UNITED STATES MARINE CORPS
ENGINEER EQUIPMENT INSTRUCTION COMPANY
MARINE CORPS DETACHMENT
1706E EAST 8TH STREET
FORT LEONARD WOOD, MISSOURI 65473-8963

LESSON PLAN

EXPEDIENT DRAINAGE

EEO/EEC-B06

WARRANT OFFICER/CHIEF COURSE

A16ACN1/A1613E1

9/2/2014

APPROVED BY ________________________ **DATE** ____________________

INSTRUCTOR NOTE

Hand out to each student a copy of Hasty Runoff Estimations worksheets #1 and #2, Triangular Ditch calculation worksheet, Trapezoidal ditch calculations worksheet, and Maximum Diameter estimations worksheet.

(ON SLIDE #1)

INTRODUCTION **(10 MIN)**

1. **GAIN ATTENTION**: During any construction mission, one of the first considerations that must be addressed is to establish a drainage plan. This plan must be laid out to include the current drainage situation, your plan for drainage during the construction of your project, and what the drainage plan is for your project once it is completed. Failure to address drainage for all three of these phases of your project can result in damage to structures, equipment, and materials. As an engineer equipment chief/officer, you must be able to subjectively evaluate an areas's drainage considerations and be prepared to provide plans for drainage improvements when necessary.

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(ON SLIDE #2)

2. **OVERVIEW**: Good morning/afternoon, my name is ________________. The purpose of this period of instruction is to provide you the knowledge to plan and design an adequate drainage system in order to ensure the longevity of your horizontal construction project. During this period of instruction you will be taught types of drainage systems, purposes, and maintenance of water runoff.

INSTRUCTOR NOTE

Introduce the learning objectives.

(ON SLIDE #3)

3. **LEARNING OBJECTIVE(S)**:

INSTRUCTOR NOTE
Have students read learning objectives to themselves.

a. **TERMINAL LEARNING OBJECTIVE**:

(1) Provided a horizontal construction mission, resources, and references, manage/supervise horizontal construction project production and logistical requirements to develop project estimates in support of mission requirements. (1310-HORZ-2002/1349-HORZ-2002)

b. **ENABLING LEARNING OBJECTIVE**:

(1) Without the aid of reference, identify sub cycles of drainage hydrology per the FM 5-430-00-1/Vol I. (1310-HORZ-2002n/1349-HORZ-2002n)

(2) Given a scenario, the requirement for a drainage structure, and without the aid of references, estimate water runoff to provide adequate drainage per the FM 5-430-00-1/Vol I, and FM 5-34. (1310-HORZ-2002o/1349-HORZ-2002o)

(3) Without the aid of references, identify structural erosion control methods per the FM 5-430-00-1/Vol I, and FM 5-34. (1310-HORZ-2002p/1349-HORZ-2002p)

(4) Given an area of a waterway, and without the aid of references, determine the size of culvert required to provide adequate drainage per the FM 5-430-00-1/Vol I (1310-HORZ-2002q/1349-HORZ-2002q)

(ON SLIDE #4)

4. **METHOD/MEDIA:** This period of instruction will be taught using the informal lecture method with aid of power point presentation, demonstrations and practical applications.

INSTRUCTOR NOTE
Explain Instructional Rating Forms and Safety Questionnaire to students.

(ON SLIDE #5)

5. **EVALUATION:** You will be evaluated by a written exam at the time indicated on the training schedule.

(ON SLIDE #6)

6. **SAFETY/CEASE TRAINING (CT) BRIEF.** There are no safety / cease training concerns for this period of instruction.

INSTRUCTOR NOTE
Ensure to explain Crane Shed fire and inclement weather procedures.

(ON SLIDE #7)

TRANSITION: Are there any questions over what is going to be taught, how it will be taught, or how you the student will be evaluated? The first topic we will cover is the sources of water.

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BODY **(8 HOURS 30 MIN)**

(ON SLIDE #8)

1. **SOURCES OF WATER** **(20 Min)**

(ON SLIDE #9)

a. **Precipitation**: Rainfall and ground water are the two primary concerns to most military drainage designers. Snowmelt may be of greater concern in wide ranging climates or in the design of reservoirs, but snowmelt estimation and reservoir hydrology is beyond our capabilities.

(ON SLIDE #10)

b. **Interception**: Vegetation decreases the velocity and amount of water. Rain will not reach the soil until the holding capacity of the vegetation as been exceeded.

(ON SLIDE #11)

c. **Infiltration:** A significant amount of water is absorbed into the soil. The amount of water absorbed depends on the type of soil, vegetal cover, and the slope of the terrain.

(ON SLIDE #12)

d. **Ground Water**:

(1) *Surface water* is water that has accumulated on the ground surface.

(2) *Subsurface water* is the water that is in the ground (water table).

(3) *Capillary water* is water that seeps up to the surface. Capillary water can come from underwater streams or aquifers.

INSTRUCTOR NOTE
An aquifer is an underground bed or layer of rock, soil or sediment that yields water sometimes in high concentrations.

(ON SLIDE #13)

TRANSITION: So far we have covered sources of water. Are there any questions?

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OPPORTUNITY FOR QUESTIONS:

1. QUESTIONS FROM THE CLASS

2. QUESTIONS TO THE CLASS:

Q. What are the four sources of water?

A. Precipitation, interception, infiltration, and ground water

Q. What are the three types of ground water?

A. Surface, subsurface, and capillary

TRANSITION: Now that we have covered the sources of water, let's take a look at methods of estimating water runoff.

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(ON SLIDE #14)

2. ESTIMATING WATER RUNOFF (3 Hrs 30 min)

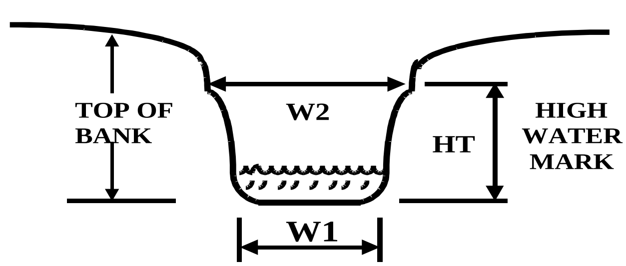
(ON SLIDE #15)

a. **HASTY METHOD**: The hasty method of runoff estimation is used when existing streams with an all-weather flow crosses or interferes with a construction site. This method provides an estimate of the cross-sectional area of water (Aw) to be expected as a result of the maximum annual runoff-producing storm.

(ON SLIDE #16, 17)

(1) This method makes the assumption that the cross section of the stream during a high water event approximates the shape of a trapezoid. The formula is:

$$Aw \quad \frac{W1 + W2}{2} \quad x\ H$$



Where:

Aw = Area of the waterway.

W1 = Width of the channel bottom.

W2 = Width at the high water mark.

H = Height from the bottom to the high water mark.

(ON SLIDE #18)

(2) Determining the measurements of the channel is the first step. The bottom width (W1) rarely presents a problem. The upper width (W2) may be more difficult. The upper width must be measured at the high water mark.

(3) The high water mark is characterized by water flowing at higher than normal velocity. The high velocity flow tends to cause notable bank erosion and undercutting. The higher flow velocity also tends to retard the growth of vegetation on the banks. Thus the high water mark is that point where bank erosion is present or vegetation ceases.

(4) The preferred location for observing the high water mark and for determining height (H) is along a straight run of the stream at, or immediately adjacent to, the construction site.

(ON SLIDE #19)

(5) Once the expected cross-sectional area of storm water runoff (Aw) has been determined, since culvert pipes rarely flow full, a safety factor is incorporated so that adequate cross-sectional area is provided. This safety factor is provided in the term Ades, the culvert design cross section. The formula is:

Ades = 2Aw

Ades = design cross section

2 = Safety factor

Aw = Area of the waterway that was previously computed

(ON SLIDE #20, 21)

Examples:

Example #1 Step (1)

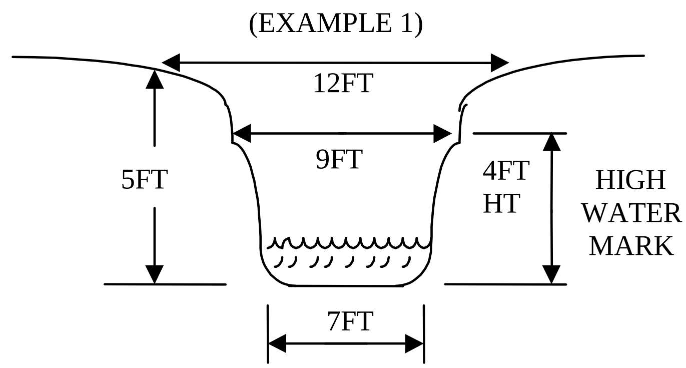
Aw= (____+____ / 2) ____ =

Aw=________ sqft.

Example #1 Step (2)

Ades= _____(sqft) X ___2___ =

Ades= _____(sqft)



Example #2 Step (1)

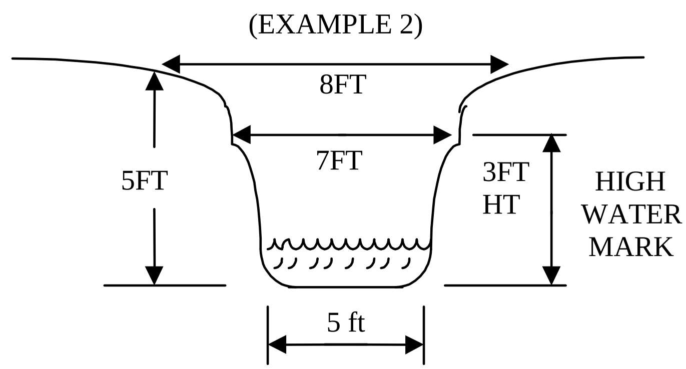
Aw= (____+____ / 2) __ _ =

Aw=________ sqft.

Example #2 Step (2)

Ades= _____(sqft) X ___2___ =

Ades= _____(sqft)



Example 1:

$\frac{7 + 9}{2}$ **X 4** = **32 Sqft. (AW)** **32 Sqft X 2 = 64 Sqft. (ADES)**

Example 2:

$\frac{5 + 7}{2}$ **X 3** = **18 Sqft. (AW)** **18 Sqft x 2 = 36 Sqft (ADES)**

(ON SLIDE #22, 23)

INTERIM TRANSITION: We have just discussed the hasty method of estimating water runoff. Now we will conduct practical application one to ensure your understanding of the formula for determining the area in square feet of storm water runoff.

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INSTRUCTOR NOTE
Introduce the following practical application (1).

PRACTICAL APPLICATION (1): **(10 MIN) Have the students complete the Hasty Runoff Estimations worksheet Number 1 and 2 using the formula:**

$$AW = \frac{W1 + W2}{2} \times H$$

PRACTICE: Students will use the formula to solve the channel area (CA) problems on worksheet 1 and 2. Channel Area and Area of Waterway are terms used in FM 5-430-001 and MCRP 3-17A. Both are two different terms that have the same meaning. The channel area and area of waterway are the same thing.

PROVIDE-HELP: The instructor will observe students, answer questions, and provide guidance. Ensure that although each student is working individually, questions by students are repeated and answered for all students to hear as many students may have the same questions.

1. **Safety Brief:** This is a classroom exercise. There are no safety concerns covering this practical application.
2. **Supervision & Guidance:** Ensure students are using the formula correctly. Review worksheets once time limit above ends and clear up any uncertainty.
3. **Debrief:** Are there any questions or comments concerning estimating the channel area of a ditch. Accurate estimations will allow you to plan, design, and construct a drainage system that will provide adequate runoff of stormwater and protect your road/airfield from erosion damage and washouts.

INTERIM TRANSITION: We have just covered hasty estimations for water runoff, are there any questions? We will take a break and then cover the field method which involves determining the amount of anticipated storm water your project will receive from rain and runoff from the surrounding areas.

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(BREAK - 10 Min)

INTERIM TRANSITION: Any questions before we talk about the field estimate method?

(ON SLIDE #24)

b. **FIELD ESTIMATE METHOD**: The field estimate method is an abbreviated version of the more deliberate rational method. The field estimate method is used to estimate the peak volume of storm water runoff. The runoff is carried in drainage paths that only carry flow during and immediately following precipitation. Results of the field estimate method are adequate for determining the size of drainage structures for temporary facilities in drainage areas of 100 acres or less.

(ON SLIDE #25)

(1) The formula is:

$$Q = 2 \times A \times R \times C$$

Where:

Q = peak volume of storm water runoff, in cubic feet per second

2 = a constant (safety factor)

A = area of drainage basin, in acres

R = design rainfall intensity based on the one hour, two year frequency rainstorm, in inches per hour

C = coefficient representing a ratio of runoff to rainfall

(ON SLIDE #26, 27)

(2) Determining Drainage Area: The fastest and most preferred method for determining the size of the drainage area is the stripper method. The first step of the stripper method is called delineation. It is done on a topographic map.

(a) Steps in determining drainage area:

(ON SLIDE #28)

1 Locate all the hilltops within the vicinity of the construction site.

(ON SLIDE #29)

2 Draw arrows that follow the contour lines from hilltop down, you will then be able to see which area(s) will drain toward the construction site. This is the drainage area.

(ON SLIDE #30)

3 Draw lines from hilltop to hilltop to delineate or outline an area.

(ON SLIDE #31)

4 Locate the longest, steepest gradient (based on contour line interval) within the drainage area. This will be the base line.

(ON SLIDE #32,33,34)

5 Now you must determine the area in square inches on the map and then convert to acres. Use a straight edge to draw a series of lines parallel to the base line, **one inch apart.** To increase accuracy of the estimation, lines separated by ¼ inch or ½ inch may be used. The sum of the length of the lines added together will then be divided by 4 if measurement is ¼ inch or by 2 if measurement is ½ inch.

6 Starting with the base line, measure the length of each line within the limits of the drainage area. Add the length of all the lines together. This is the map area in square inches.

(ON SLIDE #35,36,37)

7 Since you are concerned with acres, you must convert square inches on the map, to acres on the ground. To determine how many square feet on the ground are in one square inch on the map, divide the map scale by twelve and square the result.

(b) Second, determine how many square feet are in the drainage area. Multiply the square inches of the drainage area by the number of square feet per square inch.

(c) Now you must convert square feet to acres. Divide the total area in square feet by the number of square feet in one acre, which is 43,560.

(ON SLIDE #38)

INSTRUCTOR NOTE
Have the students follow along with the example on the power point. Q = 2 x 21 x R x C

(ON SLIDE #39,40)

INTERIM TRANSITION: We have just discussed the field estimate method of estimating water runoff. Now we will conduct a follow along demonstration.

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INSTRUCTOR NOTE
Introduce the following Demonstration (1).

DEMONSTRATION (1): (30 MIN) Walk the students through the steps in determining the drainage area. Use the example in the student handout as the demonstration. If further assistance is needed, Practical Exercise #1 can be demonstrated as well.

STUDENT ROLE: Students will observe the instructor as he/she performs the steps in the handout.

INSTRUCTOR(S) ROLE: The instructor will perform each step using dry erase board and/or overhead projector. Ensure that every student has a clear understanding of the step before moving on to the next step.
1. Safety Brief: There are no safety concerns.
2. Supervision & Guidance: Students will perform each step as it is completed by the instructor.
3. Debrief: Now that you've seen how to determine drainage area, we will do excercise number 1 to practice what you have learned.

(ON SLIDE #41)

INTERIM TRANSITION: Now you have seen first-hand how to conduct the drainage area estimate through the demonstration. Are there any questions or comments on the material covered? At this time, we will move on to the field estimate exercises #1.

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INSTRUCTOR NOTE
Introduce the following practical application (1).

PRACTICAL APPLICATION (2): (10 MIN) Have the students complete drainage area exercise #1.

PRACTICE:

1. Students will measure ½ inch lines from the already marked center line of the project site in the outlined area in exercise worksheet #1.

2. Students will then measure each line vertically and list those measurments in the box on the right side of the worksheet. (For consistency, if the student uses a fraction measurement, have them convert the fraction to a decimal.)

3. Once all measurments have been listed and converted, add Line 1 through Line 8. List the sum directly under Line 8.

4. At this point, divide the total by 2 (because we used ½ inch lines). That total is the square inches of the project area on the map.

5. Now, divide the scale of the map (in this case it is a 1/5000ths map), by the inches in a foot (12).

5000/12 = 416.67 linear feet on the ground equates to one linear inch on the map. Now square this answer to determine square feet:

416.67^2 = 173,613.89 Squre feet on the ground equals 1 Square inch on the map.

Now multiply the total measurement of all lines (this is after dividing by 2 or 4 depending on measurement used) in inches by 173,613.89. This will give the square feet in the area.

Dividing this answer by 43,560 will give the number of acres in your drainage area.

PROVIDE-HELP: The instructor will observe students, answer questions, and provide guidance. Ensure that although each student is working individually, questions by students are repeated and answered for all students to hear as many students may have the same questions.

1. Safety Brief: This is a classroom exercise. There are no safety concerns covering this practical application.

2. Supervision & Guidance: Ensure students are using the formula correctly. Review worksheets once time limit above ends and clear up any confusion.

3. Debrief: Are there any questions or comments concerning estimating the drainage area of a project site? Being able to accurately estimate the amount of water expected in an area will allow you as a Chief/Warrant Officer to determine the size, length, and frequency of drainage ditches and estimate for culverts and drainage relief ditches.

INTERIM TRANSITION: We have just covered determining the size of the drainage area for a project, are there any questions? Lets take a break and then we will get into figuring out how to estimate the approximate rainfall (precipitation) depending on the region you are in and the different factors that effect water runoff and water content of an area such as interception and infiltration.

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(BREAK - 10 Min)

INTERIM TRANSITION: Any more questions before we talk about rainfall intensity.

(ON SLIDE #42)

INSTRUCTOR NOTE
Have the students follow along with the example on the power point. Q=2 x A x R x C

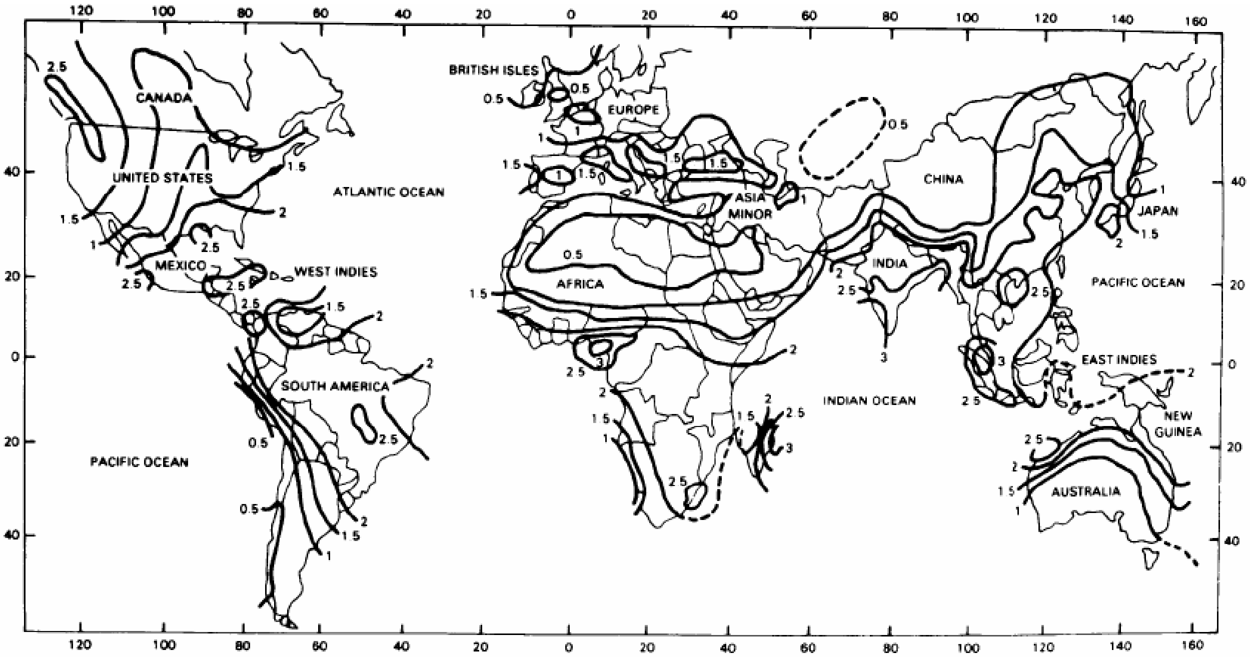
(ON SLIDE #43)

(3) Rainfall Intensity: This is the intensity of the one-hour, two-year frequency rainstorm; it can be determined two different ways.

(a) Local rainfall data may be obtainable through the weather station or the intelligence officer (S-2). This is the preferred method because it is normally more accurate.

(b) The other method is by looking up the value on an isohyetal map. A copy of this map can be found on page 6-7 of FM 5-430, or on page 8-5 of FM 5-34. **Do not interpolate.** If the project location falls on an isohyetal line, read the value of that line. If it falls between two lines, read the larger value. If it falls within an encircling isohyetal line, read the value of the encircling line.

(ON SLIDE #44)



(ON SLIDE #45)

EXAMPLE: If your project location is Eastern North Carolina, you can see that it falls between 1.5 and 2.0. Use the larger value of 2.0.

Q = 2 x 21 x 2 x C

(ON SLIDE #46)

INSTRUCTOR NOTE
Have the students follow along with the example on the power point. Q = 2 x A x R x C

(ON SLIDE #47)

(4) Runoff Coefficient: The runoff coefficient is the ratio of runoff to rainfall. It is the amount of water expected to drain from (not infiltrate) an area as the result of a specific amount of rainfall. The runoff coefficient is expressed as a decimal. There are three primary factors that affect the percentage, the soil type, surface cover and slope.

(ON SLIDE #48)

(a) *Soil Type.* If the soil is porous, a large portion of the rain will infiltrate the soil. This condition would translate to a smaller runoff coefficient. On the other hand almost all of the rainfall will pass over surfaces such as asphalt, concrete, and compacted gravel or macadam, thus resulting in a higher runoff coefficient. Refer to USCS

(ON SLIDE #49)

(b) *Surface Cover.* It is also important to know the surface cover. If the area is completely bare then it would be without turf. If the area is completely covered with vegetation then it would be with turf. If the area has some vegetation but is not completely covered then use the higher without turf value. If the area is wooded then the coefficient will be 0.20 because of the capability for the root systems to absorb water. **See Tabel 6-1**.

(ON SLIDE #50)

(c) *Slope*. As terrain becomes steeper, water flows sooner and more rapidly. This allows less time for infiltration to occur and results in the C value becoming larger for the natural cover or soil categories. **See Table 6-1**

(ON SLIDE #51)

a *Slope Percentage.* Identify the slope on the map. The difference between the top and bottom of the slope is found by reading the elevation contours. Then the horizontal distance is measured and converted to the same unit of measure as the vertical distance. The slope percentage will be used to correlate a C value from Table 6-1.

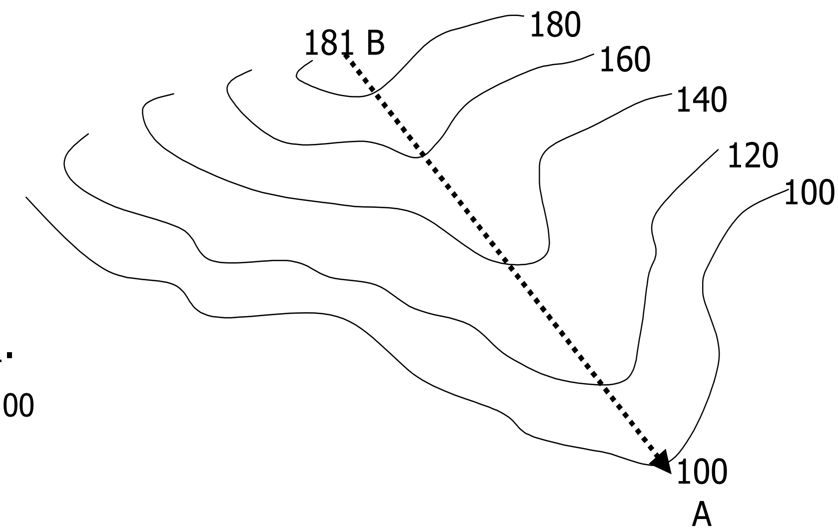
Difference in Elevation
Elevation B =181m
Elevation A =100m
Difference (Vd) **81m**

Horizontal Distance (Given) **=4150m**

Use the percent formula.

$$\frac{Vd}{Hd} X100 = \frac{\mathbf{81}}{\mathbf{4150}} x100$$

=1.9% or 2% Slope



(ON SLIDE #52)

(ON SLIDE #53)

b *Turf*. If the soil is not covered as previously explained then determine whether the area is with or without turf.

c *Safety*. In all cases where you have more than one possible runoff coefficient, use the highest value.

(ON SLIDE #54)

Soil or Cover Classification	C VALUES					
	Slope≤ 2 %		Slope >2 & <7%		Slope≥ 7%	
	w/turf	w/o turf	w/turf	w/o turf	w/turf	w/o turf
GW, GP, SW, SP	.10	.20	.15	.25	.20	.30
GMd, SMd, ML, MH, Pt	.30	.40	.35	.45	.40	.50
GMu, GC, SMu, SC CL, OL, CH, OH	.55	.65	.60	.70	.65	.75
Wooded area	.20	.20	.20	.20	.20	.20
Asphalt Pavement		.95		.95		.95
Concrete Pavement		.90		.90		.90
Gravel/macadam		.70		.70		.70

(ON SLIDE #55,56,57)

EXAMPLE: Your drainage area is made up of ML soil, with 40% turf and a slope of 2%.

*Since your area is covered with 40% turf you use the highest value, which will be without turf.

* Look up the value based on the drainage characteristics. You should obtain a value of 0.40 for your runoff coefficient.

Q = 2 x A x R x C

Q = Peak volume "cubic feet per second"

A = Area in acres, previously computed at **20.92** acres. Rounded up to the whole acre would be **21** acres.

R = Rainfall intensity for eastern North Carolina was found to be **2.0**

C = Runoff coefficient which was **0.40** ML soil without turf.

Q = 2 x 21 x 2 x 0.40

Q = 42 x 2 x 0.40

Q = 84 x 0.40

Q = 33.6 CFS

(ON SLIDE #58)

c. **Waterway Area**: Expedient culvert and ditch design is based on the waterway area. The hasty method produces a result in terms of waterway area, but the field estimate method produces a result in terms of peak volume of storm water runoff (Q). The storm water runoff must now be modified so that it is in terms of waterway area.

(ON SLIDE #59)

(1) First, look at the equation where Q = VAw.

Q = peak volume of storm water runoff.

V = velocity of water, in feet per second (fps).

Aw = waterway area, in square feet.

(ON SLIDE #60)

(2) For expedient purposes, **you will always use a velocity of 4 fps for design of expedient drainage structures.** Using simple algebra, you can rearrange the above equation so that the result will be waterway area.

(a) Q = VAw

(b) Divide both sides of the equation by the velocity (V). The result is Q/V = Aw.

(3) The final step would be to substitute the known and previously calculated values for the variables in the equation and solve for the waterway area.

EXAMPLE: You previously calculated a Q of **33.6** cfs, and the velocity is a given of 4 fps.

Aw = Q/V or Aw = 33.6 ÷ 4

Aw = 8.4 sqft

(ON SLIDE #61)

(4) As with the hasty method described earlier, you rarely design a drainage system to flow completely full. You must apply a safety factor, which is represented by Ades.

EXAMPLE: Ades = 2 x Aw

Ades = 2 x 8.4

Ades = 16.8 sqft

(ON SLIDE #62,63)

INTERIM TRANSITION: We have just covered determining methods of estimating water runoff. Are there any questions? We will now move into demonstration #2 and practical application #2, which covers the all the steps involved in the field estimate method.
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INSTRUCTOR NOTE
Introduce the following Demonstration (2).

DEMONSTRATION (2): (30 MIN) Walk the students through the steps in determining the drainage area, rainfall intensity, and the coefficient (2ARC). Use the example in the student handout for the demonstration.

STUDENT ROLE: Students will observe the instructor as he/she performs the steps in the handout.

INSTRUCTOR(S) ROLE: The instructor will perform each step using dry erase board and/or overhead projector. Ensure that every student has a clear understanding of the step before moving on to the next step.

1. **Safety Brief:** There are no safety concerns.

2. **Supervision & Guidance:** Students will perform each step as it is completed by the instructor.

3. **Debrief:** Now that you've seen how to determine drainage area, we will do excercise number 2 to practice what you have learned.

(ON SLIDE #64)

INTERIM TRANSITION: Now you have seen first-hand how to use the 2 ARC formula through the demonstration. Are there any questions or comments on the material covered? At this time, we will move on to the field estimate exercises #2.

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INSTRUCTOR NOTE

Introduce the following practical application (3).

PRACTICAL APPLICATION (3): (10 MIN) Have the students complete drainage area exercise #2.

PRACTICE: Have the students complete practical application #2 using all the steps from the previous practical application plus the additional steps for deteremining slope, turf, plus the safety factor.

PROVIDE-HELP: The instructor will observe students, answer questions, and provide guidance. Ensure that although each student is working individually, questions by students are repeated and answered for all students to hear as many students may have the same questions.

1. Safety Brief: This is a classroom exercise. There are no safety concerns covering this practical application.
2. Supervision & Guidance: Ensure students are using the formula correctly. Review worksheets once time limit above ends and clear up any confusion.
3. Debrief: Are there any questions or comments concerning using the field estimate method? Using the field estimate method, you will be able to design a drainage plan that will increase the longevity of your project during construction and after completion.

TRANSITION: We have just covered the methods used to estimate water runoff. Are there any questions? Here are some questions for you.

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(ON SLIDE #65)

OPPORTUNITY FOR QUESTIONS:

1. QUESTIONS FROM THE CLASS

2. QUESTIONS TO THE CLASS:

Q. What method of runoff estimation is used when an existing stream interferes with a construction site?

A. Hasty method

Q. The hasty method produces a result in terms of waterway area, what does the field estimate method determine?

A. A result in terms of peak volume of storm water runoff

(BREAK – 10 Min)

TRANSITION: Now that we have covered the methods of estimating water runoff, let's take a look at the different types of ditches that you may have to construct to meet your drainage requirements.

(ON SLIDE #66)

3. **DRAINAGE DITCHES (1 Hr 20 Min)**

(ON SLIDE #67,68,69,70)

a. **Triangular V-Ditches**: Triangular (V) ditches are used to move small quantities of water. A small quantity of water generally means $Q \leq 60$ cfs or $AW \leq 15$ sqft.

(1) Ditches have two sides and two associated side-slope ratios. Side slope is the slope of the banks of the channels, normally expressed as a ratio of feet horizontal to feet vertical. For example, 3:1 is a side slope of 3 feet horizontal to 1 foot vertical.

(2) When the sidewalls on opposite sides are inclined equally, the ditch is called symmetrical.

(3) *Nonsymmetrical* ditches have side slopes that differ.

(4) The designer selects appropriate side-slope ratios. The selection is critical to ensure that the ditch serves its purpose. Ditch sidewalls that are too steep invite excessive erosion and are likely to cause the ditch to clog with sediment. Even more serious is the risk of a severe accident, if a vehicle should run into the ditch and become entrapped or overturn because the side slope is too severe.

(5) For clarity, the terms *front slope* or *ditch slope* and *back slope* are used to differentiate between the dissimilar slopes. The sidewall of a roadside ditch located adjacent to the shoulder is called the front slope of the ditch. The far slope, called the back slope, is simply an extension of the cut face in an excavation.

(6) The following rules of thumb are applicable only in shallow ditches in relatively flat terrain: Roadside ditches may be cut nonsymmetrical at 3:1/1:1 (front slope/back slope). For calculation purposes, the horizontal component of the roadside ditch will be referred to as X. Likewise, the horizontal component on the back slope will be referred to as Y. There are two formulas used to determine how deep and how wide the ditch should be. They are:

(ON SLIDE #71)

(a) D = Cutting Depth. This is the water depth in feet, plus ½ foot of freeboard. The formula reads:

$$D = \sqrt{\frac{Ades}{X+Y}} + .5 \text{ (Freeboard)}$$

Where:

Ades = Design cross section. (2Aw)

X = Horizontal slope ratio of the front (or "ditch") slope.

Y = Horizontal slope ratio of the back slope.

.5 = Constant, the freeboard safety factor.

(ON SLIDE #72)

(b) W = Width at the top of the ditch. The formula reads:

W = D x (X + Y)

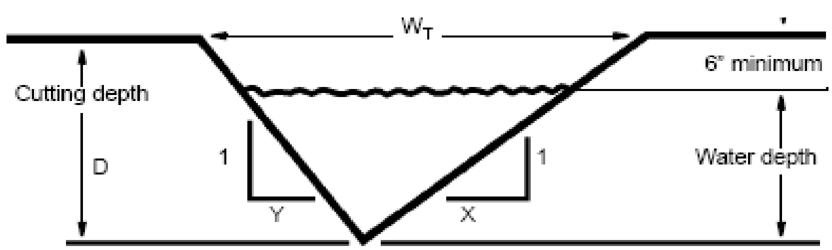
Where:

Wt = Width of the top of the ditch.

D = Depth (from preceding formula).

X = Horizontal slope ratio of the front (or "ditch") slope.

Y = Horizontal slope ratio of the back slope.



(ON SLIDE #73)

EXAMPLE: You previously computed Ades at 16.8 sqft. If the front slope has a 3:1 ratio and the back slope has a 1:1 ratio, calculate the depth and width of the ditch. (Keep in mind Ca X 2 = ADES)

$D = \sqrt{\frac{Ca \times 2}{X+Y}} + .5 \quad D = \sqrt{\frac{16.8}{3+1}} + .5 \quad D = \sqrt{4.2} + .5 \quad D = 2.05 + .5$

D = 2.55

W = D x (X + Y)   W = 2.55 x 4   **W = 10.2**

(ON SLIDE #74)

INTERIM TRANSITION: We have just covered the formula for figuring the size of triangular ditch. Now let's practice what we've learned through a practical application.

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INSTRUCTOR NOTE

Introduce the following practical application (4).

PRACTICAL APPLICATION (4): (10 MIN) Have the students complete the Triangular Ditch Calculations worksheet.

PRACTICE: Have the students complete the eight problems on the triangular ditch calculations.

PROVIDE-HELP: The instructor will observe students, answer questions, and provide guidance. Ensure that although each student is working individually, questions by students are repeated and answered for all students to hear as many students may have the same questions.

1. **Safety Brief:** This is a classroom exercise. There are no safety concerns covering this practical application.
2. **Supervision & Guidance:** Ensure students are using the formula correctly. Review worksheets once time limit above ends and clear up any confusion.
3. **Debrief:** Are there any questions or comments over using the formula for triangular ditch calculations. The triangular ditch, which is used for moving smaller amounts of water than other ditches, will allow you to make ditches using a grader instead of a dozer or back hoe. Using the grader to construct a ditch is more practical and quicker, thus allowing for a shorter overall project time, however ditch size will be smaller than if constructed with a dozer or backhoe.

INTERIM TRANSITION: We have just covered the formula for determining the size of a triangular ditch. Are there any questions? Now let's move on to trapezodial ditches.

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(ON SLIDE #75)

b. **Trapezoidal Ditches**. Trapezoidal ditches are installed for larger runoff requirements, generally for $Q \geq 60$ cfs or $Aw \geq 15$ sqft. Compute the cross-sectional area of a trapezoidal ditch as if the trapezoid were a rectangle. The slope areas are not considered. Generally the designer selects the width of the bottom of the ditch based upon the width of the cutting edge of the equipment used in constructing the ditch then solves for d, the depth of water. For example, if the ditch is to handle a peak flow rate of 75 cfs and the bottom width is 7.25 feet (the width of a D-7 blade), then:

(ON SLIDE #76,77)

$$Aw = \frac{Q}{4\text{ fps}} = \frac{75\text{ cfs}}{4\text{ fps}} = 18.75\text{ sqft}$$

$$D = \frac{Aw}{\text{bottom width}} = \frac{18.75\text{ sqft}}{11.67} = 1.61\text{ feet deep}$$

Add Freeboard: 1.61 ft. deep + 0.5 = 2.11 ft. deep.

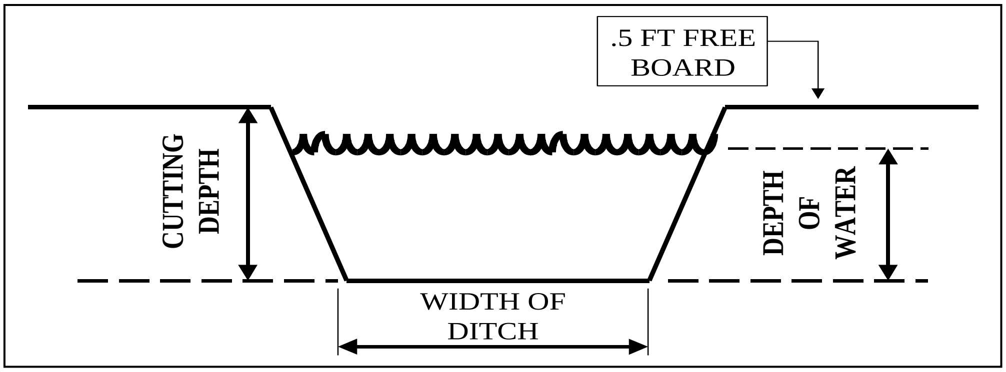
Where:

D = ditch depth in feet (Rounded two places)

Aw or Ca = Channel (waterway) area in square feet

W = Width of ditch bottom in feet

0.5 = (Constant) Safety factor (1/2 foot of freeboard)



(1) Cutting Depth. Remember to add 1/2 foot of freeboard to the depth of water to determine the cutting depth (CD). CD may be exceeded, especially if it is less than 1.5 feet, the normal minimum depth. **CD = D + 0.5 ft**

(ON SLIDE #78)

INTERIM TRANSITION: We have just covered the formula for figuring the size of trapezoidal ditch. Now let's practice what we've learned through a practical application.

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INSTRUCTOR NOTE
Introduce the following practical application (5).

PRACTICAL APPLICATION (5): (10 MIN) Have the students complete the Trapezodial Ditch Calculations worksheet.

PRACTICE: Have the students complete the six problems on the triangular ditch calculations.

PROVIDE-HELP: The instructor will observe students, answer questions, and provide guidance. Ensure that although each student is working individually, questions by students are repeated and answered for all students to hear as many students may have the same questions.
1. Safety Brief: This is a classroom exercise. There are no safety concerns covering this practical application.
2. Supervision & Guidance: Ensure students are using the formula correctly. Review worksheets once time limit above ends and clear up any confusion.
3. Debrief: Are there any questions or comments over using the formula for trapezodial ditch calculations. The trapezodial ditch, which is used for channeling large amounts of water at higher velocities, is generally constructed with a dozer as simply a flat bottom ditch. Marine 1345's get extensive practice constructing a flat bottom ditch at dozer phase here at

Fort Leonard Wood and are generally more comfortable constructing a trapezodial ditch with a dozer than a triangular ditch with a grader, therefore resulting in a well constructed ditch. Using a dozer to construct this ditch, however, may increase your footprint due to the large amounts of material that must be removed.

INTERIM TRANSITION: We have just covered the formula for determining the size of a trapezodial ditch. Are there any questions? We will take a break and then move on and learn about erosion control methods that can be used to protect your drainage system from wearing away.

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(BREAK – 10 Min)

INTERIM TRANSITION: Any more questions before we talk about erosion control methods.

(ON SLIDE #79,80)

c. **Erosion Control Methods**. There are several methods of erosion control used in ditches. The primary concern is to slow the water down. However, water that runs too slow will cause drainage systems to clog and ultimately fail. The desirable gradient for a ditch is between 0.5 percent and 2 percent. Ditches with a gradient greater than 2 percent will require erosion control.

(ON SLIDE #81,82)

(1) *Ditch Lining.* Ditches may be lined to prevent erosion. The use of concrete, asphalt, rock and mortar will not decrease the velocity of the water by any great degree, but it will protect the soil. The use of grass will not only help to protect the soil but it will also reduce the velocity of the water. Grass seed is cheap. Concrete, asphalt, rock and mortar can be rather expensive and will not be readily available.

(ON SLIDE #83,84)

(2) *Check Dams.* Check dams are nothing more than small dams built from logs or heavy timbers that reduce the gradient of the ditch.

(a) *Timbers.* The timbers should be six to eight inches in diameter or square. They will be set at least two feet into the sides and bottom of the ditch. In addition, they will be joined with drift pins and held in place by piles. The piles will be on both sides of a notch in the center of the check dam. The notch is called a weir notch.

(ON SLIDE #85)

(b) *Weir Notch.* A weir notch will be cut in the center. Normally the weir notch will be a minimum of six inches deep and twelve inches wide. Naturally a larger dam will have to have a larger weir notch.

(c) *Rock Apron.* A rock apron made of rip-rap will be placed in front of the dam, and should extend four feet in front of the dam for every one-foot of dam height.

(d) *Top of Dam.* The top of the check dam should be placed at the high water mark on an existing ditch. A new ditch will not have a high water mark, so the top of the check dam will be placed one foot below the top of the ditch.

(ON SLIDE #86)

(e) *Dam Spacing.* Check dams will have a minimum spacing of 50 feet. To reduce construction effort the dams should be placed as far apart as possible, while achieving the desired gradient.

S = Spacing in feet.

A = Present ditch gradient.

B = Desired ditch gradient.

H = Height of check dam (from the bottom of the Weir notch to the bottom of the ditch).

100 = Converts to percentage.

$$S = \frac{100(H)}{A - B}$$

% Gradient = (Rise/Run) 100

(f) Check dams should be inspected periodically to allow the free flow of water.

(ON SLIDE #87)

Example: What spacing will be needed for a 4 foot high check dam with a 10% slope.

$$S = \frac{4 \times 100}{10 - 2}$$

$$S = 50 \text{ feet}$$

(ON SLIDE #88)

TRANSITION: In this section we have covered types, purpose, and construction of ditches and drainage structures and methods of erosion control. Are there any questions?

OPPORTUNITY FOR QUESTIONS:

1. QUESTIONS FROM THE CLASS

2. QUESTIONS TO THE CLASS:

Q. The hasty method produces a result in terms of waterway area, what does the field estimate method determine?

A. A result in terms of peak volume of storm water runoff

Q. Triangular ditches can be easily constructed with what type of equipment? Trapezoidal ditches?

A. A grader. A dozer or backhoe

(Take a Break-10 Min)

TRANSITION: Now that we have covered ditches and drainage, let's take a look at the different types of culverts used to divert water from your project.

(ON SLIDE #89)

4. **CULVERTS: (50 min)**

A culvert is an enclosed waterway used to pass water through an embankment or fill. There are two classifications of culverts: permanent and expedient. The flow of water depends upon the materials the culvert is constructed of and the down stream conditions.

(ON SLIDE #90)

a. **Permanent Culverts**: There are different materials culverts may be constructed of such as corrugated metal, concrete, vitrified clay (VC), polyvinyl chloride (PVC), timber, and many other materials. As a refresher, refer back to the Military Roads class for information covering permanent culverts.

(1) Timber Box Culverts are used when standard culverts are not available. Timber culverts can be rapidly constructed but require good workmanship. They provide good strength to support superimposed loads and have hydraulic characteristics that compare favorably with other types of culverts. They are made of:

(a) Large timber (treated if possible)

(b) Made strong enough to support the heaviest vehicle that will be crossing.

(c) Must have minimum of 12" of cover

(2) Corrugated Metal Pipe Culverts (CMP)

(a) Cradled to prevent pipe shifting during back fill.

(b) Place exhaust end, at the same grade as ditch, 45-90 degrees off centerline.

(c) Multiple pipes must all be the same diameter.

(d) Multiple pipe spacing is ½ the diameter of the pipe.

(ON SLIDE #91)

(3) Concrete Pipe Culverts: When available, concrete-pipe culverts should be used instead of CMP. Concrete has two advantages; first it is stronger and requires less cover than CMP to support the same load. Second, the interior surface of a concrete pipe is smoother than CMP allowing for smoother flow of water and less problems with debris restricting the flow of water. Because of these advantages, concrete pipe of the same

diameter will carry a higher flow of water. The concern is once the water exits the pipe at a higher velocity, good erosion control methods must be in place to reduce erosion along the ditch past the pipe's exit. Here are some general rules of thumb for the concrete pipe:

(a) Can be constructed in any length or size.

(b) Requires a concrete sealant when adjoining two sections or more of pipe together.

(c) Substantial headwalls and exhaust ports are required to diminish the potential for separation at the joint ends.

(d) Transportability will be slightly more difficult do to the weight of the concrete.

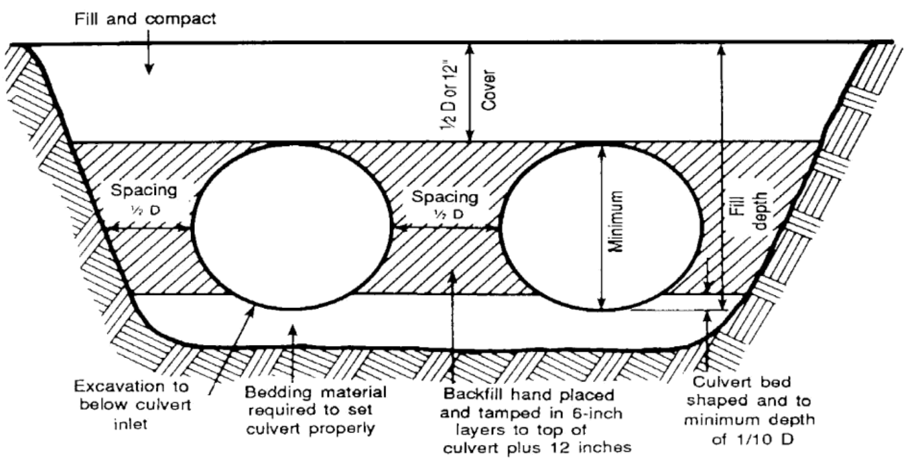
(ON SLIDE #92, 93)

b. **Maximum Allowable Culvert Diameter**. Permanent culverts are selected based on their diameter. There are two equations for determining the maximum diameter (Dmax) of a culvert. Both methods depend upon the amount of fill used to bury the culvert. Fill (F) is defined as the distance from the inside bottom (the invert) of the culvert to the finished grade of the road. Cover (C) is another term used in culvert design. Cover is measured from the top of the culvert to the finished grade. Cover depth will either be ½ the diameter of the culvert, or 12", whichever is greater.

(1) For fills greater than 36 inches, use Dmax = 2/3F.

(2) For fill less then 36 inches, use Dmax = F-12.

(ON SLIDE #94, 95)



(ON SLIDE #96)

EXAMPLE: Let's say your jobsite encompasses an all weather stream. Using the hasty method, you had an AW of 8.75 sqft and a Ades of 17.5 sqft. The stream bed itself was five feet deep with a proposed road thickness of one foot. Therefore, you have a six-foot fill.

Dmax = 2/3 F

F = 6' x 12" = 72"

Dmax = 2/3 72 inches

$$\frac{2 \times 72}{3} = \frac{144}{3} \text{ or } 48"$$

Dmax = 48 inches

(ON SLIDE #97)

INTERIM TRANSITION: We have just covered the formula for determining maximum diameter of a culvert. Now let's practice what we've learned through a practical application.

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INSTRUCTOR NOTE
Introduce the following practical application (6).

PRACTICAL APPLICATION (6): (10 MIN) Have the students complete the Maximum Diameter (DMAX) worksheet.

PRACTICE: Have the students complete the six problems on the DMAX calculations.

PROVIDE-HELP: The instructor will observe students, answer questions, and provide guidance. Ensure that although each student is working individually, questions by students are repeated and answered for all students to hear as many students may have the same questions.
1. Safety Brief: This is a classroom exercise. There are no safety concerns covering this practical application.
2. Supervision & Guidance: Ensure students are using the formula correctly. Review worksheets once time limit above ends and clear up any confusion.
3. Debrief: Are there any questions or comments over using the formula for determining DMAX? Determining the maximum diameter of a culvert will benefit you as a Chief/Equipment Officer in terms of saving money, time, and effort. When discussing culverts in terms of money and time, they can be expensive and time consuming to install. Conducting the estimations to determine the maximum culvert size will ensure that you have enough space for the expected water flow and will prevent you from having to remove a culvert that is too small and save time from removing the first culvert installed and installing the right size culvert in its place.

INTERIM TRANSITION: We have just covered the formula for determining the maximum size required for a culvert. Are there any questions? Now let's move on to types of culverts and how to order or make them.

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(ON SLIDE #98)

c. **Culvert Materials**. There are several factors that need to be considered when calculating materials. You will need to know the most economical diameter to be used as well as the total length of culvert necessary.

(ON SLIDE #99, 100)

(1) Economical Diameter. We want to save material, therefore we want to put in the least number of pipes possible

and still equal or exceed the design area. Economy also dictates that we exceed the design area by the least possible amount. Manpower, too, is a factor that we must consider when thinking of economy, for it takes less time and effort to install 2 pipes than it does to install 3.

(2) From the standpoint of economy, then, we cannot simply select the largest pipe that satisfies the fill and cover requirement. To find the most economical size, we must divide the Design Area by the end area of several different pipe sizes. We use the largest pipe that satisfies the fill and cover requirements as a starting point, and work with the next smaller size of pipe until the number of pipes required to provide necessary Design Area increases. When the number of pipes required increases, we have reached and just passed our optimal (or most economical) design, and we are no longer economical.

(a) Select the next smaller diameter culvert. Selecting the next larger diameter would lead to insufficient cover and, possibly, a culvert collapse should vehicles drive over it. Use the table below.

(ON SLIDE #101)

(b) The formula for determining Economical Diameter is:

$$N = A_{des} \div \text{Pipe End Area}$$

Where:

N = Number of Pipes

Ades = Design Cross Section

Pipe End Area = Cross-sectional end area of culvert in ft^2.

Always round up to the next whole number (pipe). Repeat this process using successively smaller pipes until you exceed economical design.

(ON SLIDE #102)

COMMON CULVERT SIZES WITH CROSS SECTIONAL AREA

Maximum Culvert Diameters in Inches	Cross Sectional Area in Square Feet
12″	00.79 sqft
18″	01.77 sqft
24″	03.14 sqft
30″	04.91 sqft
36″	07.07 sqft
42″	09.62 sqft
48″	12.57 sqft
60″	19.64 sqft
72″	28.27 sqft

(ON SLIDE #103)

EXAMPLE:

N48″ = Ades ÷ A48

N48″ = 17.5 ÷ 12.57 = 1.4 or 2

N48″ = (2) 48″ PIPES

N42″ = Ades ÷ A42

N42″ = 17.5 ÷ 9.62 = 1.8 or 2

N42″ = (2) 42″ PIPES

N36″ = Ades ÷ A36

N36″ = 17.5 ÷ 7.07 = 2.5 or 3

N36″ = (3) 36″ PIPES

42″ Culvert is the economical diameter. Cover requirements will still be met (in fact, exceeded), it will take only two culverts to drain the design area, and 42″ culvert will be cheaper to purchase and easier to install than (2) 48″ culverts. The 36″ culvert becomes uneconomical because you're increasing the number of pipes and the amount of earthwork required to install them.

(ON SLIDE #104)

(3) Culvert Length. Since corrugated metal pipe is manufactured in two-foot sections, the calculated length must be rounded up to the even foot for both the Culvert Length ***and*** the Order Length. Some other considerations include:

(a) The length will be determined using road cross sections provided by the surveyor and will include the width of the road plus the length of the fill slopes.

(b) The length of the fill slopes may not be labeled, but can be computed using the slope ratio and the height at the road shoulder. Since the slope ratio is expressed as the horizontal distance to the vertical distance, you can multiply the horizontal distance of the slope ratio by the vertical distance. The result will be the length of the fill slope.

(c) Headwalls protect the soil around the culvert from erosion.

(d) Headwalls are always required at the upstream end of the culvert and are desirable at the downstream end. If a headwall is not constructed on the downstream end of the culvert, the end must be extended an additional two feet to prevent erosion of the fill.

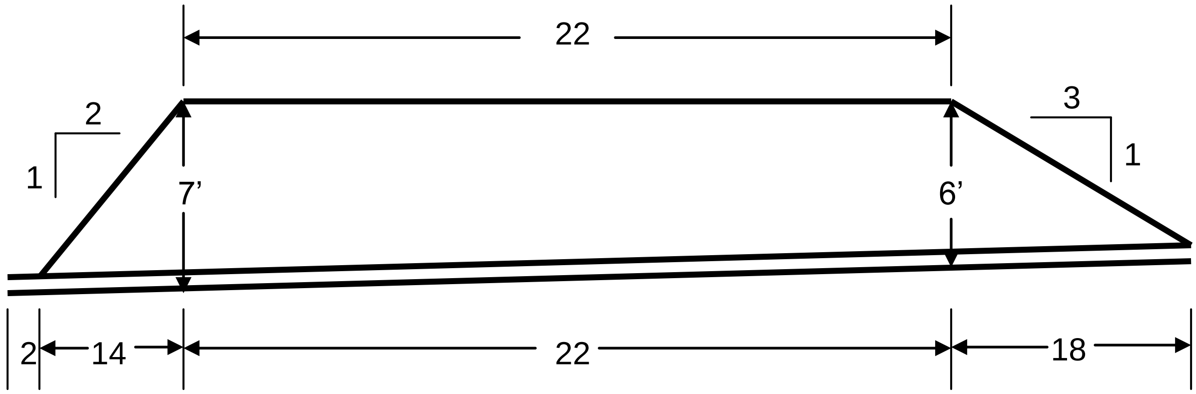
(e) Headwalls need not be built precisely at the toe of the fill slopes. Most often, headwalls are recessed some distance into the fill section. The culvert length will have to be adjusted to this length. The amount of building materials and time will dictate whether the headwalls will be recessed or not.

(4) Order Length The pipe is ordered by length needed, and comes with enough nuts and bolts for assembly. You must multiply the culvert length by the number of pipes required to determine the total order length. Additionally, a 15 percent waste factor will be added to allow for damage during shipment and construction. This is obtained by multiplying the order length by 1.15.

(ON SLIDE #105,106,107,108)

EXAMPLE: Using the cross section below and the knowledge that you will NOT place a headwall at the exhaust end, calculate order length based on the following:

Road: 22 feet wide
Left slope: 2:1 with a 7' depth.
Right slope: 3:1 with a 6' depth.
Gradient: 2%



FORMULA:

CL (culvert length) = (DL x SL) + RW + (DR x SR)
Where:

DL = Depth of fill at left shoulder

SL = Slope ratio, left side slope

DR = Depth of fill at right shoulder

SR = Slope ratio, right side slope

RW = road width including shoulders.

CL = (7x2)+ 22′ + (6x3)

= 14′ + 22′ + 18′
= 54′ + 2′ (no headwalls on exhaust end)

= 56′

FORMULA:
OL (order length) = CL x Npipes x 1.15

OL = (56′ x 2) 1.15

= (112) 1.15
= 128.8′ or 130′

(ON SLIDE #108)

d. **Strutting**. Because of the stress placed on corrugated metal pipe by large amounts of cover, it becomes necessary to support pipes 48 inches in diameter or larger with struts.

(ON SLIDE #109, 110, 111, 112)

e. **Headwalls and aprons**

(1) Headwalls and aprons are constructed at the entrance and exit of culverts. The headwalls and aprons guide water into the culvert and channel it as it exits into the intended ditch. Headwalls and aprons allow for the control of erosion, reduce seepage under the culvert preventing a washout. Erosion control methods, such as rip rap or screening, should always be used on the exhaust or discharge side of a culvert to prevent erosion downstream in the ditch. Proper planning for discharge of water out of a culvert will prevent backwash dislodging a culvert.

(ON SLIDE #113)

TRANSISTION: We have just covered culvert types and uses. Are there any questions? Here are some questions for you.

OPPORTUNITY FOR QUESTIONS:

1. **QUESTIONS FROM THE CLASS**

2. **QUESTIONS TO THE CLASS:**

Q. What is a culvert?

A. A culvert is an enclosed waterway used to pass water through an embankment or fill.

Q. Where is a headwall required when installing a culvert?

A. At the upstream end

(ON SLIDE #114)

Summary **(10 MIN)**

During this period of instruction we have covered planning and designing an expedient drainage system. Properly applying a drainage plan to your project will ensure its' longevity and bring credit to your unit's name. Proper drainage will also reduce the clean-up effort you will need to conduct upon departing your project. Planning, designing, and constructing an adequate drainage system is a must for satisfactory mission accomplishment of a construction project.

INSTRUCTOR NOTE
Ensure to collect all IRF's and safety questionnaires handed out.

(BREAK – 10 Min)

REFERENCES:

FM 5-430-00-1 ROADS, AIRFIELDS, AND HELIPORTS VOLUME I
MCRP 3-17A ENGINEER FIELD DATA