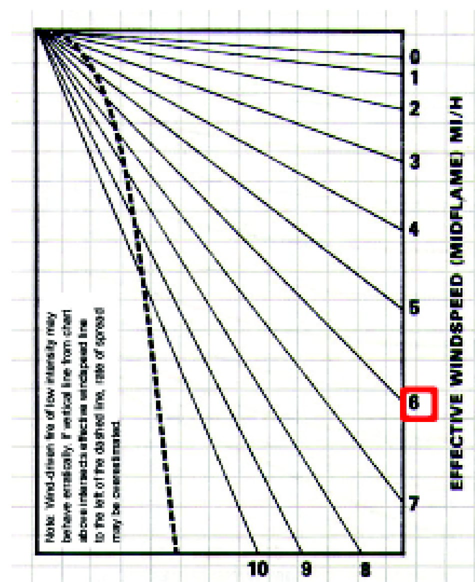

Figure 9.8—Nomogram—lower right quadrant.

Step 3. Using the upper left quadrant of the nomogram, see figure 9.9.

a. Fuel models with dead fuels require finding or approximating a line in the upper left quadrant for the dead fuel moisture. If an approximation is made, start drawing the line in the bottom right corner and estimate where the moisture value lies in relation to the index values along the edge.

b. This fuel moisture line in the upper left quadrant will serve as another turning point for the continuous line to be drawn.

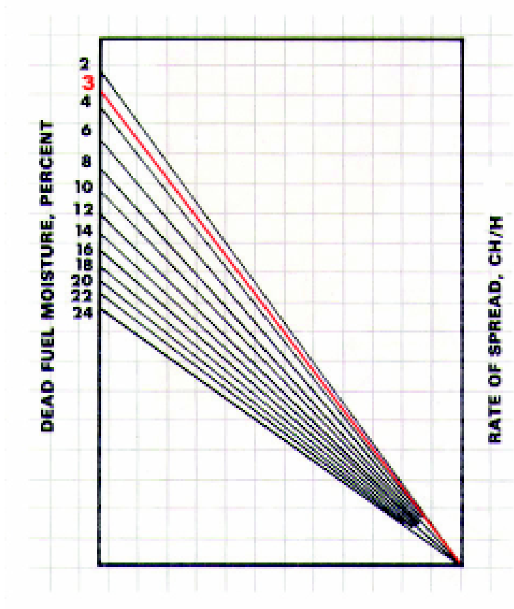

Figure 9.9—Nomogram—upper left quadrant.

Step 4. The nomogram is now set up to begin the continuous information line through the four quadrants, using the established values as turning points.

a. Starting in the upper right quadrant, draw a horizontal line from the dead fuel moisture percent value intersecting the S-shaped curve in the quadrant, see figure 9.10.

b. At this intersection, turn a right angle and draw a vertical line down to the lower right quadrant, stopping at the effective windspeed line identified in step 2a. **If the vertical line intersects the wind limit dashed line in the lower right quadrant before intersecting the effective windspeed line, stop and begin the nomogram again, using the high windspeed nomogram.**

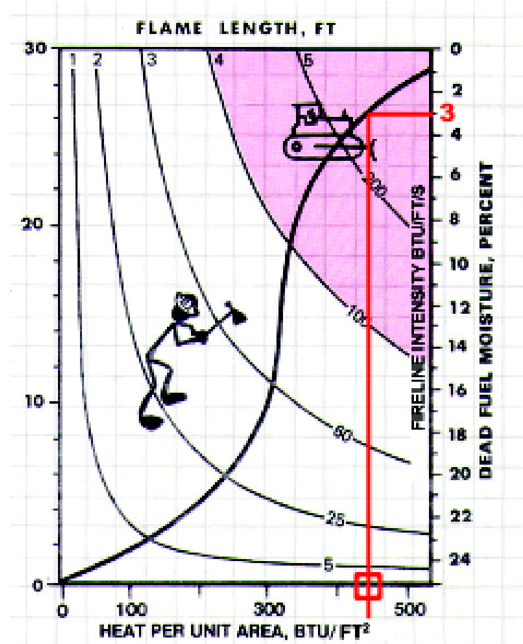

Figure 9.10—Nomogram–upper right quadrant.

c. At this intersection, turn a right angle and draw a horizontal line across to the diagonal line in the lower left quadrant.

d. At this intersection, turn a right angle and draw a vertical line up into the upper left quadrant to the diagonal line for dead fuel moisture identified in step 3.

e. At this intersection, turn a right angle and draw a horizontal line across to the vertical line in the upper right quadrant that was drawn in step 4b.

f. At this intersection, draw a small circle.

Step 5. Read the fire behavior output values off the nomogram at the intersections of the completed information line and the appropriate borders, and record the values on the fire behavior worksheet.

a. Rate of spread is read at the left margin of the upper right quadrant, where the horizontal line from step 4e enters the quadrant (16 ch/h). Record the rate of spread on the fire behavior worksheet.

b. Heat per unit area is read along the bottom margin of the upper right quadrant at the intersection of the line constructed in step 4b (450 Btu/ft^2). Record the heat per unit area on the worksheet.

c. Flame length is read by finding the small circle in the upper right quadrant that was drawn in step 4f. Follow the curved ray that lies nearest the circle to the top of the quadrant. Flame lengths are read to the nearest whole foot at the top of the quadrant (4 feet). Record the flame length on the fire behavior worksheet.

d. Fireline intensity is read from the numbers embedded in the curved lines in the upper right quadrant. Find the small circle that was drawn in step 4f and estimate the fireline intensity by the location to the nearest curved ray (120 Btu/ft/s). Record the fireline intensity in the worksheet.

See figure 9.11 for a completed nomogram and figure 9.12 for a completed worksheet.

9.3 Fire Behavior Calculations for Fuel Models Using Live and Fine Dead Fuel Moisture Values

Example 4— A fire is spreading uphill in brush, fuel model 5, with enough green fuel in the understory to affect fire behavior. The midflame windspeed is 5 miles per hour, slope is 30 percent, and the fine dead fuel moisture is 4 percent. The fuel moisture content needs to be estimated due to a live fuel component. See figure 8.2. The foliage is almost mature and comparable to older foliage, so 150 percent moisture content can be estimated.

The following nomogram and worksheet were used to solve the problem.
Figure 9.15—Nomogram–fuel model 5
Figure 9.18—Completed worksheet

Step 1. Determine the effective windspeed.

a. In the lower left quadrant, find the percent slope and draw a vertical line up. See figure 9.13.

b. Find the midflame windspeed on the right-hand side of the same quadrant. Follow the curved line down to the left until it intersects the line made in step 1a. If the midflame windspeed lies between the index values, make an approximation of the intersection.

c. From this intersection, draw a horizontal line to the left side of the lower left quadrant and read the effective windspeed (6 mi/h). Record the effective windspeed on the worksheet.

Step 2. Using the lower right quadrant of the nomogram. See figure 9.14.

a. Locate the line along the right side, which represents the effective windspeed determined in Step 1c (typically a line needs to be drawn approximating the effective windspeed value, if it does not appear along the outside edge of the lower right quadrant). This line will be the turning point in the continuous line drawn around the nomogram.

Step 3. Prepare upper quadrants and draw a horizontal line for live and dead fuels. See figure 9.16.

a. Locate the fine dead fuel moisture values on the outer axis of both upper quadrants. Draw a horizontal line across both quadrants, connecting the fine dead fuel moistures.

b. Find where this line intersects the correct live fuel moisture curve in the upper left quadrant, and draw a straight line to the lower right corner of that same quadrant. This line is referred to as the “K” line.

c. If the horizontal line does not cross the correct live fuel moisture curve, extend the curve in approximately the same arc until it intersects the fine dead fuel line and draw the “K” line from this point.

Step 4. The nomogram is now set up and ready to begin the continuous line through the 4 quadrants.

a. In the upper right quadrant, locate the point where the dead fuel moisture line drawn in step 3a intersects the appropriate live fuel moisture curve.

b. From this point, draw a vertical line down into the lower right quadrant to intersect the correct effective windspeed line. Remember to stop and go to a high windspeed nomogram if the dashed wind limit line is intersected.

c. At this intersection, turn a right angle and draw a horizontal line across to the diagonal line in the lower left quadrant.

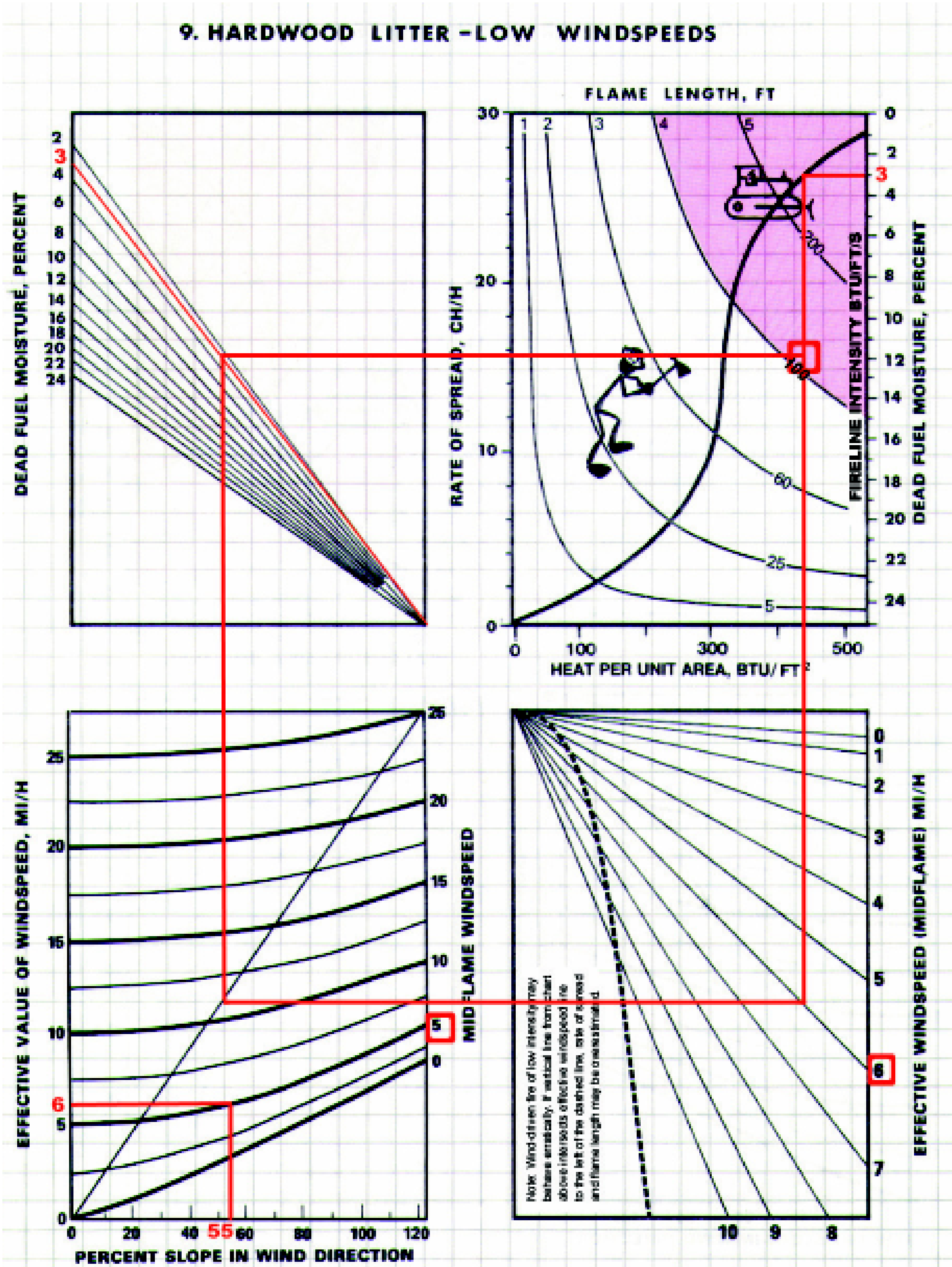

Figure 9.11—Completed nomogram.

Name of fire ________________ Fire pred spec ________________
Date ________________ Time ________________
Proj period date ____________ Proj time from __________ to ________

Fire Behavior Worksheet

Input

0	PP	Projection point	A		
1	Model #	Fuel model number (1-13)	9		
2	1H-FDFM	Fine dead fuel moisture, %	3		
3	LFM	Live fuel moisture, %	N/A		
4	MFWS	Midflame windspeed, mi/h	5		
5	SLP	slope, %	55		
6	EWS	Effective windspeed, mi/h	6		

Output

1	ROS	Rate of spread, ch/h	16		
2	HA	Heat per unit area, Btu/ft^2	450		
3	FLI	Fireline intensity, Btu/ft/s	120		
4	FL	Flame length, ft	4		
5	SD	Spread distance, ch			
		Map spread distance, in			
6	PER	Perimeter, ch			
7	AC	Area, ac			
8	SPOT	Max spotting distance, mi			
		Map distance spot, in			
9	PIG	Probability of ignition, %			

Slope Worksheet

Input

0	PP	Projection point			
1	CON INT	Contour interval, ft			
2	SLC	Map scale			
3	CF	Conversion factor, ft/in			
4	# INTVLS	Number of contour intervals			
5	RISE	Rise in elevation			
6	MD	Map distance, in (between points)			
7	HZGD	Horizontal ground distance, ft			

Output

1	SLP%	Slope, %			

Fine Dead Fuel Moisture/Probability of Ignition Worksheet

Input

0	PP	Projection point			
1	D	Daytime calculation	D	D	D
2	DB	Dry bulb temperature, °F			
3	WB	Wet bulb temperature, °F			
4	DP	Dew point, °F			
5	RH	Relative humidity, %			
6	RFM	Reference fuel moisture, % (table 2)			
7	MO	Month			
8	SH	Unshaded (U) or shaded (S)	U/S	U/S	U/S
9	T	Time			
10	CH	Elevation change B = 1,000 ft to 2,000 ft below site L = ± 1,000 ft of site location A = 1,000 ft to 2,000 ft above site	B/L/A	B/L/A	B/L/A
11	ASP	Aspect, (N, S, E, W)			
12	SLP	Slope, %			
13	FMC	Fuel moisture correction, % (table 3, 4, or 5)			

Output

1	1H-FDFM	Fine dead fuel moisture, % (line 6 + line 13)			
2	PIG	Probability of ignition, % (table 12)			

Wind Adjustment Worksheet

Input

0	PP	Projection point			
1	20' W	20-ft windspeed, mi/h			
2	MODEL #	Fuel model number (1-13)			
3	SHLTR	Wind sheltering 1 = unsheltered 2 = partially sheltered 3 = fully sheltered, open 4 = fully sheltered, closed			
4	WAF	Wind adjustment factor (table 7)			

Output

1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)			

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Figure 9.12—Partially completed worksheet.

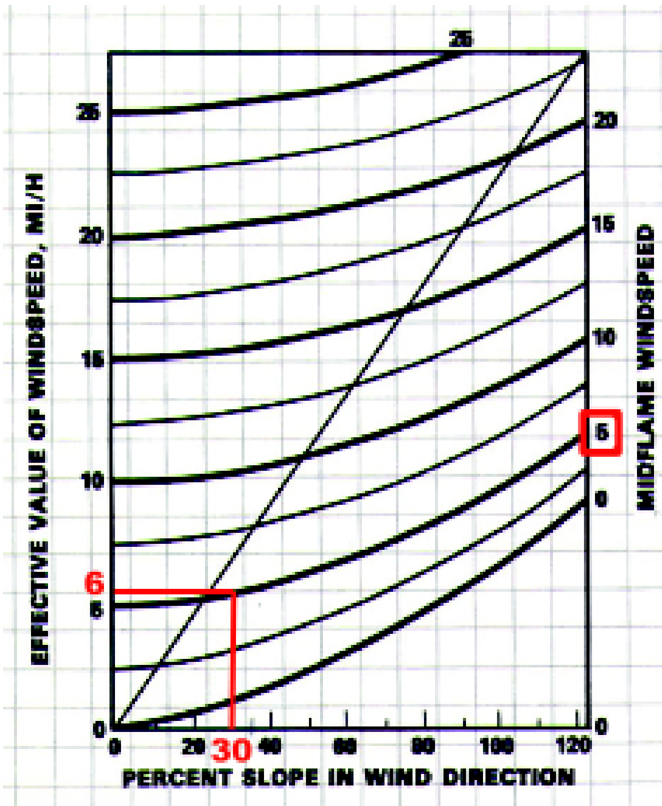

Figure 9.13—Nomogram–lower left quadrant.

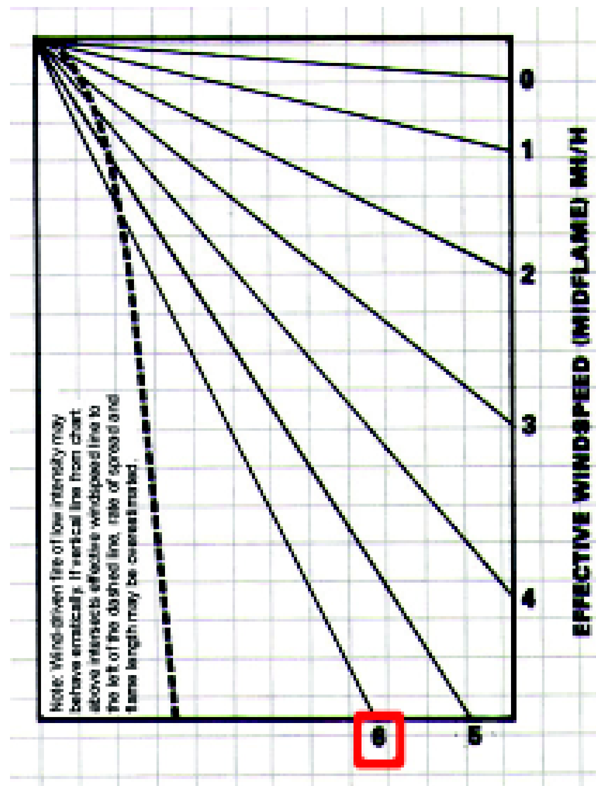

Figure 9.14—Nomogram–lower right quadrant.

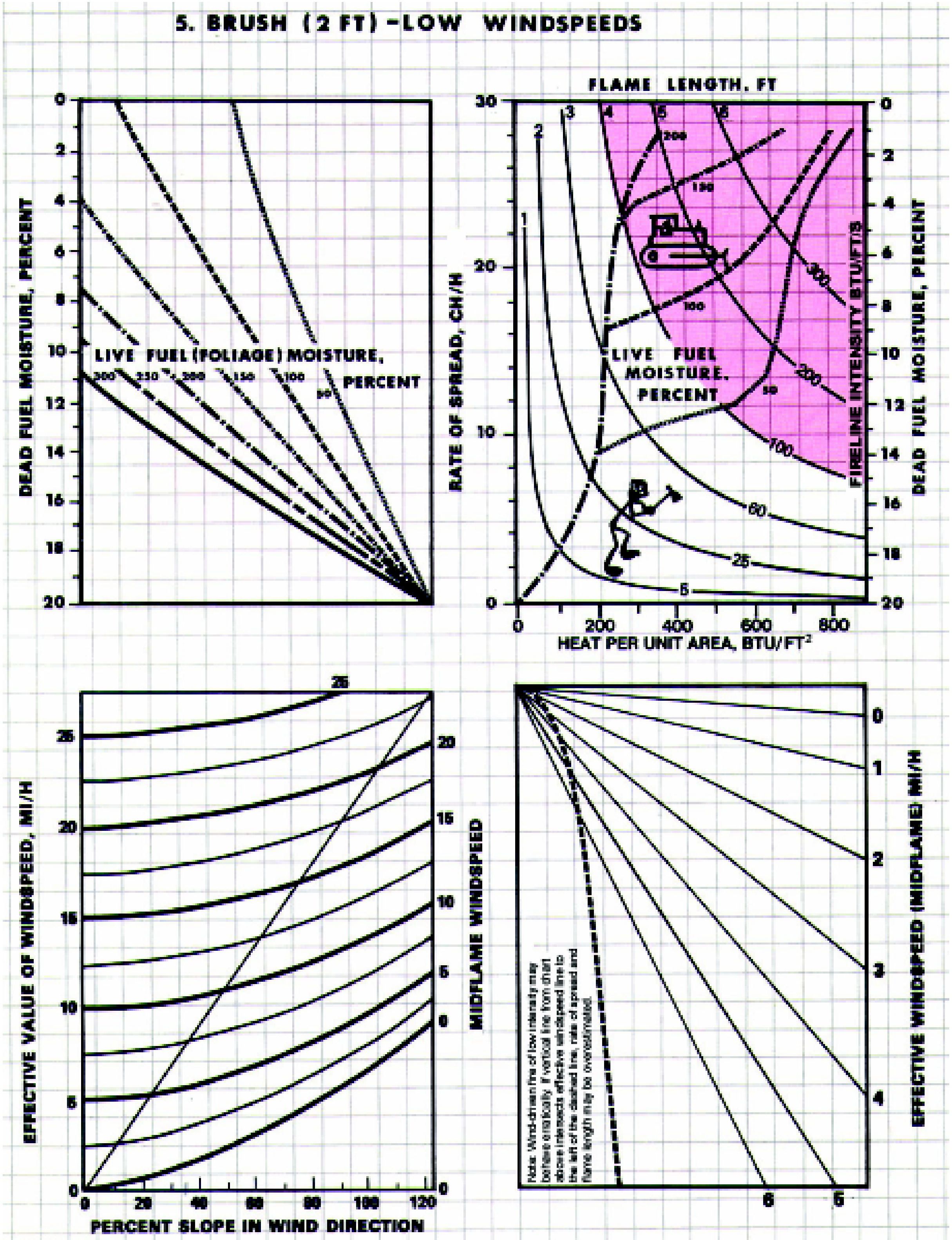

Figure 9.15—Nomogram–fuel model 5.

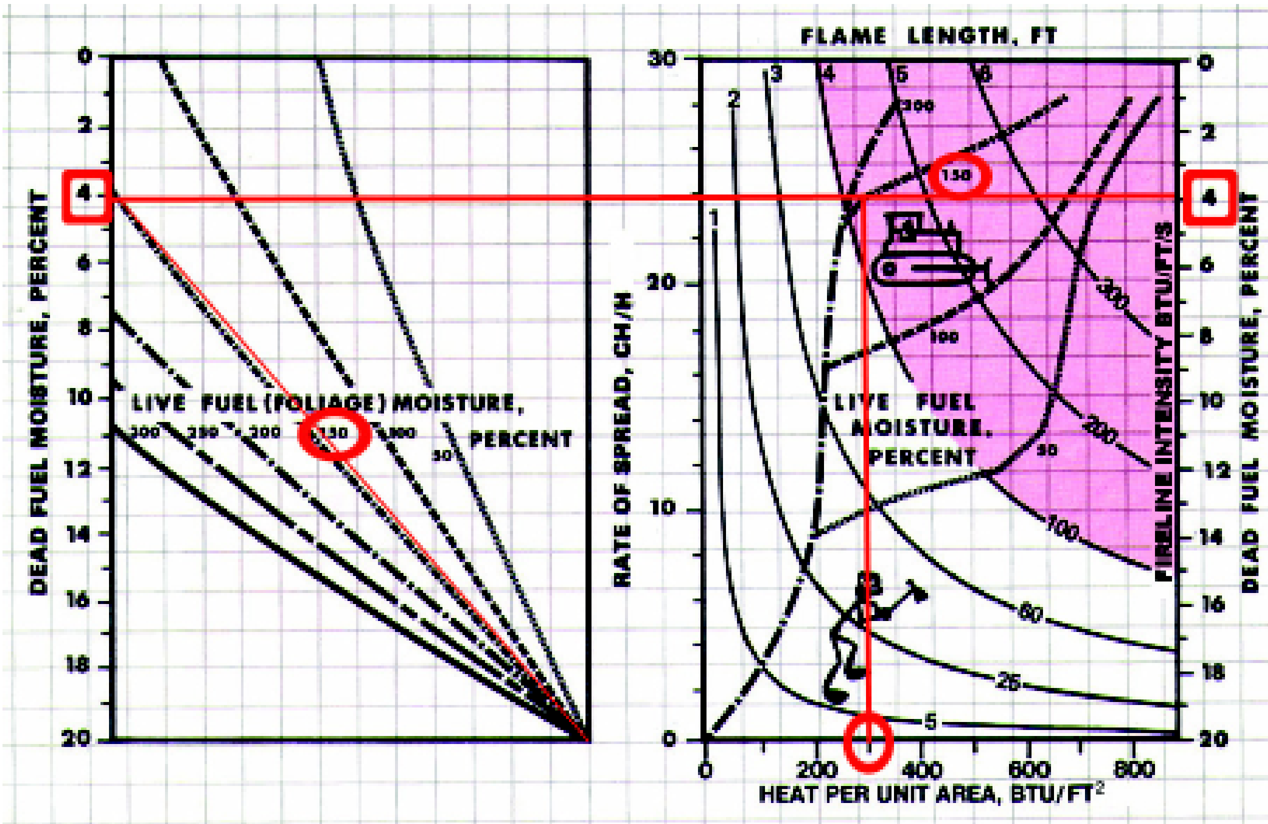

Figure 9.16—Nomogram–upper left and upper right quadrants.

d. At this intersection in the lower left quadrant, draw a vertical line up into the upper left quadrant, intersecting the "K" line.

e. At this intersection, draw a horizontal line to the vertical line drawn in step 4b.

f. At this intersection, draw a small circle.

Step 5. Read the outputs from the completed nomogram. Record the values on the fire behavior worksheet.

a. Rate of spread is read from the left margin of the upper right quadrant at the point intersected by the line drawn in step 4e (11 ch/h). Be careful not to read the rate of spread off the dead fuel moisture line. Record the rate of spread on the fire behavior worksheet.

b. Flame length is read by locating the curved line in the upper right quadrant nearest the point circled in step 4f. Follow that line to the top of the page and estimate the flame length to the nearest foot (3 feet). Record the flame length on the fire behavior worksheet.

c. Fireline intensity is read from this same point. Estimate the closest curve to that point and read the associated intensity value for that line (60 Btu/ft/s). Record the fireline intensity on the worksheet.

d. Heat per unit area is read at the lower margin of the upper right quadrant, where the line constructed in step 4b intersects the border (300 Btu/ft^2). Record the heat per unit area on the worksheet.

See figure 9.17 for a completed nomogram and figure 9.18 for a completed worksheet.

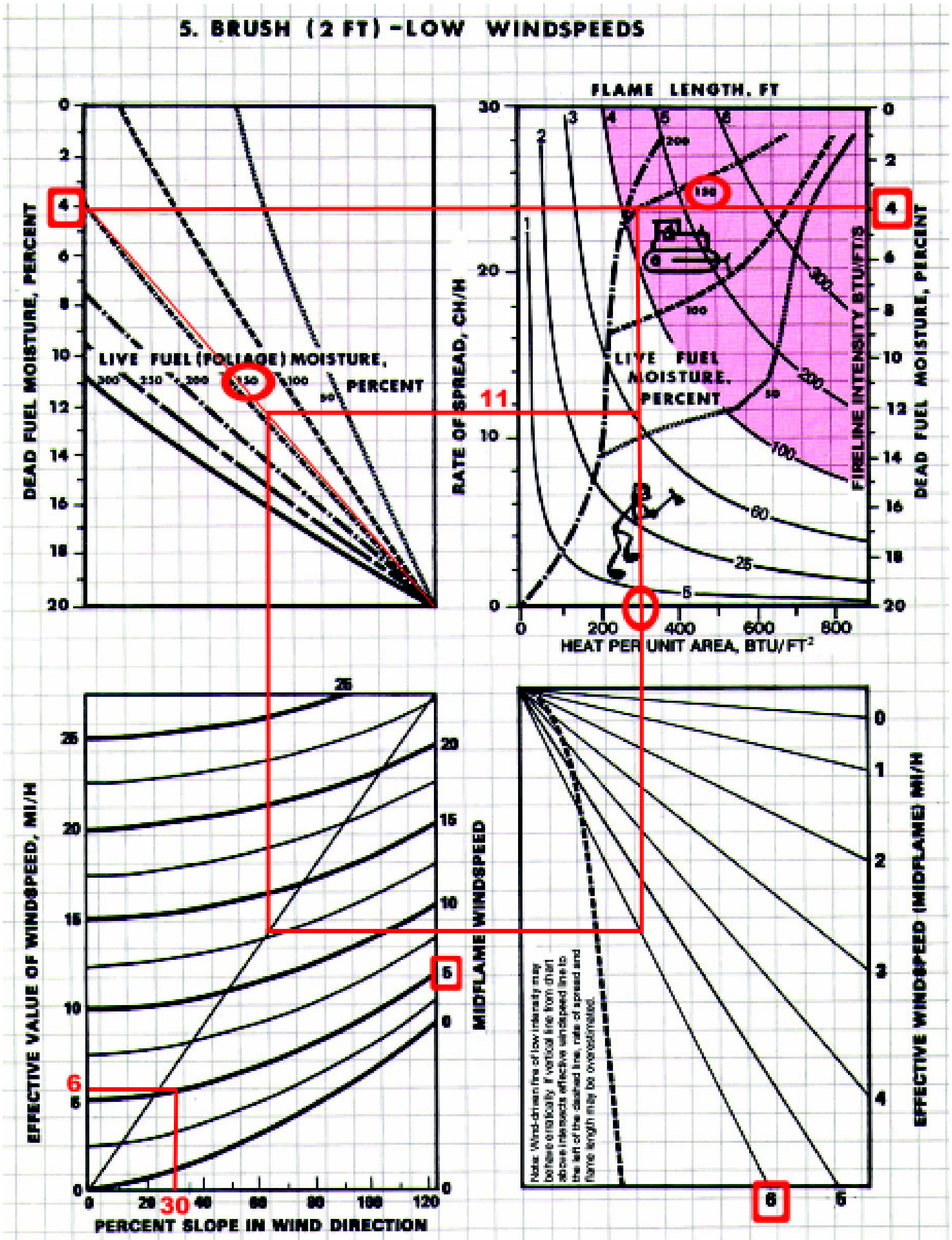

Figure 9.17—Completed nomogram.

Name of fire ________ Fire pred spec ________
Date ________ Time ________
Proj period date ________ Proj time from ________ to ________

Fire Behavior Worksheet

Input					
0	PP	Projection point	A		
1	Model #	Fuel model number (1-13)	5		
2	1H-FDFM	Fine dead fuel moisture, %	4		
3	LFM	Live fuel moisture, %	150		
4	MFWS	Midflame windspeed, mi/h	5		
5	SLP	slope, %	30		
6	EWS	Effective windspeed, mi/h	6		
Output					
1	ROS	Rate of spread, ch/h	11		
2	HA	Heat per unit area, Btu/ft^2	300		
3	FLI	Fireline intensity, Btu/ft/s	60		
4	FL	Flame length, ft	3		
5	SD	Spread distance, ch			
		Map spread distance, in			
6	PER	Perimeter, ch			
7	AC	Area, ac			
8	SPOT	Max spotting distance, mi			
		Map distance spot, in			
9	PIG	Probability of ignition, %			

Fine Dead Fuel Moisture/Probability of Ignition Worksheet

Input					
0	PP	Projection point			
1	D	Daytime calculation	D	D	D
2	DB	Dry bulb temperature, °F			
3	WB	Wet bulb temperature, °F			
4	DP	Dew point, °F			
5	RH	Relative humidity, %			
6	RFM	Reference fuel moisture, % (table 2)			
7	MO	Month			
8	SH	Unshaded (U) or shaded (S)	U/S	U/S	U/S
9	T	Time			
10	CH	Elevation change B = 1,000 ft to 2,000 ft below site L = ± 1,000 ft of site location A = 1,000 ft to 2,000 ft above site	B/L/A	B/L/A	B/L/A
11	ASP	Aspect, (N, S, E, W)			
12	SLP	Slope, %			
13	FMC	Fuel moisture correction, % (table 3, 4, or 5)			
Output					
1	1H-FDFM	Fine dead fuel moisture, % (line 6 + line 13)			
2	PIG	Probability of ignition, % (table 12)			

Slope Worksheet

Input					
0	PP	Projection point			
1	CON INT	Contour interval, ft			
2	SLC	Map scale			
3	CF	Conversion factor, ft/in			
4	# INTVLS	Number of contour intervals			
5	RISE	Rise in elevation			
6	MD	Map distance, in (between points)			
7	HZGD	Horizontal ground distance, ft			
Output					
1	SLP%	Slope, %			

Wind Adjustment Worksheet

Input					
0	PP	Projection point			
1	20' W	20-ft windspeed, mi/h			
2	MODEL #	Fuel model number (1-13)			
3	SHLTR	Wind sheltering 1 = unsheltered 2 = partially sheltered 3 = fully sheltered, open 4 = fully sheltered, closed			
4	WAF	Wind adjustment factor (table 7)			
Output					
1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)			

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Figure 9.18—Completed worksheet.

9.4 Using the Fire Behavior Nomogram Backwards for Prescribed Burns

Prescribed fire is the controlled application of fire to wildland fuels, in either their natural or modified state, under specified environmental conditions. These conditions allow the fire to be confined to a predetermined area. At the same time, these fires produce the intensity of heat, flame length, and rate of spread required to attain planned resource management objectives. Using nomograms backwards develops a range of effective windspeeds and fine fuel moistures, which will yield the desired resource management objectives.

Step 1. Using nomograms in reverse.

a. Locate the desired point on the flame length curve. Draw a line from this point, intersecting the S-curve and continuing down through all windspeed lines in the lower right quadrant.

b. Draw a horizontal line from the S-curve intersection in the upper right quadrant to determine the fine fuel moisture. Circle this fuel moisture value in the upper right and upper left quadrants.

c. In the upper right quadrant, draw a horizontal line into the left quadrant from the point intersecting the fine fuel moisture line.

d. Draw a vertical line down into the lower left quadrant, turning at the diagonal, and continuing with a horizontal line into the lower right quadrant.

e. Locate the intersecting point of the line in part d with the vertical line drawn in part a, and determine the effective windspeed.

Example 5—Prepare a prescription for a firing operation for tomorrow's shift. Handcrews are constructing indirect handline in advance of the fire. The concern is that the fire will burn through the area before the crews can complete this line. Determine a range of dead fuel moistures and effective windspeeds that will keep the fire's forward spread within a rate of 16 chains per hour, using fuel model 6.

What is the range of dead fuel moistures and effective windspeeds needed to safely complete the handline?

What are the flame lengths?

Note that the rate of spread is given, rather than a flame length.

a. The 16 chain per hour rate of spread is located.

b. A horizontal line is drawn across the upper right quadrant. The intersection at the right axis indicates the fine dead fuel moisture. See figure 9.19.

c. The fine dead fuel moisture is circled in both the upper right and upper left quadrants. For this example, 18 percent is circled.

e. A horizontal line is drawn from the intersection of the S-curve in the upper right quadrant to the line of 18 percent fine dead fuel moisture in the upper left quadrant.

f. A vertical line is drawn from the intersection with the S-curve in the upper right quadrant, down through all the effective windspeeds in the lower right quadrant.

g. A vertical line is drawn into the lower left quadrant from the fuel moisture intersection in the upper left quadrant, until the diagonal is reached. At this point, a horizontal line is drawn into the lower right quadrant.

h. The intersection point with the vertical line is located in the lower right quadrant. The effective windspeed is determined as 5 miles per hour (approximation).

i. The flame length can be approximated from the upper right quadrant as 4 feet.

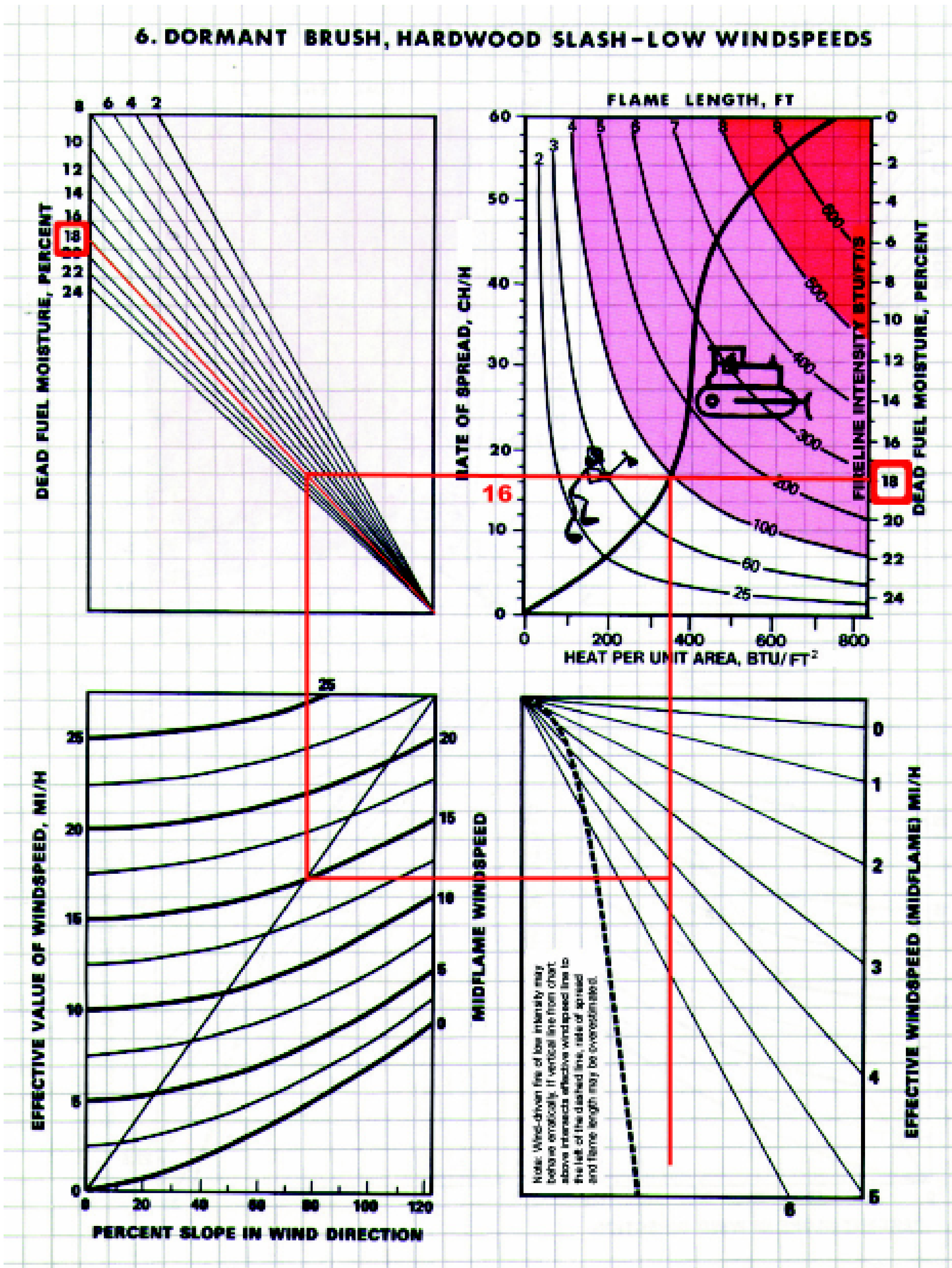


Figure 9.19—Completed nomogram.

9.5 Flame Length The flame length is the distance between the flame tip and the midpoint of the flame depth at the base of the flame. Flame length is an observable, measurable indicator of fireline intensity. Spread distance, in chains, is the distance of forward fire spread for a specified amount of time.

spread distance (SD) =
rate of spread (ROS) x projection time (PT)
SD = ROS x PT

Example 6—The rate of a fire spread is 4 chains per hour. What will the spread distance be in 3 hours?

SD = ROS x PT = 4 ch/h x 3h = 12 ch

9.6 Map Spread Map spread, in inches, is the size of a fire as scaled to a map.

Example 7—Using example 6, find the map distance for the fire spread. Plot the distance using a tenths ruler for accuracy. The map scale is 1:24,000.

Step 1. Convert the map scale to feet per inch.

$$24{,}000\ \cancel{\text{inches}} \times \frac{1\ \text{foot}}{12\ \cancel{\text{inches}}} = 2{,}000\ \text{feet}$$

Step 2. Convert the spread distance to feet.

$$12\ \cancel{\text{chains}} \times \frac{66\ \text{feet}}{1\ \cancel{\text{chain}}} = 792\ \text{feet}$$

Step 3. Convert the ground spread distance to a map spread distance.

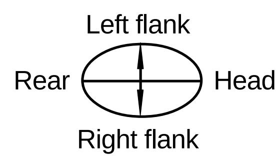
$$792\ \cancel{\text{feet}} \times \frac{1\ \text{inch}}{2{,}000\ \cancel{\text{feet}}} = 0.396\ \text{inch} = 0.4\ \text{inch}$$

Step 4. Using a ruler, measure the distance from the point of origin to the distance of the fire spread.

Map spread distance is 0.4 inch.

9.7 Head, Flank, and Rear Fire Terms Each side of the fire is described in terms of head, flank, and rear. The head is the fastest spreading part of a fire's perimeter. This is usually the side toward which the wind is blowing (leeward) or the upslope side. The head of the fire is of primary interest. The right and left flanks describe the sides of the fire. Flanks are perpendicular to the head of the fire. The rear of the fire is the side of the fire opposite the head.

Example 8—Plot the perimeter and label the head, rear, and flanks of the fire in example 7. Assume the wind is blowing from left to right across the page. ➤➤➤➤➤➤



9.8 Flame Height Flame height is the average height of flames, as measured on a vertical axis.

Example 9—The torching tree diameter at breast height (dbh) is 25 inches in a forest of ponderosa pine. What is the flame height?

Step 1. Use spotting nomogram 1, figure 9.21. Find 25 inches diameter at breast height on the horizontal axis.

Step 2. Go up to the ponderosa pine line.

Step 3. Move to the left to find the flame height on the vertical axis.

The flame height is 57 feet.

9.9 Maximum Spotting Distance Maximum spotting distance, in miles, is the maximum transported distance of a firebrand. It can be predicted for various firebrand sources using such factors as the probability of production of firebrands, windspeed, fire intensity, and the number of firebrands. The maximum spotting distance will be determined by using spotting nomograms. The maximum spotting distance can also be determined by using a computer program called Behave or by the HP-71B.

Five input values are needed to find the maximum spotting distance. They are:

1. Torching tree height, ft
2. Torching tree species
3. Torching tree diameter at breast height (dbh), in
4. Average tree cover height, ft
5. Windspeed at 20-ft height, mi/h.

Calculations are completed in stages, using spotting nomograms 1 through 4.

Example 10a—Find the maximum spotting distance.
dbh = 30 in
Torching tree species = douglas fir
Torching tree height = 100 ft
Average tree cover height = 90 ft
Windspeed at 20-ft height = 20 mi/h

The following nomograms and worksheet were used to solve example 10a.
Figure 9.20—Spotting worksheet
Figure 9.21—Spotting nomogram 1
Figure 9.22—Spotting nomogram 2
Figure 9.23—Spotting nomogram 3
Figure 9.24—Spotting nomogram 4

Step 1. Enter the given values into the spotting worksheet.

Step 2. Use spotting nomogram 1. Find 30 inches diameter at breast height on the horizontal axis.

Step 3. Go up to the douglas fir line.

Step 4. Go to the left to find flame height (75 feet) on the vertical axis. Record the value on line 2B of the spotting worksheet.

Step 5. On spotting nomogram 2 find the 30 inch diameter at breast height on the horizontal axis.

Step 6. Go up to the douglas fir line.

Step 7. Go to the left to find flame duration on the vertical axis (4.2). Record the value on line 3 of the spotting worksheet.

Step 8. Find the ratio of tree height to flame height by dividing the value of the tree height by the value of the flame height.
100 ft/75 ft = 1.33
Record on line 2 of the worksheet.

Step 9. On spotting nomogram 3, find the flame duration of 4.2 on the horizontal axis.

Step 10. Since the ratio of tree height to flame height is 1.3, move up to the “1.0 to the 1.5” line.

Step 11. Move to the left to find the ratio of lofted firebrand height to flame height on the vertical axis (6.8). *Record on line 2C of the worksheet.*

Step 12. Find the height above the tree to which a firebrand will be lofted by multiplying the flame height by the ratio of lofted firebrand height to flame height.
75 ft x 6.8 = 510 ft
Record on line 2E.

Step 13. Divide the torching tree height by 2.
100 ft/2 = 50 ft
Record on line 1D of the worksheet.

Step 14. Add this value to the lofted firebrand height.
50 ft + 510 ft = 560 ft
This is the expected height above the ground that a firebrand will be lofted. *Record on line 4 of the worksheet.*

Step 15. If the forest is open, divide average tree cover height by 2 and enter effective height. If not, enter the average of the cover height. For this example, assume that the forest has a closed canopy.
Enter 90 for effective tree cover height.

Step 16. Multiply the windspeed of 20 miles per hour by 2/3. 20 x 2/3 = 13
Record this value on line 5F on the worksheet.

Step 17. On spotting nomogram 4, find the firebrand height of 560 feet on the right portion of the horizontal axis—interpolate (insert) between 500 and 600.

Step 18. Go up to the effective tree cover height of 90 feet. Interpolate between 50 and 100.

Step 19. Go to the left to the treetop windspeed of 13 miles per hour. Interpolate between 10 and 15.

Step 20. Go down and read the maximum spotting distance on the left portion of the horizontal axis, (0.35mi le).
Record this value under output on the worksheet.

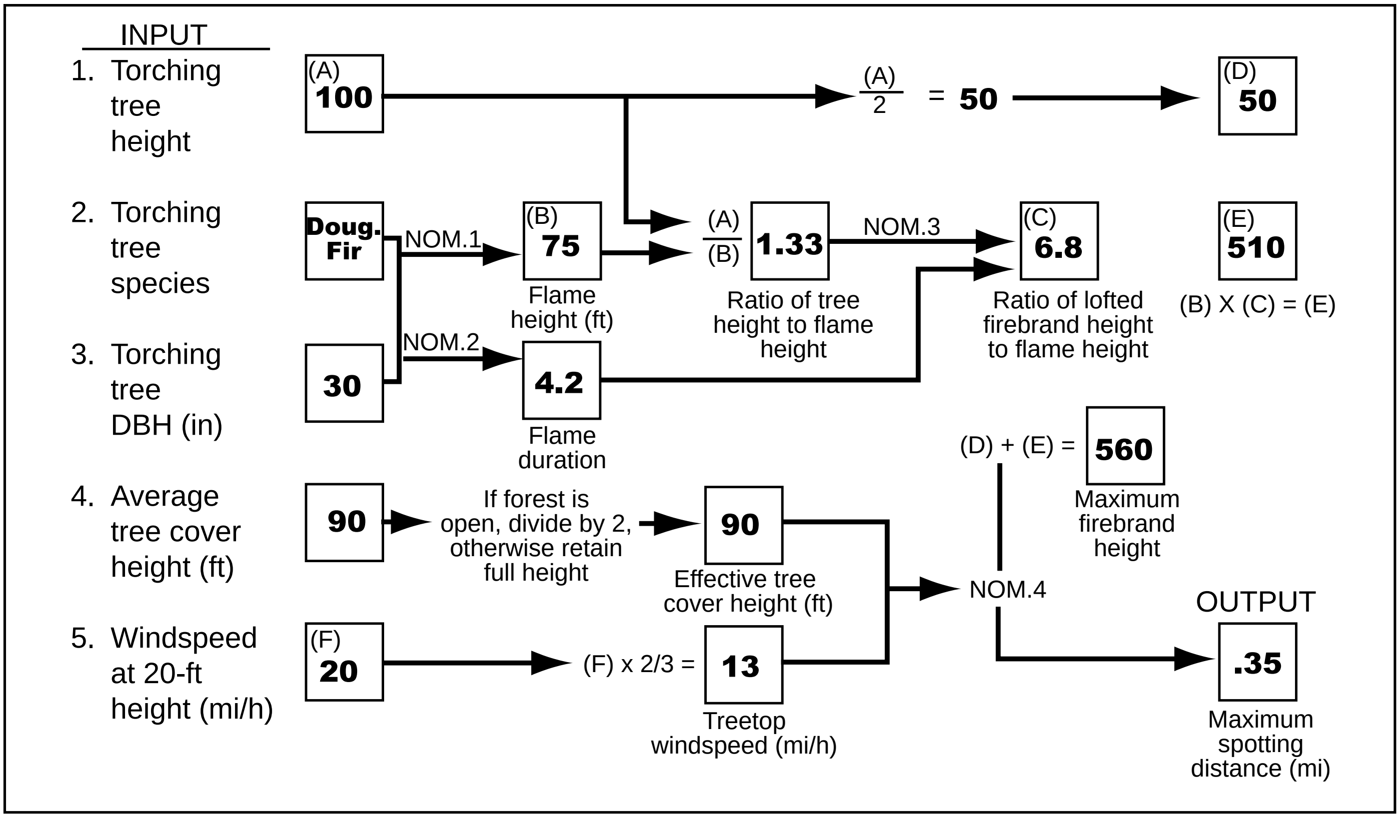


Figure 9.20—Spotting worksheet.

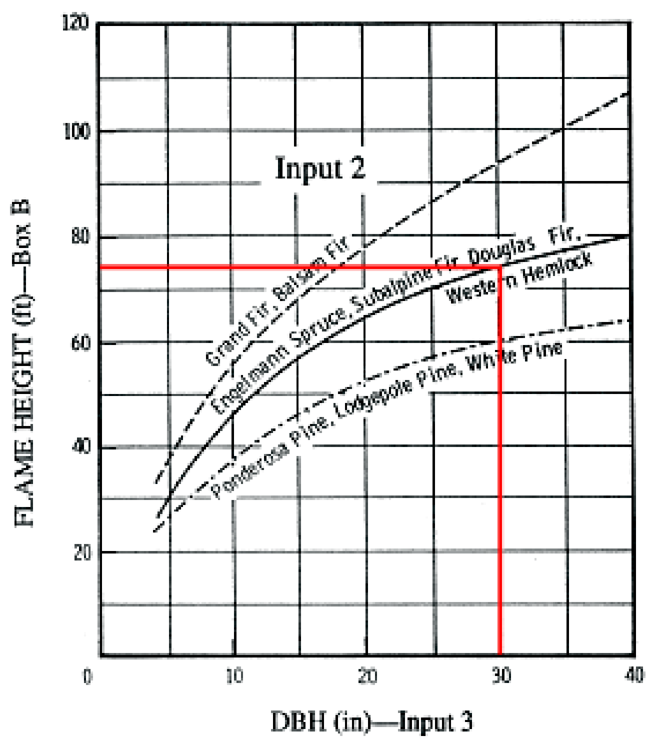


Figure 9.21—Spotting nomogram 1.

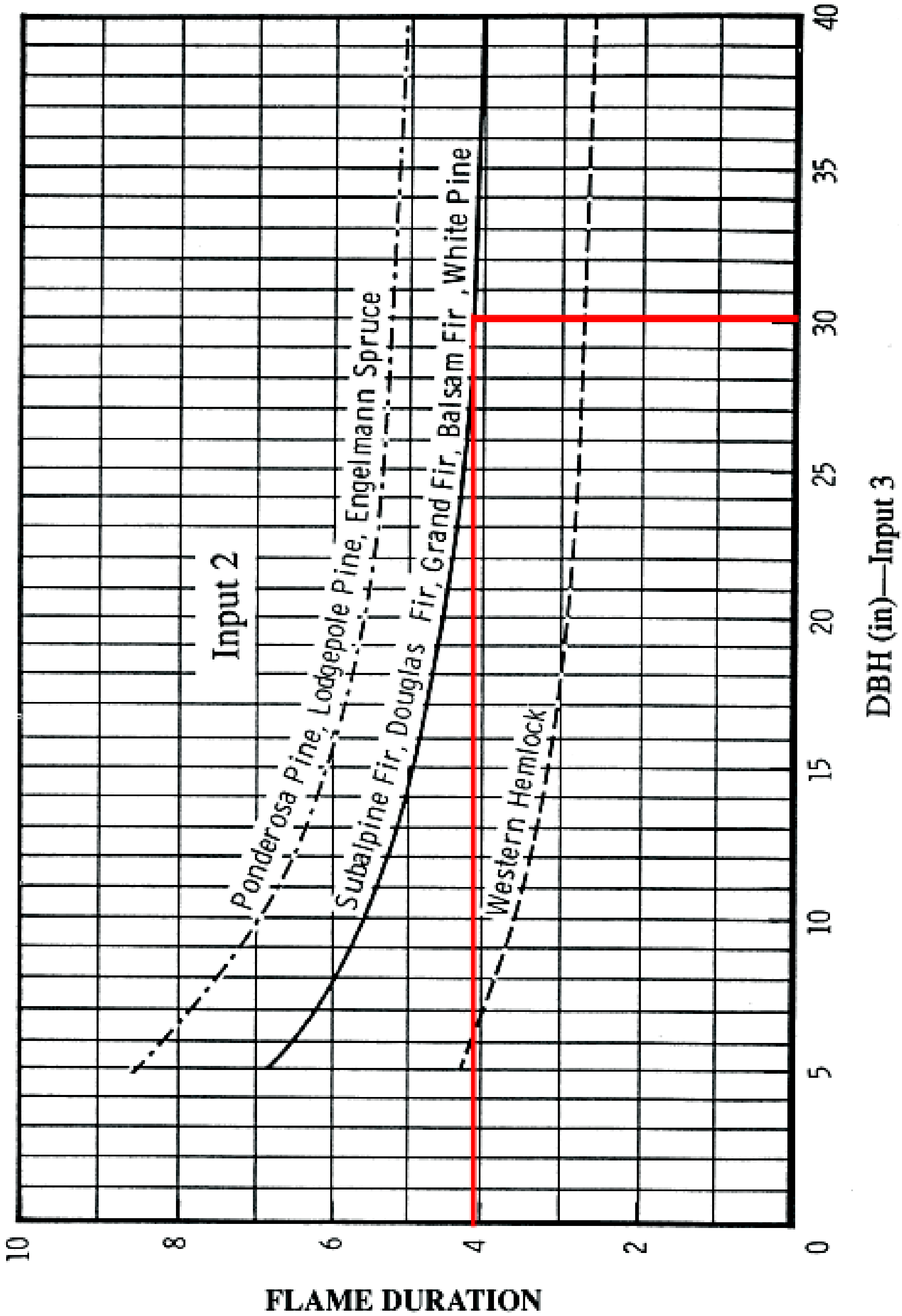


Figure 9.22—Spotting nomogram 2.

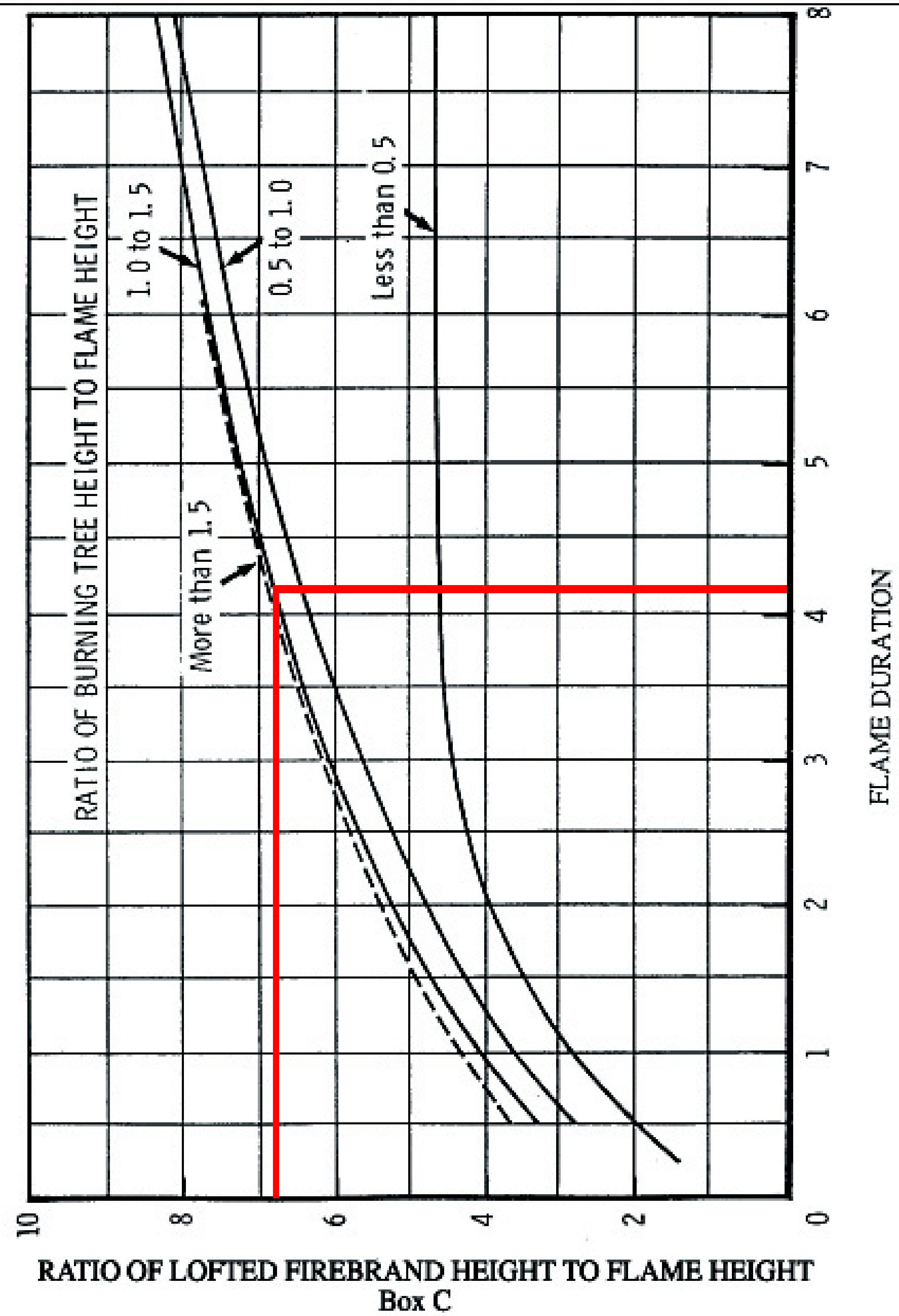


Figure 9.23—Spotting nomogram 3.

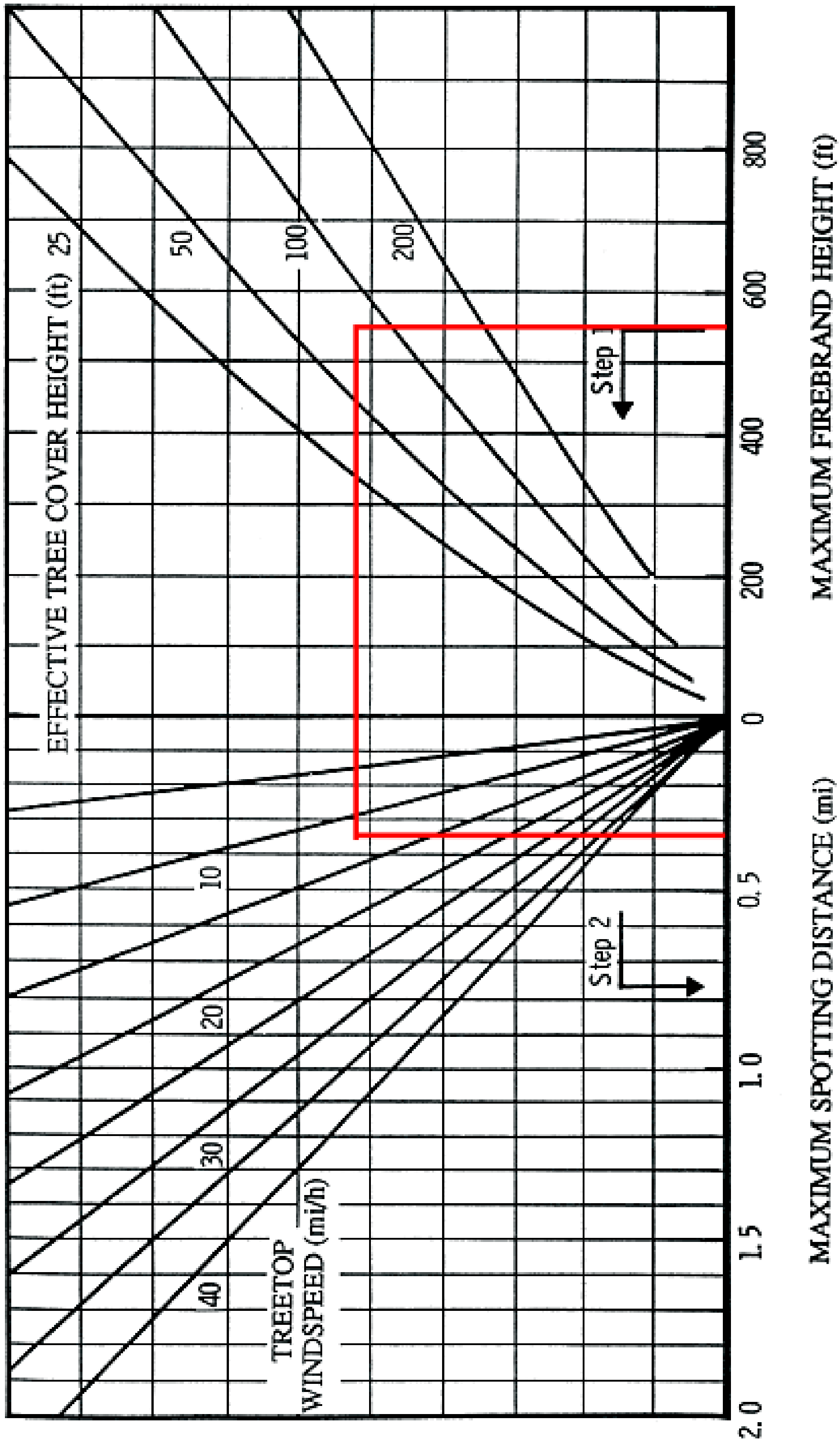


Figure 9.24—Spotting nomogram 4.

Example 10b—Based on the information from example 9a, fill out the map-spot worksheet, figure 9.25. Use a map scale of 1:24,000 to obtain the conversion factor on line 4, inch per inch map scale must be converted to feet per inch. Set up a cancellation table so all units cancel, except feet per inch.

$$\frac{24{,}000\ \cancel{\text{in}}}{\text{in}} \left| \frac{1\ \text{ft}}{12\ \cancel{\text{in}}} \right. = 2{,}000\ \text{ft/in}$$

$$\frac{.35\ \cancel{\text{mi}}}{} \left| \frac{5{,}280\ \text{ft}}{\cancel{\text{mi}}} \right. = 1{,}848\ \text{ft}$$

$$\frac{1{,}848\ \cancel{\text{ft}}}{} \left| \frac{\text{in}}{2{,}000\ \cancel{\text{ft}}} \right. = .9\ \text{in}$$

Line	Input				
0	PP	Projection point	**spot**	____	____
1	SPOTMI	Spotting distance, mi	**0.35**	____	____
2	SPOTFT	Spotting distance, ft (line 1 x 5,280 ft)	**1,848**	____	____
3	SCL	Map scale	**1:24,000**	____	____
4	CF	Conversion factor, ft/in	**2,000**	____	____
	Output				
1	SPOT	Map distance spot, in (line 2 divided by line 4)	**0.9**	____	____

Figure 9.25—Map-spot worksheet.

9.10 Rate of Spread (ROS)

The rate of spread is in chains per hour (ch/h) and is defined as the speed with which the fire is moving away from the site of origin. Wind, moisture, and slope drive the fire. The flaming zone, or fire head, moves away from the origin quickly with great intensity.

9.11 Fire Characteristic and Interpretation Charts

Several charts are available for determining rate of spread, flame length, and heat per unit area. The fire characteristics charts for both light and heavy fuels are a graphic method of indicating ROS, FL, and heat per unit area, in British thermal units per square foot. See figures 9.26 and 9.27. A table of fire suppression interpretations provides guidelines for the fire characteristics charts. See figure 9.28.

The fire characteristics charts are used to determine the best mode of attack for a fire. The main criterion used is flame length. For each category and range of flame length, a sketch on the chart indicates the best mode of attack.

Example 11—A fire burning in light fuel has a ROS of 20 chains per hour and a heat per unit area of 800 British thermal units per square foot. What is the flame length? Use the fire characteristics chart, figure 9.26, to solve example 10.

Step 1. Go to 800 British thermal units per square foot on the horizontal axis of the fire characteristics chart. Draw a vertical line up from this point.

Step 2. At the point of 20 chains per hour on the vertical axis, draw a horizontal line to the right. Intersect the horizontal and vertical lines.

Step 3. Follow this point to the right to find the flame length, interpolate between 8 feet and 4 feet, which is 6 feet.

The flame length is 6 feet.

When the combined effects of wind and slope increase the ROS, the flame length is increased.

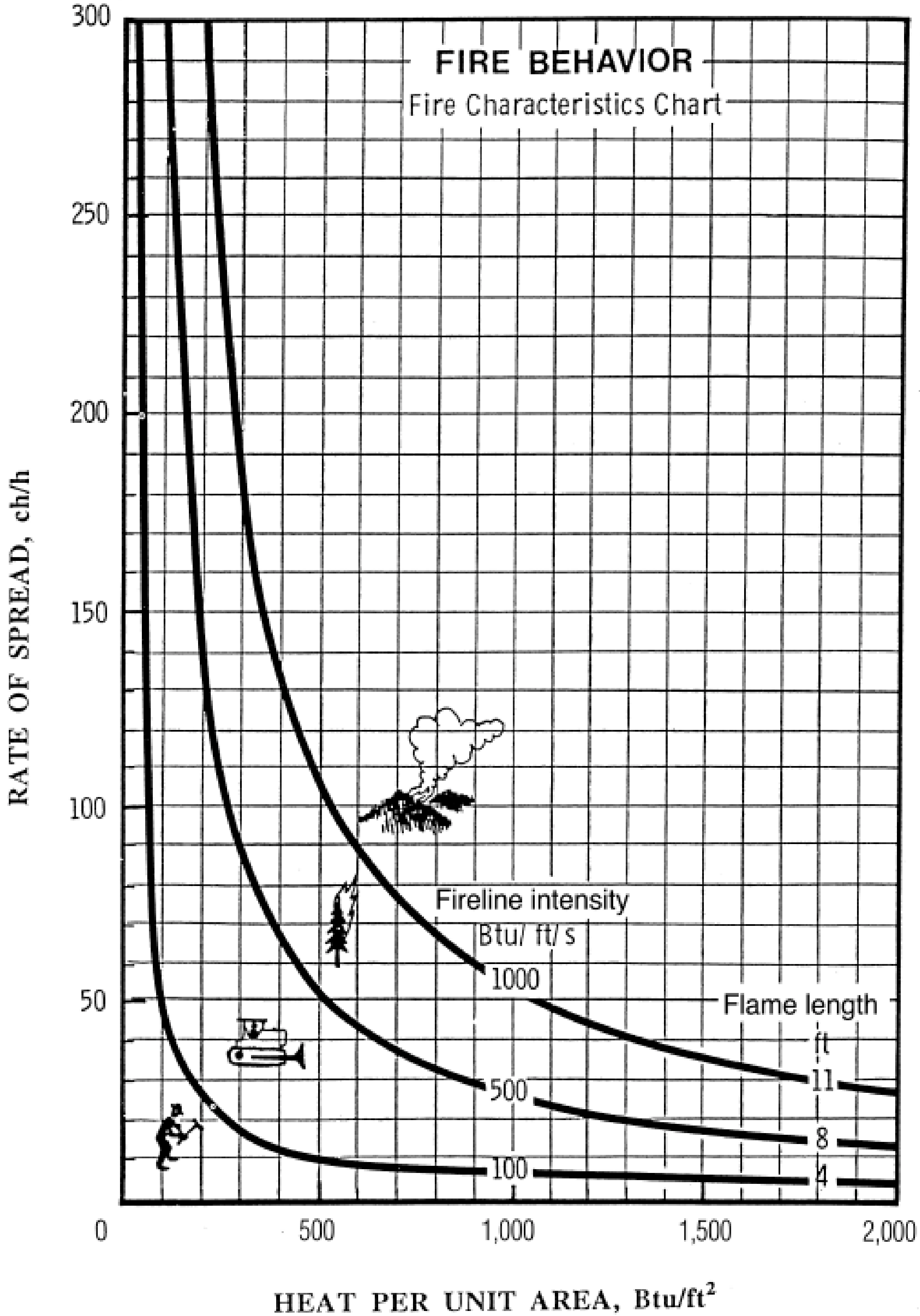


Figure 9.26—Fire characteristics chart, light fuels.

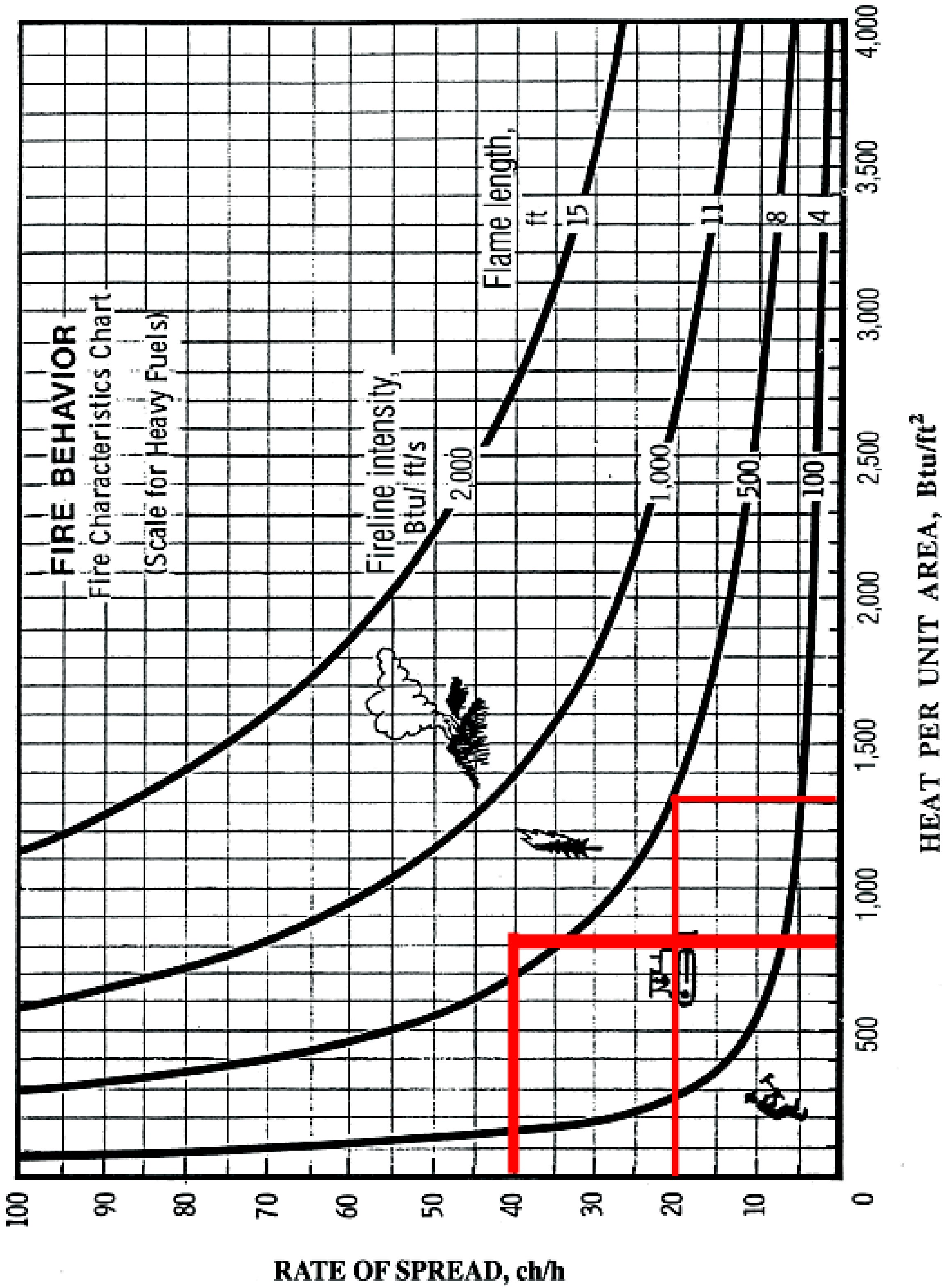


Figure 9.27—Fire characteristics chart, heavy fuels.

Flame Length (ft)	Fireline Intensity (Btu/ft/s)	Interpretations
0-4	0-100	Fires can generally be attacked at the head or flanks by persons using handtools.
4-8	100-500	Handline should hold the fire. Fires are too intense for direct attack on the head by persons using handtools. Handline cannot be relied on to hold fire. Equipment such as dozers, engines, and retardant aircraft can be effective.
8-11	500-1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the head of the fire will probably be ineffective.
11+	1,000+	Crowning, spotting, and major runs are common. Control efforts at the head of the fire are ineffective.
CAUTION: These are not guides to personal safety. Fires can be dangerous at any level of intensity. Wilson (1977) has shown that most fatalities occur in light fuels on small fires or isolated sections of large fires.		

Figure 9.28—Fire suppression interpretations.

Example 12—In example 11, assume that the fuel characteristics remain the same and the ROS increases to 40 chains per hour as a result of the slope and wind. What is the resulting flame length?

Step 1. The heat per unit area is the same. Go to 40 chains per hour on the vertical axis.

Step 2. Draw a horizontal line to the right from this point until it intersects the vertical line.

Step 3. Follow this point to the right to find the flame length, interpolate between 8 feet and 11 feet, which is 9 feet.

The flame length is 9 feet.

The fire characteristics chart can be used to find the heat per unit area if the ROS and flame length are known.

Example 13—A fire burning in heavy fuel has a flame length of 8 feet and a ROS of 20 chains per hour. What is the heat per unit area? Use figure 9.27.

Step 1. Go to 20 chains per hour on the vertical axis.

Step 2. Go to the right until the 8 foot flame length line is reached.

Step 3. Go down at this point and read the value on the horizontal axis as 1,300 British thermal units per square foot.

The heat per unit area is 1,300 Btu/ft^2.

9.12 Slope Effect on ROS When fire moves upslope, the fuel ahead of the flame front is closer to the flame than if the slope were flatter. This is called preheating of fuels. The effects of slope become greater as the slope increases. **The first tripling of slope roughly increases the rate of spread by 2. The second tripling of slope increases the rate of spread by factors of 4 to 6.**

Example 14—An area of shrubs is burning at a ROS of 4 chains per hour at an 8 percent slope. The slope increases to 24 percent. What will the ROS be? The slope went from 8 to 24 percent. This is an increase of three times the original slope. As stated above, the rate of spread will then double.

4 ch/h x 2 = 8 ch/h

9.13 Probability and Number of Ignitions Probability is the chance that an event will happen and is in terms of percent, or per 100. For example, if there is a 40 percent chance of a spot fire starting, that means that out of 100 glowing embers that fly off, 40 embers will start spot fires, 60 will not. Percent is calculated by changing the percent into a fraction by dividing by 100, then multiplying by the total number of possible situations.

Example 15—The probability of ignition is 80 percent. How many ignitions will occur if 90 glowing firebrands land on receptive fuel?

Step 1. Change 80 percent to a fraction, then into a decimal. $\frac{80}{100} = 0.8$

Step 2. Multiply by the total number of situations, in this case glowing firebrands. 0.8 x 90 = 72

Expect 72 ignitions out of 90 glowing firebrands.

9.14 Probability of Ignition Probability of ignition is a rating of the probability that a glowing firebrand will cause a fire, providing it lands on receptive fuels and the fuels are dry enough to support ignition. Probability of ignition is determined by fuel shading, fine dead fuel moisture, and the dry bulb temperature. These inputs are determined when the fine dead fuel moistures are calculated. Probability of ignition can be determined by using the Probability of Ignition Table, figure 9.29. Fuel shading can be caused by clouds, canopy cover, or both. This table is divided into two portions, fuels that have either less than or more than 50 percent cloud or canopy cover.

Example 16—A fire is burning under a dense canopy of pole-sized trees. The dry bulb temperature is 84 °F. The fine dead fuel moisture is 5 percent. What is the probability of ignition?

Step 1. In the lower portion of the probability of ignition table, >50 percent, find the dry bulb temperature range that would include 84 °F. 80-89; draw a line across.

Step 2. Find the fine dead fuel moisture of 5 on the top horizontal row. Go down until the 80-89 line is intersected. Read 60 percent off the chart.

The probability of ignition is 60 percent.

Shading (Percent)	Dry Bulb Temp. (°F)	Fine Dead Fuel Moisture (Percent)															
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Unshaded <50%	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
Shaded >50%	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30-39	80	80	60	50	50	40	30	30	20	20	20	10	10	10	10	10

Figure 9.29—Probability of ignition.

EXERCISES

Problem 1. What is the midflame windspeed in a partially sheltered area of fuel model 13 if the 20-foot windspeed is given as 16 miles per hour?

Problem 2. A fire is burning in unsheltered fuel. Joy determines that the fuel is a model 4 fuel and is told that the 20-foot winds are blowing at 11 miles per hour. What is the midflame windspeed?

Problem 3. A fire is spreading up a 35 percent slope in tall grass of fuel model 3. The midflame windspeed is 4 miles per hour and is blowing uphill. The fine dead fuel moisture in the grass is 4 percent. Determine the rate of spread, flame length, fireline intensity, and heat per unit area. Use the following nomograms and worksheet in appendix E to solve the problem.

Nomogram—3. Tall grass (2.5 ft)—Low windspeed Nomogram worksheet

Problem 4. A fire is spreading uphill in timber litter with enough green fuel in the understory to affect fire behavior. The timber is considered a fuel model 10. The midflame windspeed is 5 miles per hour, the fine dead fuel moisture is 3 percent, and the slope is 20 percent. The live fuel moisture can be approximated at 100 percent.

Determine the rate of spread, heat per unit area, flame length, and fireline intensity for this fire. Use the following nomograms and worksheet found in appendix E to solve the problem.

Nomogram –10. Timber (Litter & Understory)—Low windspeed Nomogram worksheet

Problem 5. The operations unit has asked Peg to prepare a "prescription" for an operational plan for tomorrow's day shift. Handcrews are constructing indirect handline in advance of the fire. The concern is that the fire will burn through the area before the crews can complete the line.

The operations unit needs a range of dead fuel moistures and effective windspeeds that will keep the fire's forward spread within 18 chains per hour. This will allow the handcrews to safely complete the indirect line. She determines that the fire is burning in a fuel model 9.

What is the range of dead fuel moistures and effective windspeeds needed to safely complete the handline?

What is the flame length?

Use Nomogram – 9. Hardwood litter. See appendix E.

Problem 6. The rate of spread of the fire is 6 chains per hour. What will the spread distance be in 4 hours?

Problem 7. What is the map distance of the ground spread distance from problem 6 on a map with a scale of 1:62,500?

Problem 8. There is a fire in a Grand Fir forest. The diameter at breast height is 33 inches. What is the flame height?

Problem 9. Input the following values into the spotting worksheet.
Torching tree DBH = 15 in
Torching tree height = 120 ft
Average tree cover height = 100 ft
Windspeed at 20-ft height = 30mi/h
Torching tree species—lodgepole pine

Problem 10. Using the data above, find the flame height and flame duration.

Problem 11. Using the data above, find the ratio of lofted firebrand height to flame height.

Problem 12. For a closed canopy forest with the above data, find the maximum spotting distance.

Problem 13. A fire has a ROS of 30 chains per hour and a heat per unit area of 900 British thermal units per square foot. What is the flame length?

Problem 14. If the wind and slope increase the ROS to 60 chains per hour, but the fuel characteristics remain the same, what will the resulting flame length be?

Problem 15. A fire is spreading at a rate of 40 chains per hour. The flame length is 8 feet. What is the heat per unit area?

Problem 16. In the fire in problem 15, the ROS increased to 70 chains per hour. The fuel characteristics are the same. What is the flame length?

Problem 17. There is a fire in a field of tall grass. The slope is 8 percent and the ROS is 5 chains per hour. If the slope increases to 24 percent, what will the ROS be? If it increases to 72 percent, what will the ROS be?

Problem 18. The probability of ignition is 60 percent. How many ignitions will there be if 75 glowing firebrands land on receptive fuel?

Problem 19. A fire is burning in brush under 30 percent sky cover. The dry bulb temperature is 94 °F. The fine dead fuel moisture is 4 percent. What is the probability of ignition?

CHAPTER PROBLEM

A fire is burning in the Los Padres National Forest in the middle of July. Readings are taken at a site 500 feet above the fire. The weather conditions are as follows:

20-foot windspeed of 15 mi/h	
Fuel model 4	dbh = 15 in
Dry bulb temperature of 85 °F	% slope is 40 percent
Wet bulb temperature of 52 °F	West aspect
Live fuel moisture of 150 percent	

Find the fine dead fuel moisture, effective windspeed (EWS), flame length (FL), rate of spread (ROS), fireline intensity, and midflame windspeed (MFWS).

Can crew B take direct attack of the fire at the head?

The fire is under 60 percent canopy and sky cover. What is the probability of ignition?

The time is 1400 hours. What will the forward spread distance be at 2100 hours?

Plot the forward spread distance on a map with a scale of 1:7,920. What is the probability of ignition?

The material in chapter 10 describes accuracy, precision, average, mean, range, and standard deviation of measured values. This chapter also includes planning, production rate, drought index, and the Haines index.

10.1 Accuracy Accuracy is how close the measured value is to the true value. The accuracy of a measurement refers to the number of significant digits. See appendix B.7.

Example 1—Gabe is measuring a piece of trim for the wall. He measures it three times. The values he gets are 2.1 feet, 2.2 feet, and 2.2 feet. The actual value is 2.15 feet. How accurate are Gabe's three measured values?

Step 1. The accuracy of the measurements is the difference between the true value and the measured value.
2.15 – 2.1 = 0.05

Step 2. Repeat the same process for the other measurements.
2.15 – 2.2 = – 0.05

The accuracy of the measurement is ±0.05 feet.

10.2 Precision Precision is how close the repeated measurements are to each other. Precision of a measurement refers to the smallest unit with which a measurement is made.

Example 2—Find the precision of the measurements Gabe took in example 1.

Step 1. Subtract the measurements from each other.
2.1 – 2.2 = –0.1

The precision of the measurement is ±0.1 feet.

10.3 Average The average, or the mean, is the sum of all the numbers divided by the number of terms.

Example 3—The line production rates for the members of a hand crew were as follows: 8.0 chains per hour, 7.0 chains per hour, 6.0 chains per hour, 7.5 chains per hour, and 7.0 chains per hour. What is the average number of fireline chains constructed per hour?

Step 1. Add all the numbers.
8.0 + 7.0 + 6.0 + 7.5 + 7.0 = 35.5 chains

Step 2. Count the number of terms.
5 terms

Step 3. Divide the numbers added in step 1 by the number of terms.
35.5 / 5 = 7.1 chains

The average is 7.1 chains of fireline constructed per hour.

10.4 Range/Variance Range is the difference between the smallest number and the largest number.

Example 4—Find the range in example 3.

Step 1. Arrange the numbers in ascending order (from the smallest to the largest).
6.0, 7.0, 7.0, 7.5, 8.0 (chains)

Step 2. Subtract the largest number from the smallest number.
8.0 – 6.0 = 2.0 chains

The range is from 6.0 chains to 8.0 chains or 2.0 chains.

10.5 Deviation/Variability Deviation is the difference between the average and any of the terms.

Example 5—Find the deviation of each term in example 3.

Step 1. Find the average (see example 3).
7.1 chains

Step 2. Subtract each term from the average.
7.1 – 6.0 = 1.1 chains
7.1 – 7.0 = 0.1 chains
7.1 – 7.0 = 0.1 chains
7.1 – 7.5 = – 0.4 chains
7.1 – 8.0 = – 0.9 chains

10.6 Standard Deviation Standard deviation, or variance, is a measure of the closeness of each term to the average (mean). If the terms are bunched closely around the mean, then the mean is an accurate description of distribution. To calculate: each deviation is squared, added together, divided by the number of terms minus one, and the square root taken.

Example 6—Find the standard deviation in example 3.

Step 1. Find the average (see example 3).
7.1 chains

Step 2. Find the deviation of each term (see example 5).
7.1 – 6.0 = 1.1 chains
7.1 – 7.0 = 0.1 chains
7.1 – 7.0 = 0.1 chains
7.1 – 7.5 = – 0.4 chains
7.1 – 8.0 = – 0.9 chains

Step 3. Square each deviation above.
1.1 x 1.1 = 1.21
0.1 x 0.1 = 0.01
0.1 x 0.1 = 0.01
0.4 x 0.4 = 0.16
0.9 x 0.9 = 0.81

Step 4. Add the squared deviations together.
1.21 + 0.01 + 0.01 + 0.16 + 0.81 = 2.20

Step 5. Divide the sum of the squared deviations by the number of terms minus 1.
2.2/4 = 0.55

Step 6. Find the square root
$\sqrt{0.55} = 0.74$

The standard deviation is 0.7 chains.

Example 7—Joe was determining the slope with a clinometer. The following numbers were recorded: 30, 27, 29, 30, 31, 30, 32 degrees. What are the average, range, and standard deviations of these values?

The Average

Step 1. Add all the numbers.
30 + 27 + 29 + 30 + 31 + 30 + 32 = 209 (degrees)

Step 2. Count the number of entrants. 7

Step 3. Divide the sum of all the numbers by the number of entrants.

$$\text{average} = \frac{30 + 27 + 29 + 30 + 31 + 30 + 32}{7} = \frac{209}{7} =$$
29.8 or 30 degrees

The average is 30 degrees.

The Range

Step 1. Find the smallest number, 27.

Step 2. Find the largest number, 32.

Step 3. Subtract the smallest number from the largest number.
range = 32 – 27 = 5

The range is from 27 degrees to 32 degrees or 5 degrees.

The Standard Deviation

Step 1. Find the difference between the average and each term.
30 – 30 = 0; 27 – 30 = –3; 29 – 30 = –1; 30 – 30 = 0;
31 – 30 = 1; 30 – 30 = 0; 32 – 30 = 2

Step 2. Square each of the deviations: 0 x 0 = 0;
(–3)(–3) = 9; (–1)(–1) = 1; 0 x 0 = 0; 1 x 1 = 1;
0 x 0 = 0; 2 x 2 = 4

Step 3. Add all the squares.
0 + 9 + 1 + 0 + 1 + 4 + 0 = 15

Step 4. Divide by the number of terms minus 1.
15/6 = 2.5

Step 5. Find the square root.
standard deviation = $\sqrt{2.5}$ = 1.58 = 1.6

The standard deviation is 1.6.

10.7 Planning Hand crews primarily are used to construct fireline. They also can assist on hose lays, firing operations, protecting structures, mopping up, cleaning up, and other logistical support functions. It is important to match the task to crew capabilities. Use the best, most experienced crews for the toughest jobs and the hottest fireline. Crew effectiveness is controlled by these factors:

- Leadership—Good, competent leadership is key to the success of the crew.
- Training, Physical Fitness, and Experience—A crew that is well trained, in top physical condition, with several fires under the belt, will be very effective. A crew that is greatly "trained" and "conditioned" on the fireline, greatly reduces the amount of line cut.
- Crew-Member Turnover—Frequent changes in crew membership will erode the team aspects.
- Morale—If a crew is "down," its productivity will be down.
- Fatigue—Exhausted crew members will be ineffective, with a much higher potential for accidents.
- Fuel, Weather, Topography, and Time of Day—In thick fuels and steep terrain, at the hottest time of the day, production will suffer. Working at night also will reduce production rates.
- Fire Behavior—If the level of fire behavior is high to extreme, deploying hand crews will be very dangerous.

10.8 Production Rates When planning an attack on a fire, the length and width of the line must be estimated, along with the capabilities of the hand crew(s), to determine how many crews will be needed. Generally, a 15-person crew should be able to construct a 3-foot fireline around a 1-acre grass fire in 1 hour. Below are some average ideal rates for hand crew production rates in various vegetation.

Hand Crew Production Rates

	Grass	Medium Brush	Heavy Brush	Very Heavy Brush
Line width	3 ft	6 ft	9 ft	12 ft
Length of line per crew member	60 ft	30 ft	20 ft	15 ft
Length of line per hour for a 15-person crew	900 ft	450 ft	300 ft	225 ft

Example 8—Patricia spots a fire. She determines that the fire has a perimeter of 1,800 feet. How many hand crews should she assign to construct a 3-foot line around the fire in 1 hour?

Step 1. Look under the column for grass vegetation of the hand crew production rates chart above. Go down.

Step 2. Look for the row that tells how much line a crew can cut per hour. Go across. Where the two lines intersect is the number of lines per hour an average crew can cut in those conditions.
900 feet

Step 3. Use this information to calculate the number of hours it will take one crew to construct 1,800 feet of line.

$$\frac{1{,}800\ \cancel{\text{feet}}}{} \times \frac{1\ \text{hour}}{900\ \cancel{\text{feet}}} = 2\ \text{hours for one 15-person crew}$$

Step 4. Determine how many crews it will take to construct the line in 1 hour.

$$\frac{2\ \cancel{\text{hours}}}{} \times \frac{1\ \text{crew}}{1\ \cancel{\text{hour}}} = 2\ \text{crews of 15 people}$$

Patricia will assign two crews of 15 people each.

When arriving at a fire scene, assess the entire situation, to determine the best way to suppress the fire.

Example 9—Gabe has three crews with him. He stands on a high point to survey the fire and form a complete picture. The fire is in medium brush. He estimates the length of line needed to flank the fire as 1,350 feet. How long will it take his three crews to construct this line?

Step 1. Look in the hand crew production rates chart on the previous page, under the column for medium brush. Go down.

Step 2. Find the row that tells how much line a crew can cut per hour. Go across. Where the two lines intersect is the number of lines per hour an average crew can cut in those conditions.
450 feet

Step 3. Use this information to calculate the number of hours it will take one crew to construct 1,350 feet of line.

$$\left|\begin{array}{c|c} 1{,}350\ \cancel{\text{feet}} & 1\text{ hour} \\ \hline & 450\ \cancel{\text{feet}} \end{array}\right| = \text{3 hours for 1 crew}$$

There are three crews working on the line.

$$\left|\begin{array}{c|c} 3\ \cancel{\text{hours}} & 1\text{ crew} \\ \hline & 1\ \cancel{\text{hour}} \end{array}\right| = \text{3 crews}$$

It would take 1 hour for three crews to construct 1,350 feet of line.

10.9 Drought Index The drought index is the number representing net effect of moisture in the deep duff or upper soil layers. The drought index is tracked to give a measure of fire potential. There are several indexes. Two of them are the Keetch-Byram, which is updated daily, and the Palmer, which is updated weekly. These two index values can be obtained through the Internet. Factors in the index are maximum daily temperature, daily precipitation, antecedent (previous) precipitation, and annual precipitation.

The Keetch-Byram index ranges from 0 (no drought) to 800 (extreme drought). The Palmer index ranges from –4 (extreme drought) to +4 (extremely moist). A normal range would be from –1.9 to +1.9.

10.10 Haines Index The Haines index is a stability index specially designed for fire weather. It is determined by combining the stability and moisture content of the lower atmosphere into a single number that correlates very well with large fire growth.

Dry air affects fire behavior by lowering fuel moisture, which results in more fuel available for fire, and by increasing the probability of spotting. Instability of the atmosphere affects fire behavior by enhancing the vertical size of the smoke column, resulting in strong surface winds as air rushes into the fire to replace air evacuated by the smoke column. This is the mechanism by which fires create their own wind.

Haines Index	Potential for large fire growth
2 or 3	very low
4	low
5	moderate
6	high

EXERCISES

Problem 1. The mean monthly rainfalls in the coastal plains of Georgia are listed below. Determine the average annual rainfall. What is the range of these values?

Jan—4.6 in	Jul—5.5 in
Feb—4.4 in	Aug—4.3 in
Mar—5.2 in	Sep—3.5 in
Apr—3.6 in	Oct—2.4 in
May—3.6 in	Nov—2.8 in
Jun—4.5 in	Dec—3.8 in

Problem 2. Vince has determined the windspeed with a handheld rangefinder. He took six readings: 18 chains per hour, 20 chains per hour,18 chains per hour, 21chains per hour, 21chains per hour, 22 chains per hour.

What is the average, range, and standard deviation of this group of readings? The true reading is 19 chains per hour. How accurate is each reading and what is the precision?

Problem 3. Marty has to construct 600 feet of fireline in heavy brush in half an hour. How many crews does she need to assign to the task?

Problem 4. Crystal has four crews. She needs 1,500 feet of fireline constructed in very heavy brush. How long will it take the crews to build this amount of line?

A mentor is a volunteer who is experienced in the course material, possibly someone who has already taken and passed the course, and who is willing to help a new student with the class.

Mentors can help students:
- Develop good study habits.
- Acquire motivation to work all the exercises and available end-of-chapter problems.
- Set up a good study environment.
- Review and understand the content in the self-paced math course.
- Equip themselves with the proper resources or know where to get them.
- Set reasonable goals for learning.

A good mentor:
- Encourages and motivates the student.
- Is willing to help.
- Is available and eager to meet the needs of the student.
- Is familiar with the student's needs, concerns, and situation because the mentor has been in a similar situation.
- Checks up on the student's progress.
- Sets a clear and specific strategy for problem solving and encourages the student to use this method to work all the provided exercises and comprehensive problems. (See the next page for a suggested method of solving math problems.)
- Gives helpful feedback.
- Establishes a clear target date for completion of each chapter and the final exam. See the next page for a suggested schedule table.
- Schedules a regular time to meet.
- Sets the student up for success.

Just "being there" for a student and showing that you care can motivate the student. Some other forms of motivating a student are praise, saying, "well done," or "good job" when the student has completed a difficult problem successfully. Reinforce good work in concrete terms, such as "That's good work you did on ratios/nomograms." Give student's written or verbal feedback on their work and progress.

Goals for mentors:
- Provide ongoing coaching and support.
- Provide psychological support to help firefighters develop and maintain commitment to passing this self-paced math course for future career advancement.
- Help firefighters learn math-based problem solving in firefighting by sharing knowledge and expertise that the mentor has accumulated from years of experience.
- Encourage firefighters to feel eager and motivated to advance in their field.
- Help, encourage, and motivate firefighters.

Name of Firefighter: ______________________________

Name of Firefighter Mentor: ________________________

Firefighter Math Self-Paced Math Course	Projected Begin Date	Projected End Date
Begin Course		
Chapter 1		
Chapter 2		
Chapter 3		
Chapter 4		
Chapter 5		
Chapter 6		
Chapter 7		
Chapter 8		
Chapter 9		
Chapter 10		
Final exam		

GEORGE POLYA'S FOUR PHASES IN PROBLEM SOLVING

Problem solving has a higher probability of being successful if you have a clear and specific strategy. The following has proven to be very successful, and you are encouraged to use it. This approach has been used in solving the overall chapter problems. See appendix C.

✓ Understand the problem
- What do you know from the problem?
- What question does the problem ask?
- What are we to find?
- Is there something we need to know that is not given in the problem?
- What would a reasonable answer be?

✓ Devise a plan
- Have you solved a problem like this before?
- Can you draw a picture?
- Take one part at a time.
- Organize the information you have.
- Make a graph or a table to help you see what is going on.
- Try to write a mathematical sentence or equation.

✓ Carry out the plan
- Keep a record of what you do.
- If you guess, check to see if your guess is possible.
- Solve the mathematical sentence.
- Perform the steps in your plan carefully.

✓ Look back at your work
- Can you check your answer?
- Is it reasonable?
- What does the result tell you?
- Does it answer the question asked?
- Is there another answer?
- Is there another way to find a solution?
- Can you solve other problems like the one you just did?

PROBLEM-SOLVING WORKSHEET		
P R O B L E M	Given: Goal:	Assumptions: Information needed:
D E V I S E P L A N	Strategies:	Rationale:
C A R R Y O U T P L A N	Solution process:	
L O O K B A C K	Answer:	Solution Check:

The material in this appendix describes the use of numbers, to include addition, subtraction, multiplication, division, order of operation, exponents, rounding, significant digits, and decimal places. Each math concept is developed by a text description with a graphic illustration and sample problem with a detailed solution. In addition, exercise problems to use your new skills are provided. Answers to these exercises are provided in appendix C.

B.1 Using Numbers This section includes a review of a few key facts about numbers. Numbers continue in both the positive and negative directions forever. See figure B.1. This is shown as a line with arrows pointing in both directions, extending on to infinity. The numbers to the right of the zero are called **positive** and the numbers to the left are **negative**.

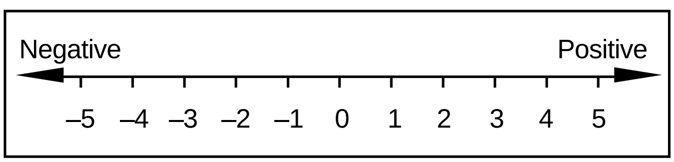


Figure B.1—Positive and negative numbers.

B.2 How to Read Large Numbers Numbers are separated into three subgroups—ones, tens, and hundreds. Each group has a name, like ones, thousands, millions, and so on. See figure B.2. When writing or reading a large number, begin at the left with the largest group, and proceed to the right. The following chart can help in reading large numbers.

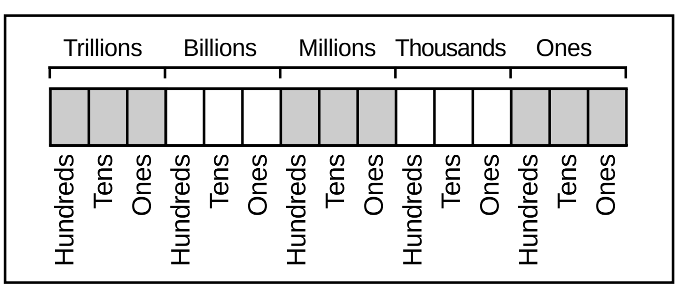
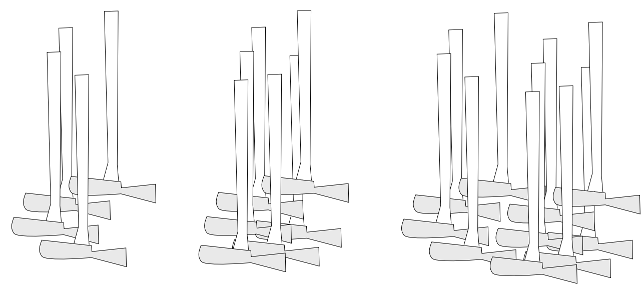


Figure B.2—The order of large numbers.

Example 1—Write 10,956,501.

ten million, nine hundred fifty six thousand, five hundred one

B.3 Addition Addition is used when combining, or putting things together. It helps answer questions such as "How many?" "How much?" or "How far?" Let's look at different ways that addition can be used. Some words used often in addition are **plus, and, the sum of, total,** or **added to.**



4 pulaskis and 6 pulaskis equals 10 pulaskis

The addition that goes with this is: 4 + 6 = 10.

Example 1—Jay has 4 fusees. To burn out a section of road he needs 15 more. How many fusees does Jay need all together? Write the addition problem that goes with the situation.

The addition that goes with this is: 4 + 15 = 19.

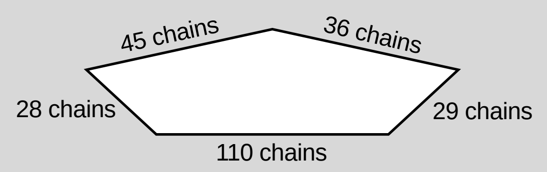
Addition is used in combining distances or lengths.

Example 2—Crew 1 constructs 14 chains of handline on the day shift. Crew 2 constructs 11 chains of handline on the night shift. How many chains did crew 1 and 2 construct altogether?

14 chains + 11 chains = 25 chains

Addition is used to find the distance around an object. This is called the perimeter.

Example 3—The Division Supervisor (DIVS) used two dozers to construct a line. The dozers cleared a line of the following shape. How many chains of dozer line were constructed?



45 chains + 36 chains + 28 chains +29 chains + 110 chains = 248 chains

Addition is used in combining areas.

Example 4—Write an addition problem for the following situation.

The day shift had two spot fires that were contained at 6 acres and 8 acres each. What was the total area of the spot fires that burned during the day shift?

6 acres + 8 acres = 14 acres

Addition is also used in combining volumes.

Example 5—Write an addition problem for the following situation.

Jose has 5 gallons of class A foam in one container, 4 gallons in another, and 2 gallons in a third container. How many gallons of foam does Jose have in all?

5 gallons + 4 gallons + 2 gallons = 11 gallons

Example 6—Herman pumped 30 gallons of fuel into one tank, 25 gallons into the next tank, and 27 gallons into the last tank. How many gallons of fuel did Herman pump?

30 gallons + 25 gallons + 27 gallons = 82 gallons

Addition is used in combining larger numbers.

When adding several numbers, especially large numbers, add the ones (1s) first, then the tens (10s), then the hundreds (100s), and so on.

Example 7—Add: 548 + 365

```
    1
  5 4 8   Add ones. There are 13 ones, or 1 ten and 3 ones.
+ 3 6 5   Write 3 in the ones column and the 1 above the tens.
      3   This is called carrying over.

  1 1
  5 4 8   Add tens. There are 11 tens, or 1 hundred and 1 ten.
+ 3 6 5   Write 1 in the tens column and the 1 above the
    1 3   hundreds.

  1 1     Add hundreds.
  5 4 8
+ 3 6 5
  9 1 3
```

Adding Positive and Negative Numbers

There are positive and negative numbers. Positive numbers are indicated with a + sign, or have no sign. If a number is written without a sign, the sign is assumed to be positive. Negative numbers are indicated with a – sign. For example, a negative pressure may be indicated as –25 inches of Hg, or as a vacuum of 25 inches of Hg. Signs are important in adding numbers. Here are some easy tips to remember:

positive number plus positive number = positive number

negative number plus negative number = negative number

large positive number minus smaller positive number = positive number

small positive number plus large negative number = negative number

Example 8—Adding numbers with like signs.

$5 + 5 = 10$

$3 + 3 = 6$

$-5 + (-5) = -10$

$-3 + (-3) = -6$

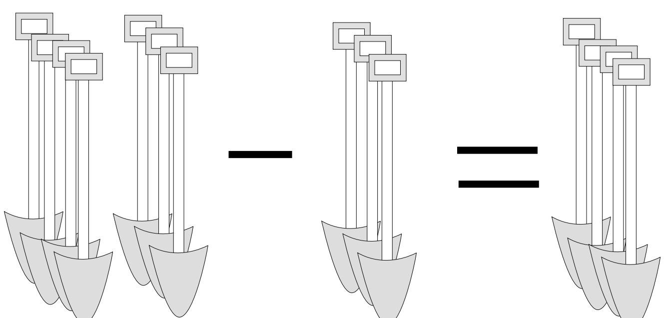
Adding numbers with unlike signs. Notice that the sign of the larger number is the sign that the answer will have.

5 + (–3) = 2
3 + (–3) = 0
3 + (–5) = –2
2 + (–3) = –1

B.4 Subtraction Subtraction is used in two kinds of situations. The first is “How much is left?” and the second is “How much more is needed?” Some words used in subtraction are **minus, take away, less, and difference**.

Example 9—How much is left?

The fire station has seven shovels.	Mark comes in and “takes away” three shovels.	The station is left with four shovels.



7 shovels minus 3 shovels equals 4 shovels

The subtraction problem that goes with this is:
7 shovels – 3 shovels = 4 shovels

To subtract numbers, subtract the ones first, then tens, then hundreds, and so on (from right to left).

Example 10—Subtracting numbers.

$$\begin{array}{r} 9\,8\,5\,4 \\ -\;\underline{5\,3\,4\,2} \\ 2 \end{array}$$ Subtract ones.

$$\begin{array}{r} 9\,8\,5\,4 \\ -\;\underline{5\,3\,4\,2} \\ 1\,2 \end{array}$$ Subtract tens.

$$\begin{array}{r} 9\,8\,5\,4 \\ -\;\underline{5\,3\,4\,2} \\ 5\,1\,2 \end{array}$$ Subtract hundreds.

$$\begin{array}{r} 9\,8\,5\,4 \\ -\;\underline{5\,3\,4\,2} \\ 4\,5\,1\,2 \end{array}$$ Subtract thousands.

Example 11—Ken knows that his crew needs to construct 17 chains of handline. He also knows that they have already finished constructing 5 chains. How many more chains of handline does Ken's crew need to construct?

This is written with numbers as 17 = 5 + ?
or 17 – 5 = ?
The solution is: 17 – 5 = 12

> Ken has 12 more chains of handline to construct.

Borrowing Numbers—If the number being subtracted is larger than the one being subtracted from, **borrowing** from the next column to the left is necessary.

Example 12—Subtract 8532 – 6784.

$$\begin{array}{rrrr} & & 2 & 12 \\ 8 & 5 & \cancel{3} & \cancel{2} \\ \hline -6 & 7 & 8 & 4 \\ & & & \mathbf{8} \end{array}$$ Because 4 cannot be taken away from 2, 1 ten must be borrowed to get 12 ones. Now take away 4 from 12.

$$\begin{array}{rrrr} & 4 & 12 & 12 \\ 8 & \cancel{5} & \cancel{3} & \cancel{2} \\ \hline -6 & 7 & 8 & 4 \\ & & \mathbf{4} & \mathbf{8} \end{array}$$ Because 8 cannot be taken away from 2, borrow 1 hundred to get 12 tens, and take away 8 from 12.

$$\begin{array}{rrrr} 7 & 14 & 12 & 12 \\ \cancel{8} & \cancel{5} & \cancel{3} & \cancel{2} \\ \hline -6 & 7 & 8 & 4 \\ & \mathbf{7} & \mathbf{4} & \mathbf{8} \end{array}$$ Because 7 cannot be taken away from 4, borrow 1 thousand to get 14 hundreds, and take away 7 from 14.

$$\begin{array}{rrrr} 7 & 14 & 12 & 12 \\ \cancel{8} & \cancel{5} & \cancel{3} & \cancel{2} \\ \hline -6 & 7 & 8 & 4 \\ \mathbf{1} & \mathbf{7} & \mathbf{4} & \mathbf{8} \end{array}$$ Subtract 6 from 7.

Subtracting Signed Numbers—Signs are important in subtracting numbers. Subtracting a number changes the sign of the number subtracted. Subtracting a "–" number makes that number a "+" number. Writing the numbers directly over each other makes it easier to subtract.

	7		7
For example	– (– 3)	becomes	+ 3
	?		10

Example 13—Subtract –20 from –50.

–50	–50
– (–20)	+20
?	–30

Example 14—Subtract 20 from –50.

–50	–50
– (+20)	–20
?	–70

See adding positive and negative numbers in appendix B.3.

B.5 Multiplication Multiplication is easier to use than repeated addition. Some words and symbols used in multiplication are **times, the product of, "x," or a dot like "•."** Sometimes numbers that are being multiplied will be put in parentheses ( ). A table-like format is used for conversions, so that the units will be sure to cancel.

Multiplication is a repeated set of additions.

For example: The multiplication of 2 x 3 is the same as the addition of three 2's, 2 + 2 + 2, or two 3's, 3 + 3.

Example 15—Sarah can do 30 pushups in one minute. If she kept at that pace, how many pushups could she do in 15 minutes?

The multiplication problem would be 30 x 15 = 450.
This is the same as adding 30 fifteen times.

When larger numbers are involved, multiplication is much easier than the repeated addition.

Example 16—Multiply 45 by 37.

Step 1. Multiply by the number in the ones spot, which is 7.

45
x 7
315

Step 2. Multiply by the number in the tens spot, or 30.

45
x 30
1,350

Step 3. Add these together.

45
x 37
315
+1,350
$\boxed{1,665}$

Example 17—Multiply 374 x 261.

Step 1. Multiply 374 by 1.

374
x 26**1**
374

Step 2. Multiply by 60. Put in 0 and then multiply 374 by 6.

4 2
374
x 2**6**1
374
22,440

Step 3. Multiply by 200. Put in 00 and then multiply 374 by 2.

```
         1
       374
     x 261
       374
    22,440
   +74,800
```

Step 4. Add the numbers. **97,614**

Multiplying Signed Numbers—When multiplying two numbers with the same sign, the answer will be a positive number. A positive number times a positive number gives a positive answer.

5 x 5 = 25
4 x 8 = 32
2 x 6 = 12

A negative number times a negative number gives a positive answer.

– 5 x (–5) = 25
– 4 x (–8) = 32
– 2 x (–6) = 12

A positive number times a negative number gives a negative answer.

5 x (–5) = – 25
– 4 x 8= –32
2 x (–6) = –12

B.6 Division Division is used to split groups up into smaller sections. Some words and symbols often seen in division are **divided by, into, "÷," and "/."** Just as multiplication is thought of as repeated additions, division can be thought of as repeated subtractions.

Divisior—the number by which a dividend is divided (a).
Dividend—a sum or amount to be divided and distributed (b).
Quotient—the number resulting from the division of one number by another (c).
Remainder—the number left after subtraction that is smaller than the divisior.

$$\frac{b}{a} = c$$

Example 18—There are 20 nozzles for 5 engines. If the nozzles were to be divided evenly for the engines, how many nozzles would go on each engine?

```
 20
– 5
 15
– 5
 10
– 5
  5
– 5
  0
```

Subtraction was performed four times.

So, 20 ÷ 5 = 4

Example 19—Divide 15 by 4.

```
 15
– 4
 11
– 4
  7
– 4
  3
```

Because 4 cannot be subtracted from 3, the 3 is called the **remainder** and is noted by the symbol "R".

The remainder is never larger than the divisor. The divisor in example 19 is 4. So, 15 / 4 = 3 R 3

If these were fifteen nozzles for four engines on your district, four nozzles would go on three engines and only three nozzles would go on the last engine.

Long division can also be used. Here the repeated subtraction is done in a different way. To divide, start from the digit of highest place value and finish with the digit in the lowest place value. At each step, ask if there are multiples of the number in the answer.

Example 20—Divide 3,654 by 5.

$5\overline{)3654}$

1. Start with the thousands digit in the number being divided. Can 5 go into 3? No—5 is bigger than 3.

$$\begin{array}{r} 7 \\ 5\overline{)3654} \\ \underline{3500} \\ 154 \end{array}$$

2. Look at the hundreds place. Can 5 go into 36? Yes—7 x 5 = 35.

3. Subtract.

$$\begin{array}{r} 730 \\ 5\overline{)3654} \\ \underline{3500} \\ 154 \\ \underline{150} \\ 4 \end{array}$$

4. Go to the tens place of the first remainder that was subtracted in the previous step (154). Can 5 go into 15? Yes—5 x 3 = 15.

5. Subtract.

6. Go to the ones place. Can 5 go into 4? No—4 is smaller than 5. Put a 0 in the ones spot of the answer. There is a remainder of 4.

3,654 ÷ 5 = 730 R 4

To check the answer to this long division problem, multiply 730 x 5 to give 3,650. Adding the remainder of 4 gives 3,654. The dividend is 3,654, so the answer is correct.

Dividing signed numbers—Division follows the same general rules as multiplication. When dividing any two numbers having the same sign, the answer is positive, while that of two numbers of opposite sign is negative.

$\frac{8}{4} = 2 \quad \frac{-8}{-4} = 2$ When dividing numbers with like signs, the answer is positive.

$\frac{-8}{4} = -2 \quad \frac{8}{-4} = -2$ When dividing numbers with unlike signs, the answer is negative.

B.7 Using Decimals Reading a decimal type number depends on where the decimal point is placed. See figure B.3. This chart is similar to the chart for large numbers.

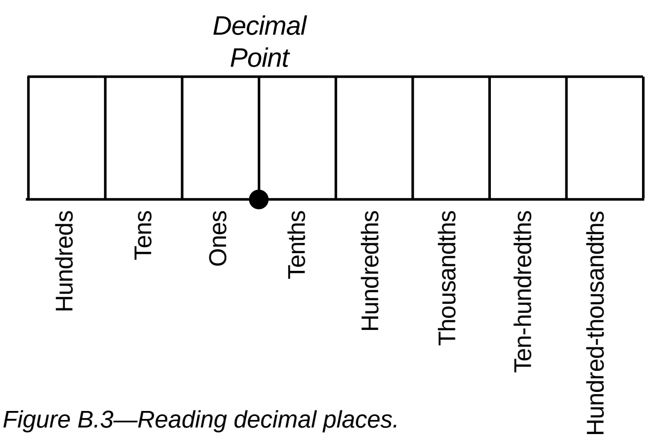


Figure B.3—Reading decimal places.

Dividing by Moving the Decimal Place. Division is possible with certain numbers by only moving the decimal place. These numbers are 10, 100, 1,000, 10,000, and so on through other mulitples of 10. Count the number of zeros in the denominator and move the decimal point that many spaces to the left.

Example $\frac{100}{10} = \frac{100.0}{10.0} = 10.00 = 10$

There is one zero in the 10, so move the decimal point in the 100 to the left by one place.

Example 21—

$\frac{8679}{1000}$ There are three zeros.

8.679 Move the decimal point three places to the left. Remember that whole numbers have a decimal point at the end that's been dropped off.

$\frac{8679}{1000} = 8.679$

Example 24 = 24. 16 = 16., etc

Significant Figures and Rounding for Accuracy—The decimal place indicates the accuracy of the given number. The accuracy of an answer is determined by the lowest level of accuracy of the original numbers being added, subtracted, multiplied, or divided. Accuracy does not improve with addition, subtraction, multiplication, or division. This is especially important with multiplication and division with decimal places.

8.2 + 0.25 = ? The lowest level of accuracy is to the 1/10th decimal place, so the correct answer is to the 1/10th decimal place. Rounding up or down is a method of bringing the answer to the correct level of accuracy. 8.2+0.25 = 8.45? The answer is only accurate to the 1/10th. Round up if the numbers are 5 to 9, and round down if the numbers are 4 to 1. What is 8.45 to the nearest 1/10th? Round up .45 to .5 to give an answer of 8.5 with the correct accuracy.

Example: 10 x 20 = 10. x 20. = 200. = 200

10 x 20 ≠ 200.0

```
  986.1
– 459.8
  526.3
```

Example 22—Round 984.23644 to the nearest hundredth.

Since the number to the right of the 3 is greater than 5—round up.

984.24

Example 23—Round 543.64 to the nearest tenth.

Since the number to the right of 6 is less than 5, *keep the number as it is.*

543.6

All digits of a number are significant. For example, there are 4 significant digits/places in 37.40 grams. The zero in 37.40 grams is significant because it implies a precision of ± 0.01 gram. This means that the answer before rounding up or down was between 37.395 grams and 37.414 grams. When adding, subtracting, multiplying, or dividing digits, all numbers must have the same number of significant digits as the least accurate original number.

Example 24—Add the following weights:
20.11 lb, 1,035.000 lb, and 5.1794 lb.

```
     20.11
   1035.000
+     5.1794
   1060.2894 lb
```

Round the answer to the correct number of significant places. The least accurate is 20.11, so round the answer to the nearest 1/100th.

1,060.2894 rounded to the correct accuracy = 1,060.29 lb

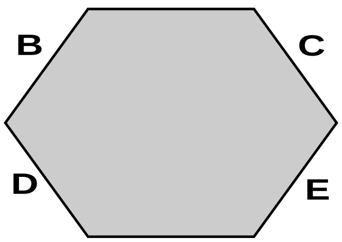
Example 25—43,357.9 + 8,764.003

```
   43,357.9
+   8,764.003
   52,121.903  =  52,121.9
```

Example 26—878.6003 – 32.15

```
   878.6003
–   32.15
   846.4503  =  846.45
```

Example 27—A helicopter landing pad is in the shape of a six-sided figure. Side A is 12.50 feet long. Side B is 6.57 feet long. Side C is 7.80 feet long. Side D is 11.00 feet long. Side E is 5.50 feet long. Side F is 8.15 feet long. What is the total perimeter of the helicopter pad?



This is an addition problem using decimal notation.

```
   12.50
    6.57
    7.80
   11.00
    5.50
+   8.15
   51.52
```

The perimeter of the helicopter pad is 51.52 feet.

Multiplication and Division with Decimals—Accuracy in the answer is indicated by placement of the decimal point in multiplying and dividing numbers.

In multiplication, deal with the decimal point after the numbers have been multiplied totally. After the numbers have been multiplied, count the number of places to the right of both of the original numbers. The lower amount of decimal places is then applied to the sum total as the number of places to the right of the decimal.

Example: 10.1 x 10.23 = 103.323
There are a total of three places to the right of the answer = 103.323. Since one of the original numbers (10.1) has one decimal place accuracy, round off the final answer to 103.3.

Example 28—Multiply 0.9 x 1.53.

```
  0.9     (1 decimal space)
x 1.53    (2 decimal spaces)
   27
  450
 0900
1.377     (3 decimal spaces) = 1.4 (1 decimal place)
```

Division with Decimals—To divide, it is important to look at the dividedend. If it is a whole number, long division is performed by placing the decimal point in the answer directly above the decimal point in the number being divided.

Example 29—89.76 ÷ 12

```
     7.48
12 )89.76
  – 8400
     576
   – 480
      96
    – 96
       0
```

If the divisor is not a whole number, the decimal places need to be moved in both the divisior and dividend to make sure that the decimal in the quotient is correctly placed. First, move the decimal point to the right, in order to make the divisior into a whole number. Then, move the decimal point in the number being divided (the dividend), by the same number of spaces to the right. Now, place the decimal point directly above the point in the number being divided and divide as though dividing whole numbers.

Example 30— 4.067 ÷ 0.83

To make the divisor a whole number, the decimal point must be moved two places to the right so the division becomes 083. So, the dividend becomes 406.7

```
                       4.9
0.83)4.067   =   083)406.7
                   – 3320
                      747
                    – 747
                        0
```

B.8 Powers and Roots When a number is multiplied by itself several times, instead of writing each repetition of the multiplication, it is easier to use **exponential notation.** For example, $3 \times 3 \times 3 \times 3 \times 3$ would be 3^5. The number being multiplied is called the **base** and the number of times it is multiplied by itself is called the **exponent**. In the above case, the base is 3 and the exponent is 5. When a number has an exponent of 2, it is "squared." When the exponent is 3, it is "cubed." When the exponent is 4, it is "to the fourth power."

Example 31—Write $6 \times 6 \times 6$ in exponential notation and in words.

$6 \times 6 \times 6 = 6^3$ or "six cubed" It can also be solved as $6^3 = 216$.

This can also be worked backwards by finding the **square root** of the number and will appear under a square root sign: "$\sqrt{\ }$." The square root of a number is the original number that would have to be squared in order to get that number.

For example, the square root of 4 would be 2, since $2^2 = 4$.

Example 32—Find $\sqrt{49}$

$\sqrt{49} = 7$ because $7 \times 7 = 49$

Some numbers are not "perfect squares." In this situation, divide once again to see whether the number can be separated into a number that is a perfect square and the rest stays as a square root.

Example 33—Find $\sqrt{18}$

$$\sqrt{9 \times 2} = 3\sqrt{2}$$

The 2 remains under the square root symbol, since it is not a perfect square, but the square root of 9 is a perfect square, so it can be simplified to a 3 and taken outside of the square root symbol.

$\sqrt{18} = 3\sqrt{2}$

B.9 Order of Operation Some math problems are a mixture of addition, subtraction, division, and multiplication. Furthermore, the information can be true for one item but not another, so parentheses are used (). There is a specific order to follow when making calculations. This order is:

a. Parentheses: ( )
b. Exponents: 2^3
c. Multiplication and division
d. Addition and subtraction
e. Left to right

Note—The student may also add parentheses to clarify the order.

Example 34—Solve $10 + 10 \div 10$

Step 1. Division is done before addition.
$10 \div 10 = 1$

Step 2. Add.
$10 + 1 = 11$

$10 + 10 \div 10 = 11$

The same example rewritten:
$10 + 10 \div 10$
$10 + (10 \div 10)$
$10 + 1 = 11$

Example 35—Solve $6^3 \div (10 - 8)^2 \div 2 + 2$

Step 1. Parentheses.
$6^3 \div (10 - 8)^2 \div 2 + 2 = 6^3 \div 2^2 \div 2 + 2$

Step 2. Exponents.
$216 \div 4 \div 2 + 2$

Step 3. Division in order from left to right.
$216 \div 4 = 54$
$54 \div 2 = 27$

Step 4. Addition.
$27 + 2 = 29$

$6^3 \div (10 - 8)^2 \div 2 + 2 = 29$

EXERCISES

Write an addition problem for each situation. Solve.

Problem 1. Manuel earns $121 worth of overtime on Monday and $142 on Wednesday. How much overtime money does he earn in all?

Problem 2. Mike has seven hose lengths. He goes to supply and picks up six more. How many hose lengths does he have in all?

Problem 3. Carol has 200 feet of hose in her pack. Bernie has 100 feet of hose and Tyrone has 200 feet in his pack. How many feet of hose do they have in all?

Problem 4. There were two fires on the Tonto Forest yesterday. One fire burned 235 acres of national forest land and the other burned 68 acres outside of the national forest boundary. How many acres were burned in all?

Problem 5. Loren is filling containers with fire foam. In one container she put 28 gallons and in the second container she put 53 gallons. How many gallons did she fill in all?

Problem 6. Lois pumps 267 gallons of water into an engine. For the next engine she pumps 350 gallons. She pumps 288 gallons into the third engine. How many gallons did Lois pump in all?

Add.

Problem 7.
$$\begin{array}{r} 5\,3\,0\,4 \\ \underline{+\,3\,5\,4\,2} \end{array}$$

Problem 8.
$$\begin{array}{r} 7\,9\,6\,8 \\ \underline{+\,5\,4\,9\,7} \end{array}$$

Problem 9.
$$\begin{array}{r} 9\,8\,0\,4 \\ \underline{+\,7\,5\,8\,9} \end{array}$$

Problem 10.
$$\begin{array}{r} -6 \\ \underline{+\,-6} \end{array}$$

Problem 11.
$$\begin{array}{r} 7 \\ \underline{+\,-4} \end{array}$$

Write a subtraction problem for each situation. Solve.

Problem 12. Anthony is working in the supply room. He has 36 hard hats. A crew of 24 comes in and takes 1 for each person. How many hard hats does Anthony have left?

Problem 13. The foam tank on an engine is filled with 45 gallons before leaving for a fire. The crew uses up 27 gallons on that fire. How many gallons are left?

Problem 14.
$$\begin{array}{r} 23 \\ \underline{-\ \ 6} \end{array}$$

Problem 15.
$$\begin{array}{r} 4547 \\ \underline{-\ 3421} \end{array}$$

Problem 16. Joe is restocking the fire cache. Fifty pairs of gloves make up a complete set, but Joe only has nine pairs. How many more are needed to complete the set?

Problem 17.
$$\begin{array}{r} 402 \\ \underline{-139} \end{array}$$

Problem 18.
$$\begin{array}{r} 6913 \\ \underline{-\ 4479} \end{array}$$

Solve.

Problem 19. Jerry has nine lengths of hose. Each hose is 100 feet long. What is the total length of hose that Jerry has?

Problem 20. There are 19 members in crew A. Four canteens must be filled for each person. How many canteens need to be filled in total?

Multiply.

Problem 21.
$$\begin{array}{r} 210 \\ \underline{\times\ 57} \end{array}$$

Problem 22.
$$\begin{array}{r} 1350 \\ \underline{\times\ \ 99} \end{array}$$

Problem 23.
$$\begin{array}{r} 432 \\ \underline{\times 376} \end{array}$$

Problem 24. $-7 \times (-3)$

Problem 25. -6×2

Problem 26. -1×25

Problem 27. Use repeated subtraction to divide 30 by 6.

Use long division.

Problem 28. 27/3

Problem 29. $3645 \div 7$

Problem 30. $8889 \div 71$

Problem 31. $6027 \div 9$

Problem 32. $4139 \div 59$

Problem 33. $789 \div 42$

Problem 34.
$$\begin{array}{r} \underline{14} \\ -4 \end{array}$$

Problem 35. $\frac{-6}{-3}$

Solve.

Problem 36. $\frac{58}{100}$

Problem 37. $\frac{633}{10}$

Problem 38. $\frac{14.3}{1000}$

Problem 39. Round to the nearest tenth.

a) 58.153

b) 7.917

c) 4413.1269

Problem 40. Round to the nearest thousandth.

a) 731.23773

b) 9143.1544

c) 0.52791

Add.

Problem 41. 4561.0089 + 2.87 =

Problem 42. 0.2844 + 87.001 =

Problem 43. 5.681 + 12.13 =

Subtract.

Problem 44. 713.609 – 6.595 =

Problem 45. 9.901 – 0.02 =

Problem 46. 9522.01396 – 8420.356 =

Multiply.

Problem 47. 0.867 x 0.14 =

Problem 48. 1.56 x 2.801 =

Problem 49. 3.48 x 0.01 =

Problem 50. 5.95 x 0.0001 =

Divide.

Problem 51. 30 ÷ 8 =

Problem 52. 22.5 ÷ 15 =

Problem 53. 62.3 ÷ 5 =

Problem 54. $44.8 \div 3.5 =$

Problem 55. $3.75 \div 0.25 =$

Problem 56. $5.848 \div 8.6 =$

Write the following in exponential notation and solve.

Problem 57. $5 \times 5 =$

Problem 58. $2 \times 2 \times 2 \times 2 \times 2 =$

Problem 59. $3 \times 3 \times 3 \times 3 =$

Problem 60. $10 \times 10 \times 10 =$

Find the following square roots.

Problem 61. $\sqrt{25}$

Problem 62. $\sqrt{16}$

Problem 63. $\sqrt{81}$

Problem 64. $\sqrt{27}$

Solve

Problem 65. $3^2 + 6 + 2 - 2 =$

Problem 66. $(5 + 2) \times 5 + 2 =$

Problem 67. $(1 + 3)^3 + 10 \times 20 + 8 =$

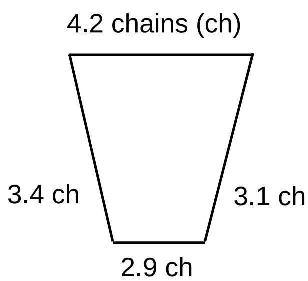
Problem 68. $95 - 2^3 \times 5 \div (24 - 4) =$

Problem 69. $7 \times 2 - (12+0) \div 3 - (5-2) =$

EXERCISE SOLUTIONS

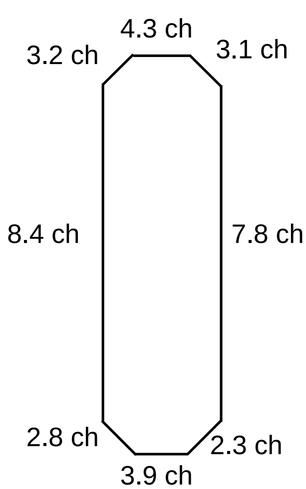
P = Perimeter L = Length P = L + L + L

Problem 1. A hotshot crew constructs a handline to contain a fire. See the diagram of the handline below. How many chains of handline did the crew put in?



Perimeter = L1 + L2 + L3. . . .
P = 4.2 ch + 3.1 ch + 2.9 ch + 3.4 ch = 13.6 chains

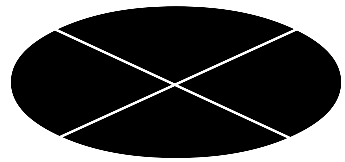
Problem 2. Find the perimeter of the fire below.



Perimeter = L1 + L2 + L3. . . .
4.3 ch + 3.1 ch + 7.8 ch + 2.3 ch + 3.9 ch + 2.8 ch + 8.4 ch + 3.2 ch = 35.8 chains

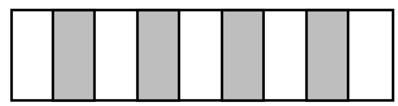
Problems 3, 4, & 5.
What fraction is shaded?
What fraction is not shaded?
What is the total amount of shaded and unshaded area?

Problem 3.



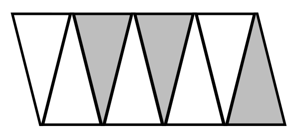
Shaded = 4/4 = 1
Unshaded = 0/4
Total = 4/4 = 1

Problem 4.



Shaded = 4/9
Unshaded = 5/9
Total = 4/9 + 5/9 = 9/9 = 1

Problem 5.



Shaded = 3/8
Unshaded = 5/8
Total = 3/8 + 5/8 = 8/8 = 1

Simplify.

Problem 6. $\frac{4}{4} = 1$

Problem 7. $\frac{22}{1} = 22$

Problem 8. $\frac{3}{11}$ = cannot be simplified

Simplify.

Problem 9. $\frac{6 \div 2}{10 \div 2} = \frac{3}{5}$

Problem 10. $\frac{84 \div 2}{90 \div 2} = \frac{42 \div 3}{45 \div 3} = \frac{14}{15}$

Problem 11. $\frac{18 \div 2}{24 \div 2} = \frac{9 \div 3}{12 \div 3} = \frac{3}{4}$

Problem 12. $\frac{8 \div 2}{36 \div 2} = \frac{4 \div 2}{16 \div 2} = \frac{2}{9}$

Problem 13. $\frac{15 \div 3}{9 \div 3} = \frac{5}{3}$

$$\begin{array}{r} 1 \\ 3\overline{)5} \\ -3 \\ \hline 2 \end{array} \text{ remainder}$$

= 1 remainder 2
= 1-2/3

Problem 14. $\frac{4}{3}$

$$\begin{array}{r} 1 \\ 3\overline{)4} \\ -3 \\ \hline 1 \end{array} \text{ remainder}$$

= 1 remainder 1
= 1-1/3

Problem 15. $\frac{6 \div 2}{4 \div 2} = \frac{3}{2}$

$$\begin{array}{r} 1 \\ 2\overline{)3} \\ -2 \\ \hline 1 \end{array} \text{ remainder}$$

= 1 remainder 1
= 1-1/2

Multiply and simplify.

Problem 16. $5 \times \frac{2}{3}$

$\frac{5 \times 2}{1 \times 3} = \frac{10}{3}$

$$\begin{array}{r} 3 \\ 3\overline{)10} \\ -9 \\ \hline 1 \end{array} \text{ remainder}$$

= 3 remainder 1
= 3-1/3

Problem 17. $9 \times \frac{2}{5}$

$\frac{9 \times 2}{1 \times 5} = \frac{18}{5}$

$$\begin{array}{r} 3 \\ 5\overline{)18} \\ -15 \\ \hline 3 \end{array} \text{ remainder}$$

= 3 remainder 3
= 3-3/5

Problem 18. $\frac{4}{7} \times \frac{3}{9}$

$$\frac{4 \times 3}{7 \times 9} = \frac{12 \div 3}{63 \div 3} = \frac{4}{21}$$

Problem 19. $\frac{8}{13} \times \frac{11}{19}$

$$\frac{8 \times 11}{13 \times 19} = \frac{88}{247}$$

Problem 20. $\frac{3}{5} \times \frac{4}{7}$

$$\frac{3 \times 4}{5 \times 7} = \frac{12}{35}$$

Find the reciprocal.

Problem 21. $\frac{5}{9}$

$\frac{9}{5}$

Problem 22. $\frac{5}{32}$

$\frac{32}{5}$

Problem 23. 5

$\frac{1}{5}$

Problem 24. $\frac{1}{2}$

2

Divide and simplify.

Problem 25. $\frac{5}{7} \div \frac{9}{12}$

$$\frac{5}{7} \times \frac{12}{9} = \frac{60 \div 3}{63 \div 3} = \frac{20}{21}$$

Problem 26. $\frac{8}{13} \div \frac{11}{50}$

$$\frac{8}{13} \times \frac{50}{11} = \frac{400}{143}$$

$$\begin{array}{r} 2 \\ 143 \overline{)400} \\ -286 \\ \hline 144 \end{array} \text{ remainder}$$

= 2 remainder 114
= 2-114/143

Problem 27. $\frac{4}{5} \div \frac{2}{3}$

$$\frac{4}{5} \times \frac{3}{2} = \frac{12}{10} = \frac{6}{5}$$

$$\begin{array}{r} 1 \\ 5 \overline{)6} \\ -5 \\ \hline 1 \end{array} \text{ remainder}$$

= 1 remainder 1
= 1-1/5

Problem 28. $\frac{5}{8} \div 2$

$$\frac{5}{8} \times \frac{1}{2} = \frac{5}{16}$$

Problem 29. $\frac{3}{4} \div \frac{1}{5}$

$\frac{3}{4} \times \frac{5}{1} = \frac{15}{4}$

$$\begin{array}{r} 3 \\ 4\overline{)15} \\ -12 \\ \hline 3 \end{array}$$ remainder

= 3 remainder 3
= 3-3/4

Add and simplify.

Problem 30. $\frac{1}{6} + \frac{7}{18}$

$\frac{1}{6} \times \frac{3}{3} = \frac{3}{18} + \frac{7}{18} = \frac{10}{18}$

$\frac{10 \div 2}{18 \div 2} = \frac{5}{9}$

Problem 31. $\frac{2}{9} + \frac{5}{6}$

$\frac{2}{9} \times \frac{2}{2} = \frac{4}{18}$

$\frac{5}{6} \times \frac{3}{3} = \frac{15}{18}$

$\frac{4}{18} + \frac{15}{18} = \frac{19}{18}$

$$\begin{array}{r} 1 \\ 18\overline{)19} \\ -18 \\ \hline 1 \end{array}$$ remainder

= 1 remainder 1
= 1-1/18

Problem 32. $\frac{7}{10} + \frac{2}{21} + \frac{1}{7}$

$\frac{1}{7} \times \frac{3}{3} = \frac{3}{21}$

$\frac{2}{21} + \frac{3}{21} = \frac{5}{21}$

Now we need a common denominator for 21 and 10. Best is 210. So...

$\frac{7}{10} \times \frac{21}{21} = \frac{147}{210}$

$\frac{5}{21} \times \frac{10}{10} = \frac{50}{210}$

$\frac{147}{210} + \frac{50}{210} = \frac{197}{210}$

Problem 33. $\frac{2}{5} + \frac{11}{10} + \frac{7}{15}$

$\frac{2}{5} \times \frac{2}{2} = \frac{4}{10}$

$\frac{11}{10} + \frac{4}{10} = \frac{15}{10}$

Now we need a common denominator for 10 and 15. Best is 30. So...

$\frac{7}{15} \times \frac{2}{2} = \frac{14}{30}$

$\frac{15}{10} \times \frac{3}{3} = \frac{45}{30}$

$\frac{14}{30} + \frac{45}{30} = \frac{59}{30}$

$$\begin{array}{r} 1 \\ 30\overline{)59} \\ -30 \\ \hline 29 \end{array}$$ remainder

= 1 remainder 29
= 1-29/30

Problem 34. $\frac{1}{2} + 2$

$\frac{2}{1} \times \frac{2}{2} = \frac{4}{2}$

$\frac{1}{2} + \frac{4}{2} = \frac{5}{2}$

$$\begin{array}{r} 2 \\ 2\overline{)5} \\ -4 \\ \hline 1 \end{array}$$ remainder

= 2 remainder 1
= 2-1/2

<u>Subtract and simplify.</u>

Problem 35. $\frac{9}{10} - \frac{4}{100}$

$\frac{9}{10} \times \frac{10}{10} = \frac{90}{100}$ so,

$\frac{90}{100} - \frac{4}{100} = \frac{86}{100}$

$\frac{86 \div 2}{100 \div 2} = \frac{43}{50}$

Problem 36. $\frac{4}{5} - \frac{2}{3}$

$\frac{4}{5} \times \frac{3}{3} = \frac{12}{15}$ and

$\frac{2}{3} \times \frac{5}{5} = \frac{10}{15}$

$\frac{12}{15} - \frac{10}{15} = \frac{2}{15}$

Problem 37. $\frac{5}{12} - \frac{5}{16}$

$\frac{5}{12} \times \frac{4}{4} = \frac{20}{48}$

$\frac{5}{16} \times \frac{3}{3} = \frac{15}{48}$

$\frac{20}{48} - \frac{15}{48} = \frac{5}{48}$

Problem 38. $3\frac{1}{3} - \frac{5}{6}$

$\frac{10}{3} - \frac{5}{6}$

$\frac{10}{3} \times \frac{2}{2} = \frac{20}{6}$

$\frac{20}{6} - \frac{5}{6} = \frac{15}{6}$

$$\begin{array}{r} 2 \\ 6\overline{)15} \\ -12 \\ \hline 3 \end{array}$$ remainder

= 2 remainder 3
= 2-3/6
= 2-1/2

Problem 39. Raul's crew is composed of 13 men and 5 women. What is the ratio of men to women? What is the ratio of women to men? Convert this to a percentage. What is the ratio of men to the total crew? What is the ratio of women to the total crew?

ratio of men to women is 13:5
ratio of women to men is 5:13
$\frac{5}{13} \times 100 = 38.46 = 38\%$
total crew is 13 + 5 = 18
ratio of men to total crew is 13:18 or 72%
ratio of women to total crew is 5:18 or 28%

Convert to a percentage.

Problem 40. 5/50
0.1 x 100 = 10%

Problem 41. 0.194
0.194 x 100 = 19.4 = 19%

Problem 42. 1 to 3
1/3 = 0.333 x 100 = 33.3 = 33%

Problem 43. 4:5
4/5 = 0.8 x 100 = 80%

Problem 44. 3 to 4
3/4 = 0.75 x 100 = 75%

Convert to a decimal.

Problem 45. 21.7%
0.217

Problem 46. 61.0%
0.610

Problem 47. 50/100
0.50

Problem 48. 43/1000
0.043

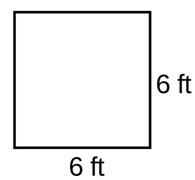
Problem 49. Rick worked in unit supply at fire camp. There were a total of 56 tools. Ten were shovels, 33 were pulaskis, and 13 were mcLeods. What percentage were shovels?

10/56 x 100 = 17.857 = 18%

A	=	Area
s	=	side
l	=	length
w	=	width
b	=	base
h	=	height
P	=	Perimeter

Find the area and perimeter of each figure below.

Problem 50.

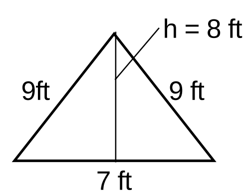


Area = s • s = 6 ft x 6 ft = 36 ft^2
Perimeter = s + s + s + s = 4 • s = 4(6 ft) = 24 ft

Problem 51.

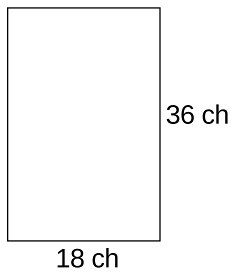
Area = l x w = 8 ch x 5 ch = 40 ch^2
Perimeter = 8 ch + 8 ch + 5 ch + 5 ch = 26 ch
Perimeter = (8 + 8 + 5 + 5) ch = 26 ch

Problem 52.



Area = 1/2 x b x h = 1/2 (7 ft x 8 ft) = 28 ft^2
Perimeter = (9 + 9 + 7) ft = 25 ft

Problem 53.



d = diameter
r = radius
diameter = 2 radius
1/2 diameter = radius
C = circumference
$\pi = 3.14$

Problem 54. Find the area and circumference of the circle. r = 5.3 cm

$A = \pi r^2 = 3.14\ (5.3\ cm)^2 = 88.2\ cm^2$
$C = 2\pi r = 2\ (3.14)(5.3\ cm) = 33.3\ cm$

Problem 55. A spot fire burns in the shape of a circle. The diameter of the circle is 268 feet. What is the perimeter (circumference) and the area of the fire?

$r = 1/2d = 1/2\ (268\ ft) = 134\ ft$
$A = \pi r^2 = 3.14\ (134\ ft)^2 = 56{,}381.84\ ft^2$
$C = 2\pi r = 2\ (3.14)(134\ ft) = 841.52\ ft$

Problem 56. Pizza Galore has two 7-inch pizzas for $9.99 or one 14-inch pizza for $9.99. Which is a better deal (has more surface area)?

$r = 1/2d = 1/2\ (7\ in) = 3.5\ in$
$A = \pi r^2 = 3.14\ (3.5\ in)^2 = 38.465\ in^2 \times 2 = 76.93\ in^2$

$r = 1/2d = 1/2\ (14\ in) = 7\ in$
$A = \pi r^2 = 3.14\ (7\ in)^2 = 153.86\ in^2$
One 14-inch pizza has more surface area.

PROBLEM-SOLVING WORKSHEET

PROBLEM

Given:

Measurements of several burned areas

Goal:

Find the perimeter of the main fire.
Find the area of the three fires.

Assumptions:

Information needed:

Area & perimeter formulas

DEVISE PLAN

Strategies:

Break burned area into shapes area for which area can be computed. Add the areas.

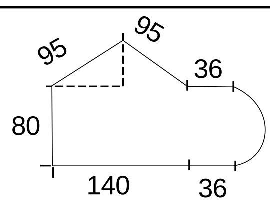
Perimeter: start in one corner and solve for lengths of sides. Add all sides of the main burn.

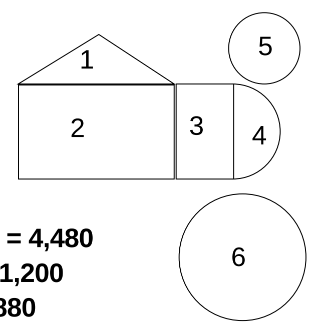
Rationale:

We know the formulas to find area & perimeter of circles, squares & triangles.

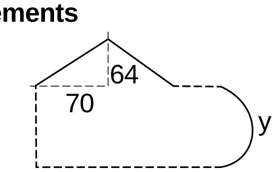
CARRY OUT PLAN

Solution process:





Missing measurements



$y = 1/2\ 2\pi\ r$
$y = \pi\ 40$
$y = 125.6 = 126$

$A1 = 1/2\ (140)(64) = 4{,}480$
$A2 = (140)(80) = 11{,}200$
$A3 = (80)(36) = 2{,}880$
$A4 = 1/2\pi\ r^2 = 1/2\pi\ (40)(40) = 2{,}512$
$A5 = \pi\ r^2 = \pi\ (32)(32) = 3{,}215$
$A6 = \pi\ (47.5)(47.5) = 7{,}085$

LOOK BACK

Answer:

Area in chains

A1	**4,480**
A2	**11,200**
A3	**2,880**
A4	**2,512**
A5	**3,215**
A6	**7,085**
	31,372 ch^2

Perimeter (main burn)

80
95
95
36
126
36
140
608 ch

Solution Check:

PROBLEM-SOLVING WORKSHEET		
P R O B L E M	Given: **Burn area measurements** Goal: **Find perimeter of line constructed by dozer.** **Find percentage of line constructed by dozer & by handcrew.**	Assumptions: Information needed: **Perimeter solution**
D E V I S E P L A N	Strategies: **Subtract line constructed by handcrew to find dozer construction.** **Divide dozer construction by total to find percent.** **Divide handcrew construction by total to find percent.**	Rationale: **Amount constructed by handcrew plus amount constructed by dozer is the total amount.**
C A R R Y O U T P L A N	Solution process: **Total perimeter = 608 chains** **Handcrew –50** **Dozer line 558 chains** **Handcrew / Total** $\frac{50}{608}$ **= .082 x 100 = 8% (rounded)** **Dozer / Total** $\frac{558}{608}$ **= .918 x 100 = 92% (rounded)**	
L O O K B A C K	Answer: **Dozer line length = 558 ch** **Handcrew constructed 8%** **Dozer constructed 92%**	Solution Check: **92% + 8% = 100%**

EXERCISE SOLUTIONS

Problem 1. How many quarters can Kim get for 15 dimes?

$$\begin{array}{|l|l|l|} 15\ \cancel{\text{dimes}} & 1\ \cancel{\text{dollar}} & 4 \text{ quarters} \\ \hline & 10\ \cancel{\text{dimes}} & 1\ \cancel{\text{dollar}} \end{array} = 6 \text{ quarters}$$

Problem 2. How many minutes are there in 24 hours?

$$\begin{array}{|l|l|} 24\ \cancel{\text{h}} & 60 \text{ min} \\ \hline & 1\ \cancel{\text{h}} \end{array} = 1{,}440 \text{ minutes}$$

Problem 3. How many seconds are there in 24 hours?

$$\begin{array}{|l|l|l|} 24\ \cancel{\text{h}} & 60\ \cancel{\text{min}} & 60 \text{ sec} \\ \hline & 1\ \cancel{\text{h}} & 1\ \cancel{\text{min}} \end{array} = 86{,}400 \text{ seconds}$$

Problem 4. How many gallons are in 10 pints?

$$\begin{array}{|l|l|l|} 10\ \cancel{\text{pints}} & 1\ \cancel{\text{qt}} & 1 \text{ gal} \\ \hline & 2\ \cancel{\text{pts}} & 4\ \cancel{\text{qts}} \end{array} = \frac{5}{4} = 1\text{-}1/4 \text{ gallons}$$

Problem 5. Dennis carries three canteens. Each holds 1 quart. How many pints is Dennis carrying in all? How many cups? What is the total weight of the water that Dennis is carrying?

$$\begin{array}{|l|l|} 3\ \cancel{\text{qts}} & 2 \text{ pts} \\ \hline & 1\ \cancel{\text{qt}} \end{array} = 6 \text{ pints}$$

$$\begin{array}{|l|l|} 6\ \cancel{\text{pints}} & 2 \text{ cups} \\ \hline & 1\ \cancel{\text{pint}} \end{array} = 12 \text{ cups}$$

$$\begin{array}{|l|l|l|} 3\ \cancel{\text{qts}} & 1\ \cancel{\text{gal}} & 8.3 \text{ lb} \\ \hline & 4\ \cancel{\text{qts}} & 1\ \cancel{\text{gal}} \end{array} = 6.2 \text{ lb}$$

Problem 6. Mark walks out 120 chains. How many miles has he walked? How many feet has he walked?

$$\begin{array}{|l|l|} 120\ \cancel{\text{chains}} & 1 \text{ mile} \\ \hline & 80\ \cancel{\text{chains}} \end{array} = 1.5 \text{ miles}$$

$$\begin{array}{|l|l|} 120\ \cancel{\text{chains}} & 66 \text{ feet} \\ \hline & 1\ \cancel{\text{chain}} \end{array} = 7{,}920 \text{ feet}$$

Problem 7. Ricardo mapped out a burn with a perimeter of 6 miles. What is the perimeter of the burn in chains? In feet?

$$\begin{array}{|l|l|} 6\ \cancel{\text{miles}} & 80 \text{ chains} \\ \hline & 1\ \cancel{\text{mile}} \end{array} = 480 \text{ chains}$$

$$\begin{array}{|l|l|} 6\ \cancel{\text{miles}} & 5{,}280 \text{ feet} \\ \hline & 1\ \cancel{\text{mile}} \end{array} = 31{,}680 \text{ feet}$$

Problem 8. Mona was constructing handline for 5 hours. How many minutes was she on the line? How many seconds?

$$\begin{array}{|l|l|} 5\ \cancel{\text{h}} & 60 \text{ min} \\ \hline & 1\ \cancel{\text{h}} \end{array} = 300 \text{ minutes}$$

$$\begin{array}{|l|l|l|} 5\ \cancel{\text{h}} & 60\ \cancel{\text{min}} & 60 \text{ sec} \\ \hline & 1\ \cancel{\text{h}} & 1\ \cancel{\text{min}} \end{array} = 18{,}000 \text{ seconds}$$

Problem 9. How many acres are in 78 square miles?

$$\begin{array}{|l|l|} 78\ \cancel{\text{square miles}} & 640 \text{ acres} \\ \hline & 1\ \cancel{\text{square miles}} \end{array} = 49{,}920 \text{ acres}$$

Problem 10. Isaac determines that the last fire he was on burned 89 acres. How many square chains were burned?

$$\begin{array}{|l|l|} 89\ \cancel{\text{acres}} & 10 \text{ square chains} \\ \hline & 1\ \cancel{\text{acre}} \end{array} = 890 \text{ square chains}$$

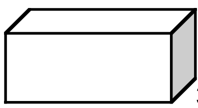
Problem 11. It is 99 degrees Fahrenheit outside. What is the temperature in degrees Celsius? See table 2.2.

$$
\begin{aligned}
C &= 5/9 \times (99-32) \\
&= 5/9 \times (67) \\
&= 335/9 \\
&= 37 \text{ degrees Celsius}
\end{aligned}
$$

EXERCISE SOLUTIONS

V = Volume
L = Length
w = Width
h = Height

Problem 1. Find the volume, in gallons, of the tank below.



$V = 4.1ft \times 3.2ft \times 5.9ft = 77.408\ ft^3$

$$V = \begin{array}{|c|c|} 77.4\,\cancel{ft^3} & 7.48\ gal \\ \hline & 1\,\cancel{ft^3} \end{array} = 578.9 \text{ gals} = 579 \text{ gallons}$$

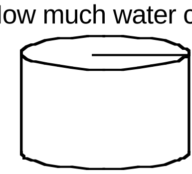
Problem 2. Diego is filling a rectangular water tank with the following dimensions: length = 10 ft, height = 8 ft, and width = 48 in. How many gallons of water can he put in the tank?

$$\begin{array}{|c|c|} 48\,\cancel{in} & 1\ ft \\ \hline & 12\,\cancel{in} \end{array} = 4\ ft$$

$$10\ ft \times 8\ ft \times 4\ ft = \begin{array}{|c|c|} 320\,\cancel{ft^3} & 7.48\ gal \\ \hline & 1\ \cancel{ft^3} \end{array} = 2{,}394 \text{ gallons}$$

V = Volume
h = height of cylinder
r = radius of the circular base

Problem 3. How much water can the tank hold?



$V = \pi r^2 \bullet h = 3.14\ (4.2ft)^2\ 8.6\ ft = 476.351 = 476\ ft^3$

Problem 4. Kate is in charge of filling her engine tank. The tank is 6.2 ft wide, 4.5 ft tall, and 18.2 ft long. What volume of water can she put into the tank to fill it?

V = width x height x length

$V = 6.2\ ft \times 4.5\ ft \times 18.2\ ft = 507.8\ ft^3 = 508\ ft^3$

Problem 5. A cylindrical canteen is 9 inches high and has a 4.5-inch diameter. What volume of water can the canteen hold in gallons?

$V = \pi\ r^2 \times$ height
$r = 1/2\ d = 1/2\ (4.5\ in) = 2.25\ in$
$v = 3.14\ (2.25\ in)^2\ (9\ in) = 143\ in^3$ (rounded)

$$\begin{array}{|c|c|} 143\,\cancel{in^3} & 1\ gal \\ \hline & 231\,\cancel{in^3} \end{array} = 0.619 \text{ gallons} = 0.62 \text{ gallons}$$

Problem 6. How many cubic inches of water are held in a fully charged 1-1/2-inch diameter hose length of 100 feet? Does this value agree with the water handling units in table 3.1?

$V = \pi\ r^2 \times$ length
$r = 1/2\ (1\text{-}1/2\ in) = 3/4\ in$

$$v = 3.14\ (3/4\ in)^2 \left(\begin{array}{c|c} 100\,\cancel{ft} & 12\ in \\ \hline & 1\,\cancel{ft} \end{array} \right) = 2{,}120\ in^3$$

Yes, from table 3.1, 1-1/2-in x 100-ft hose has a volume capacity of 9.2 gal

From table 2.1, 1 gal = 231 in^3

$$\begin{array}{|c|c|} 9.2\,\cancel{gal} & 231\ in^3 \\ \hline & 1\,\cancel{gal} \end{array} = 2{,}125\ in^3$$

Problem 7. What volume of water is held in a 15-inch length of 5/8-inch diameter hose?

$V = \pi\ r^2 \times$ length
$r = 1/2\ (5/8\ in) = 5/16\ in$
$V = 3.14\ (5/16\ in)^2\ (15) = 4.6\ in^3$

Problem 8. There are 4 gallons of water in tank A. Estimate how much weight 4 gallons of water would add to the tank.

total weight of water = volume of water x wt of 1 gal water

$$\begin{array}{|c|c|} 4\ \cancel{\text{gal}} & 8.3\text{ lb} \\ \hline & \cancel{\text{gal}} \end{array} = 33\text{ lb}$$

Problem 9. Estimate the volume of water, in gallons, that is in 8 lengths of 5/8-inch 50-foot mop-up hose in the hose lay? Use the long method from table 2.1 and the short method using table 3.1.

Long method—

Vol in gal= πr^2 x total length

r = 1/2 diameter = 1/2 (5/8 in) = 5/16 in

8 lengths of 50-ft hose per length

$$\text{total length} = \begin{array}{|c|c|} 8\ \cancel{\text{lengths}} & 50\text{ feet} \\ \hline & 1\ \cancel{\text{length}} \end{array} = 400\text{ feet}$$

volume = π (5/16 in)(5/16 in) x 400 ft

need volume in gallons, so set up conversion table

$$\text{vol} = \pi \begin{array}{|c|c|c|c|c|} 5/16\ \cancel{\text{in}} & 5/16\ \cancel{\text{in}} & 400\ \cancel{\text{ft}} & 1\text{ gal} & 12\ \cancel{\text{in}} \\ \hline & & & 231\ \cancel{\text{in}^3} & 1\ \cancel{\text{ft}} \end{array}$$

$$\text{vol gal} = \frac{3.14\ (468.8)\text{ gal}}{231} = \frac{1{,}472\text{ gal}}{231}$$

vol gal = 6.37 gallons = 6 gallons

Short Method—

One hose length of 5/8-in ID x 50 ft has 0.8 gal volume

8 lengths of this hose has a volume of =

8 lengths x 0.8 gal = 6.4 gallons = 6 gallons

Problem 10. Determine the weight of water in a 6-foot length of 2-inch diameter piping.

$$\begin{array}{|c|c|} 2\ \cancel{\text{in}} & 1\text{ ft} \\ \hline & 12\ \cancel{\text{in}} \end{array} = 0.167\text{ ft} \div 2 = .0835\text{ ft} = r$$

V = (.0835 ft)^2 (3.14)(6 ft) = .13 ft^3

$$\begin{array}{|c|c|} .13\ \cancel{\text{ft}^3} & 7.48\text{ gal} \\ \hline & 1\ \cancel{\text{ft}^3} \end{array} = \begin{array}{|c|c|} .97\ \cancel{\text{gal}} & 8.3\text{ lb} \\ \hline & 1\ \cancel{\text{gal}} \end{array} = 8.1\text{ lb}$$

Problem 11. Determine the weight of water in a rectangular tank 3 feet wide, 4 feet high, and 7 feet long.

water wt in tank = vol of tank x weight of water per gallon

vol = 3 ft x 4 ft x 7 ft = 84 ft^3

$$\begin{array}{|c|c|c|} 84\ \cancel{\text{ft}^3} & 7.48\ \cancel{\text{gal}} & 8.3\text{ lb} \\ \hline & \cancel{\text{ft}^3} & \cancel{\text{gal}} \end{array} = 5{,}215.056 = 5{,}215\text{ lb}$$

Problem 12. Determine the weight of the water in a 150-foot length of hose with a 1-inch diameter.

$$\text{finding the radius} = \begin{array}{|c|c|} 1\ \cancel{\text{in}} & 1\text{ ft} \\ \hline & 12\ \cancel{\text{in}} \end{array} = .08\text{ ft} \div 2 = .04\text{ ft} = r$$

$$\text{vol} = 3.14\ (.04\text{ ft})^2\ (150\text{ ft}) = \begin{array}{|c|c|} .75\ \cancel{\text{ft}^3} & 7.48\text{ gal} \\ \hline & 1\ \cancel{\text{ft}^3} \end{array} = 5.61\text{ gal}$$

$$\begin{array}{|c|c|} 5.61\ \cancel{\text{gal}} & 8.3\text{ lb} \\ \hline & 1\ \cancel{\text{gal}} \end{array} = 46.6\text{ lb}$$

Problem 13. Eric weighs his backpack pump when it is empty. It weighs 6.5 pounds. He fills it with 5 gallons of water. How much weight has he added to his pack?

$$\text{weight added} = \begin{array}{|c|c|} 5\ \cancel{\text{gallons}} & 8.3\text{ pounds} \\ \hline & \cancel{\text{gallon}} \end{array} = 41.5\text{ pounds}$$

Problem 14. Daniel is filling helicopter tanks with his engine at a helibase. A helicopter with an empty 360-gallon tank lands, and the pilot tells Daniel to fill the tank three-quarters full of water. How many gallons must he fill? How much weight has Daniel added to the helicopter?

gallon filled = empty tank x amount requested

gallons filled = 360 gal x 3/4 = 270 gal

wt added = volume x wt water

$$\text{wt added} = \frac{270\ \cancel{\text{gal}}}{} \cdot \frac{8.31\ \text{lb}}{1\ \cancel{\text{gal}}} = 2{,}244\ \text{lb}$$

Problem 15. Jacob reads the pressure gauge on his engine and finds the pressure to be 60 pounds per square inch. What height of water is there in the hose lay above his engine's pump?

ht of water = pressure at engine converted to feet

2 feet head = 1 psi

$$\text{vert height of water} = \frac{60\ \cancel{\text{psi}}}{} \cdot \frac{2\ \text{ft}}{1\ \cancel{\text{psi}}} = 120\ \text{feet}$$

Problem 16. What is the pressure Victor needs at the pump if his nozzle is 120 feet above the pump, he has 6 fittings in the line, and he wants a nozzle pressure of 100 pounds per square inch?

pump pressure = DNP + HL + FL

DNP = 100 psi

assume 5 psi drop across each fitting

FL = 6 x 5 psi = 30 psi

$$\text{HL} = \frac{120\ \cancel{\text{ft}}}{} \cdot \frac{0.5\ \text{psi}}{1\ \cancel{\text{ft}}} = 60\ \text{psi}$$

pump pressure = (100 + 60 + 30) psi = 190 psi

Problem 17. Carlos deployed a hose lay of 400 feet of 1-1/2-inch Forest Service cotton-synthetic hose with 3 fittings. What is the friction loss using field application approximations at a nozzle flow of 50 gallons per minute?

total fl = fl hose + fl fittings

FL = 5 psi per fitting

$$\text{fl fittings} = \frac{3\ \cancel{\text{fittings}}}{} \cdot \frac{5\ \text{psi}}{\cancel{\text{fitting}}} = 15\ \text{psi}$$

fl hose for 1-1/2" cotton synthetic at 50 gpm is 8 psi per 100 feet. See table 3.3

$$\text{fl hose} = \frac{8\ \text{psi}}{100\ \cancel{\text{ft}}} \cdot \frac{400\ \cancel{\text{ft}}}{} = 32\ \text{psi}$$

total fl = (32 + 15) psi = 47 psi

Problem 18. Ralph is pumping water from a pond to a fire 230 feet below. He has a hose lay of 600 feet of 1-1/2-inch hose with 5 fittings. The pump pressure is 20 pounds per square inch. What is his nozzle pressure?

nozzle pressure = EP + HG – FL

$$\text{HG} = \frac{230\ \cancel{\text{ft}}}{} \cdot \frac{0.5\ \text{psi}}{1\ \cancel{\text{ft}}} = 115\ \text{psi}$$

FL = 5 psi x 5 fittings = 25 psi

nozzle pressure = 20 psi + 115 psi – 25 psi = 110 psi

Problem 19. Joe lays 400 feet of 1-1/2-inch hose down a slope 100 feet below the pump. He has three brass fittings in the hose. What pump pressure will he need to produce 100 pounds per square inch nozzle pressure?

PP = DNP - HG + FL

DNP = 100 psi (given)

$$\text{FL} = \frac{3\ \cancel{\text{fittings}}}{} \cdot \frac{5\ \text{psi}}{\cancel{\text{fitting}}} = 15\ \text{psi}$$

$$\text{HG} = \frac{100\ \cancel{\text{ft}}}{} \cdot \frac{0.5\ \text{psi}}{1\ \cancel{\text{ft}}} = 50\ \text{psi}$$

PP = (100 – 50 + 15) psi = 65 psi

Problem 20. At sea level the engine can lift water 22.5 feet. What lift will the engine be able to produce at an elevation of 5,000 feet?

We know that there is a 1-foot head loss (HL) per 1,000 ft of elevation. What is the HL for a 5,000 foot elevation?

$$\frac{5{,}000\ \cancel{\text{ft}}}{\ } \cdot \frac{1\ \text{ft (loss)}}{1{,}000\ \cancel{\text{ft}}\ \text{(elev)}} = 5\ \text{ft loss}$$

engine lift = (22.5 – 5) = 17.5 =
18 ft of water can be lifted at 5,000 ft elev

Problem 21. A 15-gallon tank is emptied through a release valve. From the instant the valve is opened to the instant the tank finishes draining, the time is recorded as 3.45 minutes. What is the flow rate through the valve?

$$\text{flow rate} = \text{vol per time} = \frac{\text{vol}}{\text{time}} = \frac{15\ \text{gal}}{3.4\ \text{min}}$$

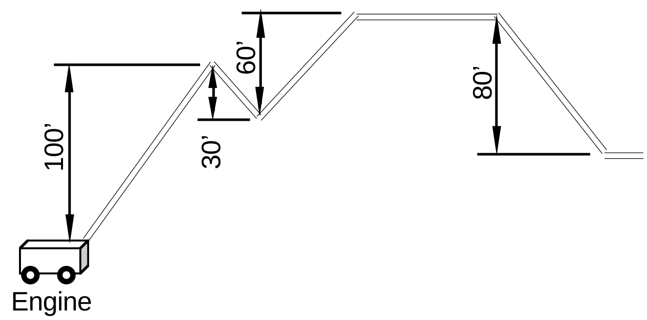
$$\text{flow rate} = \frac{15\ \text{gallons}}{3.45\ \text{minutes}} = 4.35\ \text{gallons/min} =$$

4.4 gal/min = 4.4 gpm

CHAPTER PROBLEM

The following hoselay is in place. A nozzle pressure of 100 psi is needed. What must the engine pump pressure be? There are fittings at each bend in the line (a total of five).

(Not to scale)



EP = DNP + HL or FL – HG

hose height = (100 – 30 + 60 – 80) ft = 50 ft

DNP = 100 psi (given)

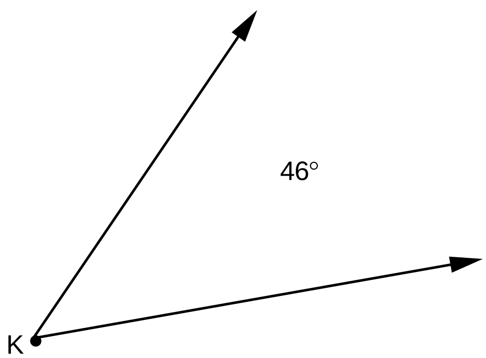
$$\text{head loss} = \frac{50\ \cancel{\text{ft}}}{\ } \cdot \frac{.5\ \text{psi}}{1\ \cancel{\text{ft}}} = 25\ \text{psi}$$

$$\text{friction loss} = \frac{5\ \cancel{\text{fittings}}}{\ } \cdot \frac{5\ \text{psi}}{1\ \cancel{\text{fitting}}} = 25\ \text{psi}$$

engine pump pressure = (100 + 25 + 25) psi = 150 psi

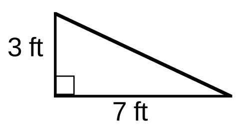
EXERCISE SOLUTIONS

Problem 1. Measure the angle.



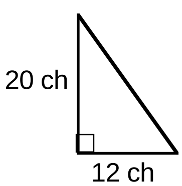
<u>Find the slope percent for problems 2 and 3.</u>

Problem 2.



$$\text{slope \%} = \frac{\text{rise}}{\text{run}} \text{ x } 100 = \frac{3 \text{ ft}}{7 \text{ ft}} \text{ x } 100 = 43\%$$

Problem 3.



$$\frac{20 \text{ ch}}{12 \text{ ch}} \text{ x } 100 = 167\%$$

Problem 4. A hill has a slope of 9 percent. The vertical distance is 5 chains. What is the horizontal distance?

$$\text{slope \%} = 9\% = \frac{\text{rise (vertical distance)}}{\text{run (horizontal distance)}} \text{ x } 100$$

$$\frac{9}{100} = \frac{\text{vd}}{\text{hd}}$$

$$\text{hd} = \frac{\text{vd}}{.09} = \frac{5}{.09} = 56 \text{ chains}$$

Problem 5. A hill has a slope of 60 percent. The horizontal distance is 80 chains. What is the vertical distance?

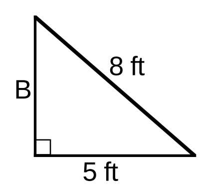
$$\frac{60}{100} = \frac{\text{vd}}{80}$$

Multiply each side by 80.

$$\frac{60(80)}{100} = \frac{\text{vd}}{\cancel{80}} \cancel{(80)}$$

$$\text{vd} = \frac{4800}{100} = 48 \text{ chains}$$

Problem 6. Find the length of side b.



Need a calculator with $\sqrt{x}$ symbol and x^2 function.
$h^2 = x^2 + y^2$

$(8 \text{ ft})^2 = (5 \text{ ft})^2 + (B \text{ ft})^2$

$64 \text{ ft}^2 = B^2 + 25 \text{ ft}^2$

Subtract 25 ft^2 from each side.

$64 \text{ ft}^2 - 25 \text{ ft}^2 = B^2 + 25 \text{ ft}^2 - 25 \text{ ft}^2$

$(64 - 25) \text{ ft}^2 = B^2 + (25 - 25) \text{ ft}^2$

$39 = B^2$

Take the square root of each side.

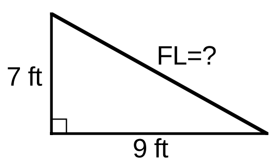
$\sqrt{B^2} = \sqrt{39}$

"$\sqrt{\ }$" is the opposite power of "squared", consequently, "$\sqrt{\ }$" cancels out a value "squared", therefore

$B = \sqrt{39}$

enter 39 into calculator, then $\sqrt{x}$
Side B = 6.25 ft

Problem 7. Raul spots a fire. He sees that the flames reach to the top of the shrubs. From this he determines that the flame height is 7 feet. The span of the fire is 9 feet. What is the flame length?



See figure 4.1 to draw a diagram.

$h^2 = x^2 + y^2$

$h^2 = (9\text{ ft})^2 + (7\text{ ft})^2$

$h^2 = 81\text{ ft}^2 + 49\text{ ft}^2 = 130\text{ ft}^2$

$h^2 = 130\text{ ft}^2$

square root ($\sqrt{\ }$) of both sides

$\sqrt{h^2} = \sqrt{130}$

$h = \sqrt{130}$ (use calculator) = 11 ft

Problem 8. Using a typical scientific calculator, find tan A = 0. 3.

a. Enter '.3' into calculator

b. Press '2nd' and then 'tan' to get $\tan^{-1}$

c. Read answer. 16.7° (rounded)

Instructions may vary for some scientific calculators. Some calculators switch a and b.

Problem 9. Find tan 40°.

a. Enter '40' into calculator

b. Push 'tan'

c. Read the answer: 0.839

Problem 10. Sergio calculates the slope percent and finds it to be 35 percent. What is the measure of the angle?

slope % = 35%

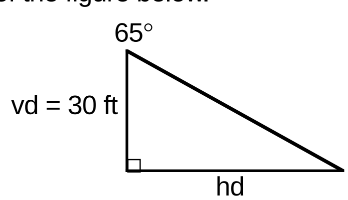
$\frac{35}{100} = 0.35$

a. Enter '.35' into calculator

b. Press '2nd' and 'tan'

c. Read the answer. 19.29°

Problem 11. Find the horizontal distance and the slope distance of the figure below.



$\tan 65° = \frac{hd}{vd} = \frac{hd}{30ft}$

hd = (2.144)(30) = 64 ft

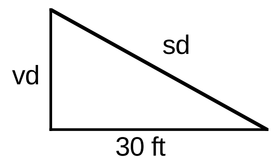
vd = 30 ft

slope distance = $\sqrt{(hd)^2 + (vd)^2}$

$sd = \sqrt{(64\text{ ft})(64\text{ ft}) + (30\text{ ft})(30\text{ ft})}$

$sd = \sqrt{4{,}096\text{ ft} + 900\text{ ft}} = 71\text{ ft}$

Problem 12. Juanita is holding a 5-foot pole at the base of a hill. John is holding a 5-foot pole at the top of the hill. Juanita reads the clinometer and gets a 40 percent slope. The horizontal distance between John and Juanita is 30 feet. Find the slope distance and the vertical distance.



$$\frac{vd}{30\text{ ft}} = 40\%$$

$$\frac{30\text{ ft }(vd)}{30\text{ ft}} = .4\ (30\text{ ft})$$

vd = 12 ft

sd = $\sqrt{(30 \times 30) + (12 \times 12)}$

sd = $\sqrt{900 + 144}$

sd = 32 ft

Problem 13. Mario is going to a fire. He has determined that his pace is 13 paces per chain. The distance to the fire is 20 chains on level ground. How many paces will Mario have to take to get to the fire?

Mario's pace $= \dfrac{13\text{ paces}}{\text{chain}}$

To the fire = 20 chains

$$\frac{20\ \cancel{\text{chain}}}{} \Big| \frac{13\text{ paces}}{\cancel{\text{chain}}} = 260 \text{ paces to get to the fire}$$

Problem 14. Julie is determining her pace length. She has marked off 2 chains on level ground. It takes her 22 paces to walk the 2-chain distance. How many paces does she walk per chain?

Julie's pace $= \dfrac{22\text{ paces}}{2\text{ chains}} = \dfrac{11\text{ paces}}{\text{chain}}$

Julie has a pace of 11 paces per chain.

Problem 15. Billy Joe's pace is 12 paces per chain. He is measuring the distance to a fire from a stream. He takes 480 paces. How many chains is it to the fire from the stream?

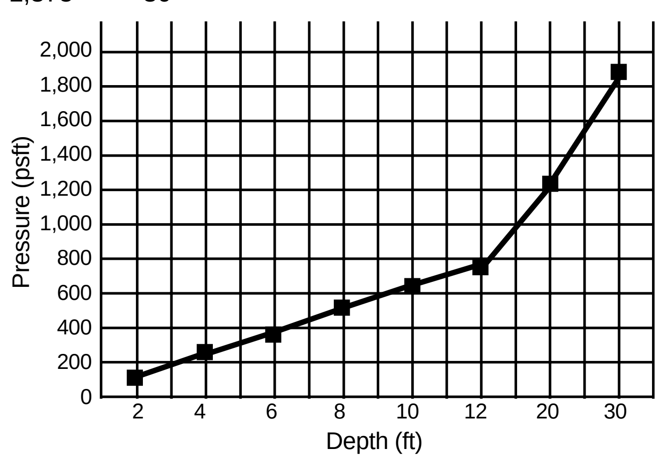
Billy Joe's pace = 12 paces/chain

Billy Joe paces 480 paces at a rate of 12 paces/ch = distance to fire

$$\text{distance to fire} = \frac{480\ \cancel{\text{paces}}}{} \Big| \frac{1\text{ chain}}{12\ \cancel{\text{paces}}} = 40 \text{ chains}$$

Problem 16. The following table shows the relationship between depth and pressure upon bodies submerged in water. Draw a line graph using this information. On the horizontal axis, represent depth in feet. On the vertical axis, represent pressure in pounds per square foot. Find the slope of the line from 2 to 12 feet.

Pressure (psft)	Depth (ft)
123	2
250	4
375	6
500	8
625	10
750	12
1,250	20
1,875	30



$$\text{slope} = \frac{750 - 123}{12 - 2} = \frac{627}{10} = 62.7 = 63$$

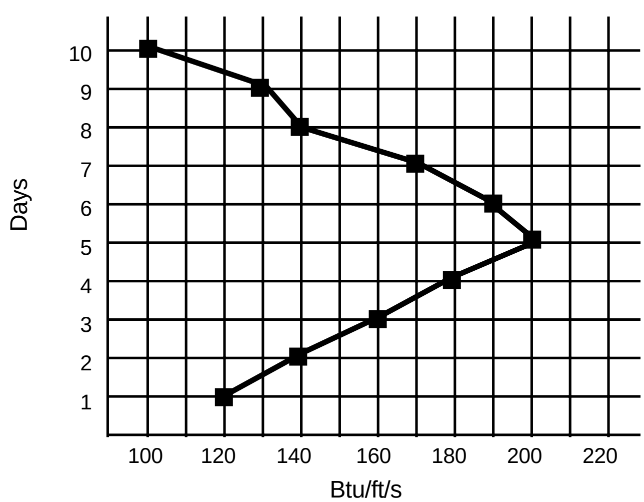
Problem 17. From the line graph in problem 16, read the pressure at 9 feet.

600 psft

Problem 18. The fireline intensity readings, in British thermal units per foot per second for the first ten days of the fire were as follows:

Day	Btu/ft/s
1	120
2	140
3	160
4	180
5	200
6	190
7	170
8	140
9	130
10	100

Draw a line graph using this information. *Note: Days and Btu/ft/s may be on either axis.*



Problem 19. What is the slope of the line graph in problem 18 as it is increasing? On what day does the intensity of the fire peak? On what days is the intensity of the fire 130 British thermal units per foot per second?

$$\text{slope} = \frac{200 - 120}{5 - 1} = 20$$

Intensity peaks on day 5.

Intensity of the fire = 130 Btu/ft/s on days 1 and 9

Problem 20. Find the value that is in grid 3B.

D	9	4	0	3	25
C	1	8	42	8	16
B	5	6	22	2	33
A	6	5	15	7	14
	1	2	3	4	5

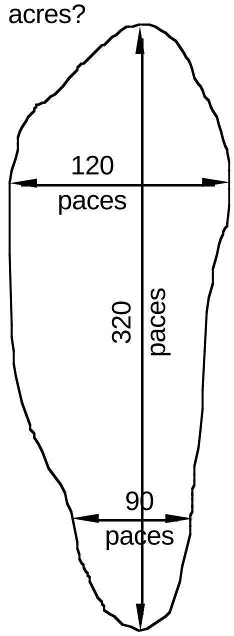
Problem 21. Using the mileage chart in example 13, find the distance between Denver, CO, and Portland, OR.

	Los Angeles, CA	Portland, OR	Albuquerque, NM	Denver, CO	Tampa, FL	Fargo, ND
Los Angeles, CA	0	967	804	1,023	2,549	1,839
Portland, OR	967	0	1,366	1,236	3,064	1,497
Albuquerque, NM	804	1,366	0	439	1,760	1,272
Denver, CO	1,023	1,236	439	0	1,874	875

1,236 miles

EXERCISE SOLUTIONS

Problem 1. Sheryl walked out the following dimensions in a burn site. Her pace is 11 paces per chain. What is the area of the fire in acres?



$$\frac{120\ \cancel{\text{paces}}}{} \bigg| \frac{1\ \text{chain}}{11\ \cancel{\text{paces}}} = 10.9\ \text{chains}$$

$$\frac{320\ \cancel{\text{paces}}}{} \bigg| \frac{1\ \text{chain}}{11\ \cancel{\text{paces}}} = 29.1\ \text{chains}$$

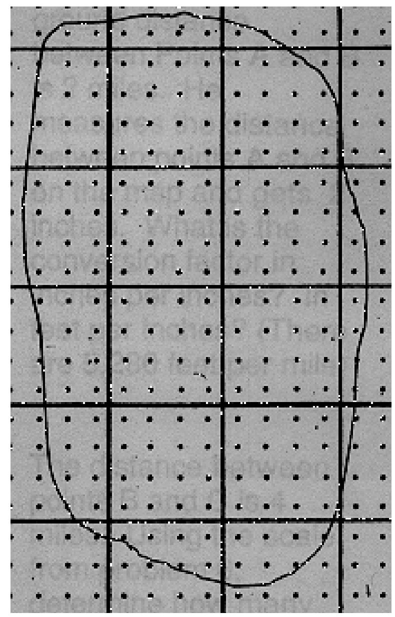
$$\frac{90\ \cancel{\text{paces}}}{} \bigg| \frac{1\ \text{chain}}{11\ \cancel{\text{paces}}} = 8.2\ \text{chains}$$

$$\text{area} = \frac{(10.9 + 8.2)}{2} \times 29.1$$

$$9.55 \times 29.1 = 277.9\ \text{sq ch}$$

$$\frac{277.9\ \cancel{\text{sq ch}}}{} \bigg| \frac{1\ \text{a}}{10\ \cancel{\text{sq ch}}} = 28\ \text{acres}$$

Problem 2. Karen sketched the following burn shape on a 7.5 minute USGS quadrangle map. Use the plastic dot acreage grid to determine the area of the fire.



$$\frac{182\ \cancel{\text{dots}}}{} \bigg| \frac{2.5\ \text{acres}}{1\ \cancel{\text{dot}}} = 455\ \text{acres}$$

Problem 3. The legend on the map shows the scale at 1: 63,000 (inch/inch). Convert this scale to feet per inch. One inch on the map equals how many feet, ground distance?

$$\frac{63{,}000\ \cancel{\text{in}}}{1\ \text{in}} \bigg| \frac{1\ \text{ft}}{12\ \cancel{\text{in}}} = 5{,}250\ \text{ft/in}$$

Problem 4. Using the scale from problem 3, determine the ground distance, in feet, for a map distance of 4 inches.

$$\frac{5{,}250\ \text{ft}}{\cancel{\text{in}}} \bigg| \frac{4\ \cancel{\text{in}}}{} = 21{,}000\ \text{ft}$$

Problem 5. Convert the distance from problem 4 into chains.

$$\frac{21{,}000\,\cancel{ft}}{} \left| \frac{1\text{ ch}}{66\,\cancel{ft}} \right. = 318 \text{ chains (rounded)}$$

Problem 6. Juan is using a map that does not have a scale. He knows the ground distance between points A and B is 2 miles. He measures the distance between points A and B on the map and gets 2 inches. What is the conversion factor in inches per inches? In feet per inches? There are 5,280 feet per mile.

$$\frac{5{,}280\,\cancel{ft}}{\cancel{mi}} \left| \frac{12\text{ in}}{\cancel{ft}} \right| \frac{2\,\cancel{mi}}{2\text{ in}} = 63{,}360 \text{ in}$$

1:63,360 in/in

$$\frac{2\,\cancel{mi}}{2\text{ in}} \left| \frac{5{,}280\text{ ft}}{\cancel{mi}} \right. = 5{,}280 \text{ ft/in}$$

1:5,280 in/ft

Problem 7. The distance between points B and C is 4 miles. Using the scale from problem 6, determine how many inches this distance would be on the map.

1 in = 1 mi
4 mi = 4 in

Problem 8. There is a fire at point C on the map. The ROS is 12 chains/hour. The PT is 3 hours. What is the spread distance?

SD = ROS x PT
SD = 12 ch/h x 3h = 36 chains

Problem 9. Using the fire above and a map scale of 1:21,120 (inch/inch), find the map distance.

1 ch = 66 ft
1 ft = 12 in

$$\frac{36\,\cancel{ch}}{} \left| \frac{66\,\cancel{ft}}{\cancel{ch}} \right| \frac{12\text{ in}}{\cancel{ft}} = 28{,}512 \text{ in}$$

$$\frac{28{,}512\,\cancel{in}}{} \left| \frac{\text{in}}{21{,}120\,\cancel{in}} \right. = 1.4 \text{ inches on the map}$$

Problem 10. Using the information from problems 8 and 9, fill out the map spread worksheet.

Map Spread Worksheet

Line	Input			
0	PP	Projection point	C	
1	ROS	Rate of spread, ch/h	12	
2	PT	Projection time, hr	3	
3	SDCH	Spread distance, ch (line 1 x line 2)	36	
4	SDFT	Spread distance, ft (line 3 x 66 ft/in)	2,376	
5	SCL	Map scale	1:21,120	
6	CF	Conversion factor, ft/in (see map scale conversion)	1,760	
	Output			
1	MD	Map spread distance, in (line 4 divided by line 6)	1.35	

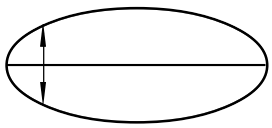
Problem 11. There is a fire that has a rate of spread of 10 chains/hour. The effective windspeed is 14 miles/hour. What will be the perimeter and area of the fire in 2 hours?

Use tables 5.5 and 5.6
perimeter = 43 chains

area = $\frac{7.6 + 6.8}{2}$ = 7.2 = 7 acres

Problem 12. Using an engineer's scale (tenth's ruler) draw a line the length of the fire burn in problem 9.

Problem 13. Use the fire shapes in figure 5.3 to draw the shape of the fire in problem 9. Use an effective windspeed of 5 miles per hour.



Problem 14. Use the information in problems 8 and 13 as well as in figures 5.5 and 5.6 to fill out the size worksheet.

Fire Area/Size Worksheet

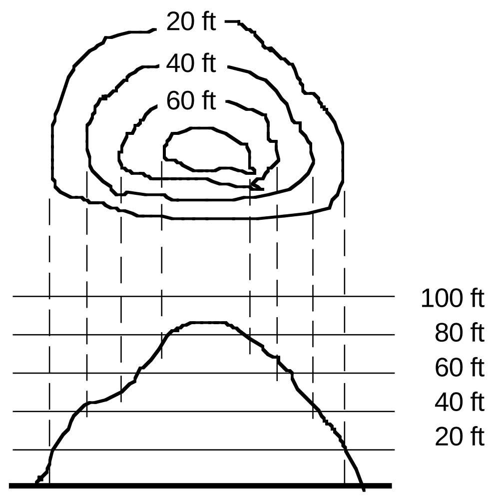
Line	Input		
0	PP	Projection point	C
1	ROS	Rate of spread, ch/h	12
2	EWS	Effective windspeed, mi/h	5
3	PT	Projection time, h	3
4	SD	Spread distance, ch	36
	Output		
	PER	Perimeter, ch	89
	AC	Area, ac	50

Line 1 starts with rate of spread (ROS)

Problem 15. What is the vertical distance between contour lines in the figure below?

50 – 40 = 10 feet

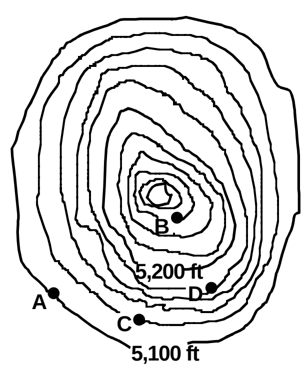
Problem 16. Draw a profile showing the elevation of the contour below.



Problem 17. If the contour lines are close together, what kind of slope will it be, steep or gentle?

steep

Problem 18. Write the elevation for each of the reference contour lines.



Scale 1:24,000 (in/in)

5,100 ft 5,200 ft 5,300 ft

Problem 19. What is the rise in elevation between each contour line in problem 18?

5,200 ft – 5,100 ft = 100/5 = 20 ft

Problem 20. What is the point C elevation on the figure in problem 18?

5,120 ft

Problem 21. How many contour lines are between points A and B on the figure in problem 18?

8 lines

Problem 22. What is the rise in elevation between points A and B?

8 x 20 = 160 ft

Problem 23. What is the slope percentage between points A and B?

between A & B is 0.75 inch

0.75 in x 24,000 in/in = 18,000 in

$$\frac{18{,}000\ \cancel{\text{inches}}}{} \Big| \frac{1\ \text{foot}}{12\ \cancel{\text{inches}}} = 1{,}500\ \text{ft}$$

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{160\ \text{ft}}{1{,}500\ \text{ft}} = 10.67\% = 11\%$$

Problem 24. Fill out the slope worksheet.

Slope Worksheet

Line	Input		
0	PP	Projection point	A-B
1	CON INT	Contour interval, ft	20 ft
2	SLC	Map scale	1:24,000
3	CF	Conversion factor, ft/in	2,000
4	# INTVLS	# of contour intervals	8
5	RISE	Rise in elevation, ft	160
6	MD	Map distance, in (between points)	0.75 in
7	HZGD	Horizontal ground distance, ft	1,500
	Output		
1	SLP %	Slope, %	11%

Problem 25. Calculate the slope for points C and D and put on the slope worksheet. Calculate the slope percent between points B and D.

distance between C & D = 0.5 in

$$0.5\ \text{in} \times \frac{24{,}000\ \text{in}}{1\ \text{in}} = 12{,}000\ \text{in}$$

12,000 in = 1,000 ft

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{60}{1{,}000} = 6\%$$

Slope Worksheet

Line	Input		
0	PP	Projection point	C-D
1	CON INT	Contour interval, ft	20
2	SLC	Map scale	1:24,000
3	CF	Conversion factor, ft/in	2,000
4	# INTVLS	# of contour intervals	3
5	RISE	Rise in elevation, ft	60
6	MD	Map distance, in (between points)	0.5 in
7	HZGD	Horizontal ground distance, ft	1,000
	Output		
1	SLP %	Slope, %	6%

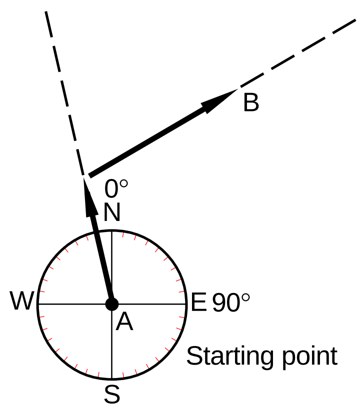
distance between B & D = 0.5 in

$$0.5\ \text{in} \times \frac{24{,}000\ \text{in}}{\text{in}} = 12{,}000\ \text{in} = 1{,}000\ \text{ft}$$

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{80}{1{,}000} = 8\%$$

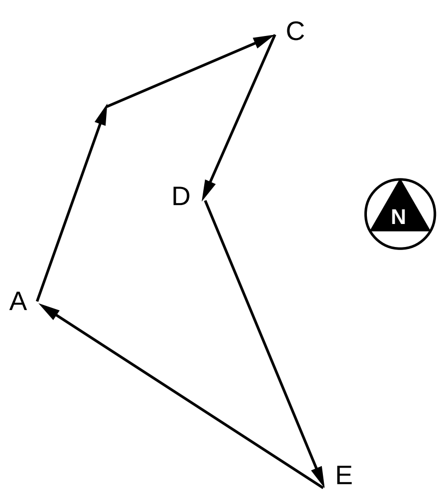
EXERCISE SOLUTIONS

Problem 1. George is going to a fire. He has to walk around a steep rock formation in his path. The diagram below shows the path he walked. What are the bearings of each line he walked?



A = N 13.5° W
B = N 60° E

Problem 2. Jerry is pacing a fire. The final figure is sketched below. Find the compass bearing and distance between each line, starting at point A and following the direction of the arrows. Use an engineer's tenths ruler and protractor. Each 1/10 inch = 10 feet.

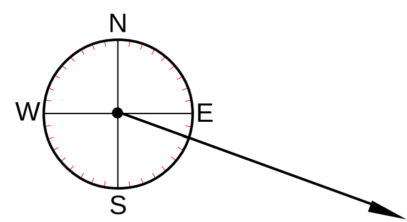


AB	110 ft	N 19° E
BC	100 ft	N 67° E
CD	100 ft	S 23° W
DE	165 ft	S 23° E
EA	180 ft	N 57.5° W

When the bearings are determined for all the lines surrounding a tract of land and they follow the courses continuously around the tract to return to the starting point. What is this called? A closed traverse.

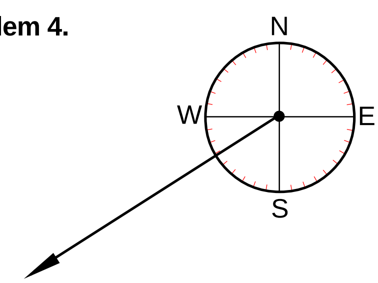
<u>In each diagram below write the azimuth angle.</u>

Problem 3.



110°

Problem 4.



240°

Problem 5. Determine the back azimuth for each of the forward azimuths in problems 3 and 4.

110° + 180° = 290°
235° – 180° = 55°

Problem 6. Mary sights a fire from a rock outcropping at 280 degrees. She starts out but loses sight of the fire. She backsights the rock outcropping and reads 130 degrees. How far off her mark is she? What direction does she have to move to get back on course?

130° + 180° = 310°
310° – 280° = 30° off to the right is needed to get back on track to 280°

Problem 7. Alan is in Ocala, FL. He takes a compass reading and gets 60 degrees. Use the declination chart (see figure 6.2) to determine the declination for the area. What is his true azimuth reading?

declination is 2°W, so subtract
60° – 2° = 58°

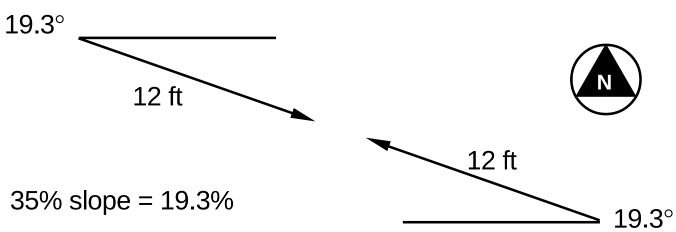
Problem 8. Brenda is in Las Cruces, NM. She takes a compass reading and reads 230°. Find her true reading.

230° + 11°E = 241°

Problem 9. Fred is in San Antonio, TX. He reads his map and gets an azimuth reading of 150° from his present location to where he is headed. What is his magnetic reading?

150° – 8° = 142°

Problem 10. Jane has a slope reading of 35 percent. The distance between points A and B, where the reading was taken, is 12 feet. Draw a vector from each point.



35% slope = 19.3%

Problem 11. Bobby is standing on a ridge with the wind blowing in her face. She is facing N45°E. What is the wind direction and the wind vector?

NE, 225°NE

Problem 12. Connie walked the perimeter of a fire. She radioed her bearings and distance to the Incident Commander. Below are the instructions. Convert each bearing into a magnetic reading, and then adjust each magnetic reading to a true magnetic reading by using a declination of 15°E. Convert the distance to feet, Connie's pace is 12 paces per chain. Then draw a scale model using an engineer's tenths ruler and a protractor. Be sure to write the scale used for the diagram.

Instructions: Connie starts at point 1 and goes north 70° east (N70°E) for 25 paces; from point 2 she goes S54°E for 18 paces; from point 3 she goes S21°E for 19-1/2 paces, from point 4 she goes S84°W for 12-1/2 paces; from point 5 she goes S37°W for 28-1/2 paces; from point 6 she goes N49°W for 20 paces; from point 7 she goes N57°E for 18 paces; from point 8 she goes N54°W for 24-1/2 paces; from point 9 she goes N35°E for 5-1/2 paces. From her final location, record the bearing (degrees) and distance (feet) from the beginning point. If the error of closure on the closed traverse is greater than 15 feet, try plotting the traverse again.

<u>pt 1</u> $\dfrac{25\ \cancel{\text{paces}}}{} \,\Big|\, \dfrac{\cancel{\text{chain}}}{12\ \cancel{\text{paces}}} \,\Big|\, \dfrac{66\ \text{feet}}{\cancel{\text{chain}}} = 137.5\ \text{ft}$

Convert the bearing to a magnetic reading. The NE quadrant starts at 0°. 70° + 0° = 70°. Adjust the magnetic reading to a true 70° + 15° (declination) = 85°

<u>pt 2</u> $\dfrac{18\ \cancel{\text{paces}}}{} \,\Big|\, \dfrac{\cancel{\text{chain}}}{12\ \cancel{\text{paces}}} \,\Big|\, \dfrac{66\ \text{feet}}{\cancel{\text{chain}}} = 99\ \text{ft}$

180° – 54° = 126°
126° + 15° = 141°

<u>pt 3</u> 107.25 ft
180° – 21° + 15° = 174°

<u>pt 4</u> 68.75 ft SW quadrant starts at 180°
180° + 84° + 15° = 279°

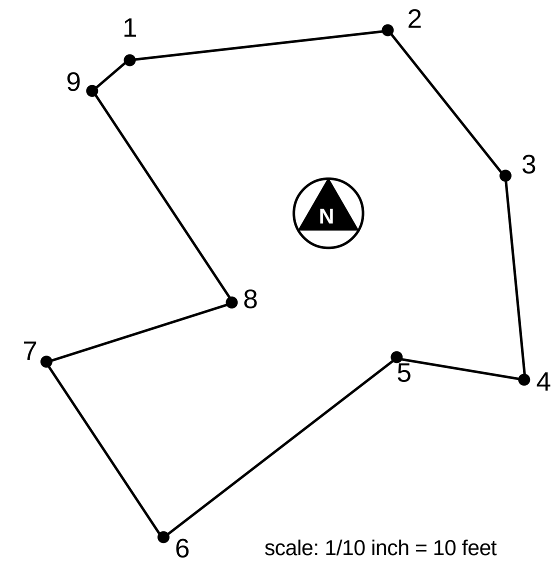
<u>pt 5</u> 156.75 ft
180° + 37° + 15° = 232°

<u>pt 6</u> 110 ft NW quadrant starts at 360°
360° – 49° + 15° = 326°

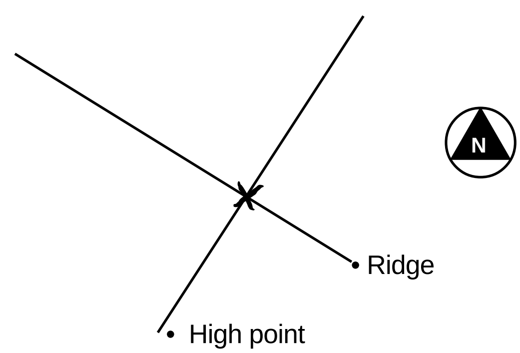
<u>pt 7</u> 100 ft NE quadrant starts at 0°
57° + 15° = 72°

<u>pt 8</u> 134.75 ft
360° – 54° + 15° = 321°

<u>pt 9</u> 30.25 ft
35° + 15° = 50°

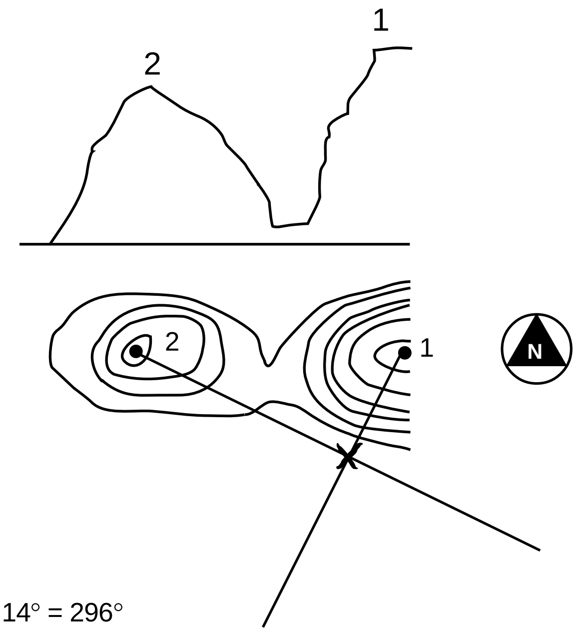


Problem 13. Alix is on a ridge when he spots a fire. He takes a compass reading and gets 290°. He walks to another high point and takes another compass reading and gets 20°. The declination for the area is 17°E. Find his location in relation to the points below.



290° + 13° = 303°
17° + 13° = 30°

Problem 14. Jim is in the woods when he becomes confused on which direction to go. He can see two mountain ridges in the distance. He locates the two ridges on his map. He takes a compass reading to the first ridge of 40°. He takes a reading to the second ridge of 310°. The declination for the area is 14°W. Plot his location below.



310° – 14° = 296°
40° – 14° = 26°

step 2. convert to back azimuths
296° – 180° = 116° (ridge 2)
28° + 180° = 208° (ridge 1)

Problem 15.

49 79 60
1~~50~~° ~~20~~′ 45″ borrow 1′ 60″ + 40″ = 100″ then subtract
– 125° 32′ 54″ 100″ – 50″ = 50″
24° 47′ 51″ borrow 1° 60′ + 10′ = 70′ then subtract
70′ – 30′ = 40′

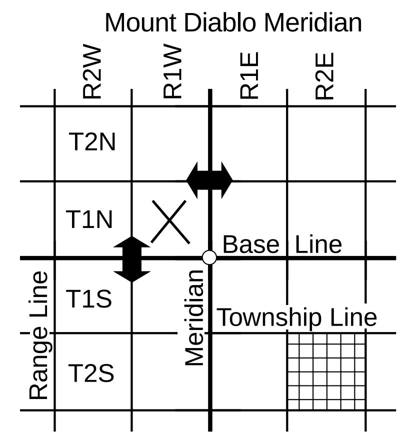
Problem 16.

1
55° 43′ 25″ 60″ = 1′ 80″ – 60″ = 20″
+ 244° 25′ 55″ 60′ = 1° 68′ + 1′ – 60′ = 9′
299° 68′ 80″ 299° + 1° = 300°
300° 09′ 20″

Problem 17. Find the range of latitude and longitude of the borders of Arizona on a map.

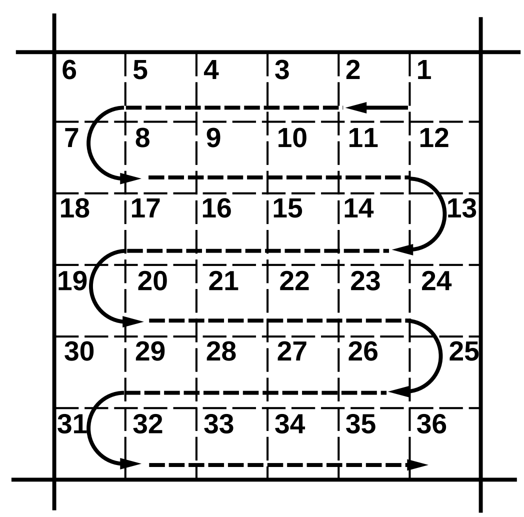
Latitude 31° to 36°N
Longitude 109° to 114°W

Problem 18. Identify the location of the X.



T1N R1W M.D.M.

Problem 19. What is the section location of square 8 in the section diagram in figure 6.5?



Sec. 8 T2S R2E

EXERCISE SOLUTIONS

Problem 1. Lupe is at an elevation of 1,000 feet. The dry bulb temperature is 80 °F. The wet bulb temperature is 52 °F. What is the relative humidity and the dew point?

Use figure 7.1
RH = 9
DP = 15

Problem 2. What is the relative humidity if the wet bulb temperature is 47 °F and the dry bulb temperature is 64 °F?

Use figure 7.1
RH = 24

Problem 3. Vivian is trying to determine what the minimum relative humidity will be at 1600 hours. She is at an elevation of 1,200 feet. The current dry bulb temperature is 67 °F. The wet bulb temperature is 56 °F. The predicted temperature for the afternoon is 80 °F.

Use figure 7.1
DP = 48
RH = 32

EXERCISE SOLUTIONS

Problem 1. What is the reference fuel moisture (RFM) at a temperature of 89 °F and a relative humidity of 23 percent?

between 800-1959, uncorrected RFM = 3% RFM

Problem 2. What is the reference fuel moisture (RFM) at a temperature of 67 °F and a relative humidity of 67 percent?

between 800-1959, uncorrected RFM = 9% RFM

Problem 3. What is the fuel moisture correction (FMC) for May 21, at 1330 with a south aspect and 19 percent slope in a clear unshaded area for elevations B, L, and A?

<u>use table 8.2</u>

FMC	1,000-2,000 feet below the site	0% FMC
	± 1,000 feet of site location	0% FMC
	1,000-2,000 feet above site	1% FMC

Problem 4. What is the fuel moisture correction (FMC) for August 12, at 0830 with a north aspect in cloudy skies (shaded fuel) on a 44 percent slope for elevations B, L, and A?

<u>use table 8.3</u>

1,000-2,000 ft below site location	= 4% FMC
±1,000 ft from site location	= 5% FMC
1,000-2,000 ft above site location	= 6% FMC

Problem 5. It is July 19, at 1500. Fuels are exposed to the sun on a west aspect. Readings from a belt weather kit taken 600 feet below the fire give a dry bulb temperature of 99 °F and a relative humidity of 12 percent. The slope is 42 percent. What is the fine dead fuel moisture (FDFM)? Input the data values on the fine dead fuel moisture worksheet (see figure 8.1).

from table 8.1 reference fuel moisture is 2%

from table 8.2 dead fuel moisture content correction is 0%FMC

Add the values together (RFM + FMC = FDFM) = 2%

Fine Dead Fuel Moisture Worksheet

Input

0	Projection point	**Prob 5**		
1	Daytime calculation	D	D	D
2	Dry bulb temperature, °F	**99**		
3	Wet bulb temperature, °F			
4	Dew point, °F			
5	Relative humidity, %	**12**		
6	Reference fuel moisture (RFM), % (from table 1)	**2**		
7	Month	**July**		
8	Unshaded (U) or shaded (S) (Circle)	U/S	U/S	U/S
9	Time	**1500**		
10	Elevation change (Circle) B = 1,000 to 2,000 feet below site L = ±1,000 feet of site location A = 1,000 to 2,000 feet above site	B/L/A	B/L/A	B/L/A
11	Aspect (N, E, S, W)	**West**		
12	Slope, %	**42**		
13	Fuel moisture correction (FMC), % (from table 2, 3, or 4)	**0**		

Output

1	Fine dead fuel moisture (FDFM), % (line 6 + line 13)	**2**		

Figure 8.1—Fine dead fuel moisture worksheet.

Worksheet for Problem 5

EXERCISE SOLUTIONS

Problem 1. What is the midflame windspeed in a partially sheltered area of fuel model 13 if the 20-foot windspeed is given as 16 miles per hour?

MFWS = 20 ft WS x Adj factor = 16 mi/h x 0.3 = 5 mi/h

Problem 2. A fire is burning in unsheltered fuel. Joy determines that the fuel is a model 4 fuel and is told that the 20-foot winds are blowing at 11 miles per hour. What is the midflame windspeed?

MFWS = 11 mi/h x 0.6 = 7 mi/h

Problem 3. A fire is spreading up a 35 percent slope in tall grass of fuel model 3. The midflame windspeed is 4 miles per hour and is blowing uphill. The fine dead fuel moisture in the grass is 4 percent. Determine the rate of spread, flame length, fireline intensity, and heat per unit area. Use the following nomograms and worksheet found in appendix E to solve the problem.

Nomogram—3. Tall grass—Low windspeed
Nomogram worksheet (see next page)

Problem 4. A fire is spreading uphill in timber litter with enough green fuel in the understory to affect fire behavior. The timber is considered a fuel model 10. The midflame windspeed is 5 miles per hour, the fine dead fuel moisture is 3 percent, and the slope is 20 percent. The live fuel moisture can be approximated to be 100 percent.

Determine the rate of spread, heat per unit area, flame length, and fireline intensity for this fire. Use the following nomograms and worksheet found in appendix E to solve the problem.

Nomogram –10. Timber (Litter & Understory)—Low windspeed Nomogram worksheet (see next page)

Problem 5. The operations unit has asked Peg to prepare a "prescription" for an operational plan for tomorrow's day shift. Handcrews are constructing indirect handline in advance of the fire. The concern is that the fire will burn through the area before the crews can complete the line.

The operations unit needs a range of dead fuel moistures and effective windspeeds that will keep the fire's forward spread within 18 chains per hour. This will allow the handcrews to safely complete the indirect line. She determines that the fire is burning in a fuel model 9.

What is the range of dead fuel moistures and effective windspeeds needed to safely complete the handline?

What is the flame length?

Use Nomogram – 9. Hardwood litter. See appendix E.

Since this is a prescribed burn, use the nomogram backwards.
DFM = 10%
EWS = 9 mi/h
FL = 4 ft

Name of fire ____________ Fire pred spec ____________
Date ____________ Time ____________
Proj period date ____________ Proj time from ________ to ________

Fire Behavior Worksheet

Input					
0	PP	Projection point	**#3**	**#4**	**#5**
1	Model #	Fuel model number (1-13)	**3**	**10**	**9**
2	1H-FDFM	Fine dead fuel moisture, %	**4**	**3**	**10**
3	LFM	Live fuel moisture, %		**100**	
4	MFWS	Midflame windspeed, mi/h	**4**	**5**	
5	SLP	slope, %	**35**	**20**	
6	EWS	Effective windspeed, mi/h	**5**	**5**	**9**
Output					
1	ROS	Rate of spread, ch/h	**140**	**10**	**18**
2	HA	Heat per unit area, Btu/ft^2	**800**	**1550**	
3	FLI	Fireline intensity, Btu/ft/s	**2300**	**280**	
4	FL	Flame length, ft	**15**	**6**	**4**
5	SD	Spread distance, ch			
		Map spread distance, in			
6	PER	Perimeter, ch			
7	AC	Area, ac			
8	SPOT	Max spotting distance, mi			
		Map distance spot, in			
9	PIG	Probability of ignition, %			

Fine Dead Fuel Moisture/Probability of Ignition Worksheet

Input					
0	PP	Projection point			
1	D	Daytime calculation	D	D	D
2	DB	Dry bulb temperature, °F			
3	WB	Wet bulb temperature, °F			
4	DP	Dew point, °F			
5	RH	Relative humidity, %			
6	RFM	Reference fuel moisture, % (table 2)			
7	MO	Month			
8	SH	Unshaded (U) or shaded (S)	U/S	U/S	U/S
9	T	Time			
10	CH	Elevation change B = 1,000 ft to 2,000 ft below site L = ± 1,000 ft of site location A = 1,000 ft to 2,000 ft above site	B/L/A	B/L/A	B/L/A
11	ASP	Aspect, (N, S, E, W)			
12	SLP	Slope, %			
13	FMC	Fuel moisture correction, % (table 3, 4, or 5)			
Output					
1	1H-FDFM	Fine dead fuel moisture, % (line 6 + line 13)			
2	PIG	Probability of ignition, % (table 12)			

Slope Worksheet

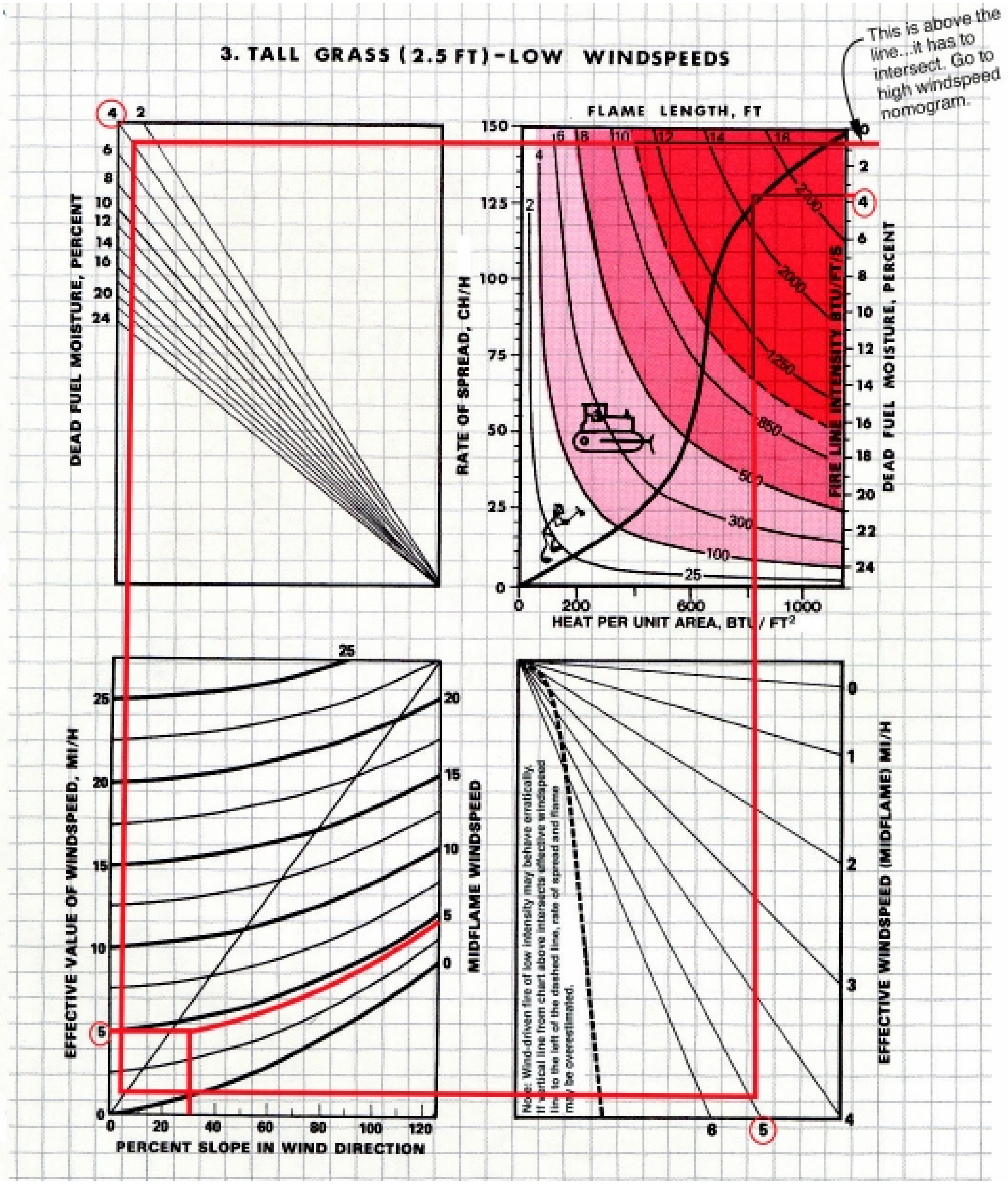
Input					
0	PP	Projection point			
1	CON INT	Contour interval, ft			
2	SLC	Map scale			
3	CF	Conversion factor, ft/in			
4	# INTVLS	Number of contour intervals			
5	RISE	Rise in elevation			
6	MD	Map distance, in (between points)			
7	HZGD	Horizontal ground distance, ft			
Output					
1	SLP%	Slope, %			

Wind Adjustment Worksheet

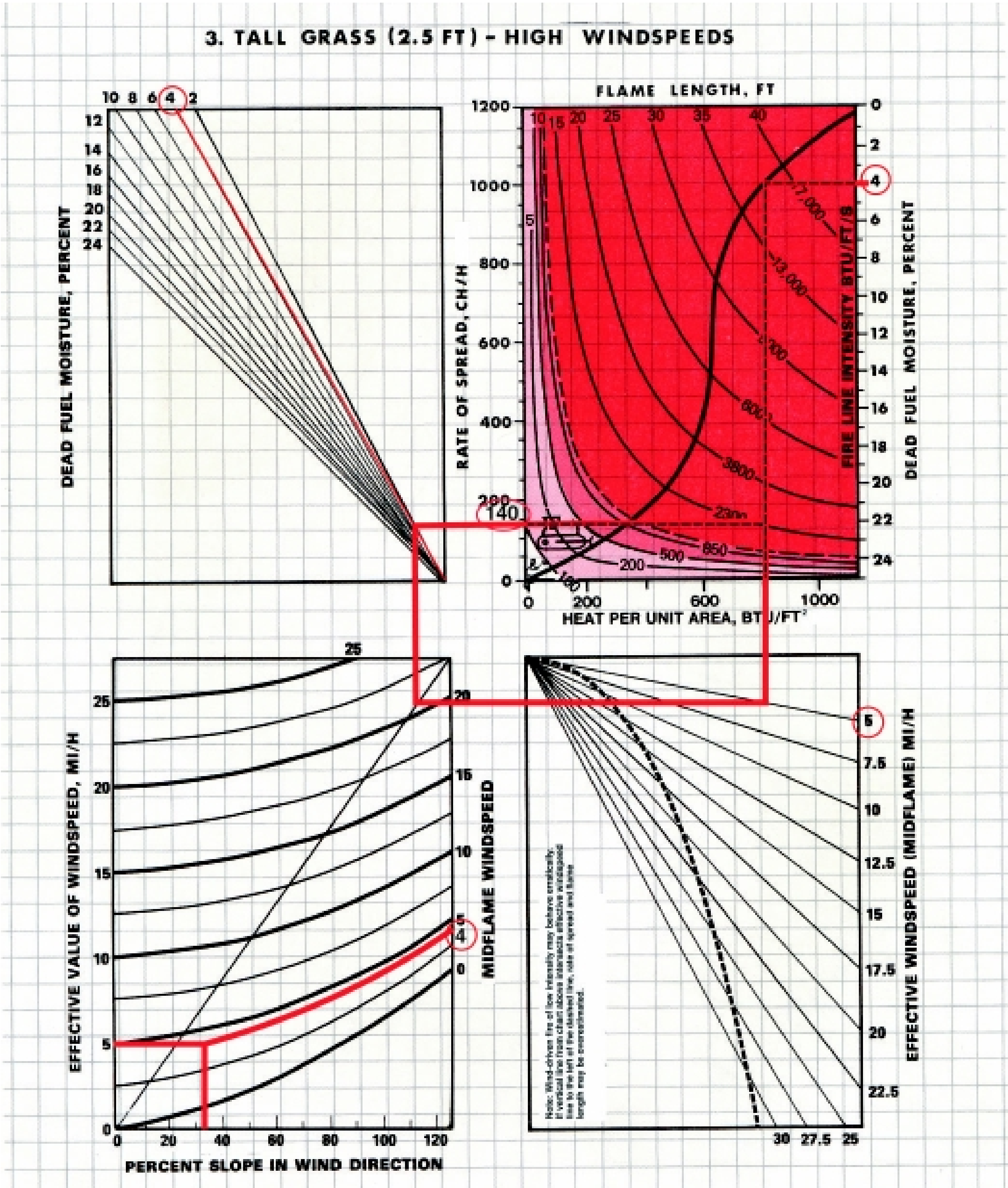
Input					
0	PP	Projection point			
1	20' W	20-ft windspeed, mi/h			
2	MODEL #	Fuel model number (1-13)			
3	SHLTR	Wind sheltering 1 = unsheltered 2 = partially sheltered 3 = fully sheltered, open 4 = fully sheltered, closed			
4	WAF	Wind adjustment factor (table 7)			
Output					
1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)			

Nomogram version – June 1993

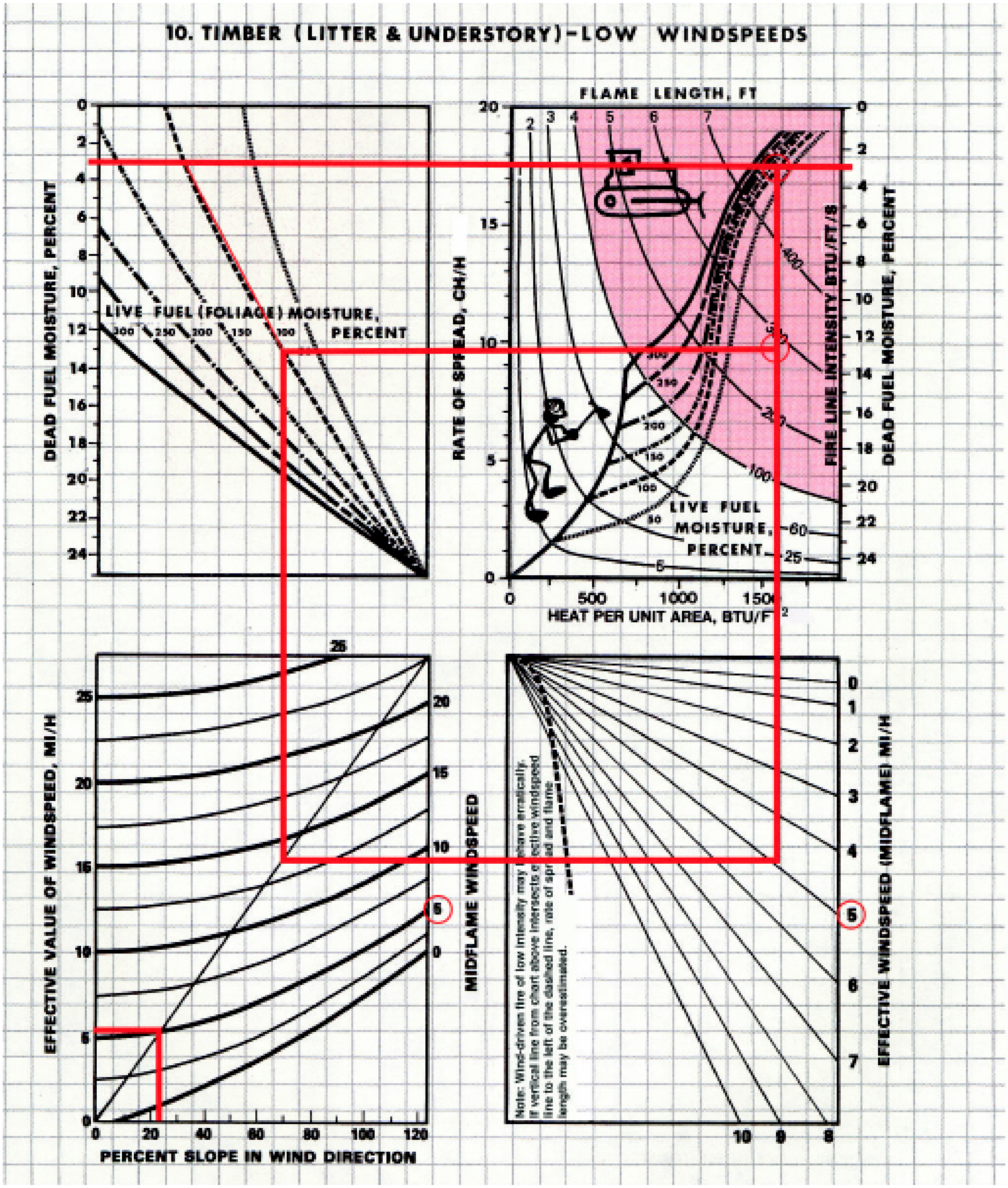
Problems 3, 4, and 5.


3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS
This is above the line...it has to intersect. Go to high windspeed nomogram.
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CH/H
FIRE LINE INTENSITY BTU/FT/S
HEAT PER UNIT AREA, BTU / FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame may be overestimated.

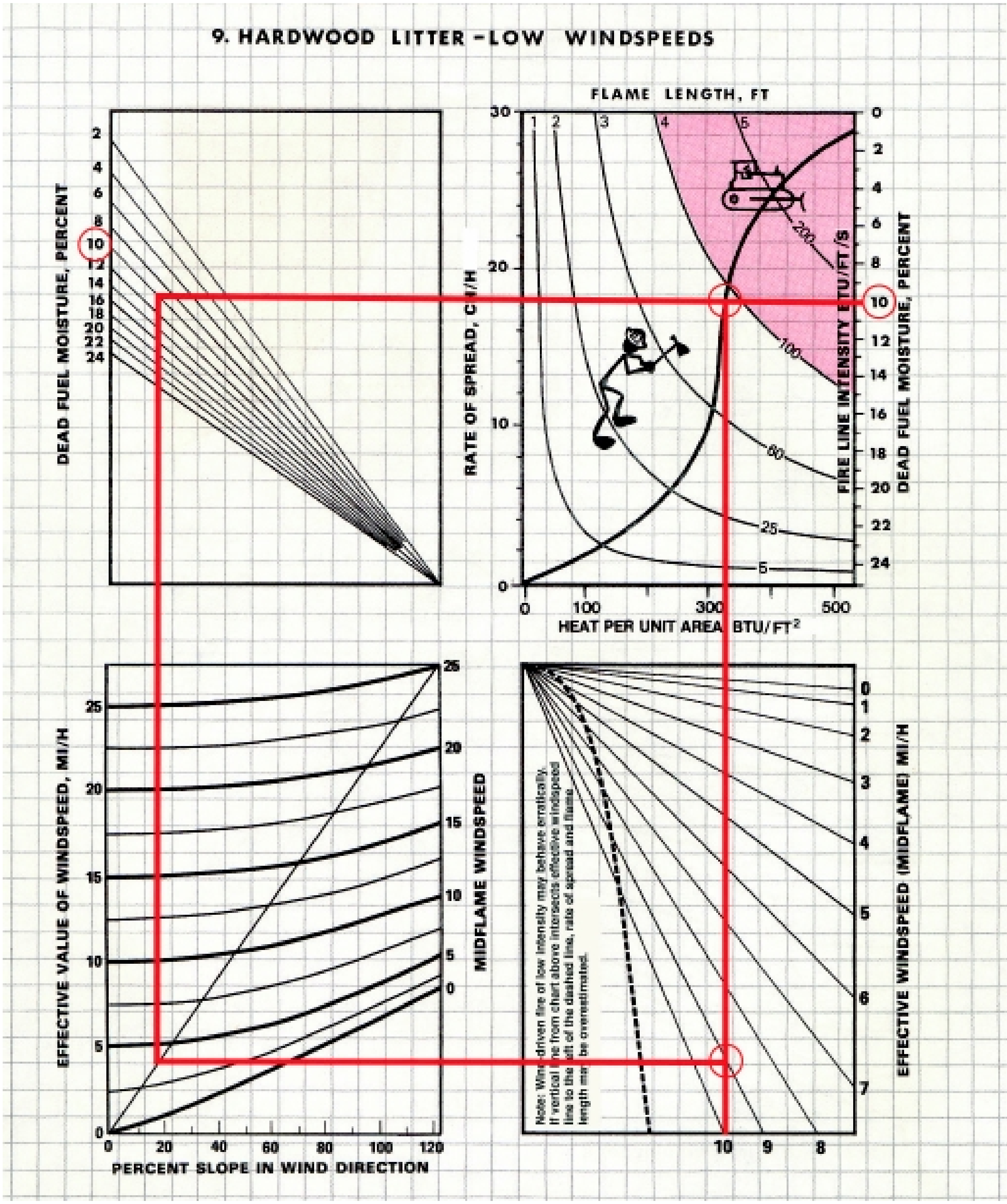
Problem 3


3. TALL GRASS (2.5 FT) - HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CH/H
FIRE LINE INTENSITY, BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
140
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H

Problem 3


10. TIMBER (LITTER & UNDERSTORY)-LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
300 250 200 150 100
RATE OF SPREAD, CH/H
FLAME LENGTH, FT
FIRE LINE INTENSITY BTU/FT/S
400
300
200
100
LIVE FUEL MOISTURE, PERCENT
60
25
5
HEAT PER UNIT AREA, BTU/FT²
0 500 1000 1500
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
0 20 40 60 80 100 120
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

Problem 4


9. HARDWOOD LITTER - LOW WINDSPEEDS
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CH/H
FIRE LINE INTENSITY BTU/FT/S
HEAT PER UNIT AREA BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
PERCENT SLOPE IN WIND DIRECTION

Problem 5

Problem 5

A. Locate 18 ch/h rate of spread.

B. Draw a horizontal line from this point to right edge of upper right quadrant.

C. Circle dead fuel moisture value in both upper left and upper right quadrants.

D. Draw horizontal line from where the line in step B intersects the s-curve to the line pertaining to the dead fuel moisture value in the upper left quadrant.

E. Draw a vertical line from the s-curve intersection down through all the effective windspeeds in the lower right quadrant.

F. Draw a vertical line from the dead fuel moisture intersection in upper left down into the lower left quadrant, until the diagonal is reached. Draw a horizontal line from this point directly into lower right quadrant until the vertical line is reached.

G. Effective windspeed is determined from this intersection point as 9mi/h.

H. Flame length can be approximated as 4 ft based on the s-curve intersection point in upper right quadrant.

Problem 6. The rate of spread of the fire is 6 chains per hour. What will the spread distance be in 4 hours?

SD = ROS x PT
SD = 6 ch/h x 4h = 24 ch

Problem 7. What is the map distance of the ground spread distance from problem 6 on a map with a scale of 1:62,500?

$$24\,\cancel{\text{ch}} \;\Big|\; \frac{66\,\cancel{\text{ft}}}{\cancel{\text{ch}}} \;\Big|\; \frac{12\text{ in}}{\cancel{\text{ft}}} = 19{,}008\text{ in}$$

$$19{,}008\,\cancel{\text{in}} \;\Big|\; \frac{1\text{ in}}{62{,}500\,\cancel{\text{in}}} = 0.3\text{ inches}$$

Problem 8. There is a fire in a Grand Fir forest. The diameter at breast height is 33 inches. What is the flame height?

97 ft
Use spotting nomogram 1

Problem 9. Input the following values into the spotting worksheet.
Torching tree DBH = 15 in
Torching tree height = 120 ft
Average tree cover height = 100 ft
Windspeed at 20-ft height = 30mi/h
Torching tree species—lodgepole pine

See next page

Problem 10. Using the data above, find the flame height and flame duration.

Use nomogram 1 for flame height of 47 ft
Use nomogram 2 for flame duration of 6.1
Input the values in the spotting worksheet

Problem 11. Using the data above, find the ratio of lofted firebrand height to flame height.

Use spotting nomogram 3 and the spotting worksheet
7:8

Problem 12. For a closed canopy forest with the above data, find the maximum spotting distance.

Use nomogram 4 and the spotting worksheet
0.4 mi

Problem 13. A fire has a ROS of 30 chains per hour and a heat per unit area of 900 British thermal units per square foot. What is the flame length?

Use the fire characteristics chart
8 ft

Problem 14. If the wind and slope increase the ROS to 60 chains per hour, but the fuel characteristics remain the same, what will the resulting flame length be?

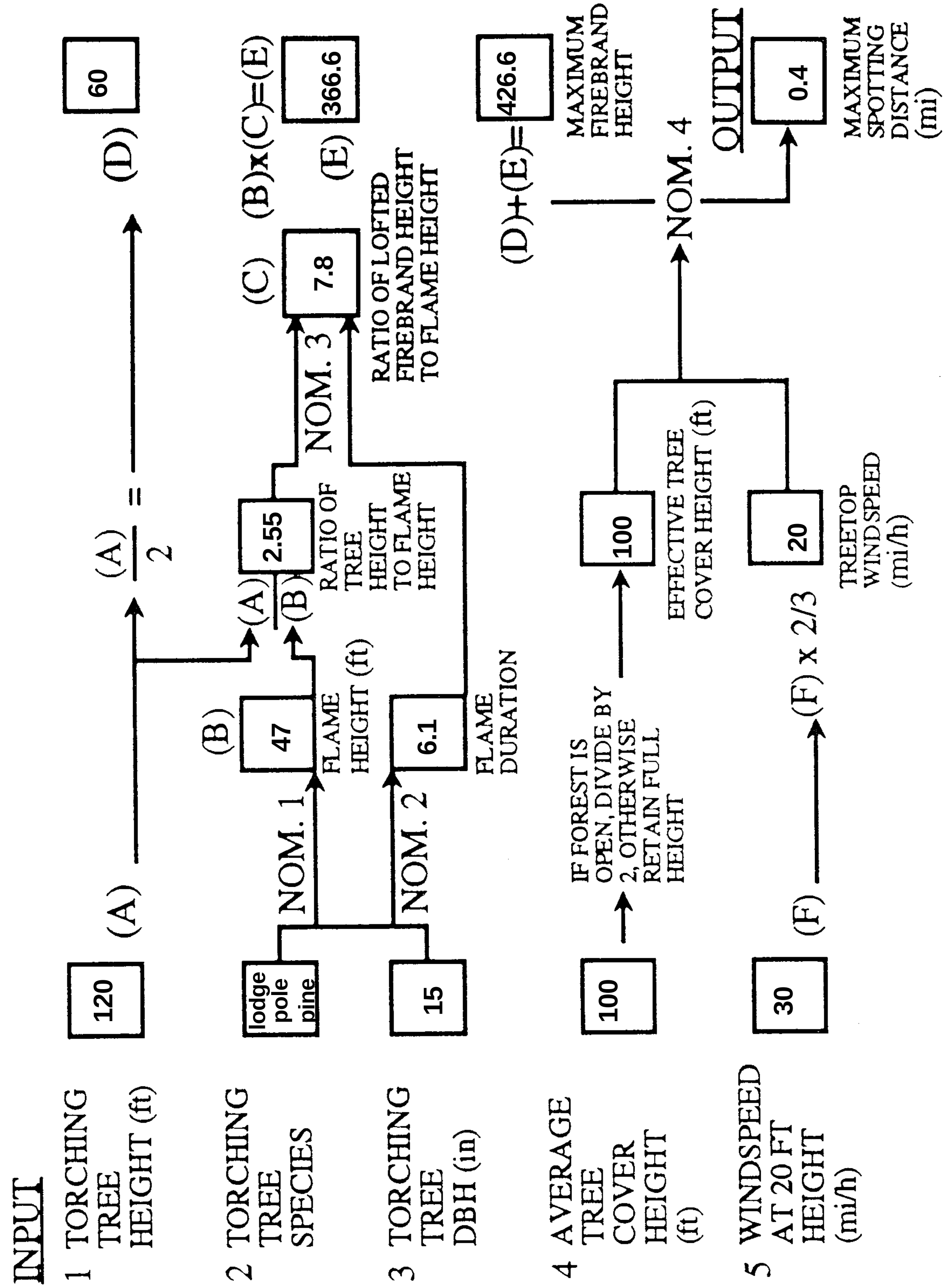
11 ft

Problem 15. A fire is spreading at a rate of 40 chains per hour. The flame length is 8 feet. What is the heat per unit area?

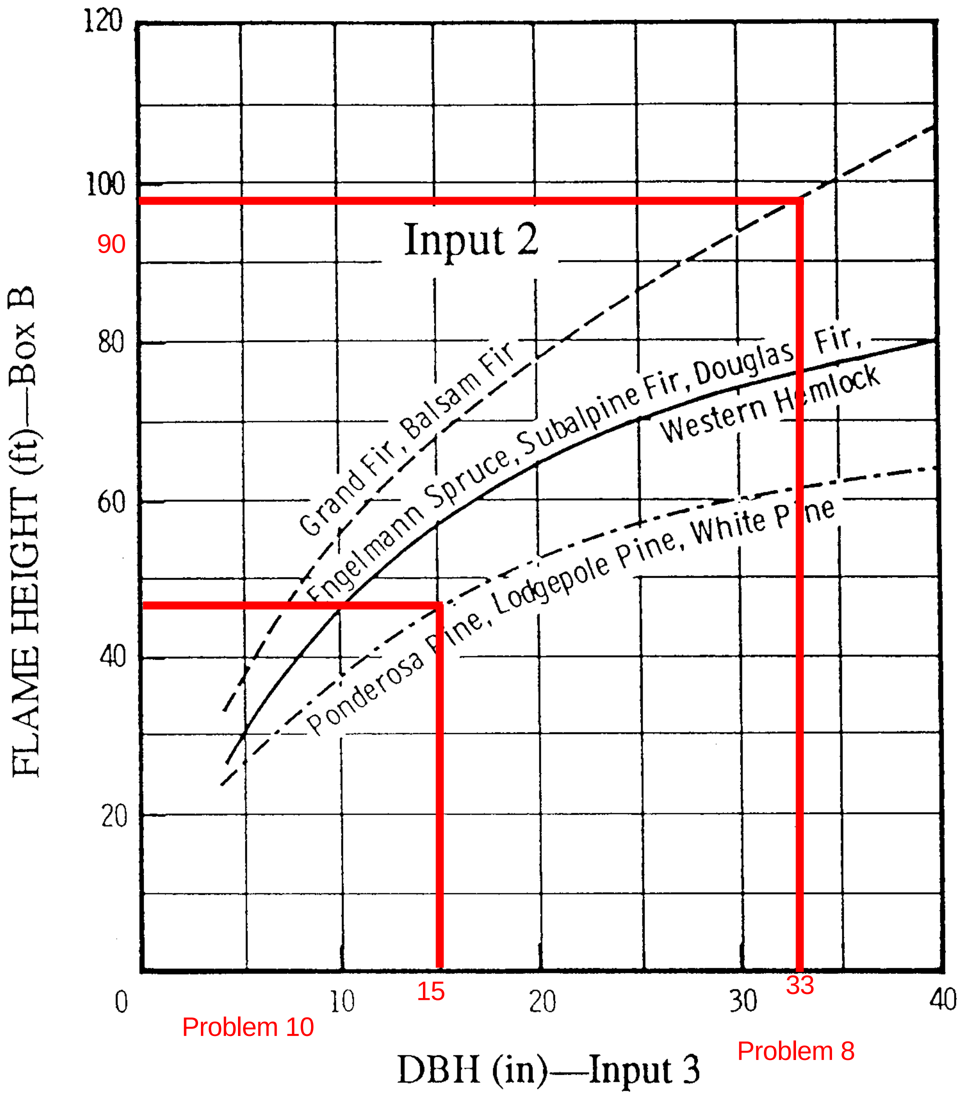
650 Btu/ft^2

Problem 16. In the fire in problem 15, the ROS increased to 70 chains per hour. The fuel characteristics are the same. What is the flame length?

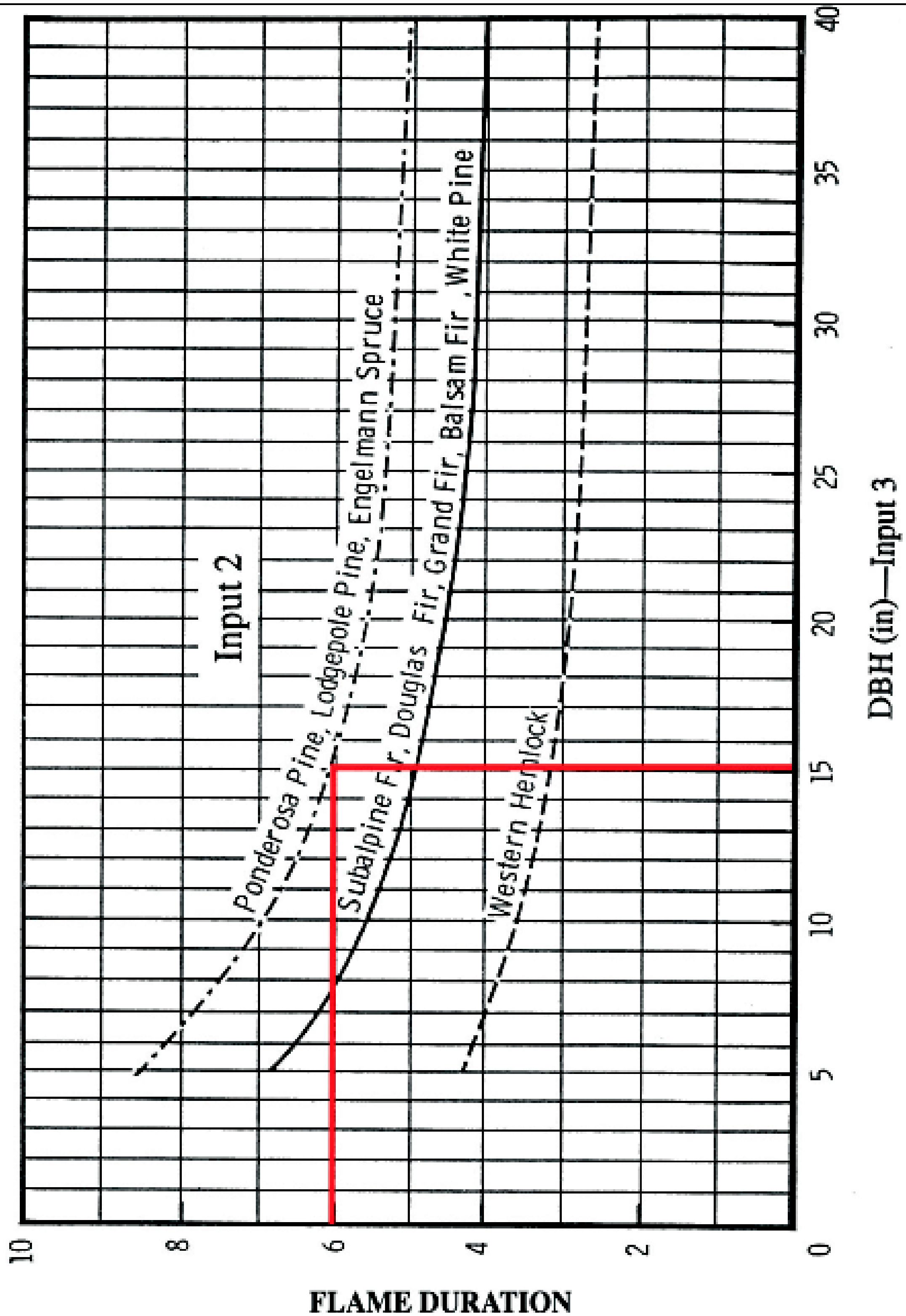
10 ft



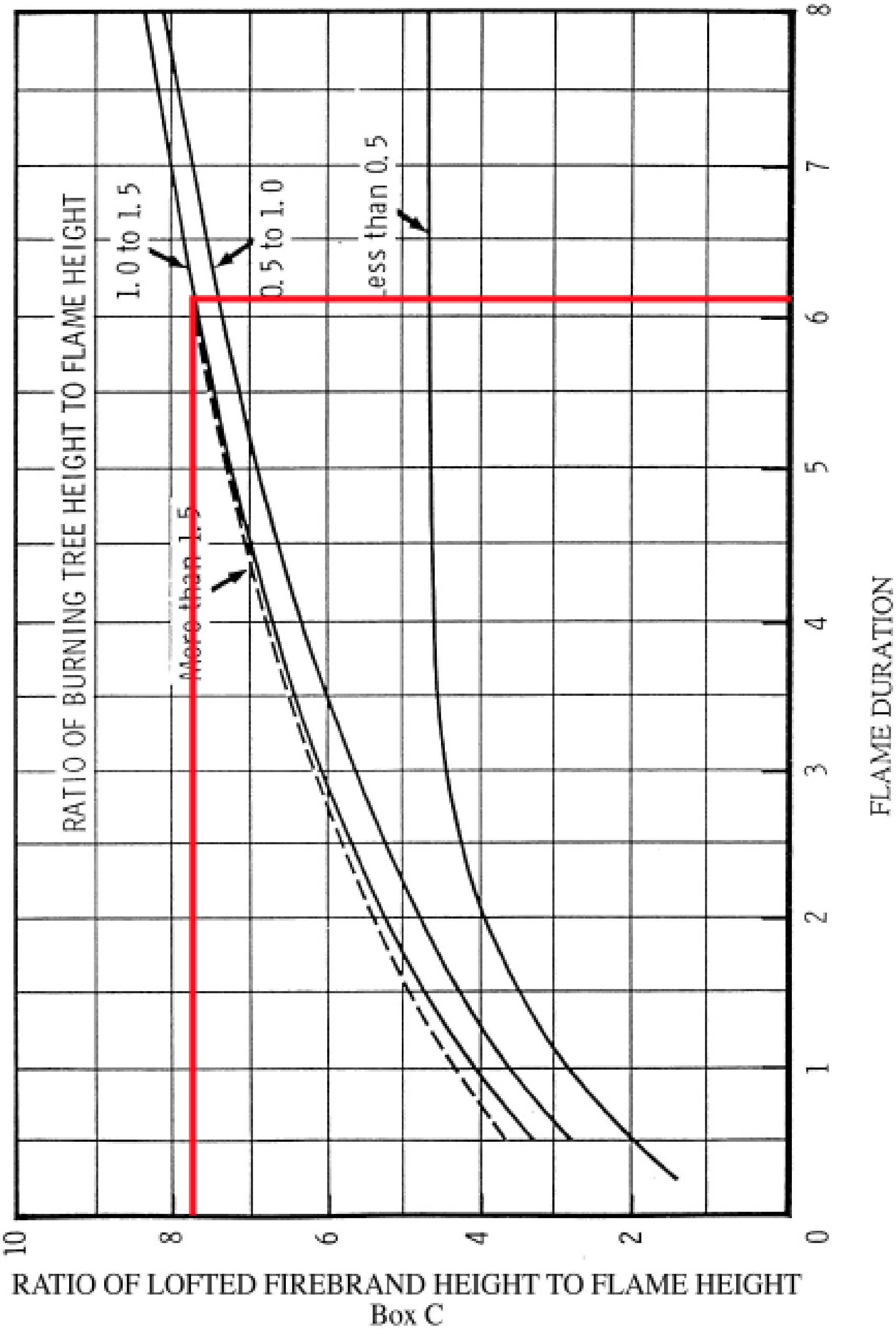
Problems 9, 10, 11, and 12



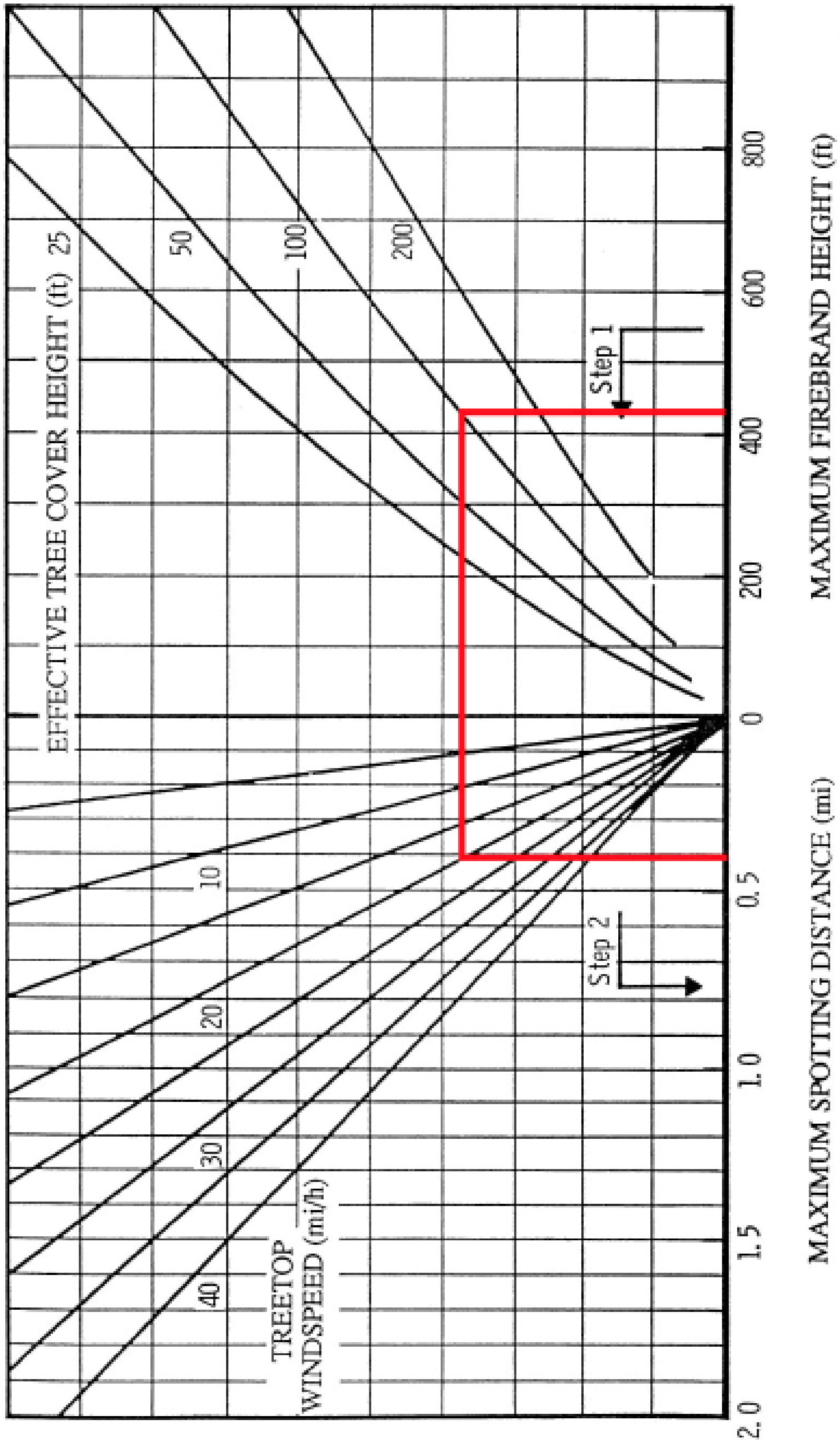
Spotting Nomogram 1—Flame Height



Spotting Nomogram 2—Flame Duration—Problem 10



Spotting Nomogram 3—Ratio of Firebrand Height to Flame Height—Problem 11



Spotting Nomogram 4—Maximum Spotting Distance—Problem 12

Problem 17. There is a fire in a field of tall grass. The slope is 8 percent and the ROS is 5 chains per hour. If the slope increases to 24 percent, what will the ROS be? If it increases to 72 percent, what will the ROS be?

Remember that the first tripling of the slope increases the rate of spread by two.
8% x 3 = 24%
ROS = 5 ch/h x 2 = 10 ch/h

Also remember that the second tripling of the slope increases the ROS by a factor of 4 to 6.
ROS is between 4 x 10 and 6 x 10
40 ch/h and 60 ch/h

Problem 18. The probability of ignition is 60 percent. How many ignitions will there be if 75 glowing firebrands land on receptive fuel?

60/100 x 75 = 45 ignitions

Problem 19. A fire is burning in brush under 30 percent sky cover. The dry bulb temperature is 94 °F. The fine dead fuel moisture is 4 percent. What is the probability of ignition?

Use the Probability of Ignition Table
80%

CHAPTER PROBLEM

A fire is burning in the Los Padres National Forest in the middle of July. Readings are taken at a site 500 feet above the fire. There is no, or sparse understory. The fire is on a high ridge where trees offer little shelter from the wind. The weather conditions are as follows:

20-foot windspeed of 15 mi/h	
Fuel model 4	dbh = 15 in
Dry bulb temperature of 85 °F	% slope is 40 percent
Wet bulb temperature of 52 °F	West aspect
Live fuel moisture of 150 percent	

Find the fine dead fuel moisture, effective windspeed (EWS), flame length (FL), rate of spread (ROS), fireline intensity, and midflame windspeed (MFWS).

Can crew B take direct attack of the fire at the head?

The fire is under 60 percent canopy and sky cover. What is the probability of ignition?

The time is 1400 hours. What will the forward spread distance be at 2100 hours?

Plot the forward spread distance on a map with a scale of 1:7,920. What is the probability of ignition?

A. Locate midflame windspeed and percent slope in the lower left quadrant. Draw a vertical line up at 40 percent slope. Estimate the line of a midflame windspeed of 9 miles per hour. At the intersection of the two lines, draw a horizontal line to the left to get the effective windspeed. Circle this number in the lower right quadrant. Notice the number is not located in the lower right quadrant. Go to the high windspeed nomogram. Repeat step A.

B. Locate the dead fuel moisture percent in the upper right quadrant, 4 percent. Draw a horizontal line to the "S" shaped curve labeled 150 percent live fuel moisture, and then vertically to the 10 miles per hour effective windspeed diagonal line in the lower right quadrant.

C. Draw a line immediately horizontally left. Over to the diagonal line in the lower left quadrant.

D. Then again immediately up vertically to the live fuel moisture percent in the upper left quadrant, 150 percent. At this point of intersection, draw a horizontal line through the upper right quadrant stopping at the intersection of the left vertical line.

E. Data gathering:
- ROS = 150 ch/h
- FL = 28 ft
- Fireline intensity = 280 Btu/ft/s
- Heat per unit area = 1,550 Btu/ft^2

PROBLEM-SOLVING WORKSHEET		
P R O B L E M	Given: **Windspeed, fuel models, wet & dry bulb temperatures, live fuel moisture** Goal: **Find the dead fuel moisture, % slope, effective windspeed, flame length, rate of spread, fireline intensity, midflame windspeed**	Assumptions: Information needed: **Fuel model 4 nomogram, nomogram worksheet**
D E V I S E P L A N	Strategies: **• Enter given information on worksheet** **• Transfer needed information to nomogram** **• Complete nomogram**	Rationale: **Worksheets & nomograms will help determine the information we're trying to find**
C A R R Y O U T P L A N	Solution process: **Enter data on worksheet** **Use wind adjustment worksheet to compute midflame WS** **Complete nomogram, use high windspeed nomogram, since effective windspeed of 10 is too high for the low windspeed nomogram**	
L O O K B A C K	Answer: **Dead fuel moisture 4%** **% slope 40%** **Effective windspeed 10 mi/h** **Flame length 28 ft** **Rate of spread 150 ch/h** **Fireline intensity 9,000 Btu/ft/s** **Midflame windspeed 9 mi/h**	Solution Check:

<table>
<tr><th colspan="3">PROBLEM-SOLVING WORKSHEET</th></tr>
<tr><td>P
R
O
B
L
E
M</td><td>Given:
Prior nomogram

Goal:

Can crew B direct attack? Find probability of ignition</td><td>Assumptions:

Information needed:</td></tr>
<tr><td>D
E
V
I
S
E

P
L
A
N</td><td>Strategies:

Use data from nomogram to determine probability of ignition</td><td>Rationale:

Nomograms & worksheets contain the information needed</td></tr>
<tr><td>C
A
R
R
Y

O
U
T

P
L
A
N</td><td colspan="2">Solution process:

Use fire suppression interpretations.

Use table & worksheet to find probability of ignition

Use the map spread worksheet.</td></tr>
<tr><td>L
O
O
K

B
A
C
K</td><td>Answer:

No, attack at the head is ineffective since flame length is over 11 ft, and fireline intensity is above 1,000 Btu/ft/s

Probability of ignition = 70%

Forward spread at 2,100 is 1,050 ch</td><td>Solution Check:</td></tr>
</table>

Name of fire ________ Fire pred spec ________

Date ________ Time ________

Proj period date ________ Proj time from ________ to ________

Fire Behavior Worksheet

Input

0	PP	Projection point			
1	Model #	Fuel model number (1-13)	**4**		
2	1H-FDFM	Fine dead fuel moisture, %	**4**		
3	LFM	Live fuel moisture, %	**150**		
4	MFWS	Midflame windspeed, mi/h	**9**		
5	SLP	slope, %	**40**		
6	EWS	Effective windspeed, mi/h	**10**		

Output

1	ROS	Rate of spread, ch/h	**150**		
2	HA	Heat per unit area, Btu/ft^2	**2,700**		
3	FLI	Fireline intensity, Btu/ft/s	**9,000**		
4	FL	Flame length, ft	**28**		
5	SD	Spread distance, ch			
		Map spread distance, in			
6	PER	Perimeter, ch			
7	AC	Area, ac			
8	SPOT	Max spotting distance, mi			
		Map distance spot, in			
9	PIG	Probability of ignition, %			

Slope Worksheet

Input

0	PP	Projection point			
1	CON INT	Contour interval, ft			
2	SLC	Map scale			
3	CF	Conversion factor, ft/in			
4	# INTVLS	Number of contour intervals			
5	RISE	Rise in elevation			
6	MD	Map distance, in (between points)			
7	HZGD	Horizontal ground distance, ft			

Output

1	SLP%	Slope, %			

Fine Dead Fuel Moisture/Probability of Ignition Worksheet

Input

0	PP	Projection point			
1	D	Daytime calculation	D	D	D
2	DB	Dry bulb temperature, °F	**85**		
3	WB	Wet bulb temperature, °F	**52**		
4	DP	Dew point, °F	**–5**		
5	RH	Relative humidity, %	**3**		
6	RFM	Reference fuel moisture, % (table 2)	**1**		
7	MO	Month	**July**		
8	SH	Unshaded (U) or shaded (S)	U/S	U/S	U/S
9	T	Time	**4:00**		
10	CH	Elevation change B = 1,000 ft to 2,000 ft below site L = ± 1,000 ft of site location A = 1,000 ft to 2,000 ft above site	B/L/A	B/L/A	B/L/A
11	ASP	Aspect, (N, S, E, W)	**W**		
12	SLP	Slope, %	**40**		
13	FMC	Fuel moisture correction, % (table 3, 4, or 5)	**3**		

Output

1	1H-FDFM	Fine dead fuel moisture, % (line 6 + line 13)	**4**		
2	PIG	Probability of ignition, % (table 12)	**70**		

Wind Adjustment Worksheet

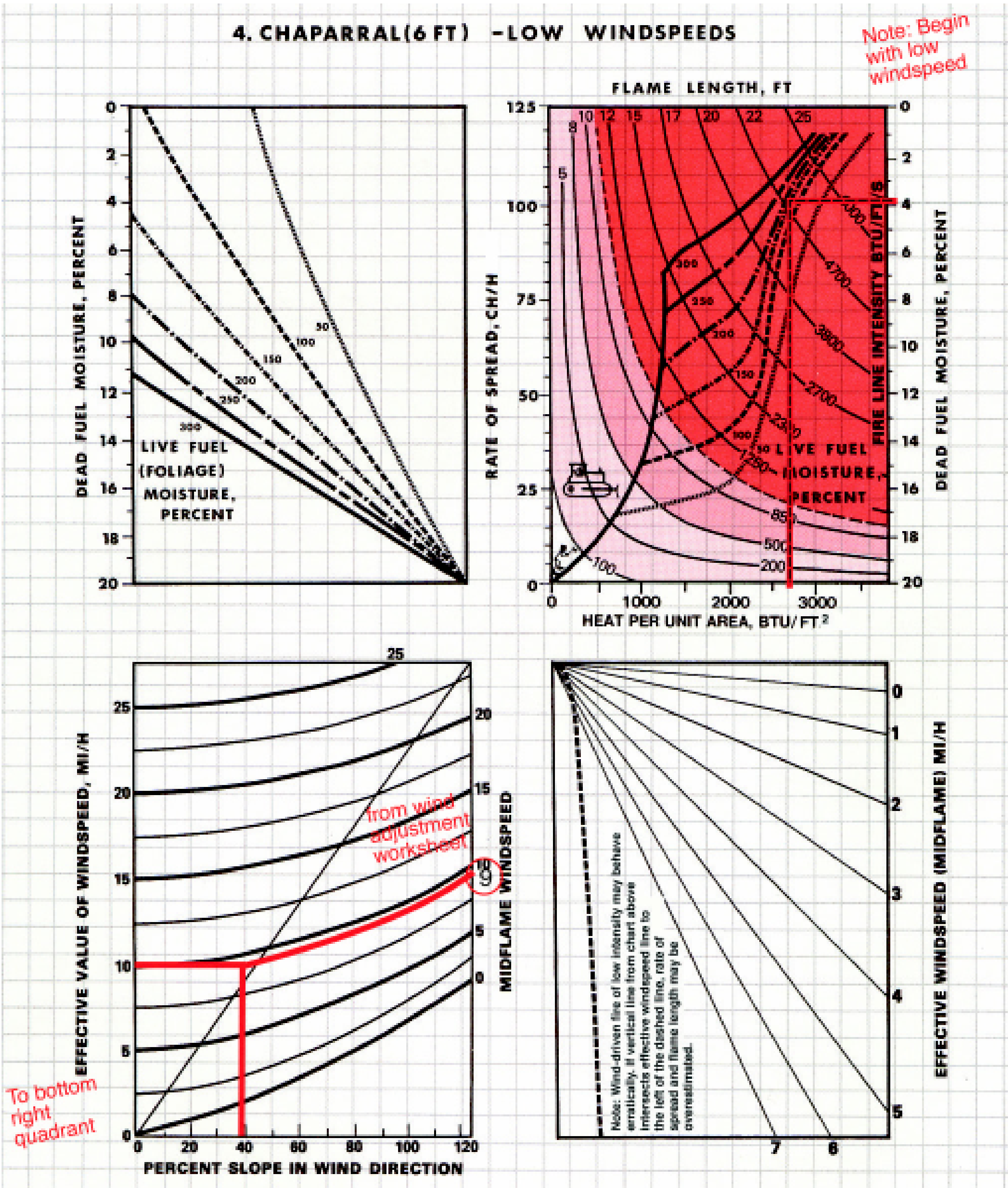
Input

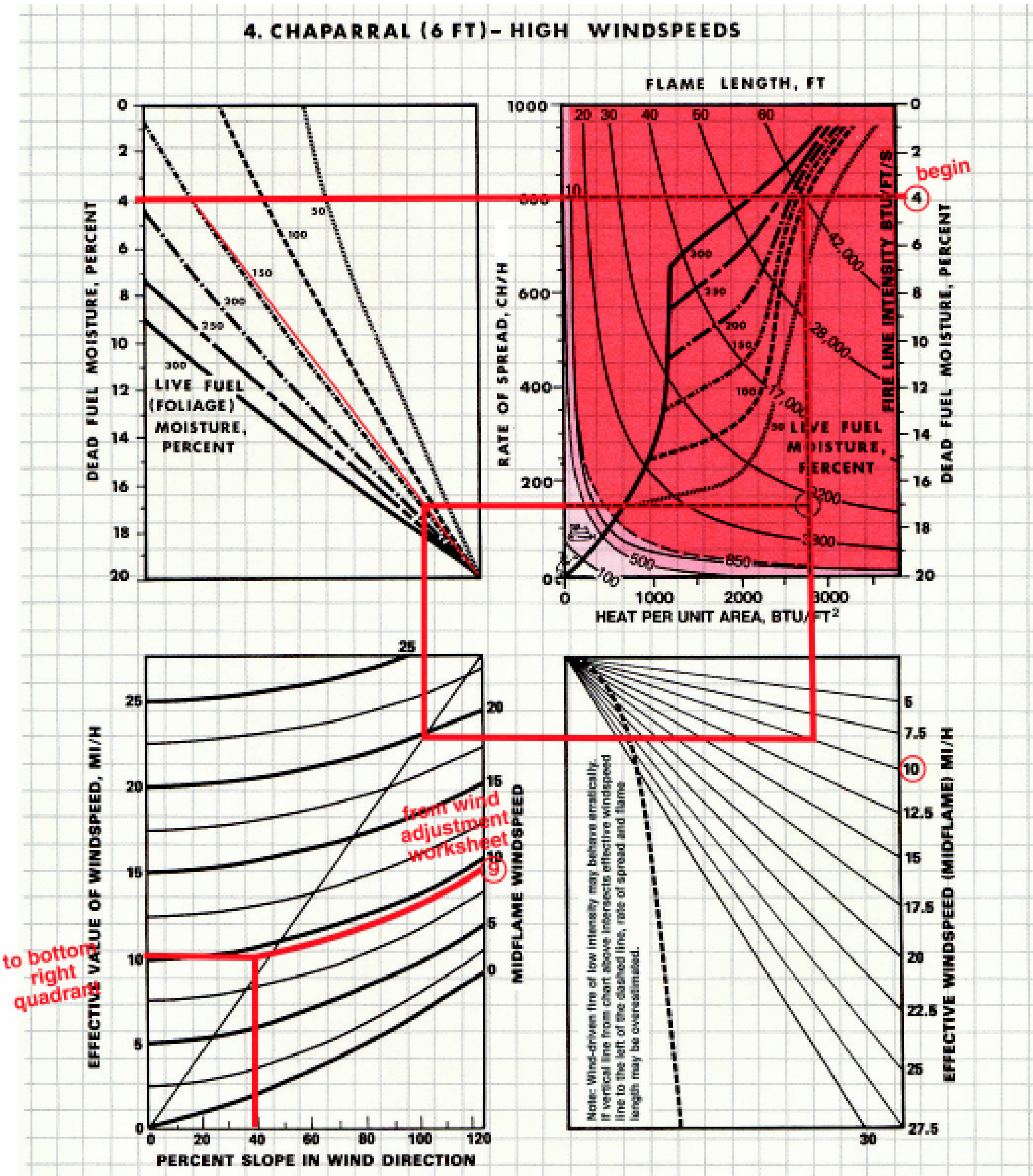
0	PP	Projection point			
1	20' W	20-ft windspeed, mi/h	**15**		
2	MODEL #	Fuel model number (1-13)	**4**		
3	SHLTR	Wind sheltering 1 = unsheltered 2 = partially sheltered 3 = fully sheltered, open 4 = fully sheltered, closed	**1**		
4	WAF	Wind adjustment factor (table 7)	**.6**		

Output

1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)	**9**		

Nomogram version – June 1993


4. CHAPARRAL (6 FT) -LOW WINDSPEEDS
Note: Begin with low windspeed
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
RATE OF SPREAD, CH/H
HEAT PER UNIT AREA, BTU/FT.²
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
from wind adjustment worksheet
To bottom right quadrant
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.


4. CHAPARRAL (6 FT)- HIGH WINDSPEEDS
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
RATE OF SPREAD, CH/H
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
begin
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
from wind adjustment worksheet
to bottom right quadrant
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

For use at elevations between
501 and 1,900 feet above sea level

DP = Top number
RH = bottom number

Wet bulb temperatures

Dry bulb temperatures

Dry bulb \ Wet bulb	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
60	-50 1	-14 4	-1 8	+8 12	14 16	19 20	24 24	28 28	31 32	34 36	37 41	40 45	42 50	44 54	47 59	49 64	51 69	53 74	54 79	56 84	58 89	59 95	61 100																													
62		-25 2	-6 6	+4 10	11 13	17 17	22 21	26 25	30 29	33 33	36 37	38 42	41 46	43 50	46 55	48 60	50 64	52 69	54 74	55 79	57 84	59 89	60 95	62 100																												
63		-58	-14 4	-1 7	+8 11	14 15	20 19	24 22	28 26	31 30	34 34	37 38	40 43	42 47	45 51	47 56	49 60	51 65	53 70	55 74	57 79	58 84	60 89	61 95	63 100																											
64			-27 2	-7 5	+4 9	11 12	17 16	22 20	26 24	30 27	33 31	36 35	39 39	41 43	44 48	46 52	48 56	50 61	52 65	54 70	56 75	58 80	59 85	61 90	62 95	64 100																										
65				-15 3	-1 7	+8 10	14 14	20 17	24 21	28 25	32 29	35 32	38 36	40 40	43 44	45 48	47 53	49 57	51 61	53 66	55 70	57 75	59 80	60 85	62 90	63 95	65 100																									
66				-28 2	-7 5	+4 8	11 12	17 15	22 19	26 22	30 26	33 30	36 33	39 37	42 41	44 45	46 49	49 53	51 58	53 62	54 66	56 71	58 76	60 80	61 85	63 90	64 95	66 100																								
67					-15 3	-1 6	+8 10	15 13	20 16	24 20	28 23	32 27	35 31	38 34	41 38	43 42	46 46	48 50	50 54	52 58	54 63	56 67	57 71	59 76	61 80	62 85	64 90	66 95	67 100																							
68					-29 2	-7 5	+4 8	12 11	18 14	22 18	27 21	30 24	34 28	37 32	40 35	42 39	45 43	47 47	49 51	51 55	53 59	55 63	57 67	59 72	60 76	62 81	63 85	65 90	67 95	68 100																						
69						-15 3	-1 6	+8 9	15 12	20 16	25 19	29 22	32 26	35 29	38 33	41 36	44 40	46 44	48 47	50 51	52 55	54 59	56 64	58 68	60 72	61 77	63 81	65 86	66 90	68 95	69 100																					
70						-29 1	-7 4	+4 7	12 10	18 14	23 17	27 20	31 23	34 27	37 30	40 34	43 37	45 41	47 44	50 48	52 52	54 56	55 60	57 64	59 68	61 72	62 77	64 81	66 86	67 90	69 95	70 100																				
71							-15 3	0 6	+9 9	15 12	21 15	25 18	29 21	33 24	36 28	39 31	42 34	44 38	46 42	49 45	51 49	53 53	55 57	57 60	58 65	60 69	62 73	63 77	65 82	67 86	68 91	70 95	71 100																			
72							-28 1	-6 4	+5 7	12 10	18 13	23 16	28 19	31 22	35 25	38 29	40 32	43 35	46 39	48 42	50 46	52 50	54 53	56 57	58 61	60 65	61 69	63 73	65 77	66 82	68 86	69 91	71 95	72 100																		
73								-14 3	0 5	+9 8	16 11	21 14	26 17	30 20	33 23	36 26	39 30	42 33	45 36	47 40	49 43	51 47	53 50	55 55	57 58	59 62	61 65	62 69	64 74	66 78	67 82	69 86	70 91	72 95	73 100																	
74								-27 1	-6 4	+5 7	13 10	19 12	24 15	28 18	32 21	35 24	38 27	41 30	44 34	46 37	48 40	51 44	53 47	55 51	57 54	58 58	60 62	62 66	64 70	65 74	67 78	68 82	70 87	71 91	73 95	74 100																
75									-13 3	+1 5	10 8	16 11	22 13	26 16	30 19	34 22	37 25	40 28	43 31	45 35	48 38	50 41	52 44	54 48	56 51	58 55	60 59	61 62	63 66	65 70	66 74	68 78	69 82	71 87	72 91	74 95	75 100															
76									-25 1	-5 4	+6 7	14 9	20 12	24 15	29 17	32 20	36 23	39 26	42 29	44 32	47 35	49 39	51 42	53 45	55 49	57 52	59 56	61 59	62 63	64 67	66 71	67 75	69 79	70 83	72 87	73 91	75 96	76 100														
77									-57	-12 3	+2 5	10 8	17 10	22 13	27 16	31 18	34 21	38 24	41 27	43 30	46 33	48 36	50 39	53 43	55 46	57 49	58 53	60 56	62 60	64 63	65 67	67 71	68 75	70 79	71 83	73 87	74 91	76 96	77 100													
78										-23 1	-4 4	+7 6	14 9	20 11	25 14	29 17	33 19	36 22	39 25	42 28	45 31	47 34	50 37	52 40	54 43	56 46	58 50	60 53	61 57	63 60	65 64	66 67	68 71	69 75	71 79	72 83	74 87	75 91	77 96	78 100												
79										-48	-11 3	+3 5	11 8	18 10	23 13	28 15	32 18	35 20	38 23	41 26	44 29	46 32	49 35	51 38	53 41	55 44	57 47	59 50	61 54	63 57	64 61	66 64	67 68	69 72	71 75	72 79	73 83	75 87	76 91	78 96	79 100											
80											-21 2	-2 4	+8 6	15 9	21 11	26 14	30 16	34 19	37 21	40 24	43 27	45 30	48 32	50 35	52 38	54 41	56 45	58 48	60 51	62 54	64 58	65 61	67 65	69 68	70 72	72 76	73 79	75 83	76 87	77 92	79 96	80 100										
81											-40 1	-9 3	+4 5	12 7	19 10	24 12	28 15	32 17	36 20	39 22	42 25	45 28	47 30	49 33	52 36	54 39	56 42	58 45	60 48	61 51	63 55	65 58	67 62	68 65	70 69	71 72	73 76	74 80	76 84	77 88	78 92	80 96	81 100									
82												-18 2	-1 4	+9 6	16 8	22 10	27 13	31 16	34 18	38 21	41 23	44 26	46 28	49 31	51 34	53 37	55 40	57 43	59 46	61 49	63 52	64 55	66 59	68 62	69 65	71 69	72 73	74 76	75 80	77 84	78 88	79 92	81 96	82 100								
83												-34 1	-7 3	+5 5	13 7	20 9	25 12	29 14	33 17	36 19	40 21	43 24	45 27	48 29	50 32	52 35	54 38	56 40	58 43	60 46	62 49	64 53	66 56	67 59	69 62	70 66	72 69	73 73	75 76	76 80	78 84	79 88	80 92	82 96	83 100							
84													-15 2	+1 4	10 6	17 8	23 10	27 13	32 15	35 17	38 20	41 22	44 25	47 27	49 30	52 33	54 35	56 38	58 41	60 44	62 47	63 50	65 53	67 56	68 59	70 63	71 66	73 70	74 73	76 77	77 80	79 84	80 88	81 92	83 96	84 100						
85													-29 1	-5 3	+7 5	14 7	21 9	26 11	30 14	34 16	37 18	40 21	43 23	46 26	48 28	51 31	53 33	55 36	57 39	59 42	61 45	63 47	65 50	66 54	68 57	69 60	71 63	73 66	74 70	76 73	77 77	78 81	80 84	81 88	82 92	84 96	85 100					
86														-12 2	+2 4	11 6	18 8	24 10	28 12	32 15	36 17	39 19	42 22	45 24	48 26	50 29	52 32	54 34	57 37	59 40	60 42	62 45	64 48	66 51	67 54	69 57	71 60	72 64	74 67	75 70	77 74	78 77	79 81	81 84	82 88	83 92	85 96	86 100				
87														-24 1	-3 3	+8 5	16 7	22 9	27 11	31 13	35 16	38 18	41 20	44 22	47 25	49 27	52 30	54 32	56 35	58 37	60 40	62 43	64 46	65 49	67 51	69 54	70 58	72 61	73 64	75 67	76 70	78 74	79 77	80 81	82 85	83 88	84 92	86 96	87 100			
88														-50	-10 2	+4 4	13 6	19 8	25 10	29 12	33 14	37 16	40 19	43 21	46 23	48 26	51 28	53 30	55 33	57 35	59 38	61 41	63 43	65 46	66 49	68 52	70 55	71 58	73 61	74 64	76 67	77 71	79 74	80 78	81 81	83 85	84 88	85 92	87 96	88 100		
89															-19 1	-1 3	+10 5	17 7	23 9	28 11	32 13	36 15	39 17	42 19	45 22	48 24	50 26	52 29	55 31	57 34	59 36	61 39	62 41	64 44	66 47	68 50	69 52	71 55	72 58	74 61	76 65	77 68	78 71	80 74	81 78	83 81	84 85	85 88	86 92	88 96	89 100	
90															-37	-7 2	+6 4	14 6	21 8	26 10	30 12	34 14	38 16	41 18	44 20	47 22	49 25	52 27	54 29	56 32	58 34	60 37	62 39	64 42	66 45	67 47	69 50	71 53	72 56	74 59	75 62	77 65	78 68	79 71	81 75	82 78	84 82	85 85	86 89	87 92	89 96	90 100

Graph from
chapter 7
page 87

Wind Adjustment Worksheet

	<u>Input</u>			
0	PP	Projection point		
1	20' W	20-ft windspeed, mi/h	15	
2	Model #	Fuel model number (1-13)	4	
3	Shltr	Wind sheltering 1 = Unsheltered 2 = Partially sheltered 3 = Fully sheltered, open 4 = Fully sheltered, closed	1	
4	WAF	Wind adjustment factor (see figure 9.2)	.6	
	<u>Output</u>			
1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)	9	

Worksheet
from chapter 9
page 101

Table 8.2—Dead Fuel Moisture Content Correctons Day (0800 to 1959) May, June, July (Input line 13)

Unshaded—Less than 50 percent shading of surface fuels																			
Aspect	% slope	0800>			1000>			1200>			1400>			1600>			1800>		
		B	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**	**B**	**L**	**A**
N	0-30	2	3	4	1	1	1	0	0	1	0	0	1	1	1	1	2	3	4
	31+	3	4	4	1	2	2	1	1	2	1	1	2	1	2	2	3	4	4
E	0-30	2	2	3	1	1	1	0	0	1	0	0	1	1	1	2	3	4	4
	31+	1	2	2	0	0	1	0	0	1	1	1	2	2	3	4	4	5	6
S	0-30	2	3	3	1	1	1	0	0	1	0	0	1	1	1	1	2	3	3
	31+	2	3	3	1	1	2	0	1	1	0	1	1	1	1	2	2	3	3
W	0-30	2	3	4	1	1	2	0	0	1	0	0	1	0	1	1	2	3	3
	31+	4	5	6	2	3	4	1	1	2	0	0	1	0	0	1	1	2	2
Shaded—50% or more shading of surface fuels																			
N	all	4	5	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
E	all	4	4	5	3	4	5	3	3	4	3	4	4	3	4	5	4	5	6
S	all	4	4	5	3	4	5	3	3	4	3	3	4	3	4	5	4	5	5
W	all	4	5	6	3	4	5	3	3	4	3	3	4	3	4	5	4	4	5

Note: when using tables 8.2, 8.3, and 8.4: B = 1,000-2,000 feet below the site location
L = 0-1,000 feet above or below the site location
A = 1,000-2,000 feet above the site location

Chart from chapter 8 page 92

Shading (Percent)	Dry Bulb Temp. (°F)	Fine Dead Fuel Moisture (Percent)															
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Unshaded <50%	110+	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100-109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80-89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60-69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30-39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
Shaded >50%	110+	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100-109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90-99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80-89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70-79	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	60-69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50-59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40-49	90	80	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30-39	80	80	60	50	50	40	30	30	20	20	20	10	10	10	10	10

Chart from chapter 9 page 128

Flame Length (ft)	Fireline Intensity (Btu/ft/s)	Interpretations
0-4	0-100	Fires can generally be attacked at the head or flanks by persons using handtools.
4-8	100-500	Handline should hold the fire. Fires are too intense for direct attack on the head by persons using handtools.
		Handline cannot be relied on to hold fire. Equipment such as dozers, engines, and retardant aircraft can be effective.
8-11	500-1,000	Fires may present serious control problems—torching out, crowning, and spotting.
		Control efforts at the head of the fire will probably be ineffective.
11+	1,000+	Crowning, spotting, and major runs are common.
	6,500	Control efforts at the head of the fire are ineffective.
CAUTION: These are not guides to personal safety. Fires can be dangerous at any level of intensity. Wilson (1977) has shown that most fatalities occur in light fuels on small fires or isolated sections of large fires.		

fireline intensity = 6,500 (from nomogram or worksheet)

Chart from chapter 9 page 126

Fire Area/Size Worksheet

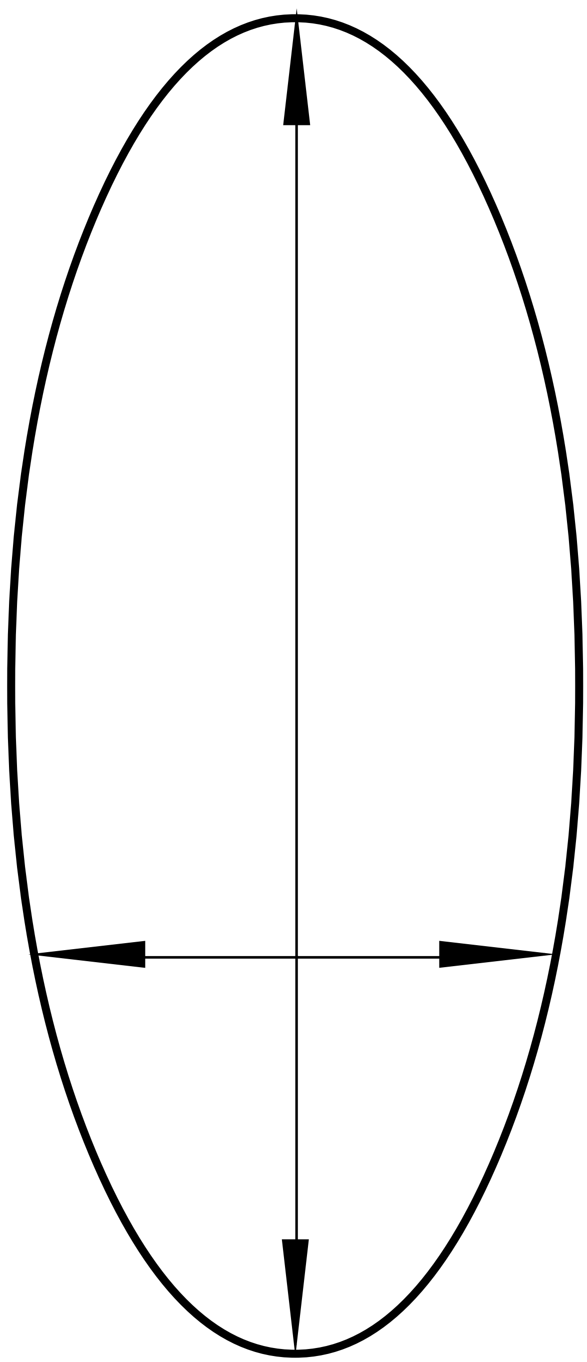
Chart from chapter 5 page 59

Line	Input		
0	PP	Projection point	
1	ROS	Rate of spread, ch/h	150
2	EWS	Effective windspeed, mi/h	10
3	PT	Projection time, h	7
4	SD	Spread distance, ch	1,050
	Output		
	PER	Perimeter, ch	
	AC	Area, ac	

Map Spread Worksheet

Chart from chapter 5 page 58

Line	Input			
0	PP	Projection point		
1	ROS	Rate of spread, ch/h	150	
2	PT	Projection time, h	10	
3	SDCH	Spread distance, ch (line 1 x line 2)	1,050	
4	SDFT	Spread distance, ft (line 3 x 66 ft/ch)	69,300	
5	SCL	Map scale	1:7,920	
6	CF	Conversion factor, ft/in (see map scale conversion)	660	
	Output			
1	MD	Map spread distance, in (line 4 divided by line 6)	105	



Plotted forward spread distance.
See chapter 5, page 58 (Fire Shape)

EXERCISE SOLUTIONS

Problem 1. The mean monthly rainfalls in the coastal plains of Georgia are listed below. Determine the average annual rainfall. What is the range of these values?

Jan—4.6 in	Jul—5.5 in
Feb—4.4 in	Aug—4.3 in
Mar—5.2 in	Sep—3.5 in
Apr—3.6 in	Oct—2.4 in
May—3.6 in	Nov—2.8 in
Jun—4.5 in	Dec—3.8 in

Range: High – Low
5.5 in – 2.4 in = 3.1 in

Average:
4.6 + 4.4 + 5.2 + 3.6 + 3.6 + 4.5 + 5.5 +4.3 + 3.5 + 2.4 + 2.8 + 3.8 = 48.2 in

$\frac{48.2 \text{ in}}{12}$ = 4.016 rounded to 4.0 in

Problem 2. Vince has determined the windspeed with a handheld rangefinder. He took six readings: 18 ch/h, 20 ch/h,18ch/h, 21ch/h, 21ch/h, 22 ch/h.

What is the average, range, and standard deviation of this group of readings? The true reading is 19 chains/hour. How accurate is each reading and what is the precision?

Average: $\frac{18 + 20 + 18 + 21 + 21 + 22}{6} = \frac{120}{6} = 20$

Range: High – Low = 22 – 18 = 4

Standard Deviation:
18 – 20 = –2 20 – 20 = 0 18 – 20 = –2 21 – 20 = 1
21– 20 = 1 22 – 20 = 2 (–2)(–2) = 4 (0)(0) = 0
(–2)(–2) = 4 (1)(1) = 1 (1)(1) = 1 (2)(2) = 4
4 + 0 + 4 + 1 + 1 + 4 = 14/5 = 2.8
$\sqrt{2.8}$ = 1.67 = 1.7 ch

Accuracy:
18 – 19 = –1 20 – 19 = 1 18 – 19 = –1 21 – 19 = 2
21 –19 = 2 22 – 19 = 3
The accuracy for each reading is: –1, 1, –1, 2, 2, 3

Precision:
18 – 20 = –2 20 – 18 = 2 18 – 21 = –3 21 – 21 = 0
21 – 22 = –1
The precision for each reading is: ±2, ±3, ±1

Problem 3. Marty has to construct 600 feet of fireline in heavy brush in half an hour. How many crews does she need to assign to the task?

$\frac{1 \cancel{\text{hr}}}{300 \cancel{\text{ft}}} \Big| \frac{600 \cancel{\text{ft}}}{.5 \cancel{\text{hr}}} = \frac{600}{150}$ = 4 15-person crews

Problem 4. Crystal has four crews. She needs 1,500 feet of fireline constructed in very heavy brush. How long will it take the crews to build this amount of line?

$\frac{1500 \cancel{\text{ft}}}{} \Big| \frac{1 \text{ h}}{225 \cancel{\text{ft}}}$ = 6.67 hours for 1 crew

$\frac{6.67 \text{ h}}{x} \Big| \frac{1 \cancel{\text{crew}}}{4 \cancel{\text{crews}}}$ = 2 h (approximately)

EXERCISE SOLUTIONS

Write an addition problem for each situation. Solve.

Problem 1. Manuel earns $121 worth of overtime on Monday and $142 on Wednesday. How much overtime money does he earn in all?

121 + 142 = $263 overtime money earned

Problem 2. Mike has seven hose lengths. He goes to supply and picks up six more. How many hose lengths does he have in all?

7 + 6 = 13 hose lengths

Problem 3. Carol has 200 feet of hose in her pack. Bernie has 100 feet of hose and Tyrone has 200 feet in his pack. How many feet of hose do they have in all?

200 + 100 + 200 = 500 feet of hose

Problem 4. There were two fires on the Tonto Forest yesterday. One fire burned 235 acres of national forest land and the other burned 68 acres outside of the national forest boundary. How many acres were burned in all?

235 + 68 = 303 acres

Problem 5. Loren is filling containers with fire foam. In one container she put 28 gallons and in the second container she put 53 gallons. How many gallons did she fill in all?

28 + 53 = 81 gallons

Problem 6. Lois pumps 267 gallons of water into an engine. For the next engine she pumps 350 gallons. She pumps 288 gallons into the third engine. How many gallons did Lois pump in all?

267 + 350 + 288 = 905 gallons pumped

Add

Problem 7.
$$\begin{array}{r} 5\,3\,0\,4 \\ \underline{+\,3\,5\,4\,2} \\ 8\,8\,4\,6 \end{array}$$

Problem 8.
$$\begin{array}{r} 7\,9\,6\,8 \\ \underline{+\,5\,4\,9\,7} \\ 13{,}4\,6\,5 \end{array}$$

Problem 9.
$$\begin{array}{r} 9\,8\,0\,4 \\ \underline{+\,7\,5\,8\,9} \\ 17,\,3\,9\,3 \end{array}$$

Problem 10.
$$\begin{array}{r} -6 \\ \underline{+\,-6} \\ -12 \end{array}$$

Problem 11.
$$\begin{array}{r} 7 \\ \underline{+\,-4} \\ 3 \end{array}$$

Write a subtraction problem for each situation. Solve.

Problem 12. Anthony is working in the supply room. He has 36 hard hats. A crew of 24 comes in and takes 1 for each person. How many hard hats does Anthony have left?

36 – 24 = 12 hard hats left

Problem 13. The foam tank on an engine is filled with 45 gallons before leaving for a fire. The crew uses up 27 gallons on that fire. How many gallons are left?

45 – 27 = 18 gallons

Problem 14.

$$\begin{array}{r} 23 \\ \underline{-\ 6} \\ 17 \end{array}$$

Problem 15.

$$\begin{array}{r} 4547 \\ \underline{-\ 3421} \\ 1126 \end{array}$$

Problem 16. Joe is restocking the fire cache. Fifty pairs of gloves make up a complete set, but Joe only has nine pairs. How many more are needed to complete the set?

50 – 9 = 41 pairs needed

Problem 17.

$$\begin{array}{r} 402 \\ \underline{-\ 139} \\ 263 \end{array}$$

Problem 18.

$$\begin{array}{r} 6913 \\ \underline{-\ 4479} \\ 2434 \end{array}$$

Solve.

Problem 19. Jerry has nine lengths of hose. Each hose is 100 feet long. What is the total length of hose that Jerry has?

9 (100) = 900 feet of hose

Problem 20. There are 19 members in crew A. Four canteens must be filled for each person. How many canteens need to be filled in total?

19 (4) = 76 canteens

Multiply.

Problem 21.

$$\begin{array}{r} 210 \\ \underline{\times\ 57} \end{array}$$

$$\begin{array}{rcrcr} 210 & & 210 & & \\ \underline{\times\ \ 7} & & \underline{\times\ 50} & & \\ 1470 & + & 10{,}500 & = & 11{,}970 \end{array}$$

Problem 22.

$$\begin{array}{r} 1350 \\ \underline{\times\ \ 99} \end{array}$$

$$\begin{array}{rcrcr} 1350 & & 1350 & & \\ \underline{\times\ \ \ 9} & & \underline{\times\ 90} & & \\ 12{,}150 & + & 121{,}500 & = & 133{,}650 \end{array}$$

Problem 23.

$$\begin{array}{r} 432 \\ \underline{\times\ 376} \end{array}$$

$$\begin{array}{rcrcrcr} 432 & & 432 & & 432 & & \\ \underline{\times 6} & & \underline{\times 70} & & \underline{\times 300} & & \\ 2592 & + & 30{,}240 & + & 129{,}600 & = & 162{,}432 \end{array}$$

Problem 24. –7 x (–3) = 21

Problem 25. –6 x 2 = –12

Problem 26. –1 x 25 = –25

Problem 27. Use repeated subtraction to divide 30 by 6.

$$\begin{array}{r} 30 \\ \underline{-\ 6} \\ 24 \end{array} \quad \begin{array}{r} 24 \\ \underline{-\ 6} \\ 18 \end{array} \quad \begin{array}{r} 18 \\ \underline{-\ 6} \\ 12 \end{array} \quad \begin{array}{r} 12 \\ \underline{-\ 6} \\ 6 \end{array} \quad \begin{array}{r} 6 \\ \underline{-\ 6} \\ 0 \end{array} \qquad 30/6 = 5$$

Use long division.

Problem 28. 27/3 = 9 check 9 x 3 = 27

Problem 29. 3645 ÷ 7

$$\begin{array}{r} 520 \text{ r5} \\ 7\,\overline{)3645} \\ \underline{35} \\ 14 \\ \underline{14} \\ 05 \\ \underline{0} \\ 5 \end{array}$$

Problem 30. 8889 ÷ 71

$$\begin{array}{r} 125 \text{ r14} \\ 71\,\overline{)8889} \\ \underline{71} \\ 178 \\ \underline{142} \\ 369 \\ \underline{355} \\ 14 \end{array}$$

Problem 31. 6027 ÷ 9

$$\begin{array}{r} 669 \text{ r6} \\ 9\,\overline{)6027} \\ \underline{54} \\ 62 \\ \underline{54} \\ 87 \\ \underline{81} \\ 6 \end{array}$$

Problem 32. 4139 ÷ 59

$$\begin{array}{r} 70 \text{ r9} \\ 59\,\overline{)4139} \\ \underline{413} \\ 09 \\ \underline{0} \\ 9 \end{array}$$

Problem 33. 789 ÷ 42

$$\begin{array}{r} 18 \text{ r33} \\ 42\,\overline{)\ 798} \\ \underline{42} \\ 369 \\ \underline{336} \\ 33 \end{array}$$

Problem 34. $\begin{array}{r} \underline{14} \\ -\ 4 \end{array}$

$$\begin{array}{r} -3 \text{ r2} \\ -4\,\overline{)14} \\ \underline{-12} \\ 2 \end{array}$$

Problem 35. $\frac{-6}{-3}$

$$\begin{array}{r} 2 \\ -3\overline{)\,-6} \\ \underline{6} \\ 0 \end{array}$$

Solve.

Problem 36. $\frac{58}{100}$

$$\begin{array}{r} 0.58 \\ 100\overline{)\,58.00} \\ \underline{500} \\ 800 \\ \underline{800} \\ 0 \end{array}$$

Problem 37. $\frac{633}{10}$

$$\begin{array}{r} 63.3 \\ 10\overline{)\,633.0} \\ \underline{60} \\ 33 \\ \underline{30} \\ 30 \\ \underline{30} \\ 0 \end{array}$$

Problem 38. $\frac{14.3}{1000}$

$$\begin{array}{r} 0.0143 \\ 1000\overline{)\,14.3000} \\ \underline{1000} \\ 4300 \\ \underline{4000} \\ 3000 \\ \underline{3000} \\ 0 \end{array}$$

Problem 39. Round to the nearest tenth.

a) 58.153 58.2

b) 7.917 7.9

c) 4413.1269 4413.1

Problem 40. Round to the nearest thousandth.

a) 731.23773 731.238

b) 9143.1544 9143.154

c) 0.52791 0.528

Add.

Problem 41. 4561.0089 + 2.87 =

$$\begin{array}{r} 4561.0089 \\ +\quad 2.87 \\ \hline 4563.8789 \end{array}$$

Problem 42. 0.2844 + 87.001 =

$$\begin{array}{r} 0.2844 \\ +\ 87.001 \\ \hline 87.2854 \end{array}$$

Problem 43. 5.681 + 12.13 =

$$\begin{array}{r} 5.681 \\ +\ 12.13 \\ \hline 17.811 \end{array}$$

Subtract.

Problem 44. 713.609 – 6.595 =

$$\begin{array}{r} 713.609 \\ -\quad 6.595 \\ \hline 707.014 \end{array}$$

Problem 45. 9.901 – 0.02 =

```
   9.901
–  0.02
   9.881
```

Problem 46. 9522.01396 – 8420.356 =

```
   9522.01396
–  8420.356
   1101.65796
```

Multiply.

Problem 47. 0.867 x 0.14 = 0.12138

Problem 48. 1.56 x 2.801 = 4.36956

Problem 49. 3.48 x 0.01 = 0.0348

Problem 50. 5.95 x 0.0001 = 0.000595

Divide.

Problem 51. 30 ÷ 8 =

```
     3.75
8 ) 30.00
    24
     60
     56
      40
      40
       0
```

Problem 52. 22.5 ÷ 15 =

```
      1.5
15 ) 22.5
     15
       75
       75
        0
```

Problem 53. 62.3 ÷ 5 =

```
    12.46
5 ) 62.30
    5
    12
    10
     23
     20
      30
      30
       0
```

Problem 54. 44.8 ÷ 3.5 =

```
        12.8
3.5 ) 44.8 0
      35
        98
        70
         280
         280
           0
```

Problem 55. 3.75 ÷ 0.25 =

```
         15.
0.25 ) 3.75
       2 5
       1 2 5
       1 2 5
           0
```

Problem 56. $5.848 \div 8.6 =$

$$\begin{array}{r} 0.68 \\ 8.6\overline{)5.848} \\ \underline{516} \\ 688 \\ \underline{688} \\ 0 \end{array}$$

Write the following in exponential notation and solve.

Problem 57. $5 \times 5 =$

$5^2 = 25$

Problem 58. $2 \times 2 \times 2 \times 2 \times 2 =$

$2^5 = 32$

Problem 59. $3 \times 3 \times 3 \times 3 =$

$3^4 = 81$

Problem 60. $10 \times 10 \times 10 =$

$10^3 = 1{,}000$

Find the following square roots.

Problem 61. $\sqrt{25} = 5$

Problem 62. $\sqrt{16} = 4$

Problem 63. $\sqrt{81} = 9$

Problem 64. $\sqrt{27} = \sqrt{9 \bullet 3} = 3\sqrt{3}$

Solve.

Problem 65. $3^2 + 6 + 2 - 2 =$

$9 + 6 = 15$

Problem 66. $(5 + 2) \times 5 + 2 =$

$7 \times 5 + 2 =$
$35 + 2 = 37$

Problem 67. $(1 + 3)^3 + 10 \times 20 + 8 =$

$4^3 + 200 + 8 =$
$64 + 200 + 8 = 272$

Problem 68. $95 - 2^3 \times 5 \div (24 - 4) =$

$-8 \times 5 \div 20 =$
$-40 \div 20 = -2$
$95 - 2 = 93$

Problem 69. $7 \times 2 - (12+0) \div 3 - (5-2) =$

$14 - 12 \div 3 - 3 =$
$14 - 4 - 3 = 7$

CUMULATIVE EXAM

Problem 1. Using the relative humidity table, find the relative humidity at an elevation of 1,600 feet. The dry bulb temperature is 71 degrees Fahrenheit and the wet bulb temperature is 48 degrees Fahrenheit.

Problem 2. Using the relative humidity table, find the relative humidity at an elevation of 1,300 feet. The dry bulb temperature is 75 degrees Fahrenheit and the dew point is 40 degrees Fahrenheit.

Problem 3. At 0800 hours the dry bulb temperature is 76 degrees Fahrenheit and the wet bulb temperature is 54 degrees Fahrenheit at an elevation of 1,100 feet. What will the minimum relative humidity be in the afternoon if the maximum temperature forecast is 86 degrees Fahrenheit.

Problem 4. Relative humidity measures the amount of moisture in the air. True or false.

Problem 5. Wind direction is determined by: A. The direction from which the wind is blowing, or B. The direction the wind is blowing to.

Problem 6. What are the four fuel groups defined in the fire behavior prediction system?

Problem 7. Define a fuel model.

Problem 8. The rate of spread of a fire is 6 chains/hour. What will the spread distance be in 3 hours?

Problem 9. The fire has spread 18 chains. The map being used has a scale of 1:21,000 inch/inch. What is the distance the fire has spread on the map?

Problem 10. Using the flame height chart, find the flame height of a fire burning in a stand of ponderosa pine with a diameter at breast height of 15 inches.

Problem 11. The probability of ignition is 40 percent. How many ignitions will occur if 80 glowing firebrands land on receptive fuel?

Problem 12. A fire is burning in an area with 55 percent cloud cover. The fine dead fuel moisture is 6 percent and the dry bulb temperature is 74 degrees Fahrenheit. What is the probability of ignition? Use the probability of ignition table.

Problem 13. Using the fire behavior chart, find the flame length of a fire with a rate of spread of 40 chains per hour and a heat per unit area of 1,300 British thermal units per square foot.

Problem 14. Using the fire behavior chart, find the heat per unit area of a fire that has a rate of spread of 80 chains per hour and a flame length of 15 feet.

Problem 15. At what flame length is it recommended that equipment such as dozers be brought in to help contain the fire?

Problem 16. Using the reference fuel moisture, fine dead fuel moisture content corrections, the relative humidity and the probability of ignition tables, find the fine dead fuel moisture and probability of ignition of the following fire.

Show all work on the fine dead fuel moisture/probability of ignition worksheet.

month	April
time of day	1300
dry bulb temperature	85 °F
wet bulb temperature	60 °F
shading	40%
aspect	north
slope	25%

The readings are taken 1,200 feet above the fire.

Problem 17. A fire is burning in a partially sheltered timber stand of about 1 foot deep. The 20-foot windspeed is 12 miles per hour. What is the midflame windspeed? Complete the wind adjustment worksheet.

Problem 18. Complete the fire behavior worksheet using the appropriate nomogram and the following information. Show all work on the nomogram.

projection point	B
fuel model	9
fine dead fuel moisture	8%
slope	35%
midflame windspeed	7.5 mi/h

Problem 19. Complete the fire behavior worksheet using the appropriate nomogram and the following information. Show all work on the nomogram.

projection point	14
fuel model	10
live fuel moisture	200%
fine dead fuel moisture	16%
slope	45%
midflame windspeed	5 mi/h

Problem 20. Determine the percent slope for slope A to B on map 1. Complete the slope worksheet and show all calculations. You will need a topographic map with a 20-foot interval, 17 lines per inch, map distance between A & B. You will also need copies of nomograms.

Problem 21. Using the spotting nomograms, find the maximum spotting distance in miles for the situation described below. Show all work on the spotting nomograms 1-4, and complete the spotting and map-spot worksheets.

d.b.h.	20 in
torching tree height	90 ft
species	Balsam Fir
average tree cover height	150 ft
20-ft windspeed	25 mi/h
downwind canopy closure	open

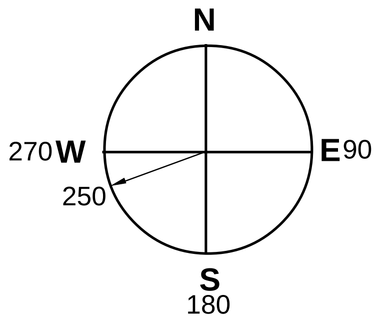
Problem 22. Using the area and perimeter estimation from point source fire tables, determine the perimeter and area for a fire with a rate of spread of 9 chains per hour and an effective windspeed of 7 miles per hour. What is the spread distance after 2, 3, and 4 hours of burning.

Problem 23. Plot the fire perimeter and label the head, rear, and flanks of the fire in question 22 for the 3 different hours of growth. Begin the fire at the point of origin, X. The wind is blowing from left to right across the page. Assume a scale of 1:15,840 inch/inch.

Problem 24. Draw a profile showing the elevations of the contour.

Problem 25. In San Diego, CA, the declination is 14° E. A compass reading of 140° is taken. What is the true azimuth reading?

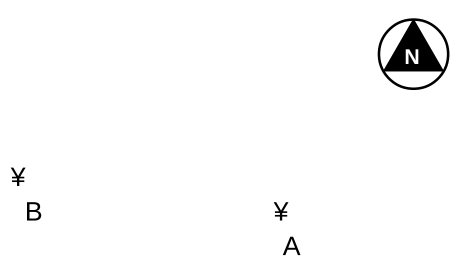
Problem 26. In the diagram below, write the azimuth angle and the back azimuth.



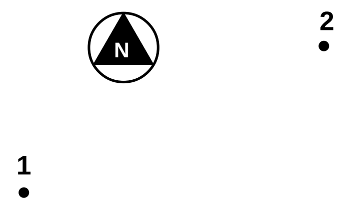
Problem 27. Draw a closed traverse for the following directions starting at point 1 and following the course continuously around the tract and returning to the starting point. The area where the tract of land was surveyed has a declination of 14.5° E. The magnetic readings and distances starting with point 1 are:

1) 340°, 133 feet
2) 280°, 118 feet
3) 5°, 215 feet
4) 100°, 118 feet
5) 168°, 168 feet
6) 176°, 154 feet
7) 243°, 25 feet

Problem 28. Find the location of a fire that has an azimuth reading of 310° from point A and 36° from point B. The declination for the area is 8° W.



Problem 29. Find JoanÕs location. She has the azimuth readings from her location to two known map locations. To mountain range 1 is a 294° azimuth reading. To mountain range 2 is a 349° azimuth reading. The declination for the area is 2° W.



CUMULATIVE EXAM ANSWERS

Problem 1. 12%

Problem 2. 28%

Problem 3. The dew point at 76° and 54° is 32. The relative humidity corresponding to 32 at 86° is 15%.

Problem 4. True

Problem 5. A

Problem 6. Grass, shrub, timber litter, and logging slash

Problem 7. A set of numbers that defines the fuel input to the fire spread model

Problem 8. 18 chains

Problem 9.

$$\frac{21{,}000\,\cancel{\text{in}}}{} \left| \frac{1\text{ ft}}{12\,\cancel{\text{in}}} \right. = 1{,}750\text{ ft}$$

$$\frac{18\,\cancel{\text{ch}}}{} \left| \frac{66\text{ ft}}{1\,\cancel{\text{ch}}} \right. = 1{,}188\text{ ft}$$

$$\frac{1{,}188\,\cancel{\text{ft}}}{} \left| \frac{1\text{ in}}{1{,}750\,\cancel{\text{ft}}} \right. = 0.68\text{ in}$$

Problem 10. 47 feet

Problem 11. 80 x .4 = 32 ignitions

Problem 12. 50%

Problem 13. 11 feet

Problem 14. 1400 Btu/ft²

Problem 15. 4 to 8 feetÑfire suppression interpretations chart is used.

Problem 16.

Fine Dead Fuel Moisture/ Probability of Ignition Worksheet

	Input		
0	PP	Projection point	**A**
1	D	Daytime calculation	**D**
2	DB	Dry bulb temperature °F	**85°**
3	WQB	Wet bulb temperature °F	**60°**
4	DP	Dew point °F	**40**
5	RH	Relative humidity %	**21**
6	RFM	Reference fuel moisture % (table 2)	**3**
7	MO	Month	**Apr**
8	SH	Unshaded (U) or shaded (S)	U/S
9	T	Time	**1300**
10	CH	Elevation change B = 1,000 ft-2,000 ft below site L = ±1,000 ft of site location A = 1,000 ft-2,000 ft above site	B/L/A
11	ASP	Aspect (N, E, S, W)	**N**
12	SLP	Slope %	**25**
13	FMC	Fuel moisture correction % (table 3, 4, or 5)	**2**
	Output		
1	1H-FDFM	Fine dead fuel moisture %	**5**
2	PIG	Probability of ignition % (table 12)	**70**

Problem 17.

Wind Adjustment Worksheet

	Input		
0	PP	Projection point	
1	20Õ W	20-ft windspeed, mi/h	**12**
2	Model #	Fuel model number (1-13)	**10**
3	Shltr	Wind sheltering 1 = Unsheltered 2 = Partially sheltered 3 = Fully sheltered, open 4 = Fully sheltered, closed	**2**
4	WAF	Wind adjustment factor (table 7)	**0.3**
	Output		
1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)	**3.6**

Problem 18.

Fire Behavior Worksheet

Input

0	PP	Projection point	**B**
1	Model #	Fuel model number, (1-13)	**9**
2	1H-FDFM	Fine dead fuel moisture, %	**8**
3	LFM	Live fuel moisture, %	
4	MFWS	Midflame windspeed, mi/h	**7.5**
5	SLP	Slope, %	**35**
6	EWS	Effective windspeed, mi/h	**8**

Output

1	ROS	Rate of spread, ch/h	**16**
2	HA	Heat per unit area, Btu/sq ft	**350**
3	FLI	Fireline intensity, Btu/ft/s	**90**
4	FL	Flame length, ft	**4**
5	SD	Spread distance, ch	
		Map spread distance, in	
6	PER	Perimeter, ch	
7	AC	Area, ac	
8	SPOT	Max spotting dist, mi	
		Map distance spot, in	
9	PIG	Probability of ignition, %	

Also, see nomogram.

Problem 19.

Fire Behavior Worksheet

Input

0	PP	Projection point	**14**
1	Model #	Fuel model number, (1-13)	**10**
2	1H-FDFM	Fine dead fuel moisture, %	**16**
3	LFM	Live fuel moisture, %	**200**
4	MFWS	Midflame windspeed, mi/h	**5**
5	SLP	Slope, %	**45**
6	EWS	Effective windspeed, mi/h	**6**

Output

1	ROS	Rate of spread, ch/h	**4**
2	HA	Heat per unit area, Btu/ft^2	**875**
3	FLI	Fireline intensity, Btu/ft/s	**100**
4	FL	Flame length, ft	**3**
5	SD	Spread distance, ch	
		Map spread distance, in	
6	PER	Perimeter, ch	
7	AC	Area, ac	
8	SPOT	Max spotting dist, mi	
		Map distance spot, in	
9	PIG	Probability of ignition, %	

Also, see nomogram.

Problem 20.

Contour interval = 20 ft
Map scale = 1:24,000
Conversion factor = 2,000 ft/in
# of contour intervals = 17
Rise in elevation = 340 ft
Map distance between points = 1 in
Horizontal ground distance, ft = 2,000
Slope, % = 17%

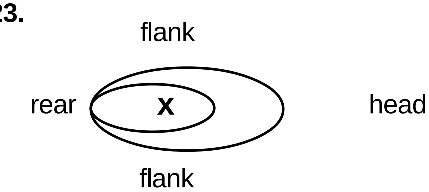
Problem 21.

Projection point = 21
Flame height = 78 ft
Flame duration = 4.5
Treetop windspeed = 17 mi/h
Effective tree cover height = 75 ft
Ratio of torching tree height to flame height = 1.2
Ratio of lofted firebrand height to flame height = 7
Maximum firebrand height = 591 ft
Maximum spotting distance = 0.5 mi

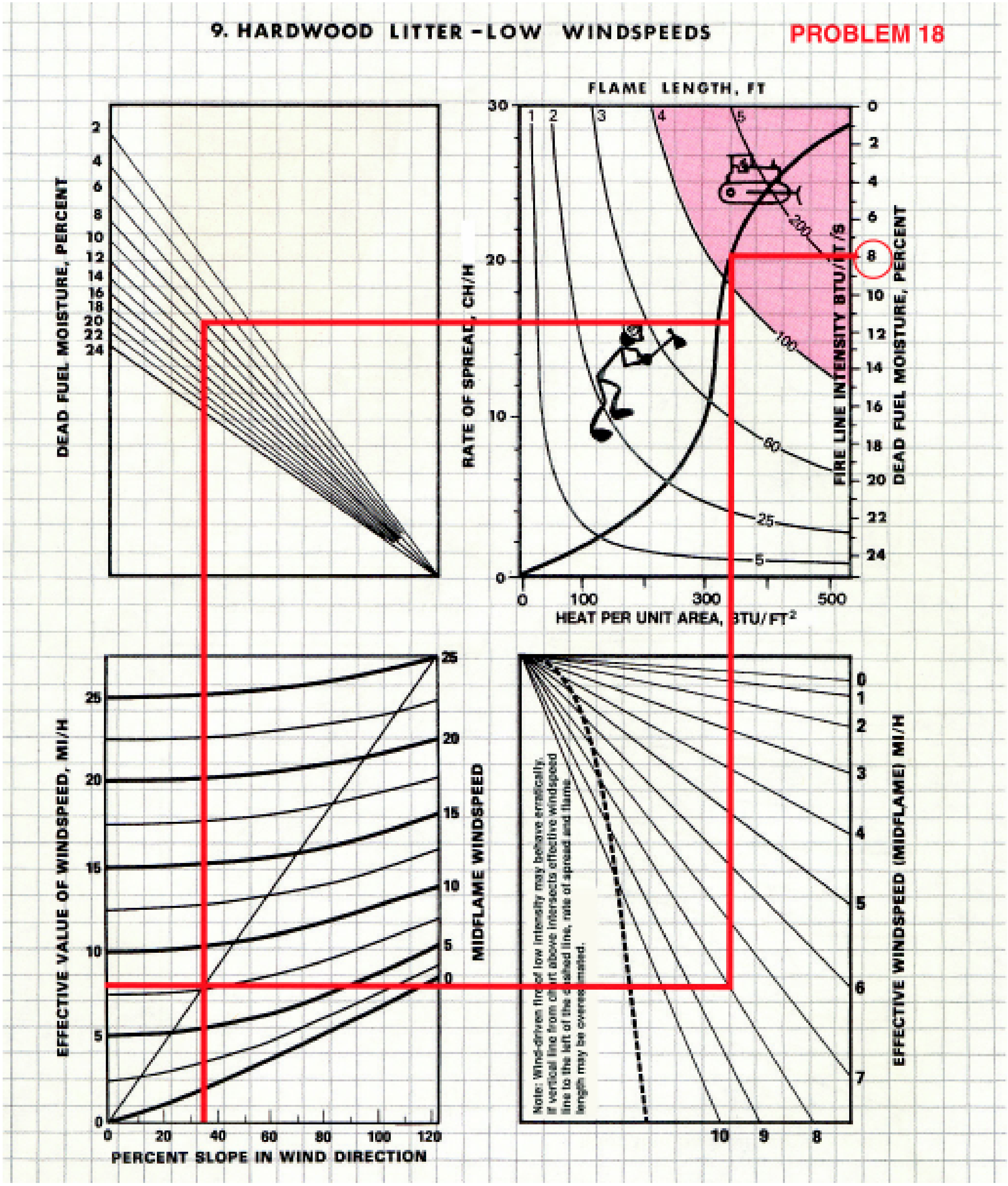
Problem 22.

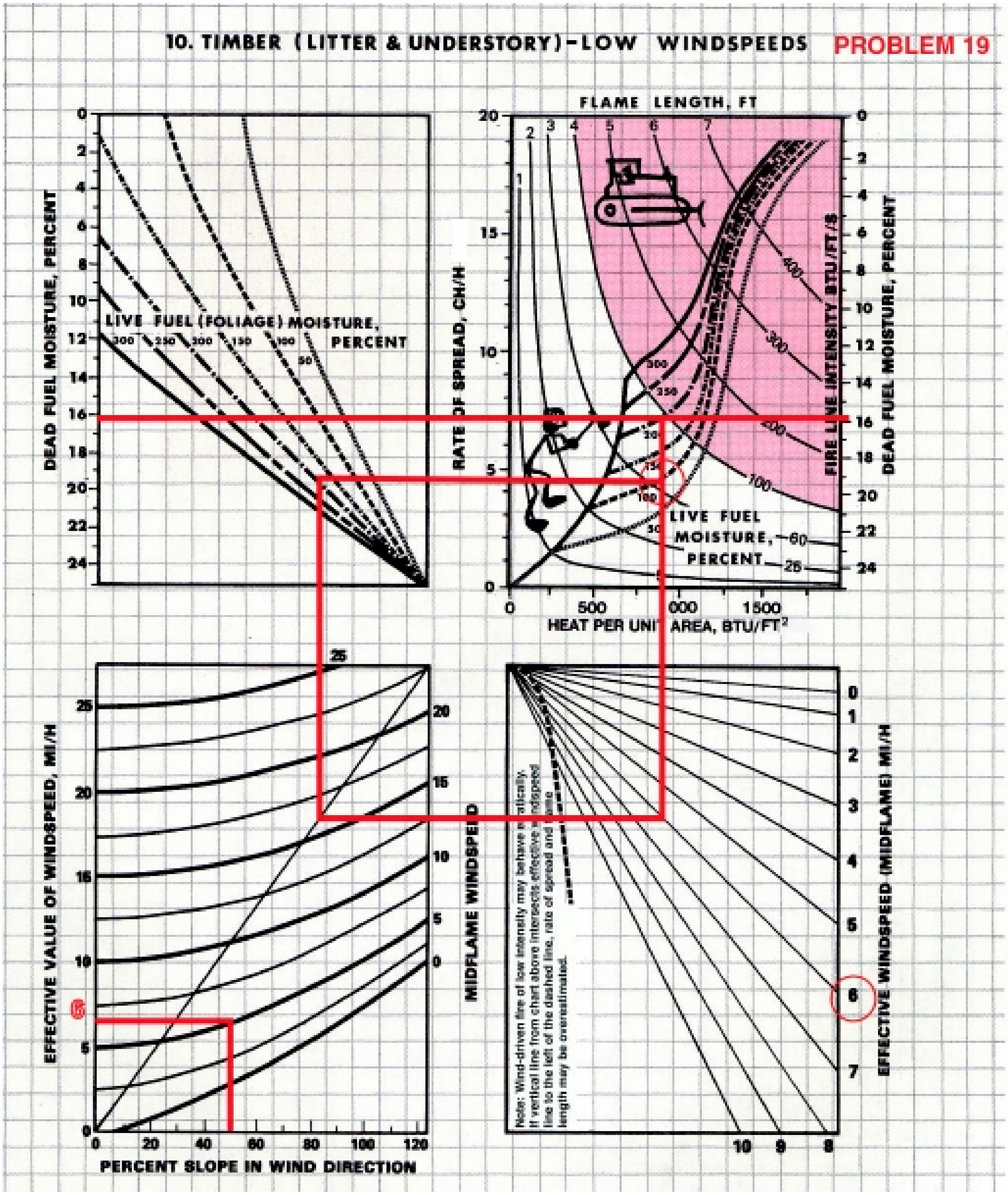
area = 2.5 acres
perimeter = 21 chains
spread distance, 2 hours = 18 chains
3 hours = 27 chains
4 hours = 36 chains

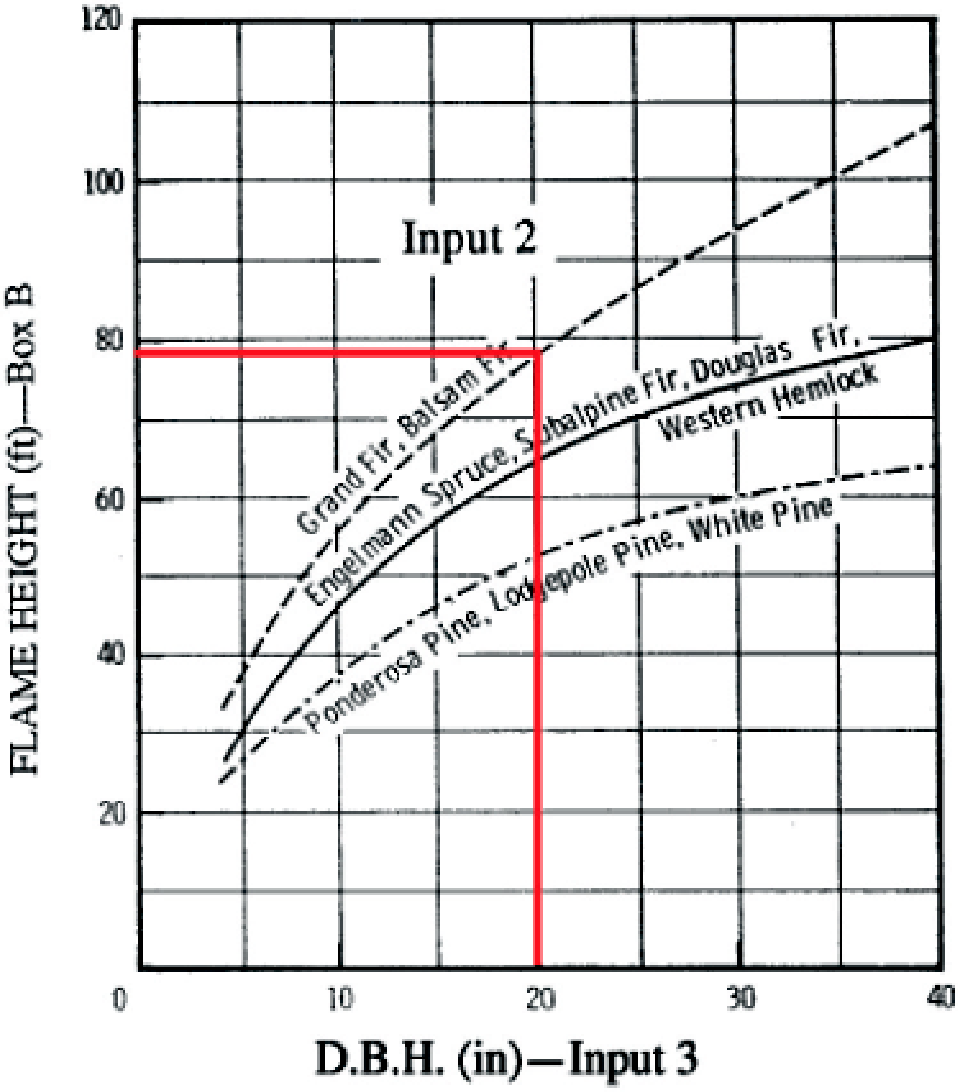
Problem 23.



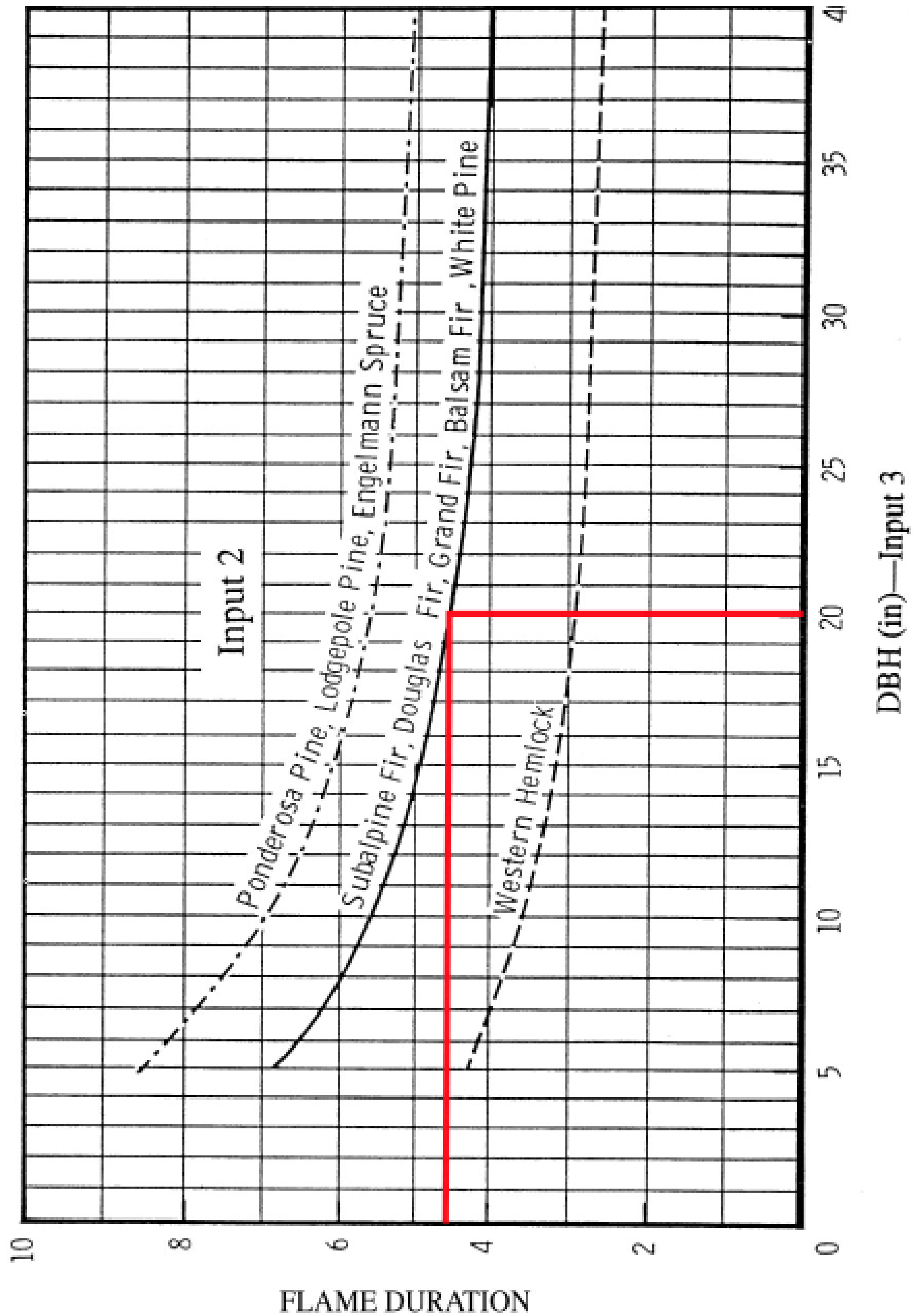
18 x 66 ft = 1,188 ft = 0.9 in
1,782 ft = 1.4 in
2,376 ft = 1.8 in


9. HARDWOOD LITTER - LOW WINDSPEEDS
PROBLEM 18
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CH/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H

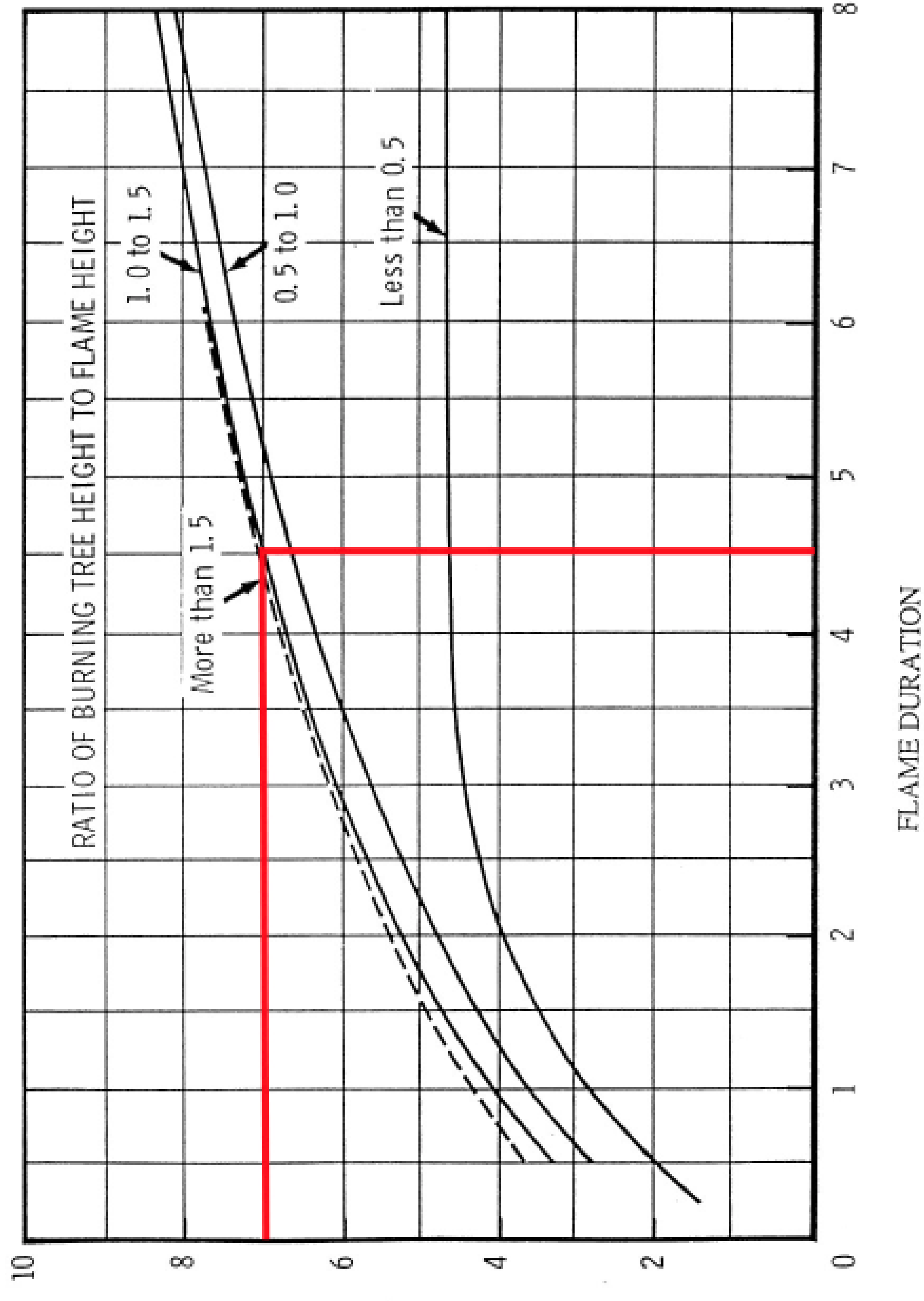

10. TIMBER (LITTER & UNDERSTORY)-LOW WINDSPEEDS
PROBLEM 19
FLAME LENGTH, FT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CH/H
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT2
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.


Input 2
FLAME HEIGHT (ft)—Box B
D.B.H. (in)—Input 3
Grand Fir, Balsam Fir
Engelmann Spruce, Subalpine Fir, Douglas Fir, Western Hemlock
Ponderosa Pine, Lodgepole Pine, White Pine
0
10
20
30
40
20
40
60
80
100
120

PROBLEM 21

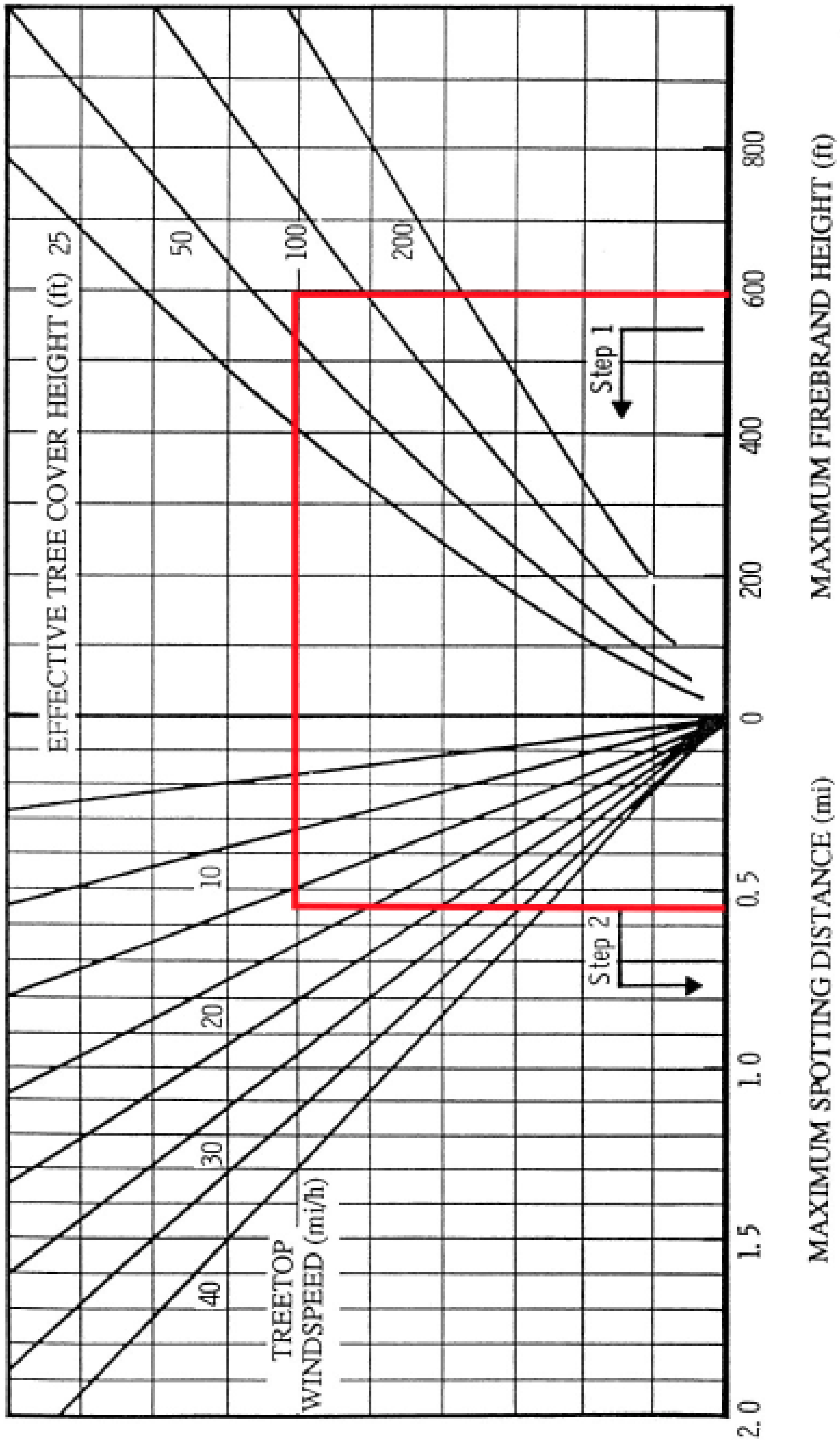

Input 2
Ponderosa Pine, Lodgepole Pine, Engelmann Spruce
Subalpine Fir, Douglas Fir, Grand Fir, Balsam Fir ,White Pine
Western Hemlock
DBH (in)—Input 3
5
10
15
20
25
30
35
40
FLAME DURATION
0
2
4
6
8
10

PROBLEM 21



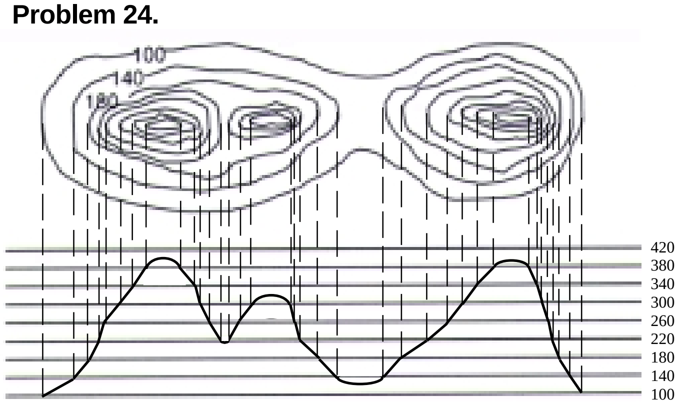
RATIO OF LOFTED FIREBRAND HEIGHT TO FLAME HEIGHT—Box C

PROBLEM 21


EFFECTIVE TREE COVER HEIGHT (ft)
25
50
100
200
Step 1
Step 2
10
20
30
40
TREETOP WINDSPEED (mi/h)
800
600
400
200
0
0.5
1.0
1.5
2.0
MAXIMUM FIREBRAND HEIGHT (ft)
MAXIMUM SPOTTING DISTANCE (mi)

PROBLEM 21

Problem 24.



Problem 25. 154°

Problem 26. 250°, back azimuth 250° Ð 180° = 70°

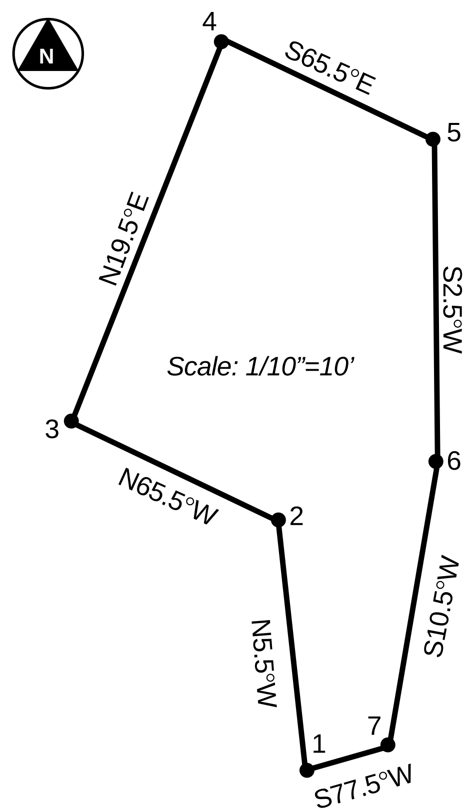
Problem 27. Adjust the magnetic readings to true readings.

1) 340° + 14.5° = 354.5°
2) 280° + 14.5° = 294.5°
3) 5° + 14.5° = 19.5°
4) 100° + 14.5° =114.5°
5) 168° + 14.5° =182.5°
6) 176° + 14.5° =190.5°
7) 243° + 14.5° = 257.5°

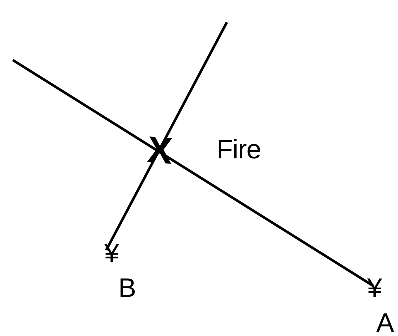
Find the bearings for each point.
(See figure in problem 26.)

1) 360° Ð 354.5° = N5.5°W
2) 360° Ð 294.5° = N65.5°W
3) 0° + 19.5° = N19.5°E
4) 180° Ð 114.5° = S65.5°E
5) 182.5° Ð 180° = S2.5°W
6) 190.5° Ð 180° = S10.5°W
7) 257.5° Ð 180° = S77.5°W

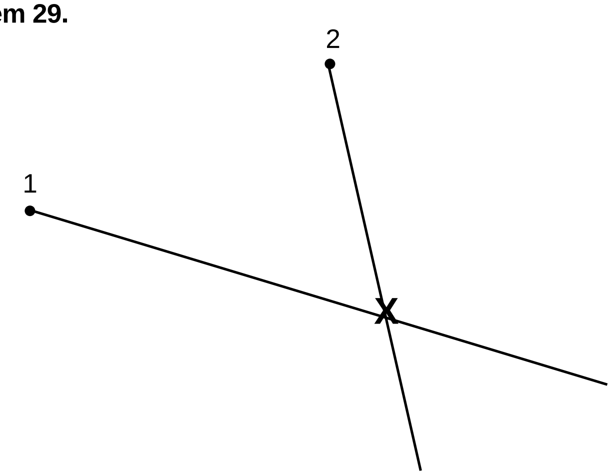
Set the protractor so that the 0°/180° line runs North-South. Put a point in the hole. This will be point 1. Read 0° (N) and put a point at 5.5°W. Draw a line from point 1 to the dot, measuring off 13.3 marks on the tenths ruler. Repeat these steps for each of the seven bearings until point 7 connects to point 1.



Problem 28. 310° Ð 8° = 302°
39° Ð 8° = 31°

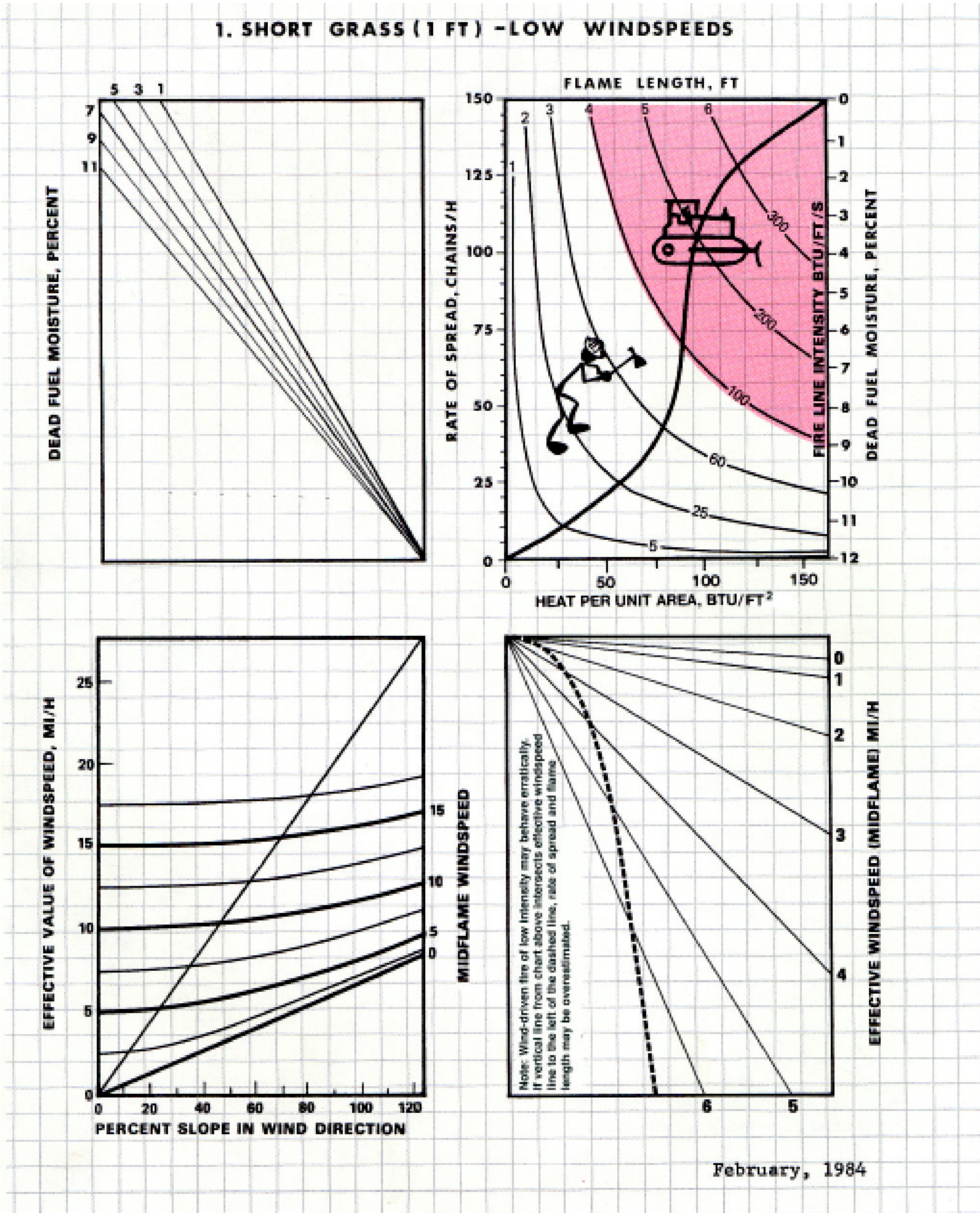


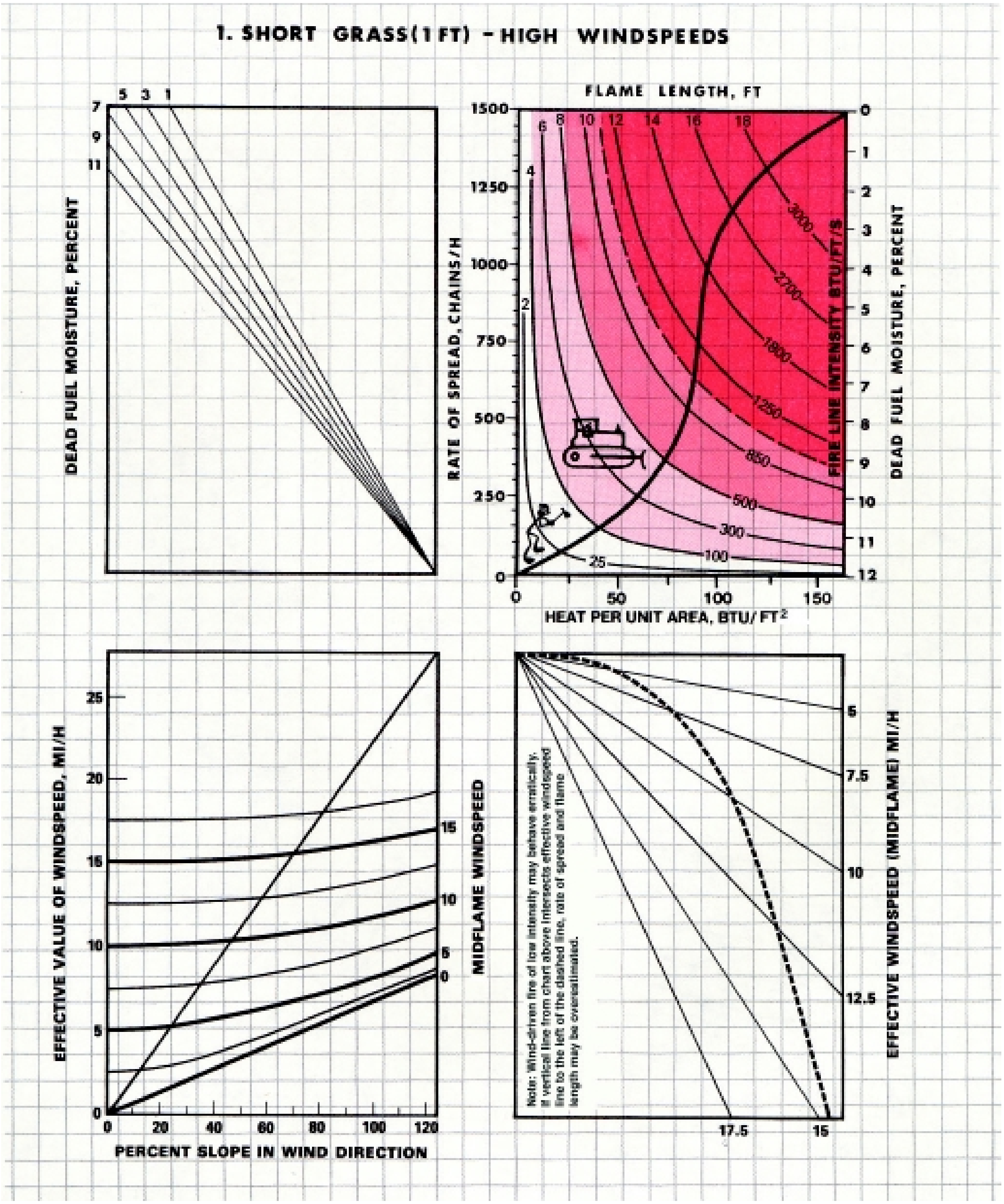
Problem 29.



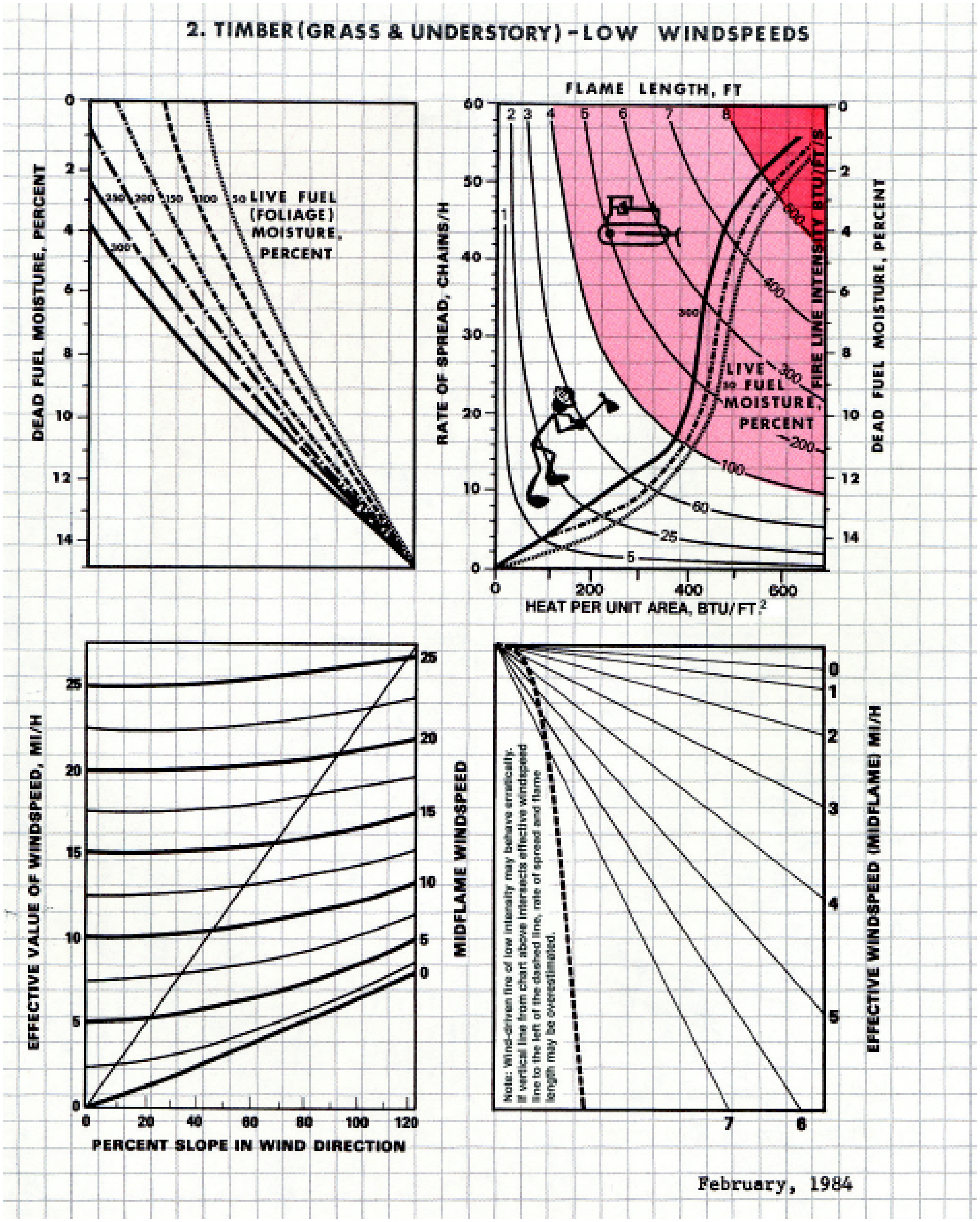
Appendix E

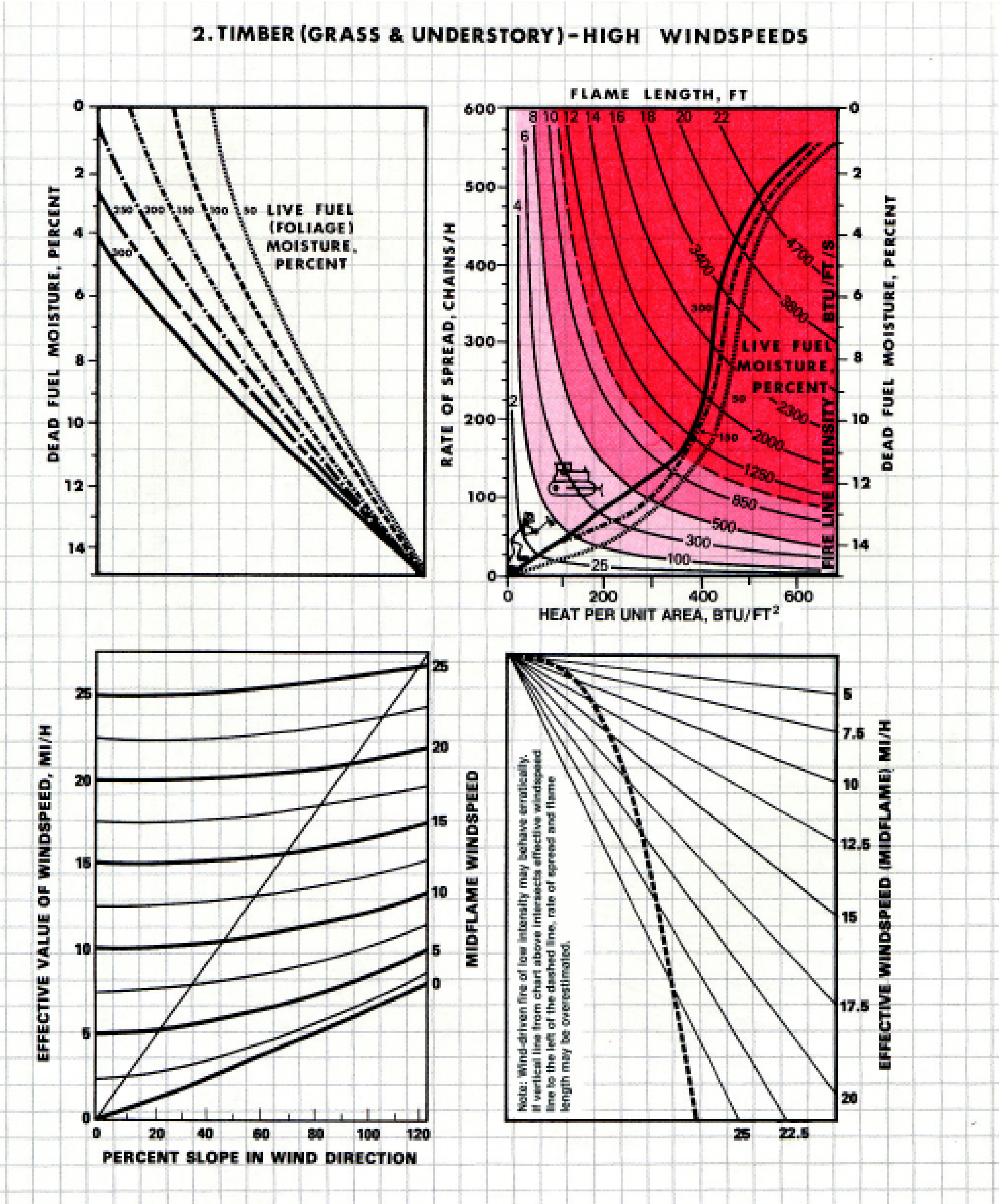
Nomograms and Worksheets

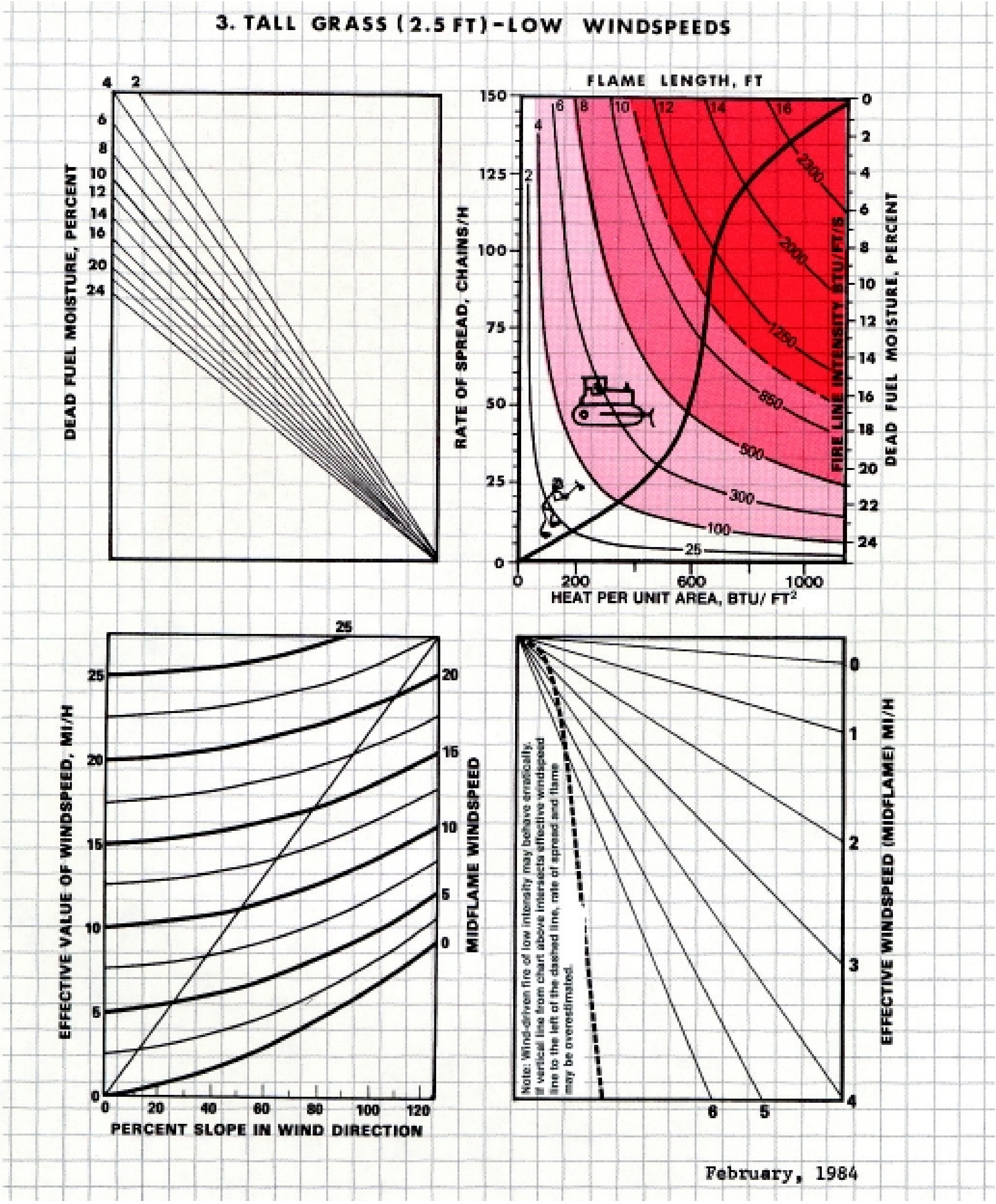

1. SHORT GRASS (1 FT) - LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
February, 1984

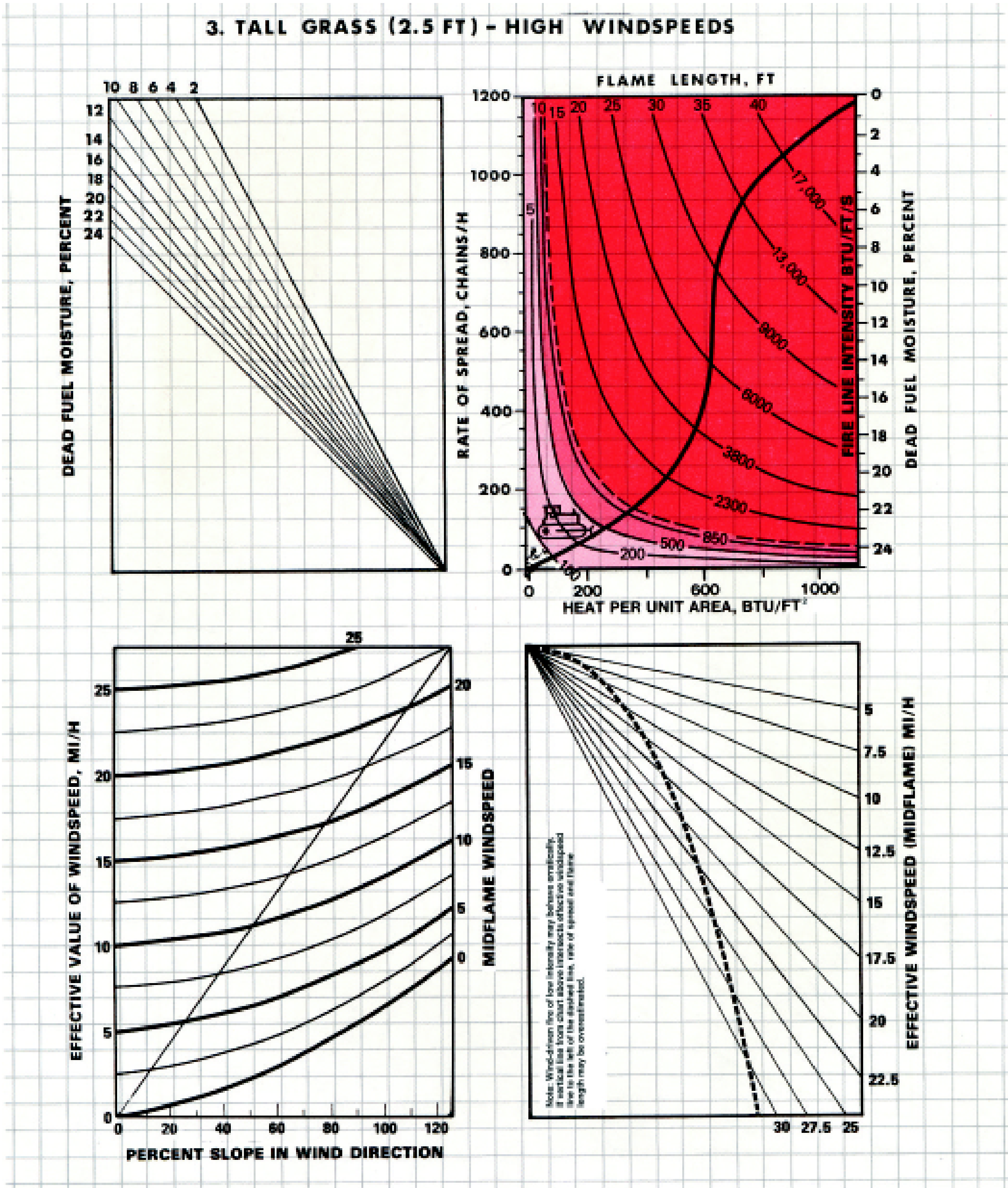


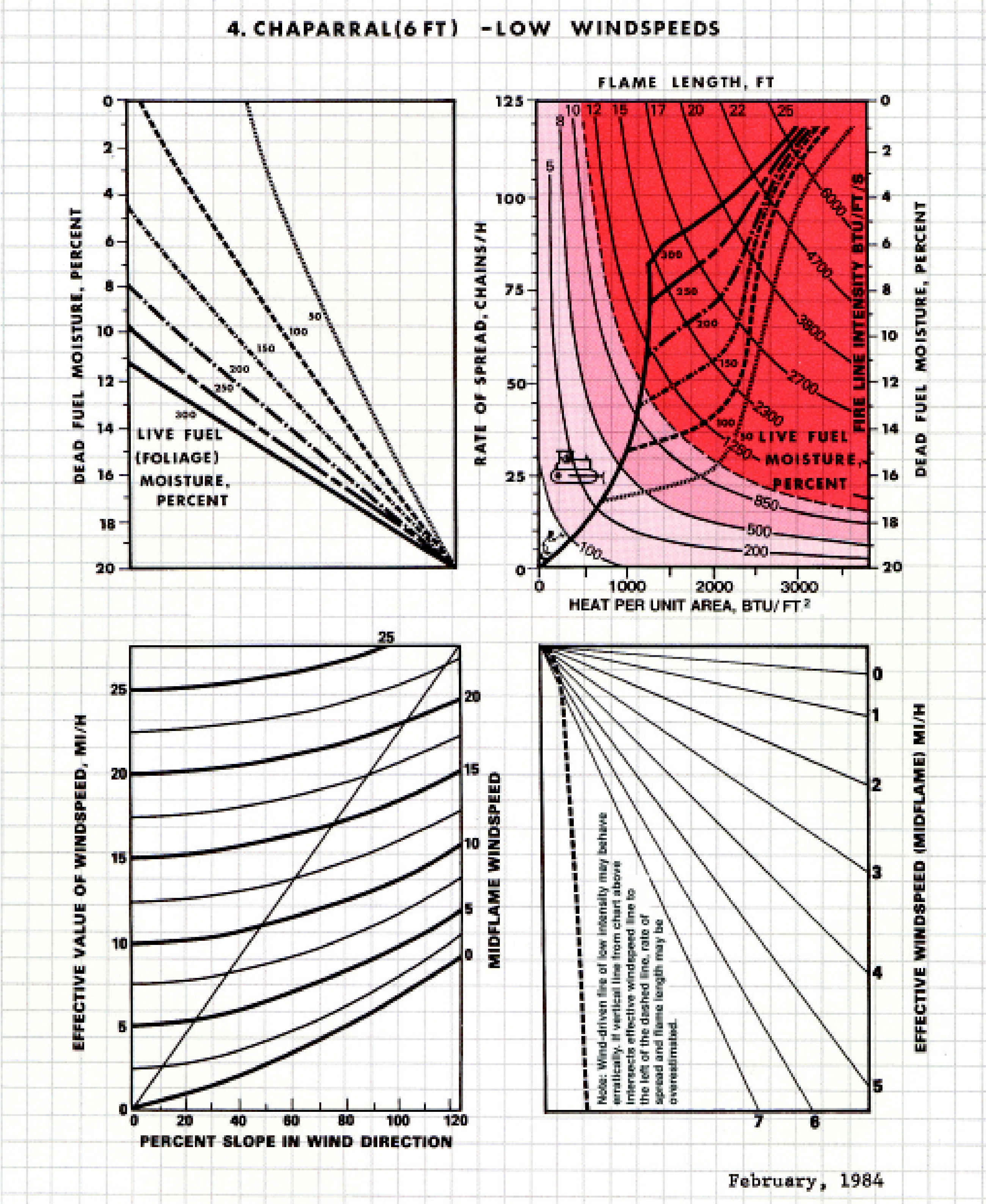
1. SHORT GRASS (1 FT) - HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
5 3 1
7
9
11
FLAME LENGTH, FT
2 4 6 8 10 12 14 16 18
RATE OF SPREAD, CHAINS/H
1500
1250
1000
750
500
250
0
FIRE LINE INTENSITY BTU/FT/S
3000
2700
1800
1250
850
500
300
100
25
DEAD FUEL MOISTURE, PERCENT
0 1 2 3 4 5 6 7 8 9 10 11 12
HEAT PER UNIT AREA, BTU/FT²
0 50 100 150
EFFECTIVE VALUE OF WINDSPEED, MI/H
25
20
15
10
5
0
15
10
5
0
PERCENT SLOPE IN WIND DIRECTION
0 20 40 60 80 100 120
MIDFLAME WINDSPEED
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
5
7.5
10
12.5
17.5
15


2. TIMBER (GRASS & UNDERSTORY) - LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
February, 1984

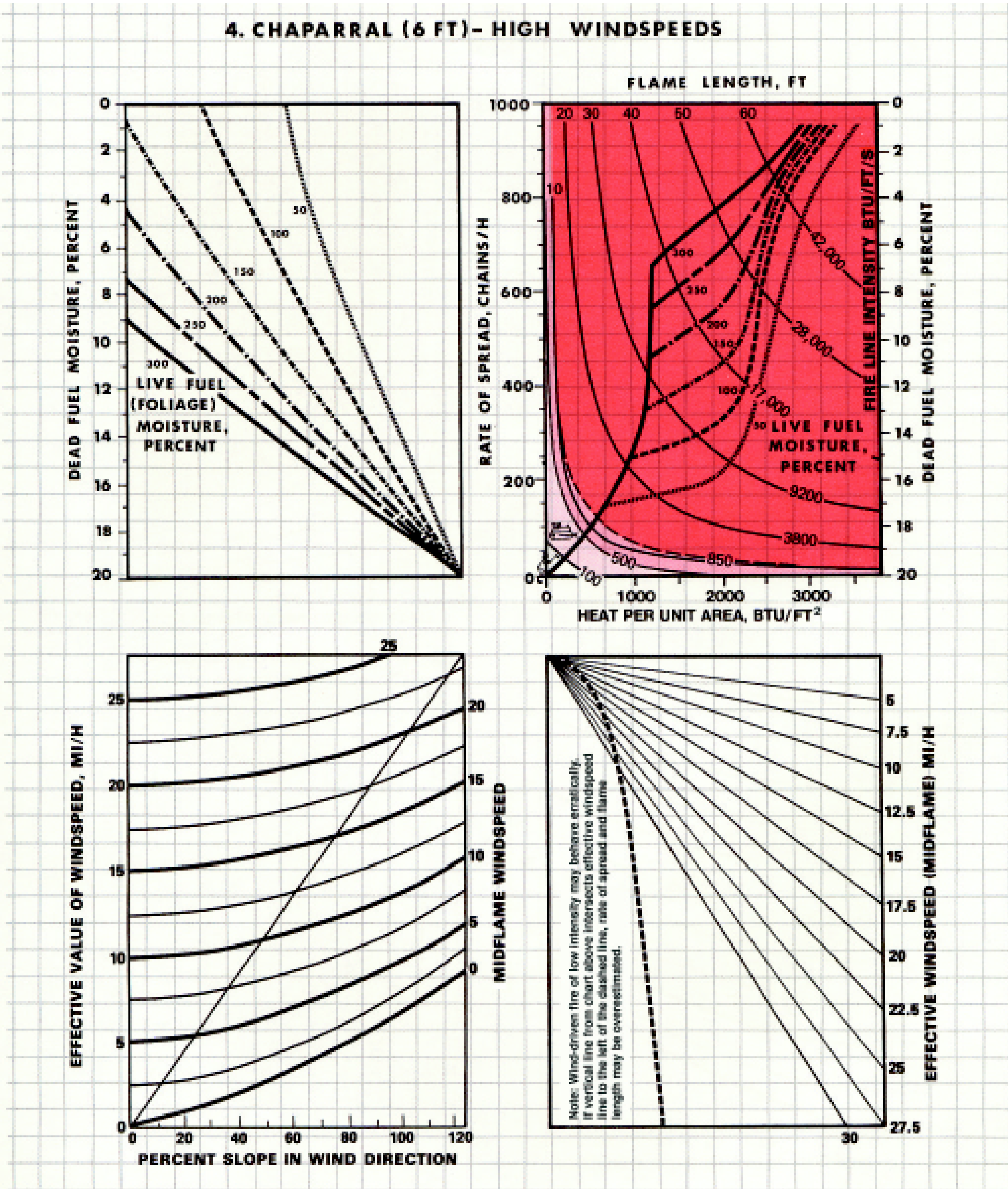

2. TIMBER (GRASS & UNDERSTORY) - HIGH WINDSPEEDS
FLAME LENGTH, FT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

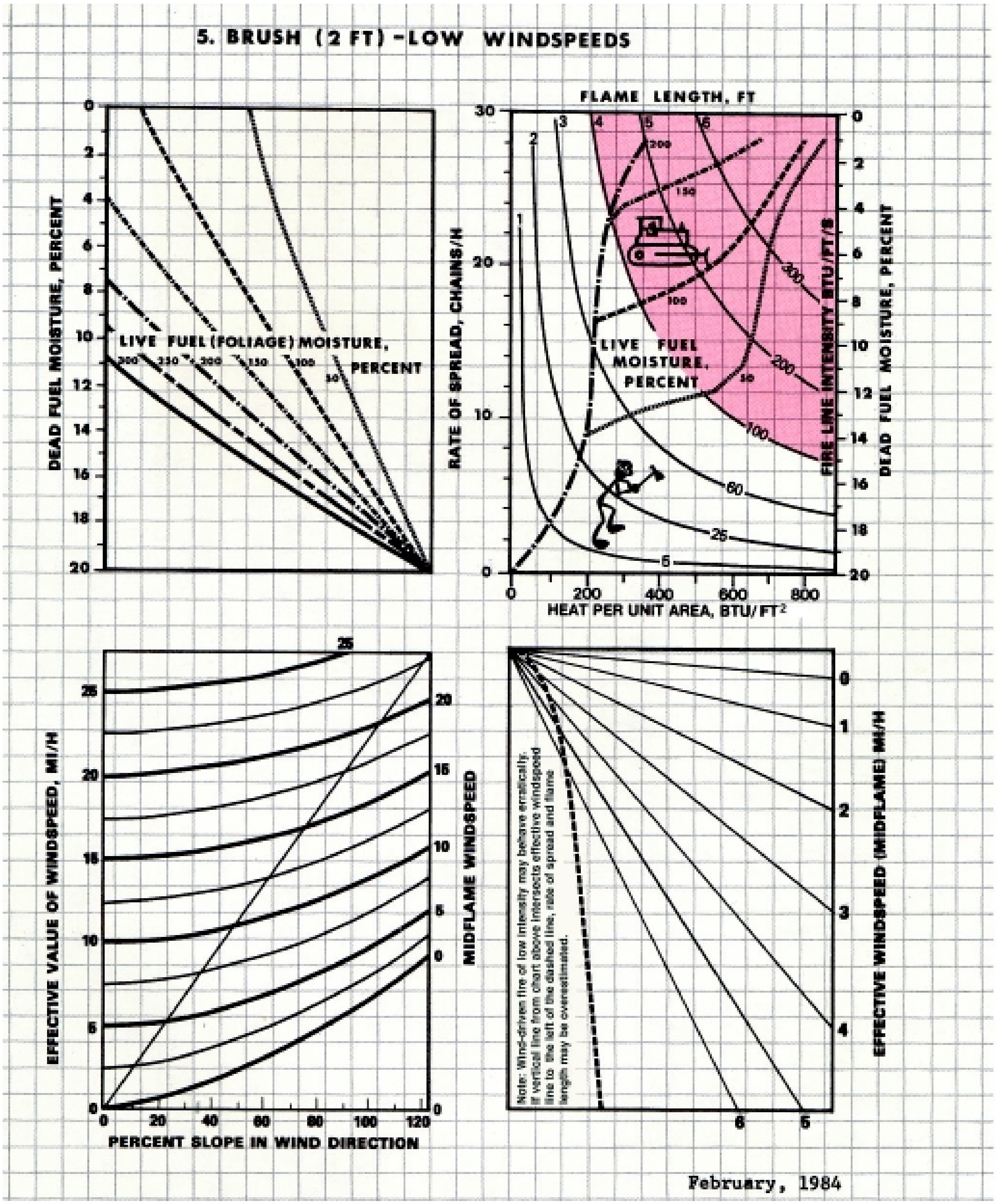

3. TALL GRASS (2.5 FT)-LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/ FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame may be overestimated.
February, 1984

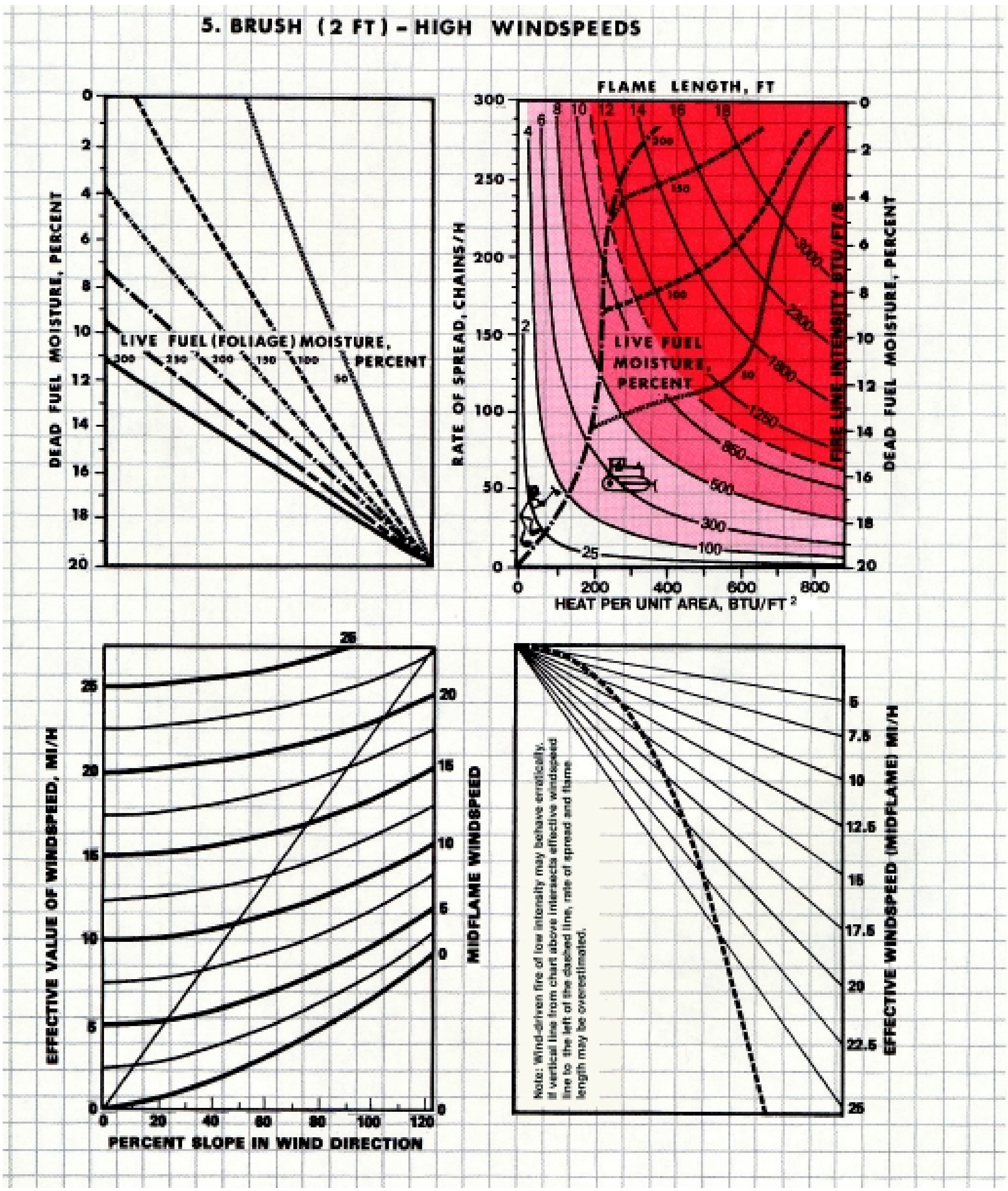

3. TALL GRASS (2.5 FT) - HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
10 8 6 4 2
12 14 16 18 20 22 24
FLAME LENGTH, FT
5 10 15 20 25 30 35 40
RATE OF SPREAD, CHAINS/H
0 200 400 600 800 1000 1200
FIRE LINE INTENSITY BTU/FT/S
100 200 500 850 2300 3800 6000 9000 13,000 17,000
DEAD FUEL MOISTURE, PERCENT
0 2 4 6 8 10 12 14 16 18 20 22 24
HEAT PER UNIT AREA, BTU/FT²
0 200 600 1000
EFFECTIVE VALUE OF WINDSPEED, MI/H
0 5 10 15 20 25
MIDFLAME WINDSPEED
0 5 10 15 20 25
PERCENT SLOPE IN WIND DIRECTION
0 20 40 60 80 100 120
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30

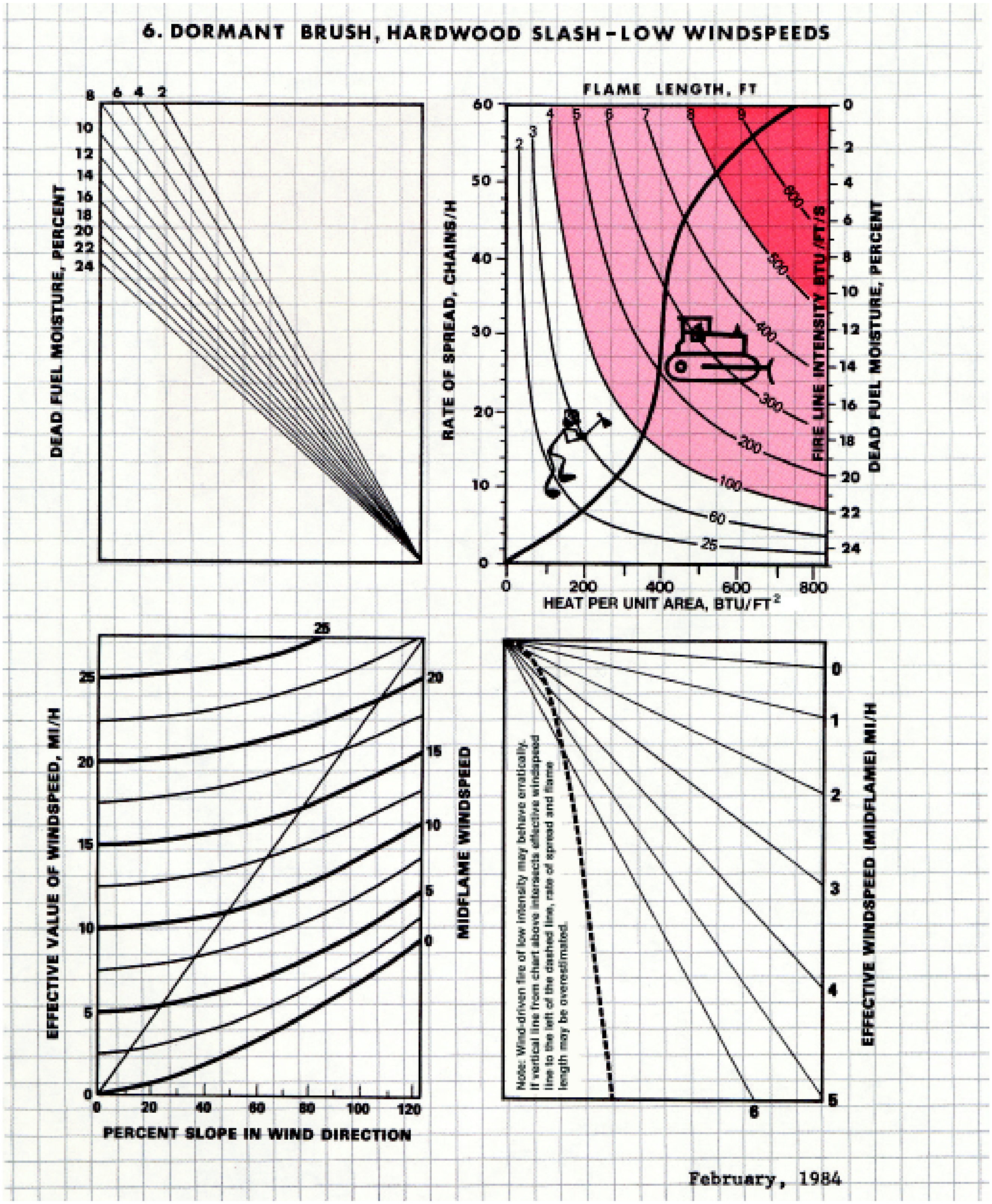


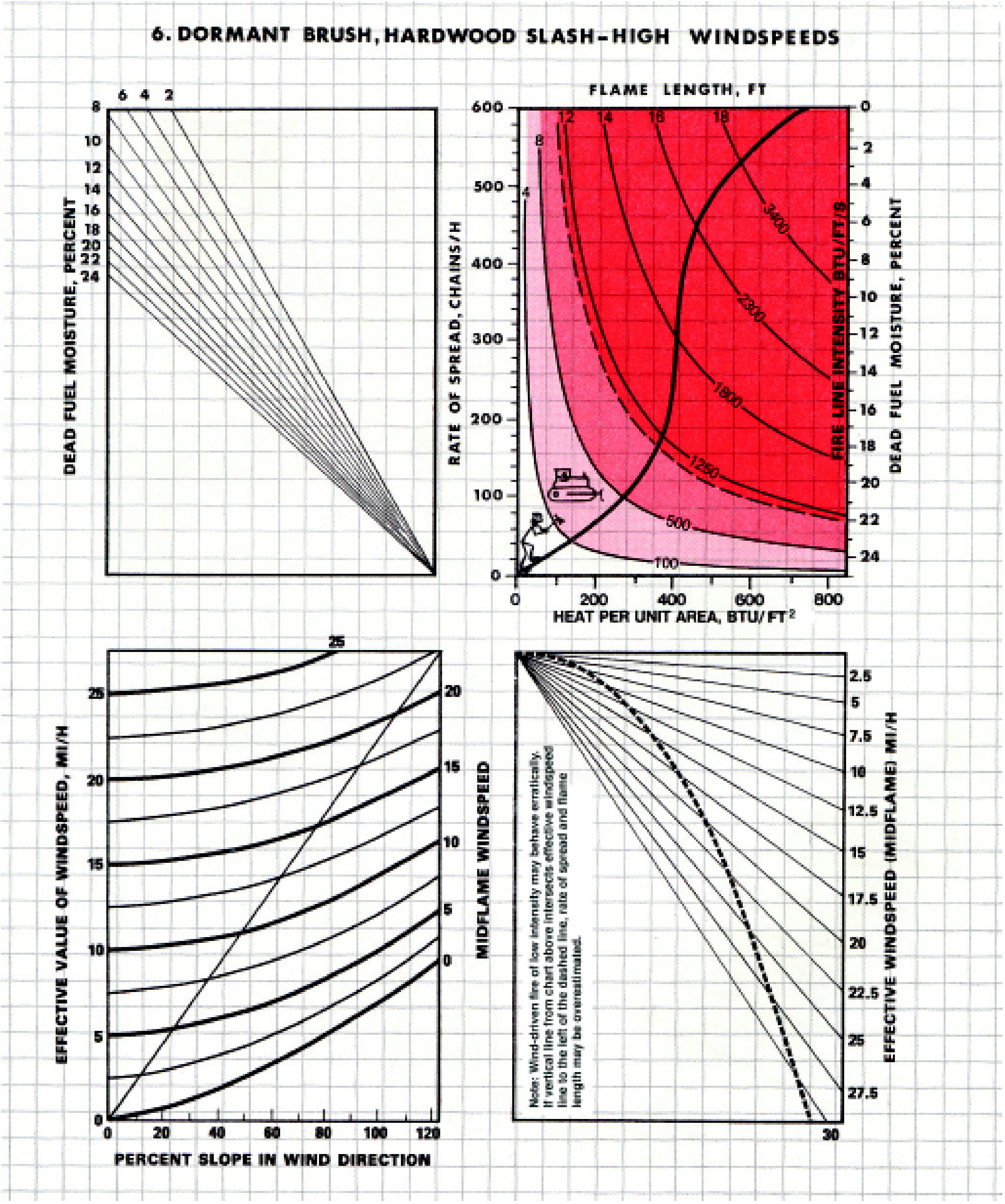
February, 1984

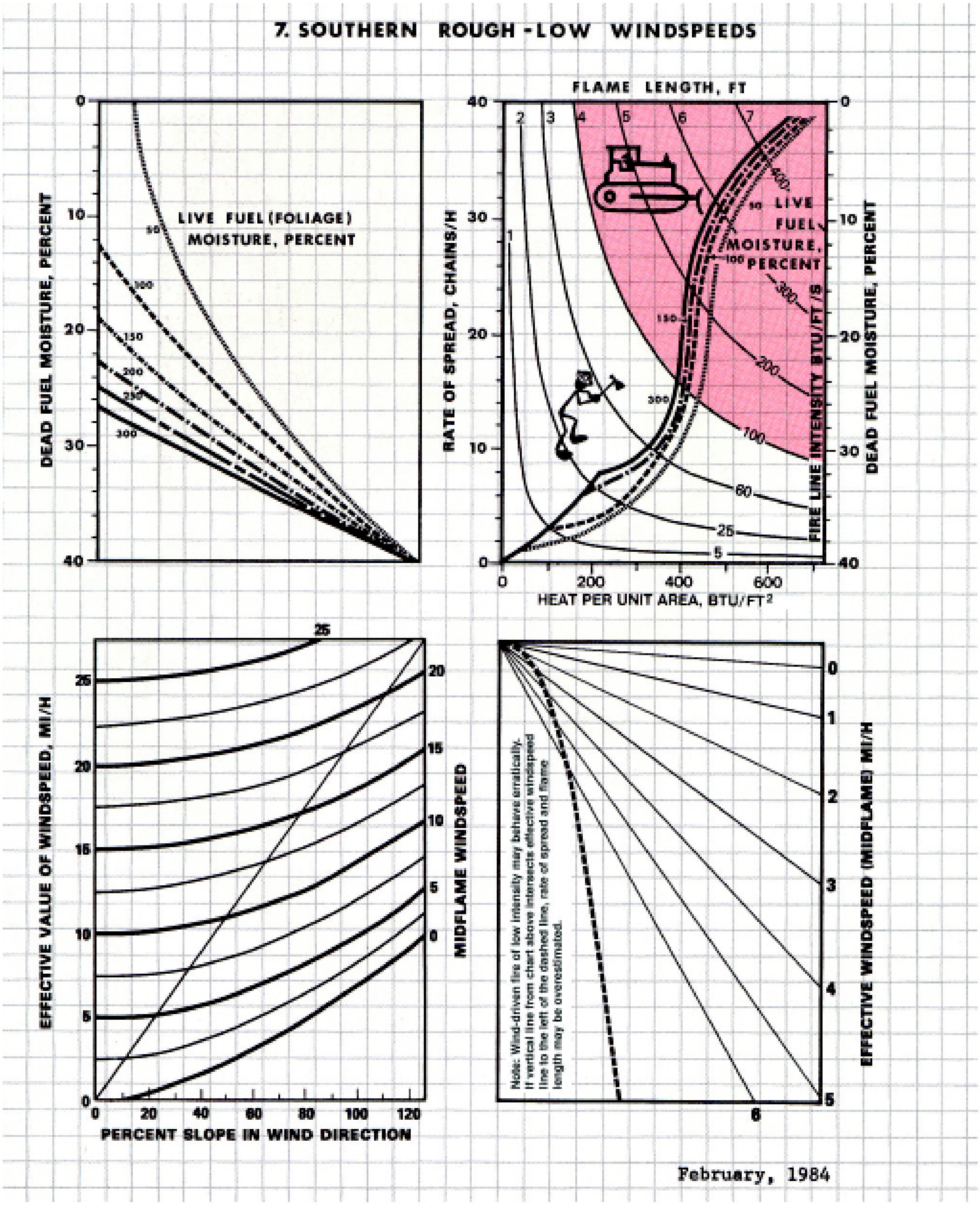

4. CHAPARRAL (6 FT)– HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
DEAD FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

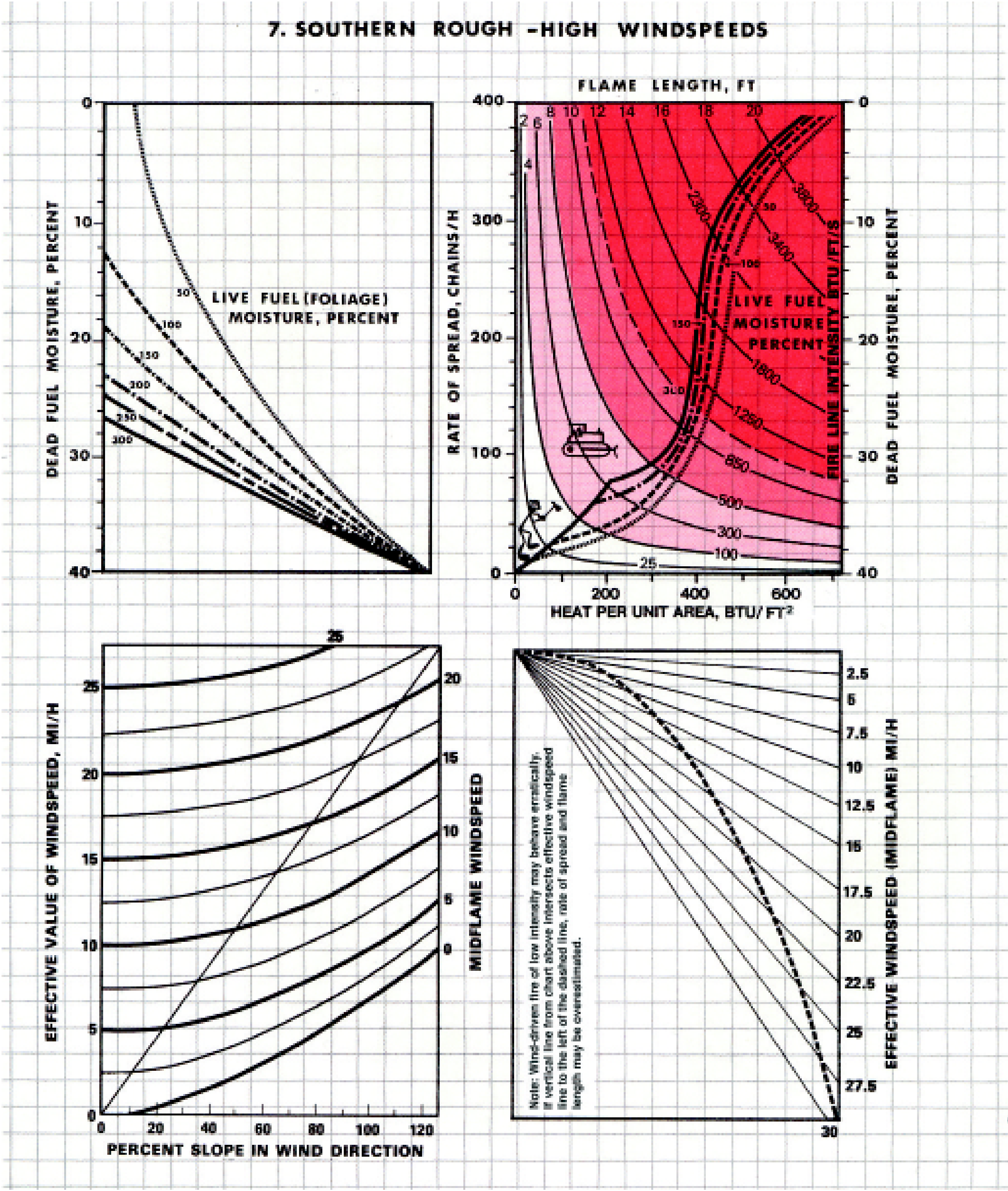

5. BRUSH (2 FT) – LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
LIVE FUEL MOISTURE, PERCENT
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
February, 1984

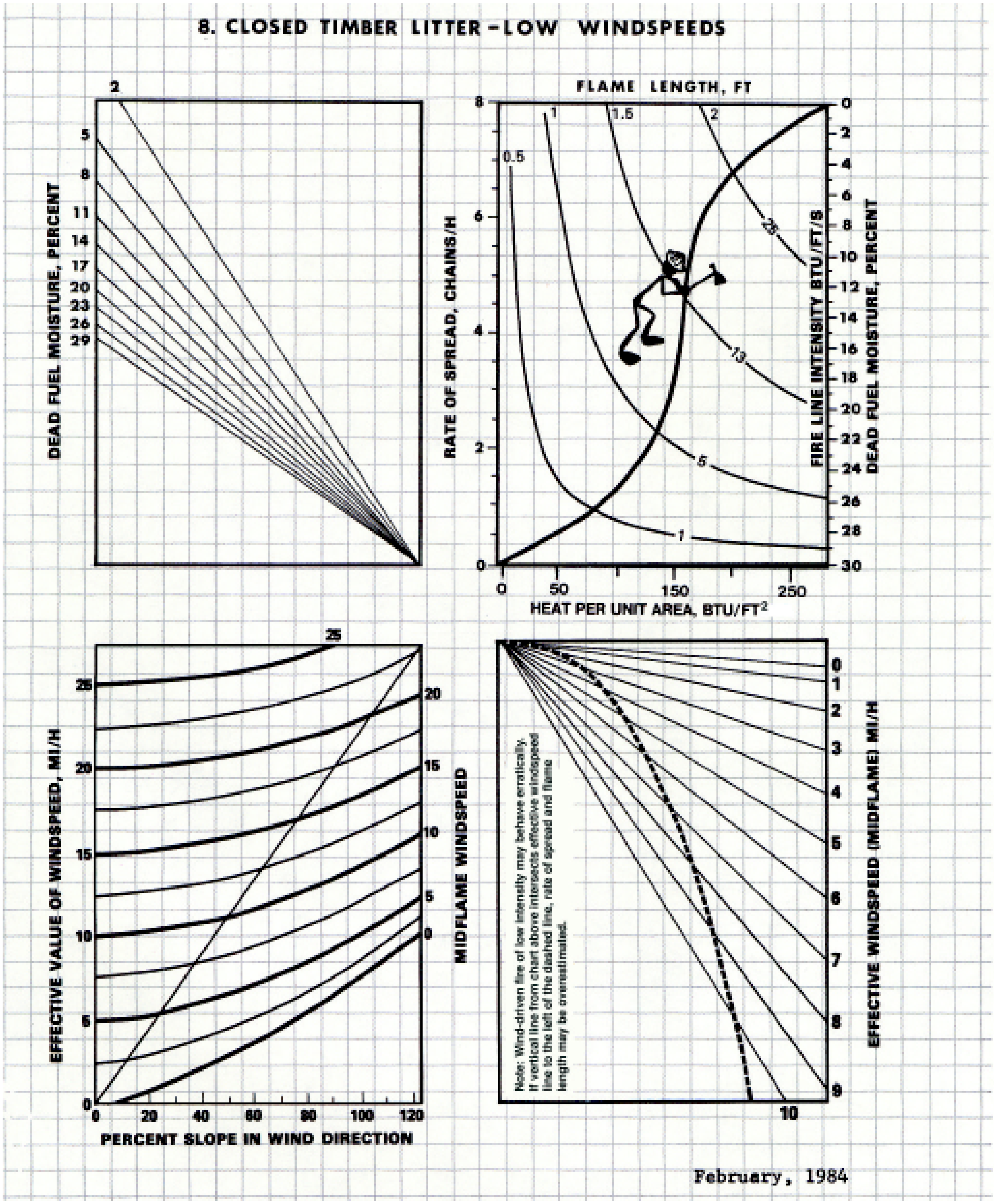

5. BRUSH (2 FT) - HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

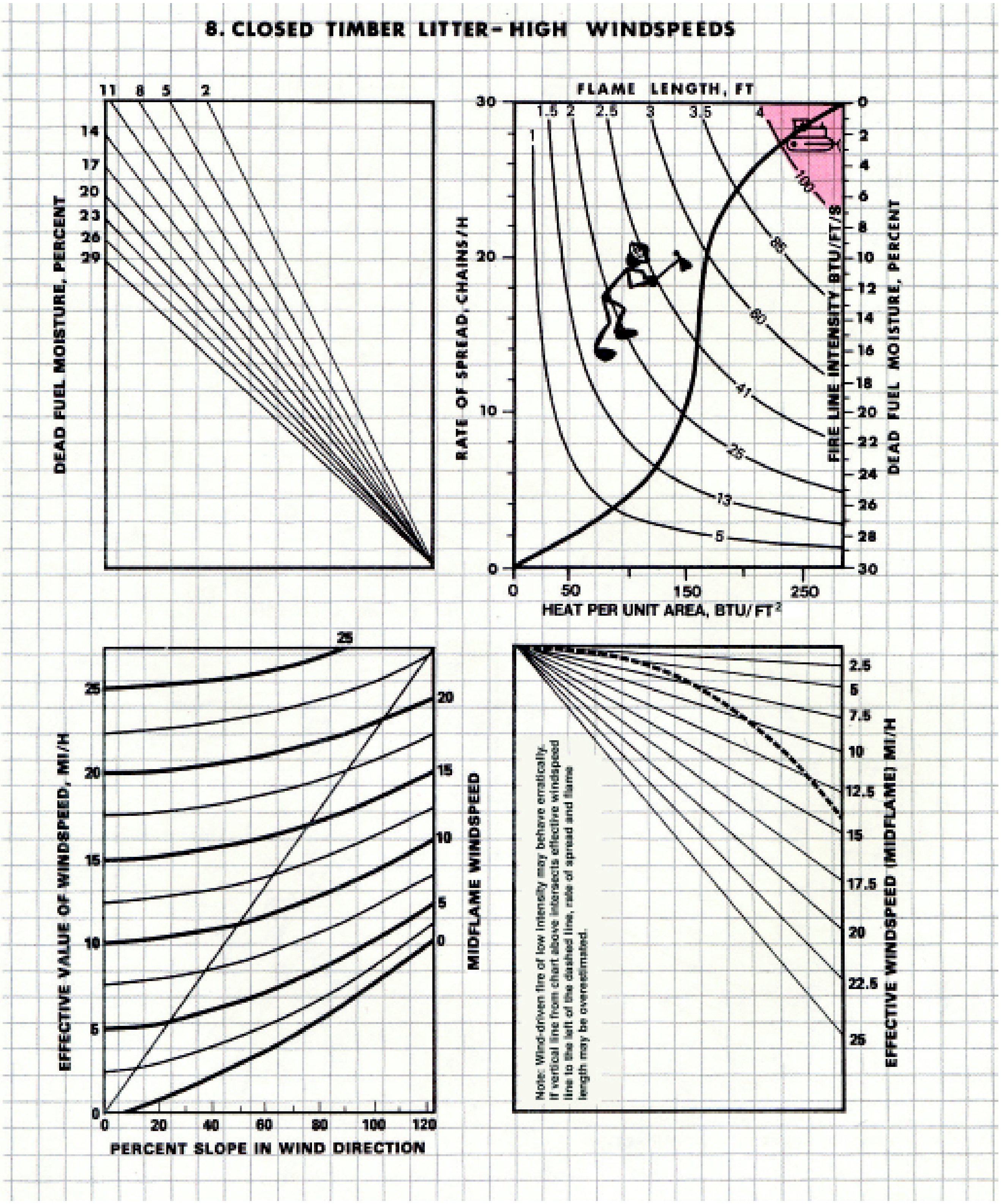

6. DORMANT BRUSH, HARDWOOD SLASH - LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
February, 1984

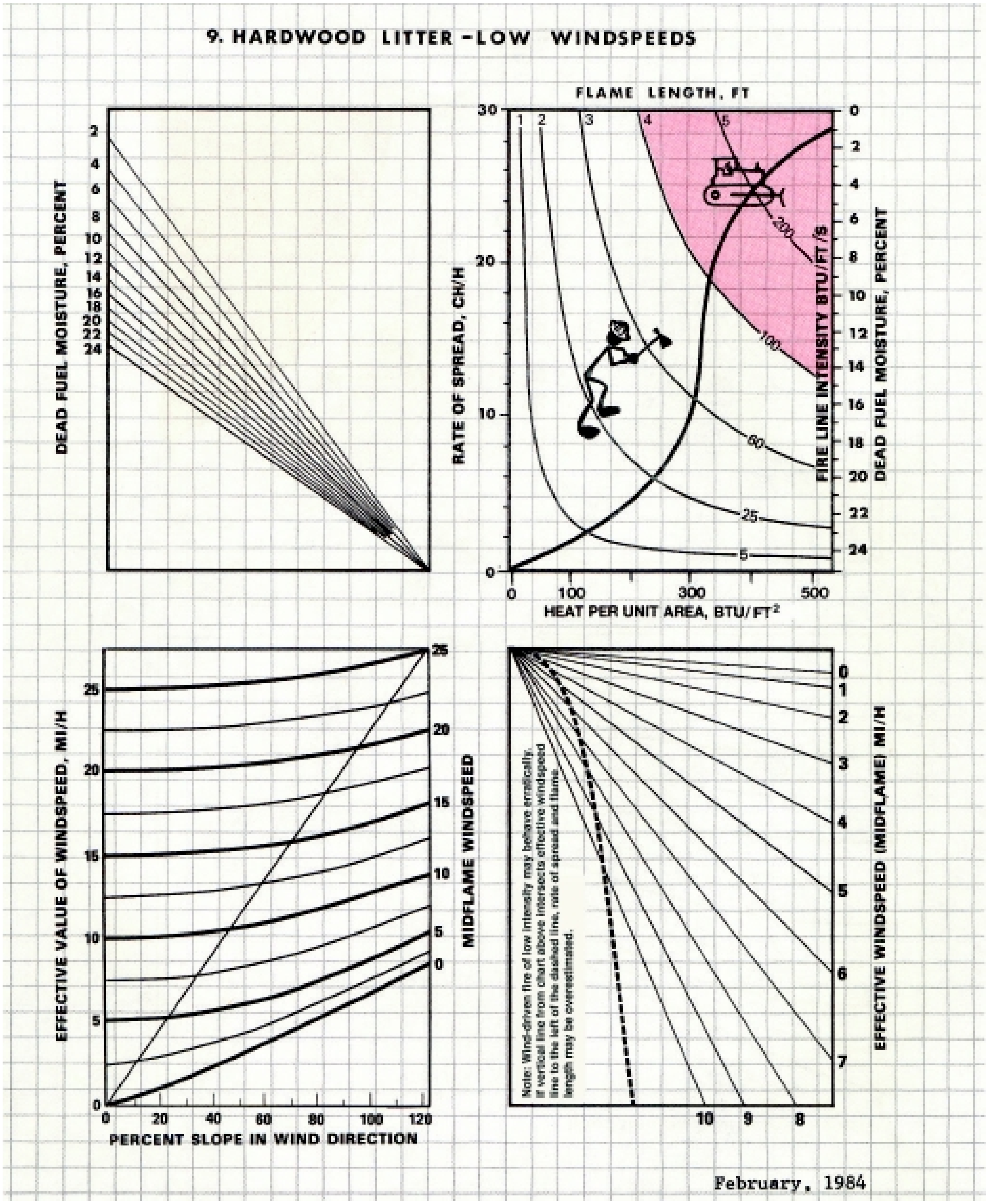

6. DORMANT BRUSH, HARDWOOD SLASH–HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
8 10 12 14 16 18 20 22 24
6 4 2
FLAME LENGTH, FT
4 8 12 14 16 18
RATE OF SPREAD, CHAINS/H
0 100 200 300 400 500 600
HEAT PER UNIT AREA, BTU/FT²
0 200 400 600 800
FIRE LINE INTENSITY BTU/FT/S
100 500 1250 1800 2300 3400
DEAD FUEL MOISTURE, PERCENT
0 2 4 6 8 10 12 14 16 18 20 22 24
EFFECTIVE VALUE OF WINDSPEED, MI/H
0 5 10 15 20 25
MIDFLAME WINDSPEED
0 5 10 15 20 25
PERCENT SLOPE IN WIND DIRECTION
0 20 40 60 80 100 120
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30

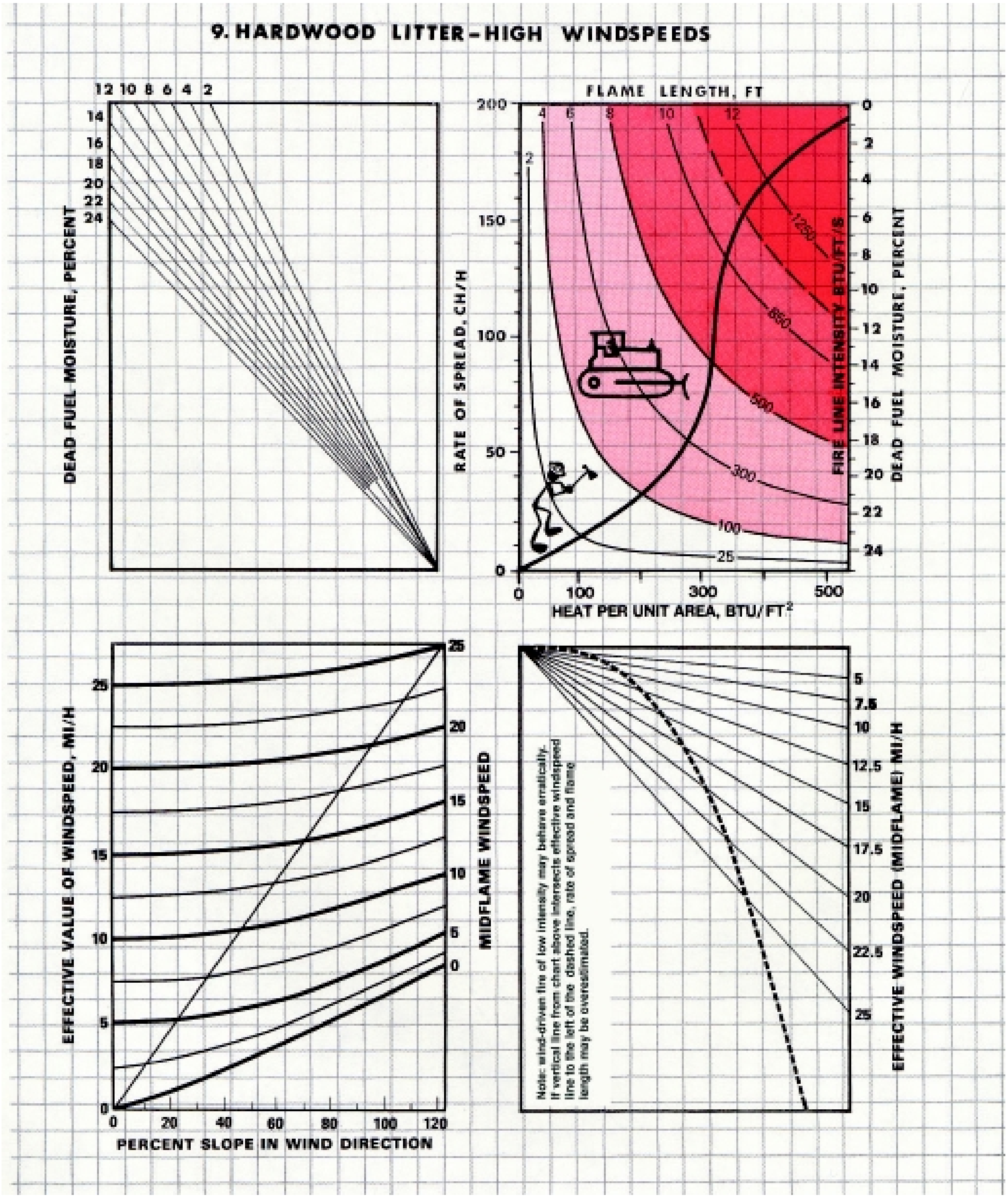

7. SOUTHERN ROUGH - LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
LIVE FUEL MOISTURE, PERCENT
FIRE LINE INTENSITY BTU/FT/S
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
February, 1984

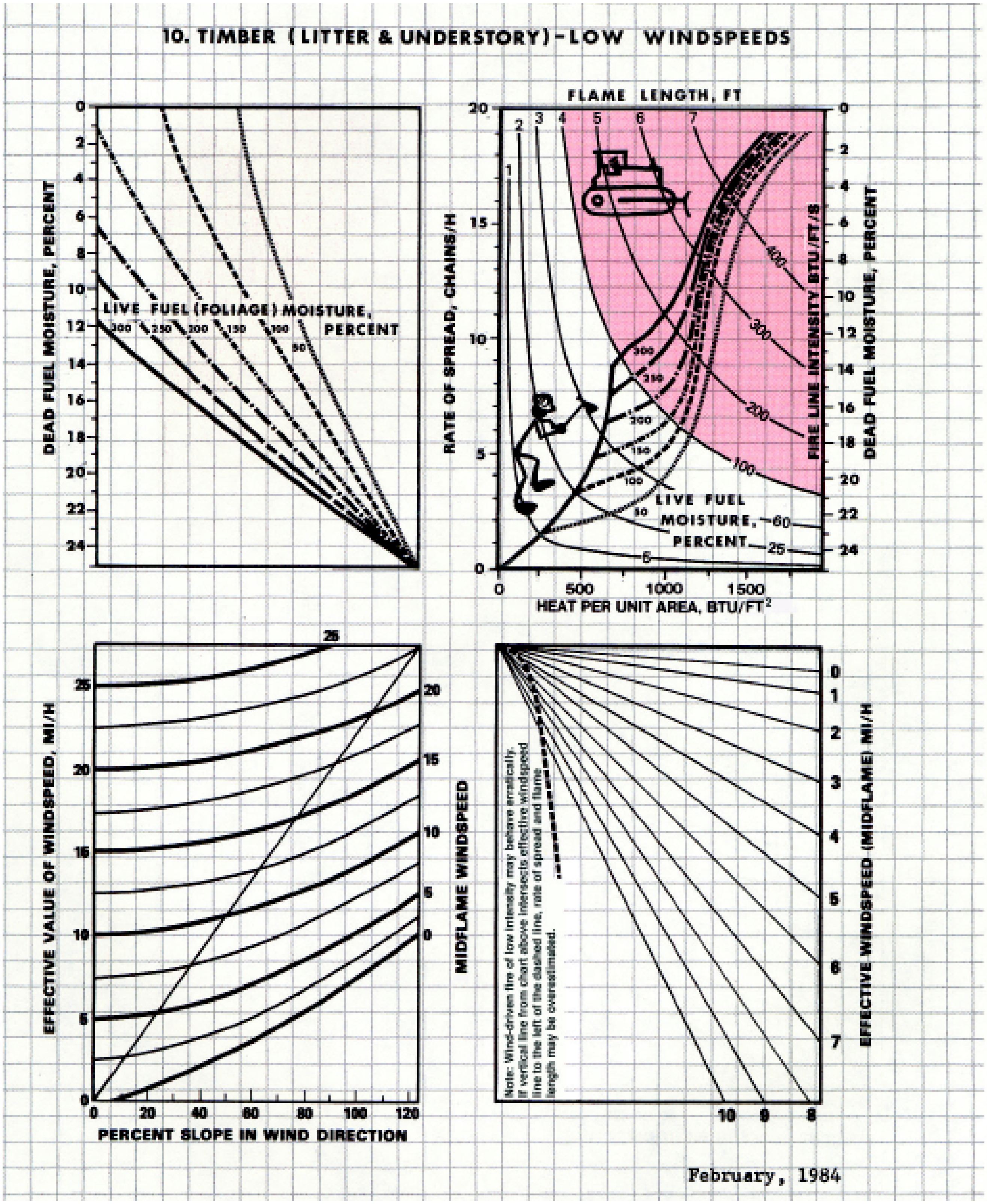

7. SOUTHERN ROUGH -HIGH WINDSPEEDS
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
RATE OF SPREAD, CHAINS/H
LIVE FUEL MOISTURE PERCENT
FIRE LINE INTENSITY BTU/FT/S
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H

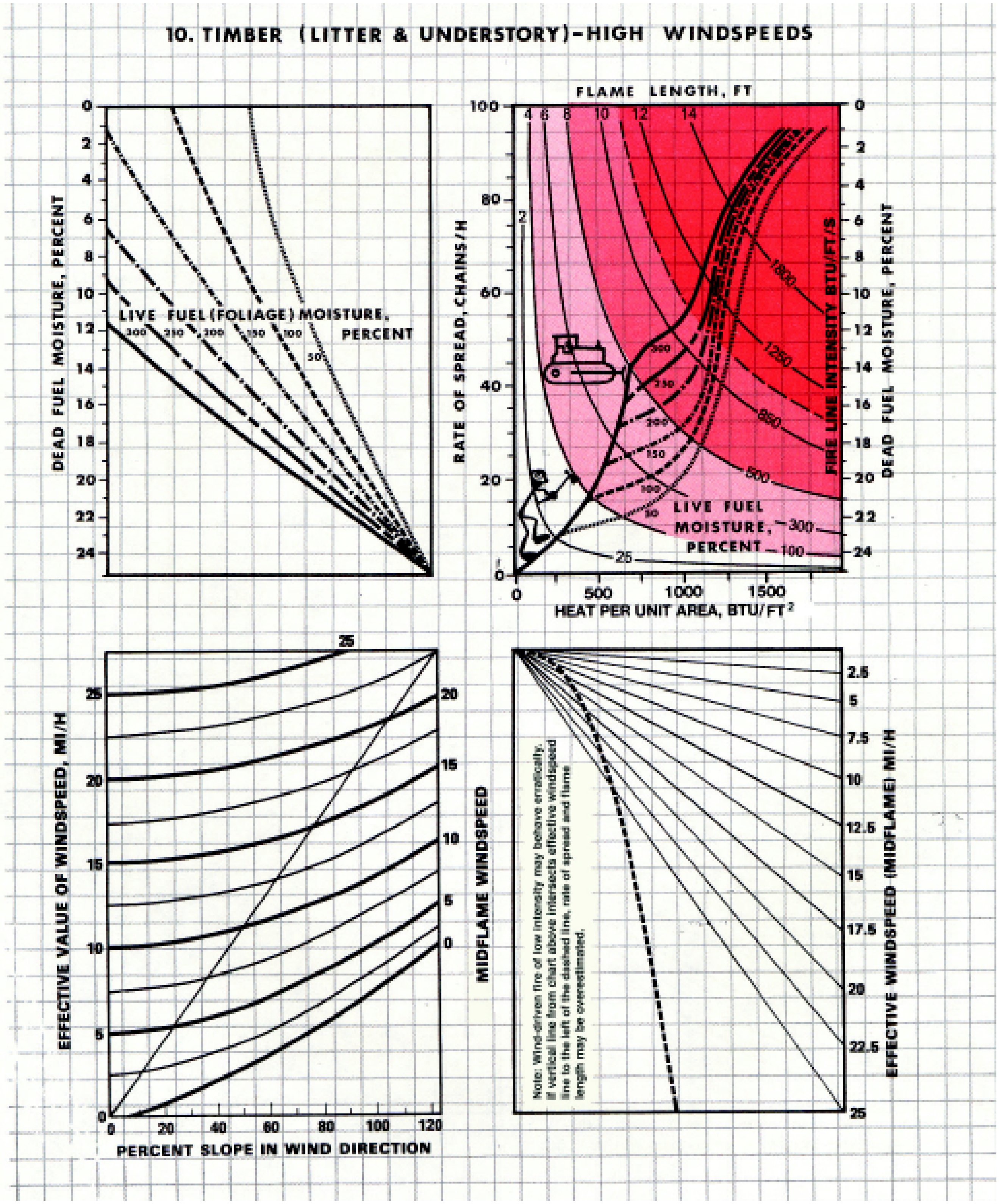

8. CLOSED TIMBER LITTER - LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CHAINS/H
FLAME LENGTH, FT
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
February, 1984


8. CLOSED TIMBER LITTER– HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
11 8 5 2
14 17 20 23 26 29
FLAME LENGTH, FT
1 1.5 2 2.5 3 3.5 4
RATE OF SPREAD, CHAINS/H
0 10 20 30
FIRE LINE INTENSITY BTU/FT/S
5 13 25 41 60 85 100
DEAD FUEL MOISTURE, PERCENT
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
0 50 150 250
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
0 5 10 15 20 25
25 20 15 10 5 0
0 20 40 60 80 100 120
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
2.5 5 7.5 10 12.5 15 17.5 20 22.5 25
EFFECTIVE WINDSPEED (MIDFLAME) MI/H

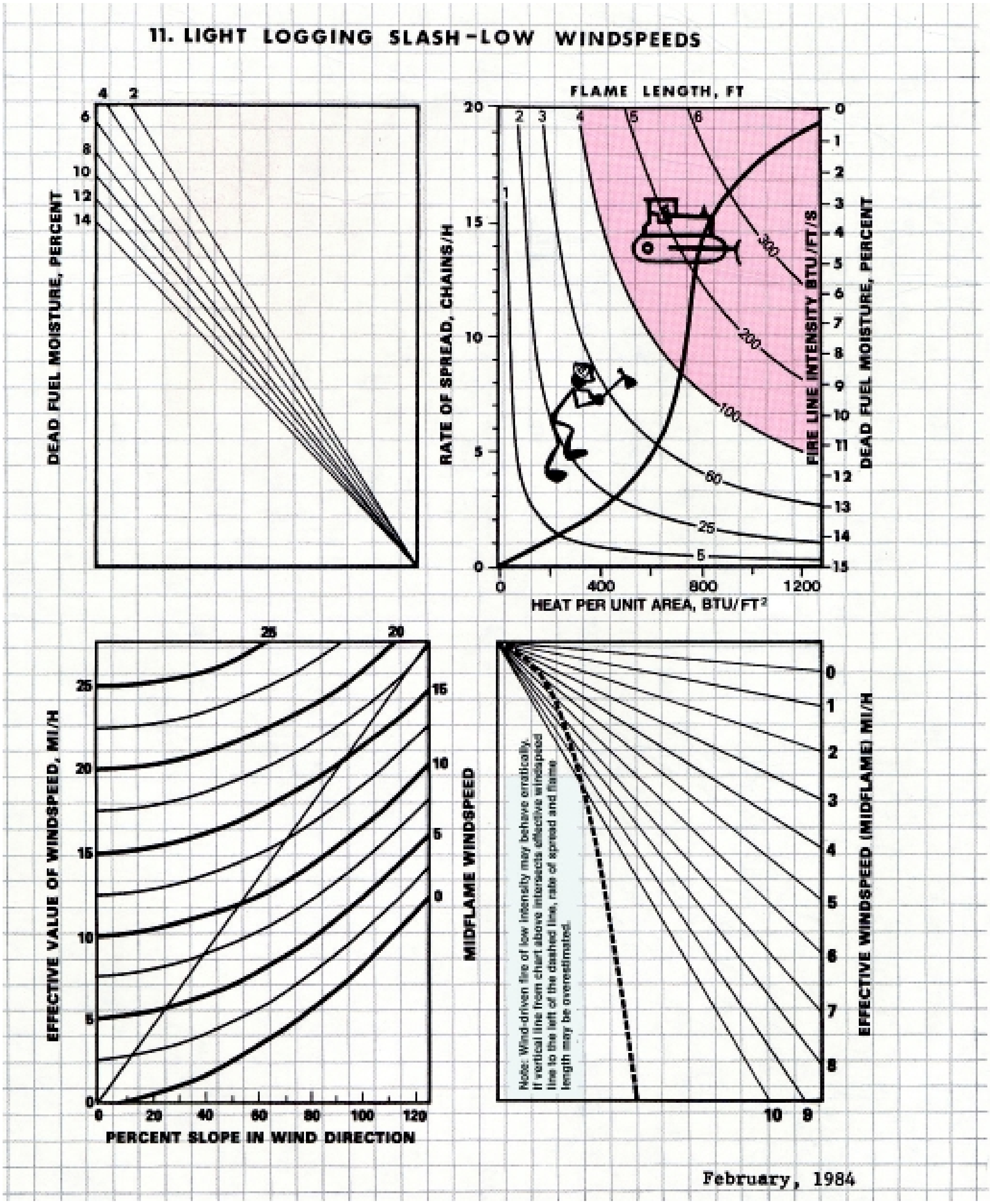

9. HARDWOOD LITTER – LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CH/H
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
February, 1984

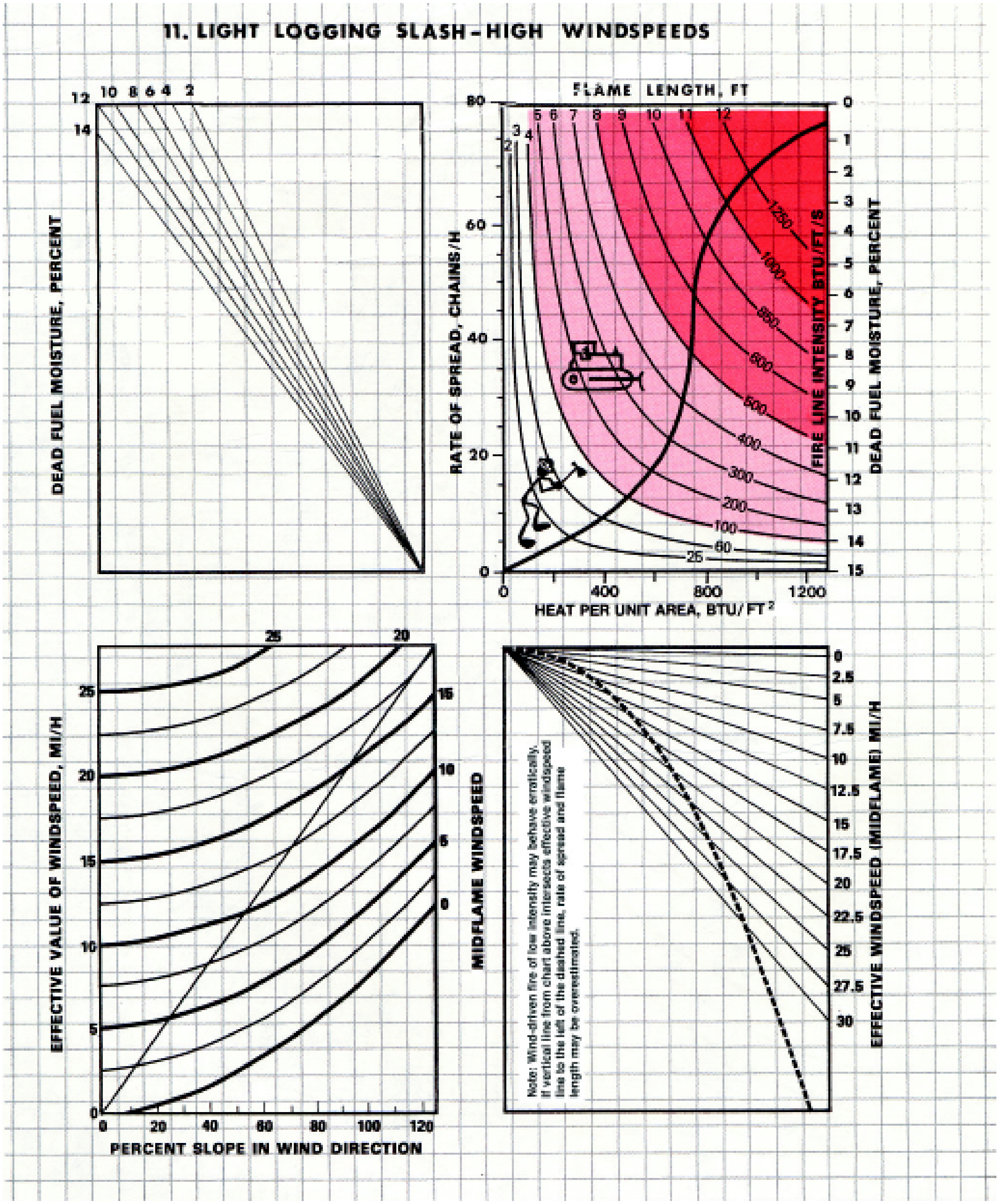

9. HARDWOOD LITTER - HIGH WINDSPEEDS
12 10 8 6 4 2
14 16 18 20 22 24
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
2 4 6 8 10 12
RATE OF SPREAD, CH/H
200 150 100 50 0
FIRE LINE INTENSITY BTU/FT/S
1250 850 500 300 100 25
0 2 4 6 8 10 12 14 16 18 20 22 24
DEAD FUEL MOISTURE, PERCENT
0 100 300 500
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
25 20 15 10 5 0
MIDFLAME WINDSPEED
25 20 15 10 5 0
0 20 40 60 80 100 120
PERCENT SLOPE IN WIND DIRECTION
Note: wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
5 7.5 10 12.5 15 17.5 20 22.5 25
EFFECTIVE WINDSPEED (MIDFLAME) MI/H

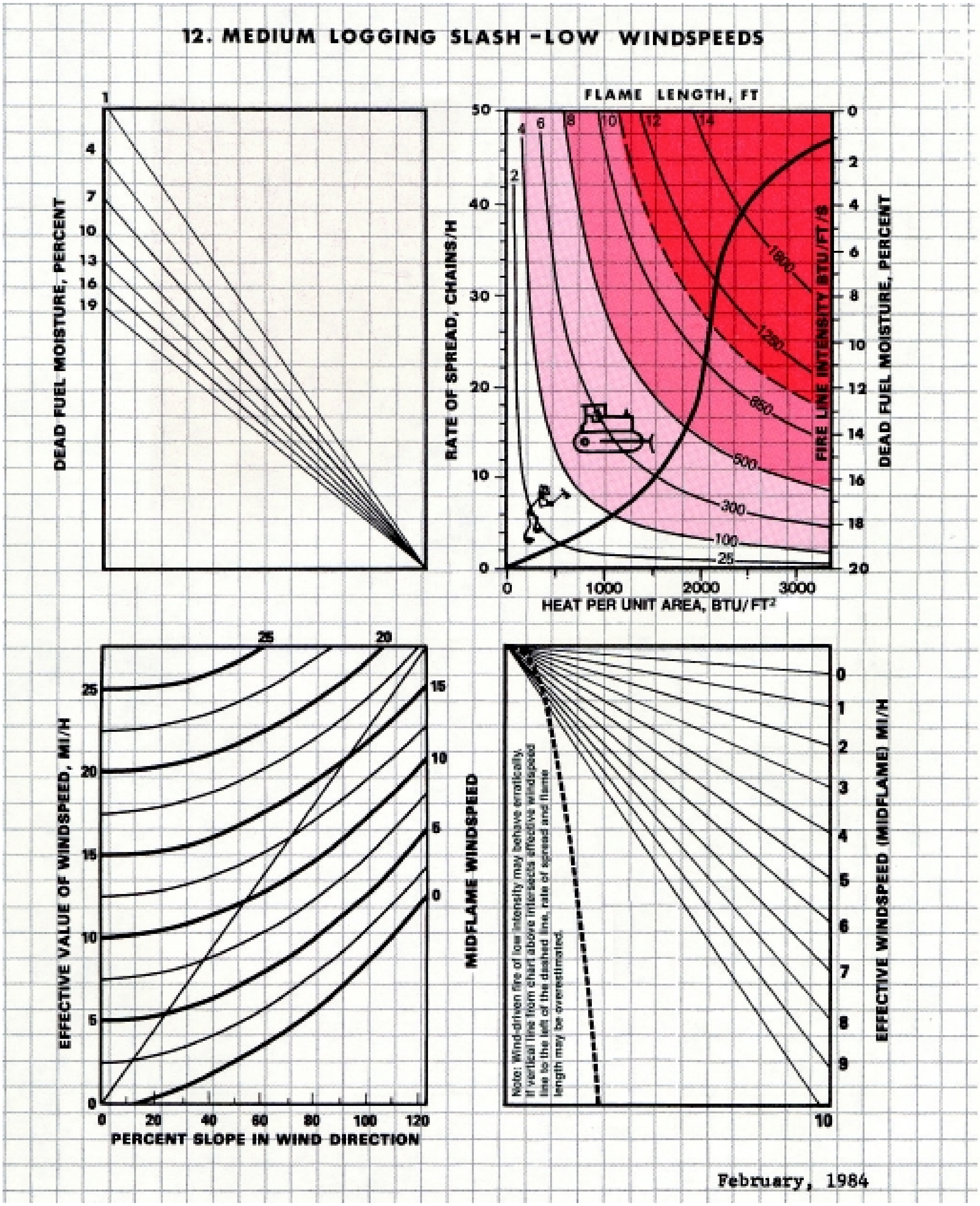

10. TIMBER (LITTER & UNDERSTORY) - LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
300 250 200 150 100 50
FLAME LENGTH, FT
1 2 3 4 5 6 7
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/FT/S
400 300 200 100
LIVE FUEL MOISTURE, PERCENT
60 25 6
HEAT PER UNIT AREA, BTU/FT²
0 500 1000 1500
EFFECTIVE VALUE OF WINDSPEED, MI/H
MIDFLAME WINDSPEED
PERCENT SLOPE IN WIND DIRECTION
0 20 40 60 80 100 120
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
0 1 2 3 4 5 6 7 8 9 10
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
February, 1984

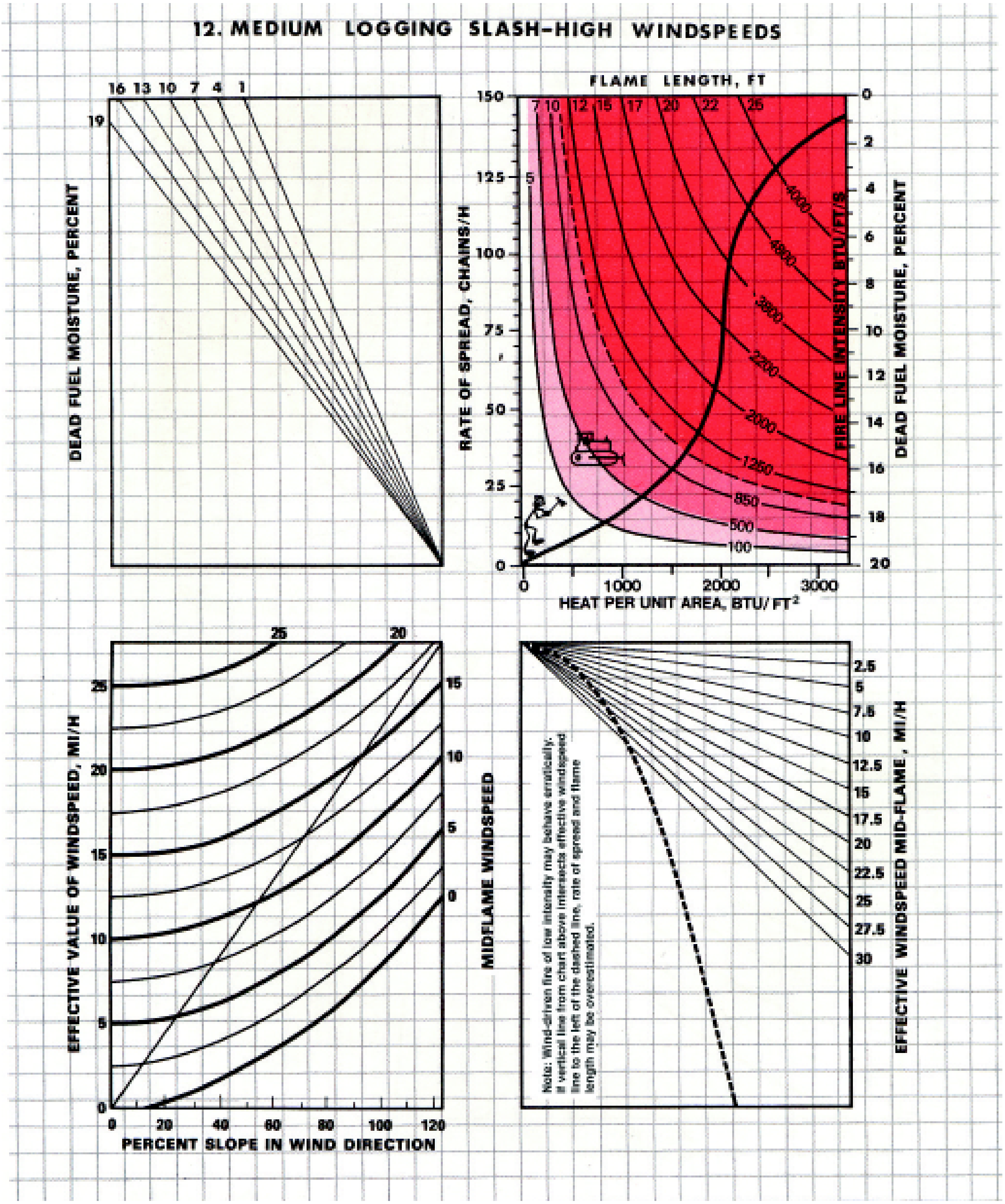


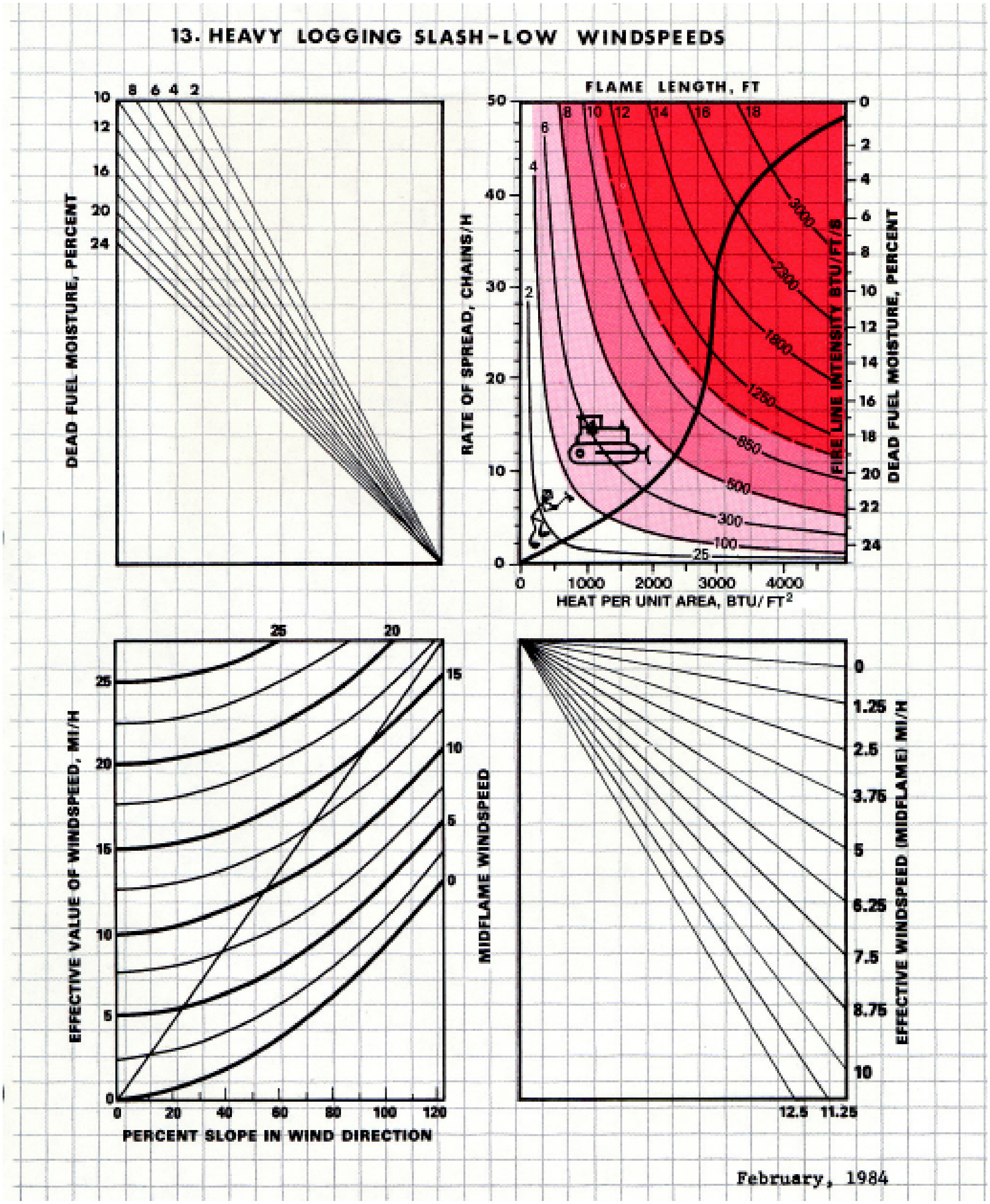
10. TIMBER (LITTER & UNDERSTORY)-HIGH WINDSPEEDS
FLAME LENGTH, FT
DEAD FUEL MOISTURE, PERCENT
LIVE FUEL (FOLIAGE) MOISTURE, PERCENT
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/FT/S
LIVE FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

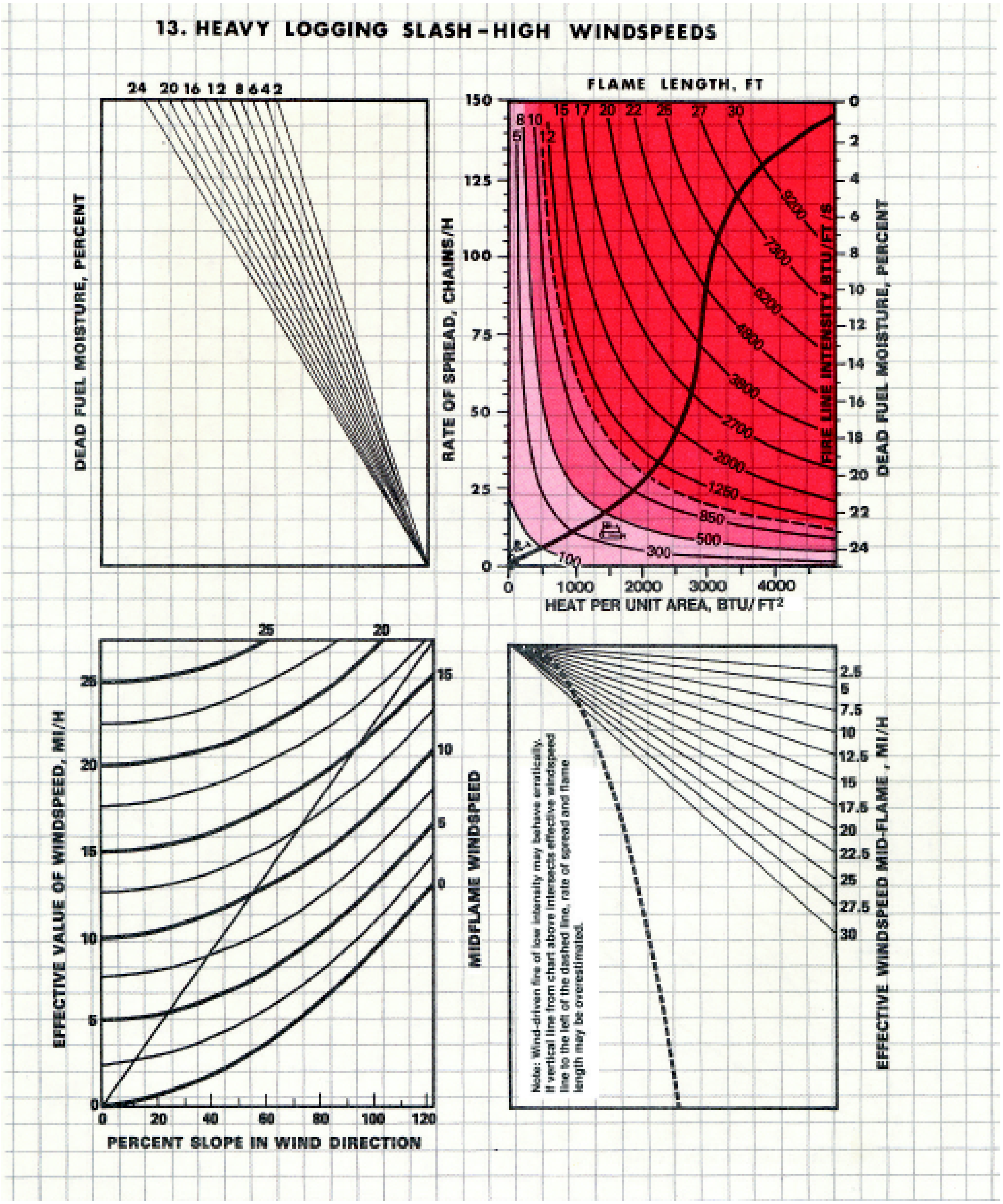

11. LIGHT LOGGING SLASH–LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
February, 1984


11. LIGHT LOGGING SLASH - HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.


12. MEDIUM LOGGING SLASH – LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
1
4
7
10
13
16
19
FLAME LENGTH, FT
2
4
6
8
10
12
14
RATE OF SPREAD, CHAINS/H
0
10
20
30
40
50
FIRE LINE INTENSITY BTU/FT/S
1800
1250
850
600
300
100
25
HEAT PER UNIT AREA, BTU/FT²
0
1000
2000
3000
DEAD FUEL MOISTURE, PERCENT
0
2
4
6
8
10
12
14
16
18
20
EFFECTIVE VALUE OF WINDSPEED, MI/H
0
5
10
15
20
25
30
PERCENT SLOPE IN WIND DIRECTION
0
20
40
60
80
100
120
MIDFLAME WINDSPEED
0
5
10
15
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
0
1
2
3
4
5
6
7
8
9
10
February, 1984


12. MEDIUM LOGGING SLASH–HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
16 13 10 7 4 1
19
FLAME LENGTH, FT
7 10 12 15 17 20 22 26
5
RATE OF SPREAD, CHAINS/H
150
125
100
75
50
25
0
FIRE LINE INTENSITY BTU/FT/S
4000
4800
3800
2200
2000
1250
850
500
100
DEAD FUEL MOISTURE, PERCENT
0
2
4
6
8
10
12
14
16
18
20
0
1000
2000
3000
HEAT PER UNIT AREA, BTU/ FT²
EFFECTIVE VALUE OF WINDSPEED, MI/H
25
20
15
10
5
0
PERCENT SLOPE IN WIND DIRECTION
0
20
40
60
80
100
120
MIDFLAME WINDSPEED
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.
EFFECTIVE WINDSPEED MID-FLAME, MI/H
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
27.5
30


13. HEAVY LOGGING SLASH–LOW WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
10 12 16 20 24
8 6 4 2
FLAME LENGTH, FT
2 4 6 8 10 12 14 16 18
RATE OF SPREAD, CHAINS/H
0 10 20 30 40 50
FIRE LINE INTENSITY BTU/FT/S
25 100 300 500 850 1250 1800 2300 3000
HEAT PER UNIT AREA, BTU/FT²
0 1000 2000 3000 4000
DEAD FUEL MOISTURE, PERCENT
0 2 4 6 8 10 12 14 16 18 20 22 24
EFFECTIVE VALUE OF WINDSPEED, MI/H
0 5 10 15 20 25
PERCENT SLOPE IN WIND DIRECTION
0 20 40 60 80 100 120
MIDFLAME WINDSPEED
0 5 10 15 20 25
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
0 1.25 2.5 3.75 5 6.25 7.5 8.75 10 11.25 12.5
February, 1984


13. HEAVY LOGGING SLASH–HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
24 20 16 12 8 6 4 2
FLAME LENGTH, FT
RATE OF SPREAD, CHAINS/H
HEAT PER UNIT AREA, BTU/FT²
FIRE LINE INTENSITY BTU/FT/S
DEAD FUEL MOISTURE, PERCENT
EFFECTIVE VALUE OF WINDSPEED, MI/H
PERCENT SLOPE IN WIND DIRECTION
MIDFLAME WINDSPEED
EFFECTIVE WINDSPEED MID-FLAME, MI/H
Note: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

PROBLEM SOLVING WORKSHEET

PROBLEM	Given: Goal:	Assumptions: Information needed:
DEVISE PLAN	Strategies:	Rationale:
CARRY OUT PLAN	Solution process:	
LOOK BACK	Answer:	Solution Check:

Name of fire ____________ Fire pred spec ____________
Date ____________ Time ____________
Proj period date ____________ Proj time from ________ to ________

Fire Behavior Worksheet

Input

0	PP	Projection point			
1	Model #	Fuel model number (1-13)			
2	1H-FDFM	Fine dead fuel moisture, %			
3	LFM	Live fuel moisture, %			
4	MFWS	Midflame windspeed, mi/h			
5	SLP	slope, %			
6	EWS	Effective windspeed, mi/h			

Output

1	ROS	Rate of spread, ch/h			
2	HA	Heat per unit area, Btu/ft^2			
3	FLI	Fireline intensity, Btu/ft/s			
4	FL	Flame length, ft			
5	SD	Spread distance, ch			
		Map spread distance, in			
6	PER	Perimeter, ch			
7	AC	Area, ac			
8	SPOT	Max spotting distance, mi			
		Map distance spot, in			
9	PIG	Probability of ignition, %			

Fine Dead Fuel Moisture/Probability of Ignition Worksheet

Input

0	PP	Projection point			
1	D	Daytime calculation	D	D	D
2	DB	Dry bulb temperature, °F			
3	WB	Wet bulb temperature, °F			
4	DP	Dew point, °F			
5	RH	Relative humidity, %			
6	RFM	Reference fuel moisture, % (table 2)			
7	MO	Month			
8	SH	Unshaded (U) or shaded (S)	U/S	U/S	U/S
9	T	Time			
10	CH	Elevation change B = 1,000’ to 2,000’ below site L = ± 1,000’ of site location A = 1,000’ to 2,000’ above site	B/L/A	B/L/A	B/L/A
11	ASP	Aspect, (N, S, E, W)			
12	SLP	Slope, %			
13	FMC	Fuel moisture correction, % (table 3, 4, or 5)			

Output

1	1H-FDFM	Fine dead fuel moisture, % (line 6 + line 13)			
2	PIG	Probability of ignition, % (table 12)			

Slope Worksheet

Input

0	PP	Projection point			
1	CON INT	Contour interval, ft			
2	SLC	Map scale			
3	CF	Conversion factor, ft/in			
4	#INTVLS	Number of contour intervals			
5	RISE	Rise in elevation			
6	MD	Map distance, in (between points)			
7	HZGD	Horizontal ground distance, ft			

Output

1	SLP%	Slope, %			

Wind Adjustment Worksheet

Input

0	PP	Projection point			
1	20” W	20-ft windspeed, mi/h			
2	MODEL#	Fuel model number (1-13)			
3	SHLTR	Wind sheltering 1 = unsheltered 2 = partially sheltered 3 = fully sheltered, open 4 = fully sheltered, closed			
4	WAF	Wind adjustment factor (table 7)			

Output

1	MFWS	Midflame windspeed, mi/h (line 1 x line 4)			

Nomogram version – June 1993

For use at elevations between
501 and 1,900 feet above sea level

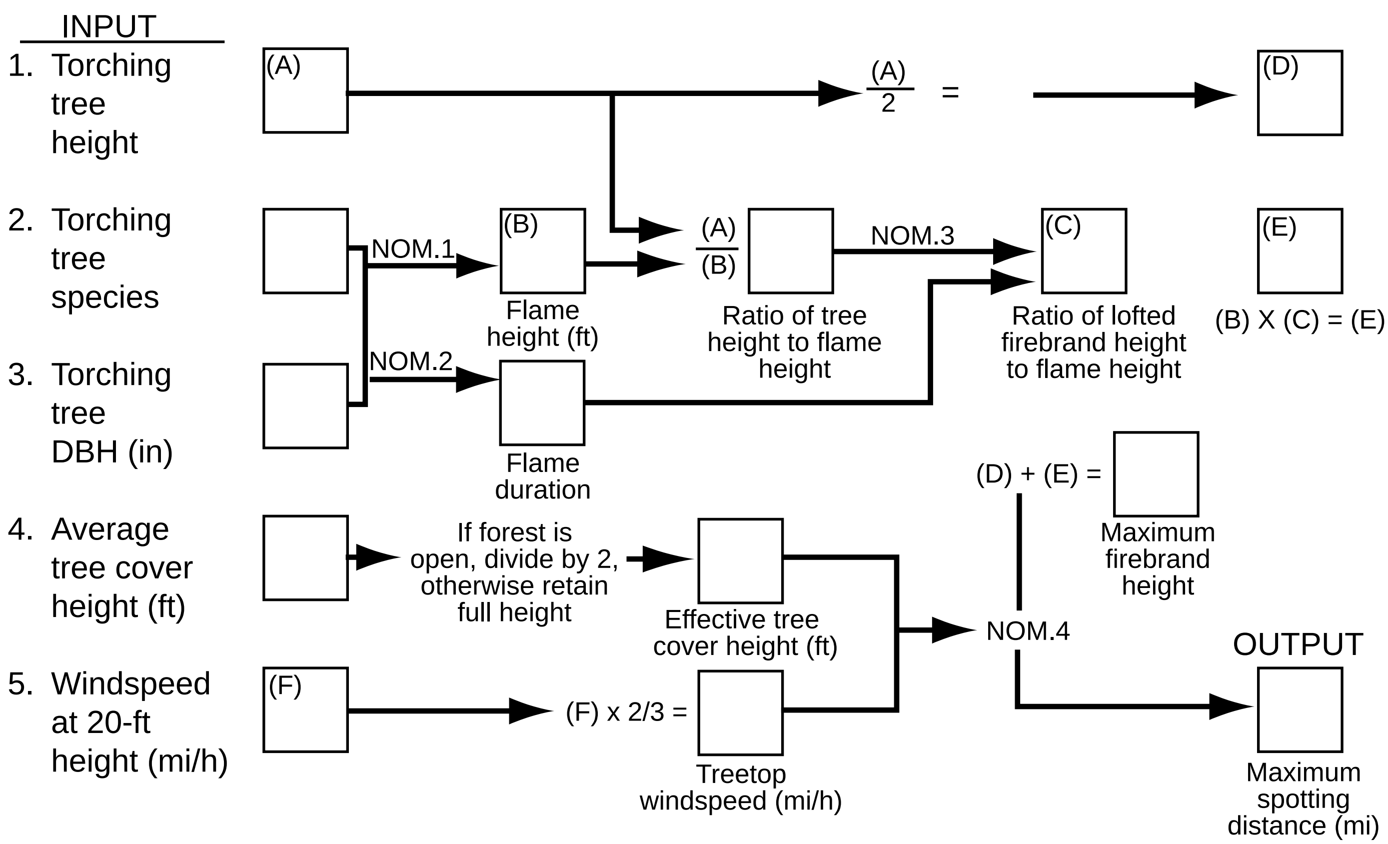
DP = Top number
RH = bottom number

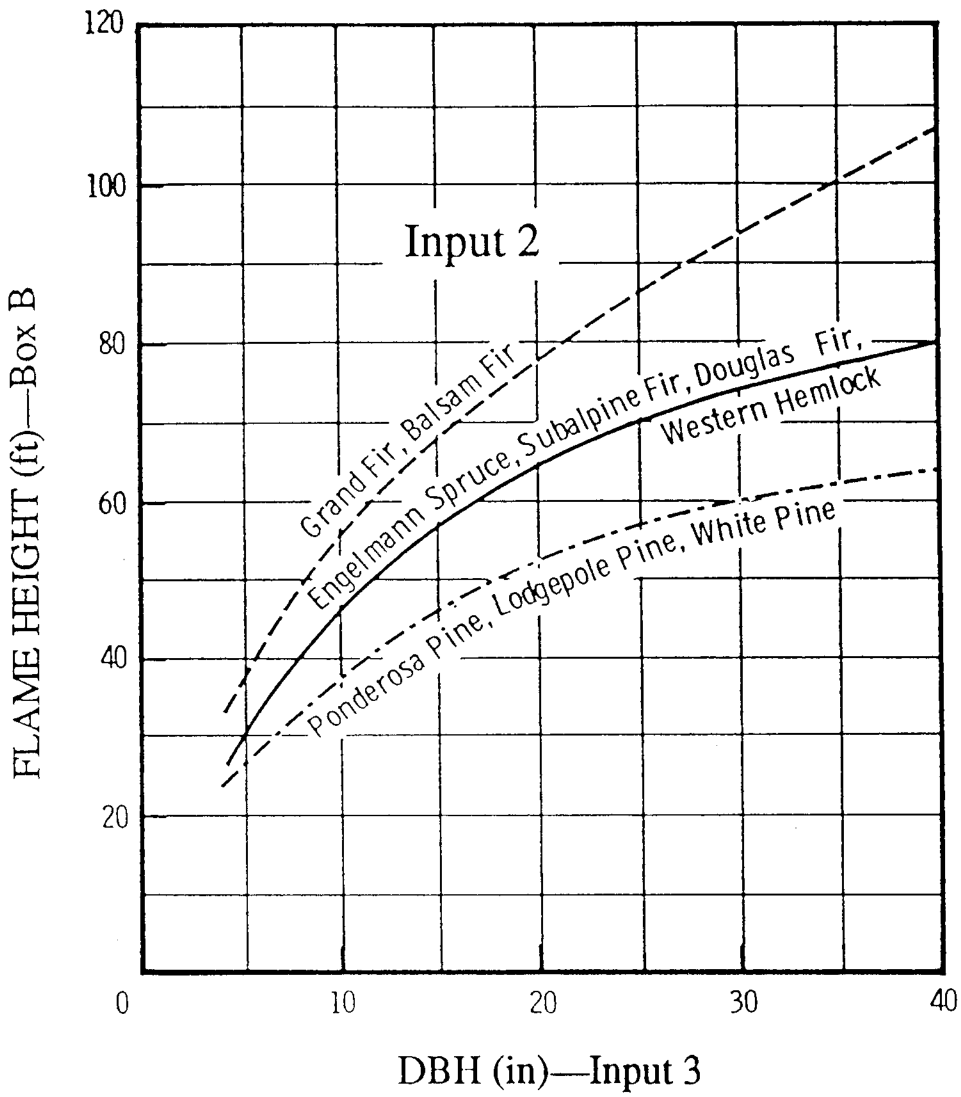
Wet bulb temperatures (columns) / **Dry bulb temperatures** (rows); cells: DP / RH

Dry bulb	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
60	-50 / 1	-14 / 4	-1 / 8	+8 / 12	14 / 16	19 / 20	24 / 24	28 / 28	31 / 32	34 / 36	37 / 41	40 / 45	42 / 50	44 / 54	47 / 59	49 / 64	51 / 69	53 / 74
62		-25 / 2	-6 / 6	+4 / 10	11 / 13	17 / 17	22 / 21	26 / 25	30 / 29	33 / 33	36 / 37	38 / 42	41 / 46	43 / 50	46 / 55	48 / 60	50 / 64	52 / 69
63		-58	-14 / 4	-1 / 7	+8 / 11	14 / 15	20 / 19	24 / 22	28 / 26	31 / 30	34 / 34	37 / 38	40 / 43	42 / 47	45 / 51	47 / 56	49 / 60	51 / 65
64			-27 / 2	-7 / 5	+4 / 9	11 / 12	17 / 16	22 / 20	26 / 24	30 / 27	33 / 31	36 / 35	39 / 39	41 / 43	44 / 48	46 / 52	48 / 56	50 / 61
65				-15 / 3	-1 / 7	+8 / 10	14 / 14	20 / 17	24 / 21	28 / 25	32 / 29	35 / 32	38 / 36	40 / 40	43 / 44	45 / 48	47 / 53	49 / 57
66				-28 / 2	-7 / 5	+4 / 8	11 / 12	17 / 15	22 / 19	26 / 22	30 / 26	33 / 30	36 / 33	39 / 37	42 / 41	44 / 45	46 / 49	49 / 53
67					-15 / 3	-1 / 6	+8 / 10	15 / 13	20 / 16	24 / 20	28 / 23	32 / 27	35 / 31	38 / 34	41 / 38	43 / 42	46 / 46	48 / 50
68					-29 / 2	-7 / 5	+4 / 8	12 / 11	18 / 14	22 / 18	27 / 21	30 / 24	34 / 28	37 / 32	40 / 35	42 / 39	45 / 43	47 / 47
69						-15 / 3	-1 / 6	+8 / 9	15 / 12	20 / 16	25 / 19	29 / 22	32 / 26	35 / 29	38 / 33	41 / 36	44 / 40	46 / 44
70						-29 / 1	-7 / 4	+4 / 7	12 / 10	18 / 14	23 / 17	27 / 20	31 / 23	34 / 27	37 / 30	40 / 34	43 / 37	45 / 41
71							-15 / 3	0 / 6	+9 / 9	15 / 12	21 / 15	25 / 18	29 / 21	33 / 24	36 / 28	39 / 31	42 / 34	44 / 38
72							-28 / 1	-6 / 4	+5 / 7	12 / 10	18 / 13	23 / 16	28 / 19	31 / 22	35 / 25	38 / 29	40 / 32	43 / 35
73								-14 / 3	0 / 5	+9 / 8	16 / 11	21 / 14	26 / 17	30 / 20	33 / 23	36 / 26	39 / 30	42 / 33
74								-27 / 1	-6 / 4	+5 / 7	13 / 10	19 / 12	24 / 15	28 / 18	32 / 21	35 / 24	38 / 27	41 / 30
75									-13 / 3	+1 / 5	10 / 8	16 / 11	22 / 13	26 / 16	30 / 19	34 / 22	37 / 25	40 / 28
76									-25 / 1	-5 / 4	+6 / 7	14 / 9	20 / 12	24 / 15	29 / 17	32 / 20	36 / 23	39 / 26
77									-57	-12 / 3	+2 / 5	10 / 8	17 / 10	22 / 13	27 / 16	31 / 18	34 / 21	38 / 24
78										-23 / 1	-4 / 4	+7 / 6	14 / 9	20 / 11	25 / 14	29 / 17	33 / 19	36 / 22
79										-48	-11 / 3	+3 / 5	11 / 8	18 / 10	23 / 13	28 / 15	32 / 18	35 / 20
80											-21 / 2	-2 / 4	+8 / 6	15 / 9	21 / 11	26 / 14	30 / 16	34 / 19
81											-40 / 1	-9 / 3	+4 / 5	12 / 7	19 / 10	24 / 12	28 / 15	32 / 17
82												-18 / 2	-1 / 4	+9 / 6	16 / 8	22 / 10	27 / 13	31 / 16
83												-34 / 1	-7 / 3	+5 / 5	13 / 7	20 / 9	25 / 12	29 / 14
84													-15 / 2	+1 / 4	10 / 6	17 / 8	23 / 10	27 / 13
85													-29 / 1	-5 / 3	+7 / 5	14 / 7	21 / 9	26 / 11
86														-12 / 2	+2 / 4	11 / 6	18 / 8	24 / 10
87														-24 / 1	-3 / 3	+8 / 5	16 / 7	22 / 9
88														-50	-10 / 2	+4 / 4	13 / 6	19 / 8
89															-19 / 1	-1 / 3	+10 / 5	17 / 7
90															-37	-7 / 2	+6 / 4	14 / 6

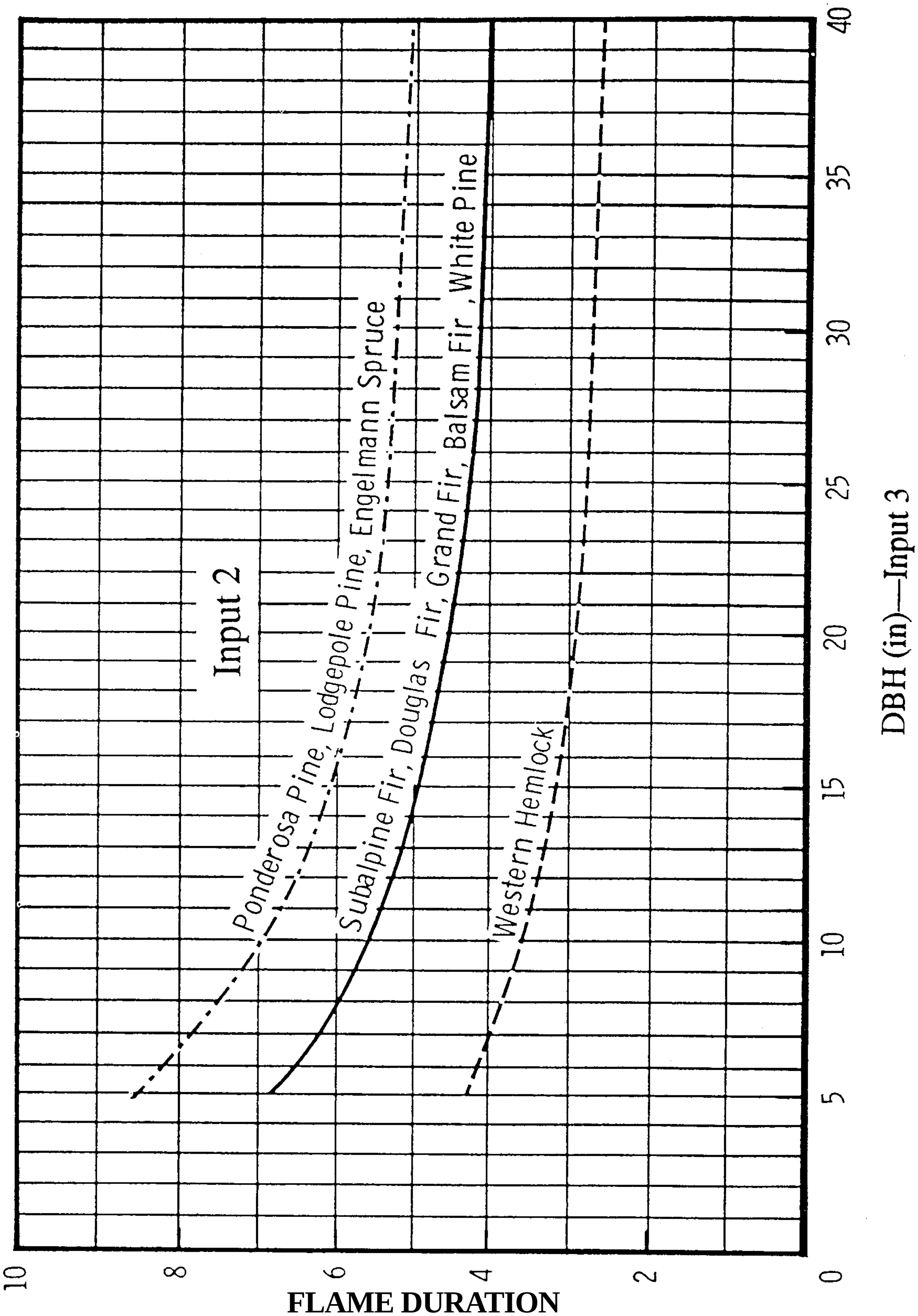
Dry bulb	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73
60	54 / 79	56 / 84	58 / 89	59 / 95	61 / 100												
62	54 / 74	55 / 79	57 / 84	59 / 89	60 / 95	62 / 100											
63	53 / 70	55 / 74	57 / 79	58 / 84	60 / 89	61 / 95	63 / 100										
64	52 / 65	54 / 70	56 / 75	58 / 80	59 / 85	61 / 90	62 / 95	64 / 100									
65	51 / 61	53 / 66	55 / 70	57 / 75	59 / 80	60 / 85	62 / 90	63 / 95	65 / 100								
66	51 / 58	53 / 62	54 / 66	56 / 71	58 / 76	60 / 80	61 / 85	63 / 90	64 / 95	66 / 100							
67	50 / 54	52 / 58	54 / 63	56 / 67	57 / 71	59 / 76	61 / 80	62 / 85	64 / 90	66 / 95	67 / 100						
68	49 / 51	51 / 55	53 / 59	55 / 63	57 / 67	59 / 72	60 / 76	62 / 81	63 / 85	65 / 90	67 / 95	68 / 100					
69	48 / 47	50 / 51	52 / 55	54 / 59	56 / 64	58 / 68	60 / 72	61 / 77	63 / 81	65 / 86	66 / 90	68 / 95	69 / 100				
70	47 / 44	50 / 48	52 / 52	54 / 56	55 / 60	57 / 64	59 / 68	61 / 72	62 / 77	64 / 81	66 / 86	67 / 90	69 / 95	70 / 100			
71	46 / 42	49 / 45	51 / 49	53 / 53	55 / 57	57 / 60	58 / 65	60 / 69	62 / 73	63 / 77	65 / 82	67 / 86	68 / 91	70 / 95	71 / 100		
72	46 / 39	48 / 42	50 / 46	52 / 50	54 / 53	56 / 57	58 / 61	60 / 65	61 / 69	63 / 73	65 / 77	66 / 82	68 / 86	69 / 91	71 / 95	72 / 100	
73	45 / 36	47 / 40	49 / 43	51 / 47	53 / 50	55 / 55	57 / 58	59 / 62	61 / 65	62 / 69	64 / 74	66 / 78	67 / 82	69 / 86	70 / 91	72 / 95	73 / 100
74	44 / 34	46 / 37	48 / 40	51 / 44	53 / 47	55 / 51	57 / 54	58 / 58	60 / 62	62 / 66	64 / 70	65 / 74	67 / 78	68 / 82	70 / 87	71 / 91	73 / 95
75	43 / 31	45 / 35	48 / 38	50 / 41	52 / 44	54 / 48	56 / 51	58 / 55	60 / 59	61 / 62	63 / 66	65 / 70	66 / 74	68 / 78	69 / 82	71 / 87	72 / 91
76	42 / 29	44 / 32	47 / 35	49 / 39	51 / 42	53 / 45	55 / 49	57 / 52	59 / 56	61 / 59	62 / 63	64 / 67	66 / 71	67 / 75	69 / 79	70 / 83	72 / 87
77	41 / 27	43 / 30	46 / 33	48 / 36	50 / 39	53 / 43	55 / 46	57 / 49	58 / 53	60 / 56	62 / 60	64 / 63	65 / 67	67 / 71	68 / 75	70 / 79	71 / 83
78	39 / 25	42 / 28	45 / 31	47 / 34	50 / 37	52 / 40	54 / 43	56 / 46	58 / 50	60 / 53	61 / 57	63 / 60	65 / 64	66 / 67	68 / 71	69 / 75	71 / 79
79	38 / 23	41 / 26	44 / 29	46 / 32	49 / 35	51 / 38	53 / 41	55 / 44	57 / 47	59 / 50	61 / 54	63 / 57	64 / 61	66 / 64	67 / 68	69 / 72	71 / 75
80	37 / 21	40 / 24	43 / 27	45 / 30	48 / 32	50 / 35	52 / 38	54 / 41	56 / 45	58 / 48	60 / 51	62 / 54	64 / 58	65 / 61	67 / 65	69 / 68	70 / 72
81	36 / 20	39 / 22	42 / 25	45 / 28	47 / 30	49 / 33	52 / 36	54 / 39	56 / 42	58 / 45	60 / 48	61 / 51	63 / 55	65 / 58	67 / 62	68 / 65	70 / 69
82	34 / 18	38 / 21	41 / 23	44 / 26	46 / 28	49 / 31	51 / 34	53 / 37	55 / 40	57 / 43	59 / 46	61 / 49	63 / 52	64 / 55	66 / 59	68 / 62	69 / 65
83	33 / 17	36 / 19	40 / 21	43 / 24	45 / 27	48 / 29	50 / 32	52 / 35	54 / 38	56 / 40	58 / 43	60 / 46	62 / 49	64 / 53	66 / 56	67 / 59	69 / 62
84	32 / 15	35 / 17	38 / 20	41 / 22	44 / 25	47 / 27	49 / 30	52 / 33	54 / 35	56 / 38	58 / 41	60 / 44	62 / 47	63 / 50	65 / 53	67 / 56	68 / 59
85	30 / 14	34 / 16	37 / 18	40 / 21	43 / 23	46 / 26	48 / 28	51 / 31	53 / 33	55 / 36	57 / 39	59 / 42	61 / 45	63 / 47	65 / 50	66 / 54	68 / 57
86	28 / 12	32 / 15	36 / 17	39 / 19	42 / 22	45 / 24	48 / 26	50 / 29	52 / 32	54 / 34	57 / 37	59 / 40	60 / 42	62 / 45	64 / 48	66 / 51	67 / 54
87	27 / 11	31 / 13	35 / 16	38 / 18	41 / 20	44 / 22	47 / 25	49 / 27	52 / 30	54 / 32	56 / 35	58 / 37	60 / 40	62 / 43	64 / 46	65 / 49	67 / 51
88	25 / 10	29 / 12	33 / 14	37 / 16	40 / 19	43 / 21	46 / 23	48 / 26	51 / 28	53 / 30	55 / 33	57 / 35	59 / 38	61 / 41	63 / 43	65 / 46	66 / 49
89	23 / 9	28 / 11	32 / 13	36 / 15	39 / 17	42 / 19	45 / 22	48 / 24	50 / 26	52 / 29	55 / 31	57 / 34	59 / 36	61 / 39	62 / 41	64 / 44	66 / 47
90	21 / 8	26 / 10	30 / 12	34 / 14	38 / 16	41 / 18	44 / 20	47 / 22	49 / 25	52 / 27	54 / 29	56 / 32	58 / 34	60 / 37	62 / 39	64 / 42	66 / 45

Dry bulb	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
74	74 / 100																
75	74 / 95	75 / 100															
76	73 / 91	75 / 96	76 / 100														
77	73 / 87	74 / 91	76 / 96	77 / 100													
78	72 / 83	74 / 87	75 / 91	77 / 96	78 / 100												
79	72 / 79	73 / 83	75 / 87	76 / 91	78 / 96	79 / 100											
80	72 / 76	73 / 79	75 / 83	76 / 87	77 / 92	79 / 96	80 / 100										
81	71 / 72	73 / 76	74 / 80	76 / 84	77 / 88	78 / 92	80 / 96	81 / 100									
82	71 / 69	72 / 73	74 / 76	75 / 80	77 / 84	78 / 88	79 / 92	81 / 96	82 / 100								
83	70 / 66	72 / 69	73 / 73	75 / 76	76 / 80	78 / 84	79 / 88	80 / 92	82 / 96	83 / 100							
84	70 / 63	71 / 66	73 / 70	74 / 73	76 / 77	77 / 80	79 / 84	80 / 88	81 / 92	83 / 96	84 / 100						
85	69 / 60	71 / 63	73 / 66	74 / 70	76 / 73	77 / 77	78 / 81	80 / 84	81 / 88	82 / 92	84 / 96	85 / 100					
86	69 / 57	71 / 60	72 / 64	74 / 67	75 / 70	77 / 74	78 / 77	79 / 81	81 / 84	82 / 88	83 / 92	85 / 96	86 / 100				
87	69 / 54	70 / 58	72 / 61	73 / 64	75 / 67	76 / 70	78 / 74	79 / 77	80 / 81	82 / 85	83 / 88	84 / 92	86 / 96	87 / 100			
88	68 / 52	70 / 55	71 / 58	73 / 61	74 / 64	76 / 67	77 / 71	79 / 74	80 / 78	81 / 81	83 / 85	84 / 88	85 / 92	87 / 96	88 / 100		
89	68 / 50	69 / 52	71 / 55	72 / 58	74 / 61	76 / 65	77 / 68	78 / 71	80 / 74	81 / 78	83 / 81	84 / 85	85 / 88	86 / 92	88 / 96	89 / 100	
90	67 / 47	69 / 50	71 / 53	72 / 56	74 / 59	75 / 62	77 / 65	78 / 68	79 / 71	81 / 75	82 / 78	84 / 82	85 / 85	86 / 89	87 / 92	89 / 96	90 / 100

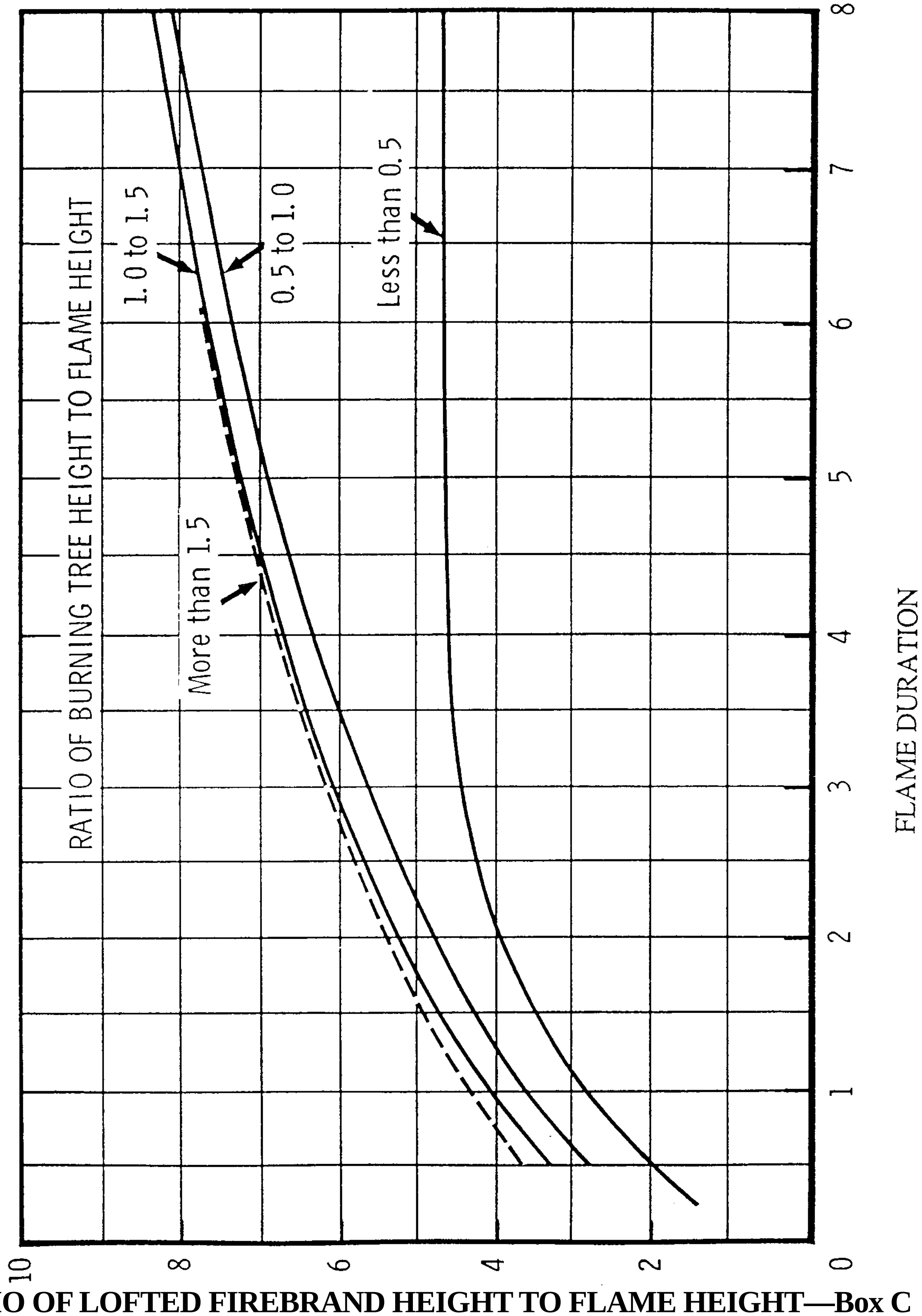

INPUT
1. Torching tree height
2. Torching tree species
3. Torching tree DBH (in)
4. Average tree cover height (ft)
5. Windspeed at 20-ft height (mi/h)
(A)
(A) / 2 =
(D)
NOM.1
(B)
Flame height (ft)
(A) / (B)
Ratio of tree height to flame height
NOM.3
(C)
Ratio of lofted firebrand height to flame height
(E)
(B) X (C) = (E)
NOM.2
Flame duration
(D) + (E) =
Maximum firebrand height
If forest is open, divide by 2, otherwise retain full height
Effective tree cover height (ft)
NOM.4
OUTPUT
(F)
(F) x 2/3 =
Treetop windspeed (mi/h)
Maximum spotting distance (mi)



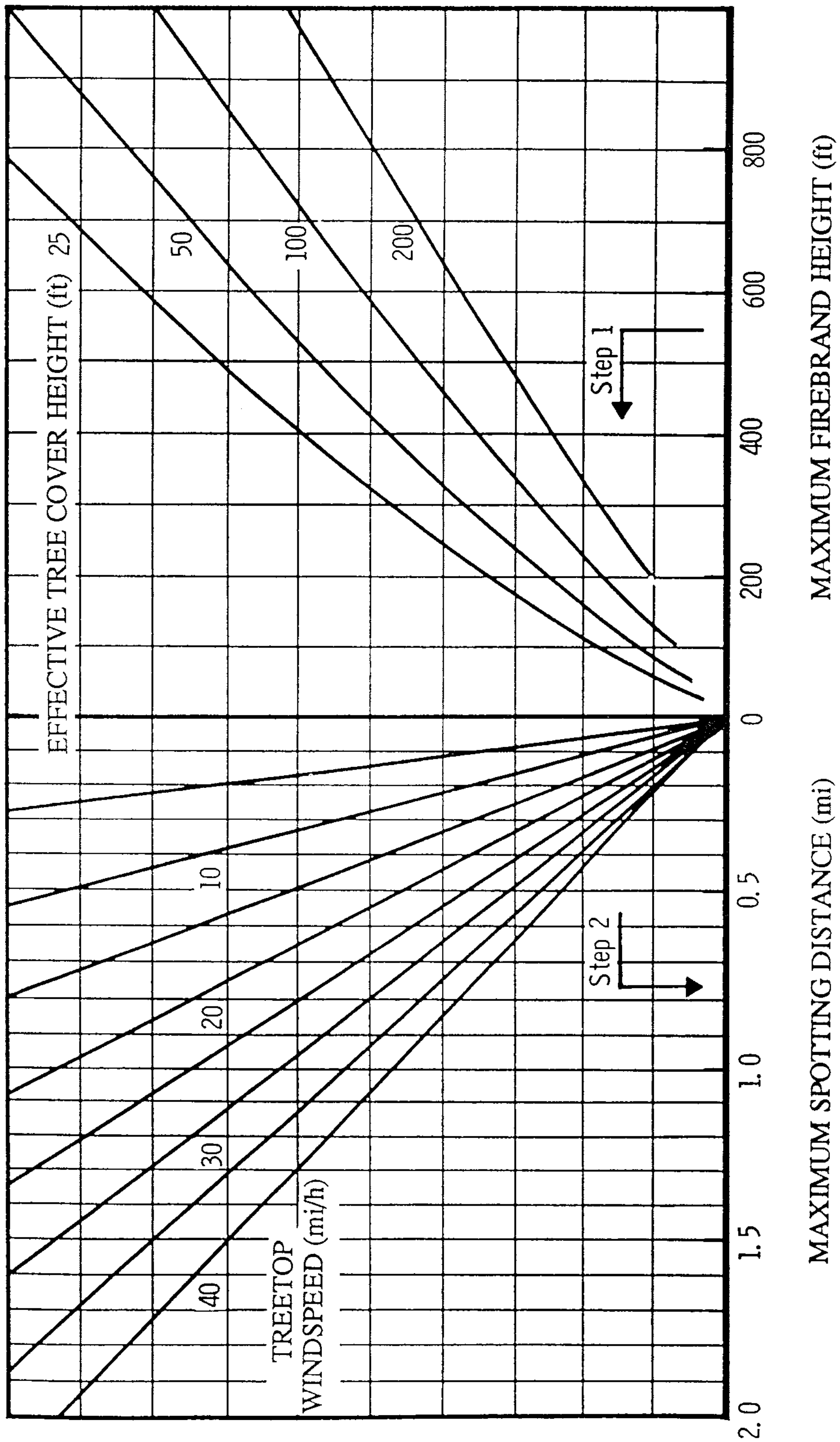
Spotting nomogram 1.



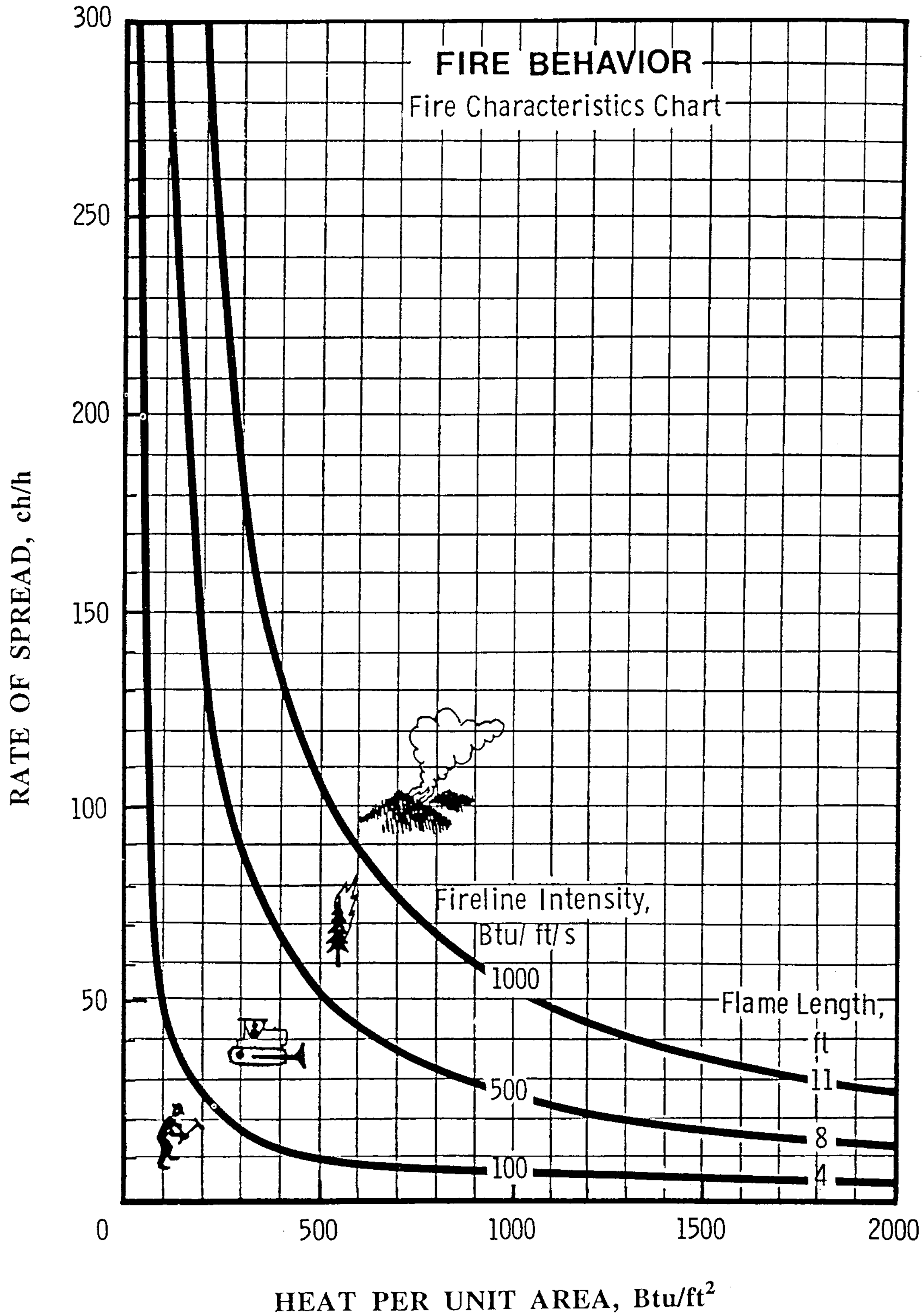
Spotting nomogram 2.



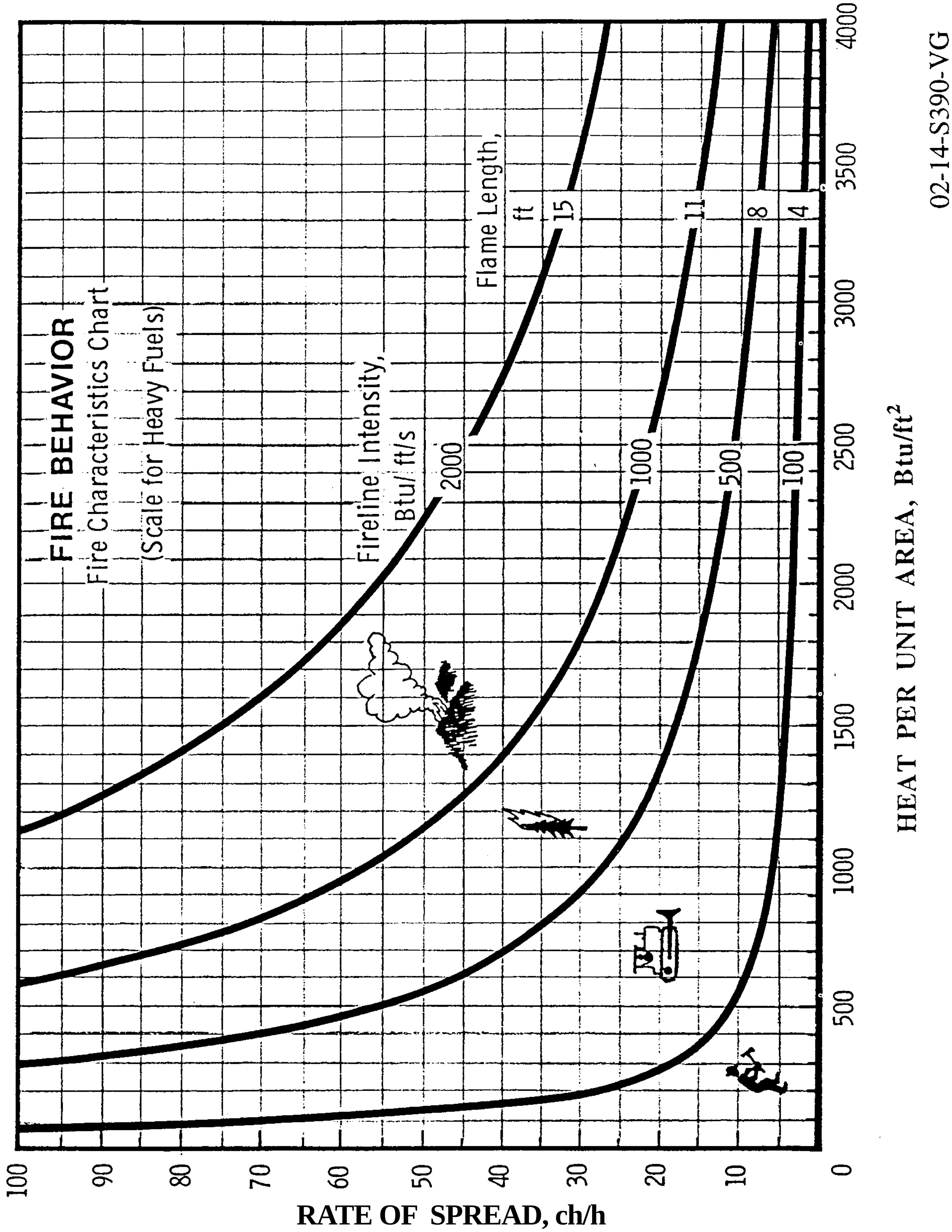
Spotting nomogram 3.



Spotting nomogram 4.



Fire characteristics chart, light fuels.



Fire characteristics chart, heavy fuels.