# ADAPTING SELECTED SOIL AND WATER ENGINEERING TECHNOLOGY TO THAILAND CONDITIONS

by

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# INTRODUCTION

Thailand has a land area of 321,250,000 rai (200,000 square miles) and is located in Southeast Asia. It is surrounded by several countries: Burma and Laos on the north, Burma and Cambodia on the east, Federation of Malaysia and Gulf of Thailand on the south, and Burma together with the Indian Ocean on the west.

The Northern, Northeastern, and Southern parts of Thailand are mountainous areas, whereas the central part of Thailand is plain area. Mountain ranges lying close to the seas bordering Thailand affect climatic conditions, particularly the amount of rainfall. Thailand can be described as having two major climates, Tropical Savanna and Tropical Rainy. A description of these climates is as follows:

1. Tropical Savanna Climate

   This type of climate is found astride the head of the Gulf of Thailand and extends to the extreme north of the country inclusive of the East Coastal Region of the Gulf of Thailand. During the Southwest Monsoon Season, which is from May to September, it is rainy, and the peak of this wet period is in September; while in the Northeast Monsoon Season (November to February) there is a distinct dry period during which it becomes cool. For this reason the climate can be classified as Tropical Savanna.

2. Tropical Rainy Climate

   In the southern part, rains are abundant in the Southwest

Monsoon Season (May to September), and even in the Northeast Monsoon Season, although from the head of the Gulf northwards the weather is rather dry during the latter season. The coastal region from Chumporn southwards is rainy at this season. Therefore, the southern part can be reckoned as rainy throughout the year or as Tropical Rainy Climate.

Generally speaking, rains in Thailand are good and beneficial to agriculture with the annual mean of 1550 millimeters or 60 inches. However, in certain portions of the country, that is, in the Central part and especially on the west of the leeward side of the Tenneausri Range as well as along the southern portion of the northeastern part, the mean rainfall is somewhat meagre in comparison with other localities. In certain years rainfall may amount to only 1000 mm or 40 inches.

The region of heaviest rainfall is along the West Coast of the southern part of Ranong to the border, and also along the East Coast of the Gulf of Thailand from Ranong southwards, where abundant rains occur during the Southwest Monsoon Season. Another region of copious rain is located along the east coast of the southern part particularly from Chumporn southwards, where there are heavy downpours during the Northeast Monsoon Season. Within these regions, the yearly rainfall is usually 2000 mm or 78 inches and in some years the amount may be more than 2500 mm or 100 inches. In the other parts of the country rainfall is much less (21).

Thailand has three seasons; the winter season from November to February, the summer season from March to June, and the rainy season from July to October.

Due to an inland location, the northern, northeastern, and central parts of the country have long periods of hot weather, with average temperatures ranging from 25°C to 30°C. Along the coastal regions, the temperatures are more moderate. During the northeast monsoon wind, or in the winter, the temperatures are much milder, and average between 13°C to 20°C. Occasionally the cold wind from the China mainland reduces the temperatures in the northern and northeastern parts down to 5°C. Because of the maritime exposure, temperatures in the southern part are generally mild throughout the year and range between 22°C-33°C (36).

According to the latest data, about 23.53 percent of the total area is farmland. Approximately 82 percent or four-fifths of the total farm holding is under cultivation; wood land occupies 8.03 percent; other uses about 9.24 percent. Forest area makes up 56.23 percent of the total country area. Swamps and unclassified land occupies 0.53 percent and 19.71 percent, respectively (Table 1)(8).

The total population of Thailand is 27.03 millions according to the statistics in 1960 and over 34.5 millions in 1970 (the last census of National Statistics Office and the birth rate from 1960-1970 is 2.7)(8). The statistics of 1960 show that the density of the population was 56 persons per square kilometer (31).

Table 1. Summary of Land Utilization of Thailand (in rais*)

| Region | Total Land (1) | Forest Land (2) | Swamp Land (3) | Farm Holding Land (4) |
|---|---|---|---|---|
| Northern | 55,927,500 | 44,250,742 | 19,273 | 4,567,529 |
| North-Eastern | 106,391,250 | 41,065,858 | 395,665 | 26,561,040 |
| Central Plain | 115,063,125 | 62,411,552 | 364,739 | 33,668,095 |
| Southern | 43,868,125 | 23,232,842 | 624,994 | 13,918,853 |
| Whole Kingdom | 321,250,000 | 170,960,994 | 1,394,671 | 78,715,517 |
| <u>Percentage</u> | | | | |
| Northern | 100% | 79.12 | 0.03 | 8.17(100) |
| North-Eastern | 100% | 38.60 | 0.37 | 24.97(100) |
| Central Plain | 100% | 54.24 | 0.31 | 29.26(100) |
| Southern | 100% | 52.96 | 1.42 | 31.73(100) |
| Whole Kingdom | 100% | 56.23 | 0.53 | 23.53(100) |

*2.5 rai = 1 acre, 6.25 rai = 1 hectare.

Table 1. Summary of Land Utilization of Thailand (in rais) (Continued)

| | Types of Land Use of Farm Holdings | | | | | Summary | |
|---|---|---|---|---|---|---|---|
| Region | Paddyland (5) | Tree Land (6) | Wood Land (7) | Upland Crops (8) | Others (9) | Total Classified (10) | Total Unclassified (11) |
| Northern | 2,678,855 | 251,178 | 201,321 | 1,029,186 | 406,989 | 48,837,544 | 7,089,956 |
| North Eastern | 15,183,180 | 547,752 | 3,487,781 | 4,348,006 | 2,994,321 | 68,022,563 | 38,368,687 |
| Central Plain | 19,390,672 | 2,146,966 | 1,806,879 | 7,554,007 | 2,829,571 | 96,434,386 | 18,628,739 |
| Southern | 3,238,599 | 7,486,363 | 1,282,081 | 720,216 | 1,191,594 | 37,776,689 | 6,091,436 |
| Whole Kingdom | 40,491,306 | 10,432,256 | 6,778,062 | 13,641,515 | 7,422,475 | 251,071,182 | 70,178,818 |
| <u>Percentage</u> | | | | | | | |
| Northern | 58.65 | 5.50 | 4.41 | 22.53 | 8.91 | 87.32 | 12.68 |
| North Eastern | 57.16 | 2.06 | 13.13 | 16.37 | 11.27 | 63.94 | 36.06 |
| Central Plain | 57.49 | 6.37 | 5.36 | 22.40 | 8.39 | 83.81 | 16.19 |
| Southern | 23.27 | 53.79 | 9.21 | 5.17 | 8.56 | 86.11 | 13.89 |
| Whole Kingdom | 51.40 | 13.24 | 8.60 | 17.33 | 9.42 | 80.29 | 19.71 |

Thailand is basically an agricultural country. Agricultural products are the major sources of economic development. In 1968 agriculture, including forestry and fishing, accounted for about 30.2 percent of Gross Domestic Product by industry as shown in Table 2 (8).

Agriculture is the main occupation of the Thai people as well as the major source of economic development. Due to the high amount of rainfall, the types of the soil and the types of vegetation, there are many serious erosion problems such as gully, sheet, and rill on the farmland. In addition, there are water control problems due to limited irrigation systems and flood control devices throughout the country.

The problems of erosion and water control are compounded by improper land use. Shifting cultivation and farming on the steep slope without proper soil and water conservation practices have yet to be restricted by the government of Thailand.

Effective erosion and sediment practices have been implemented on a limited scale. The main reasons for this are few trained extension personnel, village attitudes toward adopting new practices, and limited mechanical machinery to construct soil and water conservation structures. In addition, research and experience have been very limited and more needs to be done.

These same factors also account for limited water management procedures. Particular attention needs to focus, however, on the collection of data concerning the effectiveness of existing channel

Table 2. The Estimated Gross Domestic Product (GDP) of Thailand in 1968, 1969, 1970, and 1971.

| | % of | Million of Baht (1 U.S. dollar=20.8 Bahts) | | | |
|---|---|---|---|---|---|
| | GDP | GDP | GDP | GDP | GDP |
| Products | 1968 | 1968 | 1969 | 1970 | 1971 |
| Agriculture | 30.2 | 31,319.0 | 32,759.7 | 34,266.6 | 35,842,9 |
| Crops | 20.9 | 21,729.2 | 22,684.9 | 23,670.2 | 24,685.1 |
| Rice | 9.7 | 10,163.5 | 10,478.6 | 10,803.4 | 11,138.3 |
| Rubber | 1.5 | 1,600.3 | 1,633.9 | 1,668.2 | 1,703.2 |
| Corn | 0.8 | 893.1 | 924.4 | 956.8 | 990.3 |
| Tapioca | 0.5 | 540.1 | 540.1 | 540.1 | 540.1 |
| Kenat | 0.4 | 428.0 | 435.8 | 582.6 | 684.6 |
| Others | 7.8 | 8,110.2 | 8,612.1 | 9,119.1 | 8,628.6 |
| Livestock | 3.8 | 3,967.0 | 4,026.5 | 4,086.9 | 4,148.2 |
| Fishery | 2.8 | 2,887.1 | 3,175.8 | 3,493.8 | 3,842.7 |
| Forestry | 2.6 | 2,735.7 | 2,872.5 | 3,016.1 | 3,166.9 |
| Mining and Quarrying | 1.8 | 1,934.6 | 2,056.6 | 2,305.4 | 2,584.4 |
| Manufacturing | 14.5 | 15,098.8 | 16,669.1 | 18,402.7 | 20,316.6 |
| Construction | 7.8 | 8.503.5 | 8.503.5 | 8,858.8 | 9,744.7 |
| Electricity and Water Supply | | 6,670.0 | 7,110.2 | 7,579.5 | 8,179.7 |
| Transportation and Communication | 6.4 | 20,265.2 | | | |
| Wholesale and Retail Trade | 19.5 | 3,525.3 | 21,987.7 | 23,856.7 | 25,884.5 |
| Banking, Insurance and Real Estate | 3.4 | 2,082.4 | 4,085.8 | 4,735.4 | 5,488.3 |
| Ownership of Dwellings | 2.0 | 4,615.2 | 2,147.0 | 2,213.6 | 2,282.2 |
| Public Administration and Defense | 4.4 | 9.098.8 | 4,956.7 | 5,323.5 | 5,717.4 |
| Services | 8.8 | -- | 9,662.9 | 10,262.0 | 10,898.2 |
| GDP | 100.0 | 103,773.5 | 111,781.2 | 120,515.8 | 130,055.4 |

design and water control devices in operation, before they are implemented on a wider scale.

# OBJECTIVE

This study was designed to develop model recommendations and specifications for selected soil and water conservation engineering practices by applying modern technical design procedures to Thailand's climatic, land use, soil, and topographic conditions.

# REVIEW OF LITERATURE

In past years, many efforts have been made to develop an equation for estimating the peak rate of runoff from small watersheds. The Swiss engineer, Bürkli-Ziegler (1) in 1880 developed a storm water runoff formula that was introduced into American practice by Herring (15) in 1881.

The Bürkli-Ziegler formula for discharge q in c.f.s. per acre is as follows:

$$q = CI \sqrt[4]{\frac{S}{A}}$$

where A = drainage area in acres

S = average slope of ground in feet per 1,000 ft

I = average rate of rainfall in inches per hour during the heaviest storm

C = coefficient depending on nature or relative imperviousness of ground surface, equal to 0.31 for an average condition, 0.20 for rural sections, 0.25 for farm country, 0.30 for village with lawns.

Later on, one of the well-known formulae which was proposed was the <u>Rational Formula</u>. This formula was first mentioned in 1889 by Emil Kuichling (12). According to Dooge (11), the principles of the method were explicit in the work of Mulvaney (23) in 1851. This formula was developed by Ramser (26,27) to obtain the curves with values of C and times of concentration. It was based largely on the results of measurements made in 1918 on six small drainage basins ranging in the size from 1.25 to 112 acres near Jackson, Tennessee (28).

The Rational Formula (30) to predict the peak rate of runoff is as follows:

$$Q = CIA$$

which $Q$ = the design peak rate of runoff in c.f.s.

$C$ = the runoff coefficient (the ratio of the peak rate of runoff to the rainfall intensity and dimensionless), Horn and Schwab (1963) showed that the primary effects were the infiltration rate, surface cover, and rainfall intensity.

$I$ = rainfall intensity in inches per hr for the design return period and for a duration equal to the "time of concentration" of the watershed.

$A$ = the watershed area in acres.

Kirpich (18) developed the methods of computing the time of concentration by the equation

$$T_C = 0.0078\ L^{0.77}\ S^{-0.385}$$

which $T_C$ = time of concentration in min

$L$ = maximum length of flow in ft, and

$S$ = the watershed gradient in feet per foot or the difference in elevation between the outlet and the most remote point divided by the length, L.

The rainfall intensity in Rational Formula can be written as

$$I = \frac{KF^m}{(t+b)^n}$$

where t = duration of rainfall in minutes

F = frequency factor indicating the frequency of occurrence of the rainfall

K,b, and m,n = coefficient, constant, and exponents, respectively, depending on conditions which affect the rainfall intensity.

The Rational Formula was developed on the assumptions that:

(1) rainfall occurs at uniform intensity for a duration equal to the time of concentration of the watershed, and

(2) rainfall occurs at a uniform intensity over the entire area of the watershed.

Howard L. Cook (80,34) developed a different formula for estimating the runoff from small watersheds. In this method the runoff from watersheds is determined under four categories. They are relief soil, infiltration, vegetable cover, and surface storage. The formula is:

$$q = PRF$$

where $q$ = the peak runoff for a specified geographic location and return period

$P$ = the peak runoff (from chart in Figure 1)

$R$ = the geographic rainfall factor

$F$ = the return period factor

M. M. Culp and others (3) modified the Cook Method for use by the Soil Conservation Service. In this procedure, the probable maximum peak discharge from a given drainage basin is computed by the following formula:

$$Q = PxRxF$$

where $Q$ = the maximum peak discharge, c.f.s.

$P$ = the peak flow, c.f.s.

$R$ = the rainfall factor

$F$ = the frequency factor

It can be noted that this formula is almost identical to the formula that Cook developed. The peak flow P is estimated from a chart in Figure 1. It depends on runoff producing characteristics which are measured by the summation of weight as shown in Table 3. For a given drainage area, the runoff producing characteristics are evaluated by the sum of the weights, $\Sigma W$ from the chart. The rainfall factor R varies with location as indicated in the map of Figure 1. The frequency factor F is 1.00 for 50-year frequency,

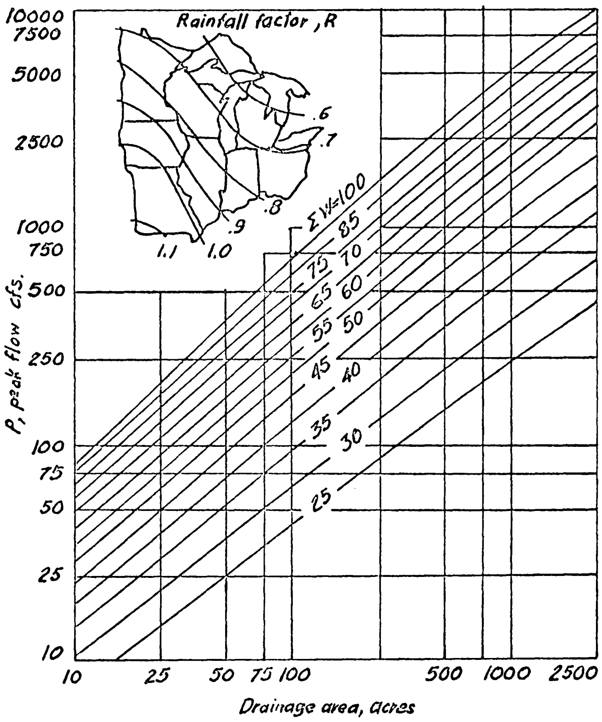

Figure 1. Chart and Map for Peak Flow Determination by the Cook Method.

Table 3. Runoff Producing Characteristics of Drainage Basins with Corresponding Weights, W (The weights are shown in brackets).

| Designation of Characteristics | Runoff Producing Characteristics | | | |
|---|---|---|---|---|
| | (100) Extreme | (75) High | (50) Normal | (25 Low |
| Relief | [40] Steep, rugged, terrain, with average slopes generally above 30 percent. | [30] Hilly, with average slopes of 10 to 30 percent | [20] Rolling, with average slopes of 5 to 10 percent | [10] Relatively flat land with average slopes of 0 to 5 percent |
| Soil Infiltration | [20] No effective soil cover, either rock or thin soil mantle of negligible infiltration capacity. | [15] Slow to take up water, clay or other soil of low infiltration capacity, such as heavy gumbo. | [10] Normal, deep loam with infiltration about equal to that of typical prairie soil. | [5] High, deep sand or other soil that takes up water readily and rapidly. |
| Vegetable Cover | [20] No effective plant cover, bare except for very sparse cover. | [15] Poor to fair, clean cultivated crops or poor natural cover, less than 10 percent of drainage area under good cover. | [10] Fair to good, about 50 percent of drainage area in good grassland, wood land, or equivalent cover not more than 50 percent of area in clean-cultivated crops. | [5] Good to or excellent, about 30 percent of drainage area in good grassland, wood land, or equivalent |

Table 3. Runoff Producing Characteristics of Drainage Basins with Corresponding Weights, W (The weights are shown in brackets) (Continued)

| Designation of Characteristics | Runoff Producing Characteristics | | | |
|---|---|---|---|---|
| | (100)<br>Extreme | (75)<br>High | (50)<br>Normal | (25)<br>Low |
| | [20] | [15] | [10] | [5] |
| Surface Storage | Negligible, surface depressions are few and shallow, drainage ranges steep and small, no ponds or marshes. | Low, well defined system of small drainage ways, no ponds or marshes. | Normal, considerable surface depression storage, drainage system similar to that of tropical prairie lands, Lakes, ponds, and marshes less than 2% of drainage area. | High, surface-depression storage high, drainage system not sharply defined, large flood-plain storage or a large number of lakes, ponds or marshes. |

0.83 for 25-year frequency, and 0.71 for 10-year frequency.

Later on, the research engineers of the Bureau of Public Roads developed another procedure which is similar to the Cook Method (8). Their formula is as follows:

$$Q_{design} = RF \times LF \times FF \times Q$$

where $Q_{design}$ = the design peak discharge from a given drainage basin, to be selected from the curve in Figure 2 corresponding to the given drainage area

RF = the rainfall factor, obtained from Figure 3

LF = the land use and slope factor, to be selected as indicated above

FF = the frequency factor, to be selected from the table in Figure 2

Q = the peak rate of runoff

More recently, R. P. Beasley (2,6) developed the following equation for estimating the peak rate of runoff from small watersheds from research at the University of Missouri.

$$Q = Q_T \times L \times I \times T \times S \times V \times C \times P \times F$$

where Q = peak rate of runoff, c.f.s.

$Q_T$ = peak rate of runoff from a watershed with a specific set of watershed conditions

L = watershed location factor

I = soil infiltration factor

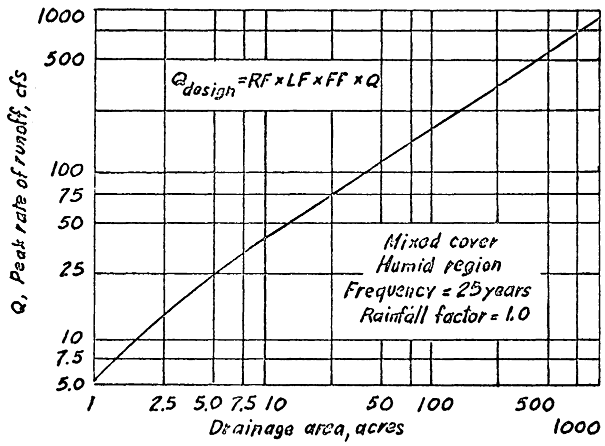

Figure 2. Peak Rates of Runoff for Drainage Basins Under 1,000 Acres (from Bureau of Public Roads Manual, August, 1951).

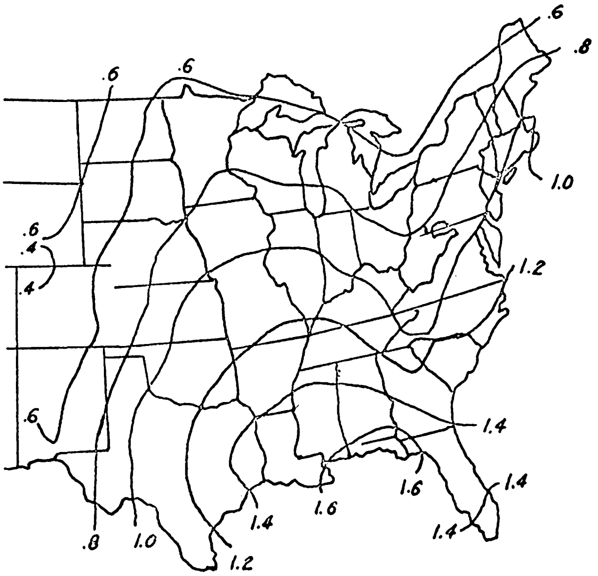

Figure 3. Rainfall Factors - Use with Figure 2 in Estimating Peak Rates of Runoff (from Bureau of Public Roads Manual, July, 1951).

T = topographic factor

S = watershed shape factor

V = vegetative cover factor

C = contour farming

P = surface storage factor

F = runoff frequency factor

The values of $Q_T$ are to be specified under the following conditions:

1. Watersheds located along line 1 (Figure 4)
2. Soils with an average infiltration rate
3. Land slopes average 8 percent
4. A typical watershed shape
5. In row crops, with the crop rows planted across the slope without terraces
6. No appreciable surface storage
7. Ten-year frequency runoff

The theories of design of various soil and water conservation structures have been included in numerous textbooks and handbooks (2,3,4,5,6,7,9,25,27,34). On the basis of field experiments and practice with these theories over the past 40 years, the Soil Conservation Service has modified and expanded these basic theories to provide procedures for field application (35) and combined them into an Engineering Field Manual for conservation practices which was published in 1969 (34). This manual together with the works of Beasley (2,3,4,5,6,7) served as a basis for the design of soil and

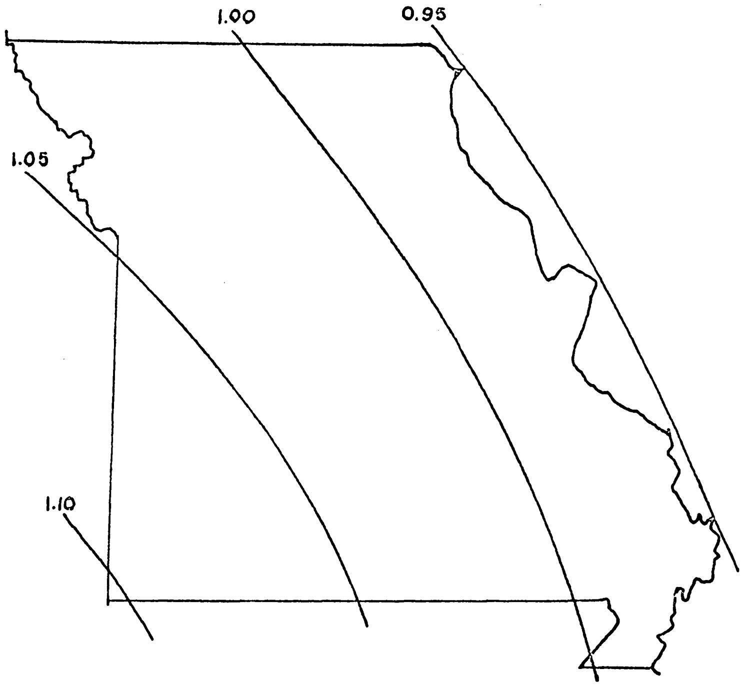

Figure 4. Location Factor, L.

water conservation structures undertaken in this thesis.

The equations used in designing the grass waterways and diversions were developed by Beasley (2,4,5,) and also based on the Engineering Field Manual for conservation practices published in 1969 (34) are as follows:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where $V$ = mean velocity, in feet per second

$n$ = the coefficient of roughness

$R$ = the hydraulic radius, in feet

$S$ = the hydraulic gradient, in feet per feet

and

$$Q = AV$$

where $Q$ = capacity, in c.f.s.

$A$ = cross-sectional area of channel, in square feet

$V$ = the average velocity, in feet per second

The relation between V, R, and A can be obtained by trial and error. When the values of V and Q are known, the dimensions of the waterways can be obtained. The relation between R and A is from Tables 5 and 6.

$$R = \frac{A}{P}$$

where $R$ = the hydraulic radius, in feet

$A$ = cross-sectional area of channel, in square feet

$P$ = wet perimeter of the channel, in feet

Beasley (2,3) developed an equation to determine the terrace spacing based on the Engineering Field Manual for conservation practices published in 1969 (34). It is as follows:

$$VI = XS+Y$$

where $VI$ = vertical interval between terraces, in feet

$X$ = a variable with values from 0.4 to 0.8 for graded terraces and 0.8 for level terraces. Usually, we use 0.6

$S = \frac{VI}{HI} \times 100$ = the average slope of the land in feet per 100 feet or percent

$HI$ = horizontal interval between terraces, in feet

$Y$ = a variable depending upon the erodibility of the soil, cropping systems, and crop management practices.

USE $Y = 1.3$ if the field to be terraced has erodible soils and the slopes are such that there will be excessive concentration of runoff between terraces.

USE $Y = 2.0$ if the field has less erodible soils and the slopes are such that there will not be excessive concentration of runoff between terraces.

Keith H. Beauchamp (34) compiled the method of determining terrace spacing given in the Engineering Field Manual published in 1969 (34) by using the Universal Soil Loss equation:

$$E = KRLSCP$$

which when used for terrace determination, becomes:

$$SL = \frac{E}{KRCP}$$ , where

L = slope length factor

S = land slope factor

E = allowable soil loss in tons per acre per year

K = soil factor

R = rainfall errosion factor

C = cropping management factor

P = mechanical practice factor

After SL are determined, the horizontal interval (HI) can be calculated as follows (34):

$$SL = \frac{\sqrt{HI}}{100} (0.76 + 0.53\ S_1 + 0.076\ S_1^2) \text{ or}$$

$$HI = \left(\frac{100\ SL}{0.76 + 0.53S_1 + 0.076S_1^2}\right)^2$$

where '$S_1$' is the land slope in percent.

# PROCEDURE AND ANALYSIS

## Region According to Climate, Land Use, Soil Types, and Topography

All data available on the climate, land use, soil capability, soil type, and topography of Thailand were assembed and analyzed. From these studies, it was possible to divide the country into four geographical regions having distinct but somewhat uniform soil and water conservation problems. These regions are (1) Northern, (2) Northeastern, (3) Central Plain, and (4) Southern.

Although further subdivision of these regions could be indicated for specific purposes, this was not attempted in this study. Instead the predominant features of each region were summarized and the major soil and water conservation problems are characterized in the following sections.

### 1. Northern Region

This region comprises large areas of river flood plains, valleys, plateaus, and mountain land with characteristics as summarized in the following sections.

#### A. Climate

The average annual temperature in this part of the country is between 24°-30°C. The annual rainfall ranges between 1200-2000 mm. The annual evaporation ranges between 600-1200 mm. The intensity of rainfall is moderate with short to moderate duration. The distribution is mostly uniform in the wet season from July to October (21).

### B. Land Use

About 75-80 percent of the area is forest lands which consist of mostly soft wood and teak wood. Agricultural lands cover about 8-10 percent of the land (8). Rice is the major food crop in most parts of the region, but there are sizeable areas of various row crops such as corn, peanuts, cotton, small grains, forage, and tree crops. Sod, tree crops, and forests prevail on the steeper mountainous slopes (29).

### C. Soils

In the mountainous areas, the soils are predominantly shallow, stony Red-Yellow Podsolic, coarse to medium texture, well drained and moderate permeable loams and sandy loams with pH in the 4.0-6.0 range. The soils of the high plateau are mostly reddish brown laterites formed from intermediate and basic rocks. They are coarse to medium texture, well drained, and have moderate permeability with pH in the 5.0-7.0 range. The valley soils are very fertile reddish brown loams and sandy clay loams, fine texture, well drained, and moderately permeable with pH in the 5.0-7.0 range. The soils in the flood plain are rich dark brown sandy clay loam and silty clay loam formed on recent water-deposited materials. They are fine texture, somewhat poorly drained, slowly permeable with pH in the 5.0-7.5 range (29).

D. Topography

In the mountainous area, generally the slopes of the lands range from 0-12 percent except in some places the forest land may go up to 30 percent. The slope in the high plateau is generally between 0-12 percent. In the flood plains the slope is generally level and ranges from 0-3 percent. The slope in the valley is gently undulating and generally between 0-8 percent (29).

E. Soil and Water Conservation Problems

Due to the high amount of rainfall, medium to coarse textured soils, and medium to steep slopes, erosion problems are very severe in this region. Many types of soil and water conservation structures are needed due to the fact that erosion is caused by various combinations of the previously mentioned characteristics. For example, terraces are needed in the areas where there are steep slopes. On the other hand, grassed waterways and diversions are needed in areas with a low slope range.

2. Northeastern Region

This region is characterized by large areas of mountains, high plateaus, valleys, and rolling land with characteristics as summarized in the following sections.

A. Climate

The average annual temperature in this area is between

26°-28°C. The annual rainfall ranges between 1000-2800 mm. The rainfall in the mountainous area is much higher than in the other areas. The intensity of rainfall is high with short duration and variable distribution. The annual evaporation ranges between 600-1200 mm (21).

B. Land Use

The forest land located on mountain slopes is mostly dipterocarp and comprises about 35-40 percent of the area. Agricultural land, mostly in the high plateaus and in the valleys comprises about 25-30 percent (8). Rice is the major crop in this part of the region. Row crops such as corn, beans, vegetable, coconut, rubber, kenof, cassava, cotton, and bananas are grown as secondary crops (29).

C. Soils

The soils in the mountainous areas are red-yellow podzolic, coarse texture, excessively drained, and moderately rapid permeable grayish brown loams with pH in the 4.0-5.5 range. On the high plateau, the soils are hydromorphic gray podzolic which weathered from acid granite. They are medium texture, somewhat poorly drained, and moderately permeable with pH in the 4.5-6.5 range. In the rolling area, the soils are regosol gray podzolic with reddish brown lateritic developed from intermediate rocks and basic rocks, coarse texture, well drained, and moderately permeable grayish brown sandy loam and yellowish red sandy clay loam with pH 5.0-6.5. The valley soils are humic gley dark grayish brown silty clay loam and silty clay, fine texture, poorly drained, and slowly permeable with pH 5.0-7.0. Mostly the soils in this area are very dry and dusty in the dry season and easy to be eroded by the wind and the water from the very first rain of the wet season (29).

## D. Topography

In the mountainous area, the slope is steep ranging from 10-25 percent, and may go up to as high as 50% in some places. The slope in the high plateau is undulating and between 0-8 percent. The slope in the rolling area is gently sloping to rolling and ranges from 0-8 percent. In the valley, the slope is flat between 0-3 percent (29).

## E. Soil and Water Conservation Problems

In this region, gully and sheet erosion are serious problems. These problems are due to the coarse texture of the soil, the high grade of land slopes, and a high intensity of rainfall over a relatively short period of time. Terraces, diversions, and grassed waterways should be established to divert the excessive runoff during the wet season to reservoirs or farm ponds for use during the long dry season.

## 3. Central Plain Region

This region is formed by extensive areas of flood and rolling plain land with characteristics as summarized in the following sections:

### A. Climate

The average annual temperature is between 26°-28°C (21). As for the average annual rainfall, this varies widely within the region, ranging from 1400-2800 mm. The mountainous area accounts for the higher part of this range, whereas the other areas account for the lower part of this range. Generally, the intensity of rainfall is not high with long duration and the rainfall is fairly evenly distributed throughout the wet season. The annual evaporation ranges between 600-1200 mm (21).

### B. Land Use

The forest lands consist of about 55 percent of the area whereas agricultural land consists of about 30 percent of the area (8). Rice is the main crop of the region. Other crops grown are corn, beans, peanuts, cotton, kapok, and vegetables. Evergreen forest with bamboo is found in the forest area which is being cut for commercial purposes on a limited scale (29).

### C. Soils

In the flood plain, the soils are alluvial and humic gley dark brown clay loam formed on the recent alluvial plains. These soils are fine texture, poorly drained, and have slow permeability with a pH range of 5.0-7.0. On the other hand, the rolling plain soils are dark brown, fine sandy loam and clay, moderately well drained and moderately permeable with a pH range of 4.0-7.0. The soils in this part of the country are rich and have a high water table level (29).

D. Topography

The slope of the land is mostly level to gently undulating in the flood plain and ranges between 0-3 percent. In the rolling plain, the slope is gently undulating to rolling and ranges between 0-5 percent. In some parts, the slope goes up to as high as 12 percent (29).

E. Soil and Water Conservation Problems

In this region, erosion problems are of a minor nature in comparison to other regions. Instead efforts in the area of soil and water conservation should be focused on the development of irrigation and drainage techniques in order to convey the water from the rivers to the cultivated area with proper drainage. For this study, only grassed waterways and diversions will be considered, given the need to limit the scope of this study.

4. Southern Region

This region consists of mainly mountain, rolling land areas and small amounts of flat land with characteristics as summarized in the following sections.

A. Climate

The average annual temperature is between 27°-28°C. The annual rainfall ranges between 1200-3200 mm (21). The reason for this wide range is that a large part of this region is bordered by the Gulf of Thailand on the East and the Indian Ocean on the West. The width of the land between these two water bodies ranges from eight to fifty miles so that the rain brought by the Southwest Monsoons covers the full width of this land area. On the other hand, the Northern part of this region is a part of the mainland and it is not as affected by the rains resulting from the Southwest Monsoons. Generally, the rainfall intensity is not high with long duration and the distribution spread is year round. The annual evaporation ranges between 600-1000 mm.

B. Land Use

About 50-55 percent of the land is forest. Agricultural land is about 30-35 percent (9). Rubber, coconuts, and many kinds of fruits are widely cultivated in this part of the country. Rice can be grown in some areas (36).

C. Soils

The soils are sandy throughout this region, fine texture, moderately drained and moderately permeable with a

5.0-7.0 pH range. The soils are fertile with moderate to high moisture content resulting from the groundwater.

D. Topography

Generally, the slope of the land is between 0-8 percent. In the mountainous area, however, it may go up to 12 percent (36).

E. Soil and Water Conservation Problems

There are some serious erosion problems caused by the high amount of rainfall. Terrace, grassed waterways, and diversions should be constructed to protect the fertile land from serious erosion.

## Selection of Engineering Soil and Water Conservation Practices

From the previous study of all those areas mentioned before, the soil and water conservation practices expected to have widest application in Thailand are:

### 1. Grassed Waterways

Generally, grassed waterways can be used as outlets for terraces and for disposal of runoff from diversion channels in the northern, northeastern, and southern regions of the country because of the high amount of runoff resulting from the rainfall and the moderate slope of the areas. They can also be used to receive the runoff from the upper parts of agricultural areas and slow the velocity of the water down within a range so that it will not cause erosion.

### 2. Diversions

Diversions are constructed to divert water from areas where it is in excess to locations where it can be disposed of safely. Diversions should be used widely all over the country due to the fact that they can be used to protect cropland, pasture land, and farmsteads from runoff. They may be used to intercept shallow subsurface flow and runoff from the hillsides and mountainous areas. In the rolling and plateau areas diversions can be used also to divert runoff from terrace outlets to the place where it can be disposed of safely. Conversely, they can be used to transport additional water to the farm ponds and reservoirs.

### 3. Terraces

Terraces can be constructed to reduce runoff and soil losses and thus prevent the forming of rills and gullies. They can assist in reclaiming badly gullied fields by intercepting the runoff before it becomes concentrated and attains an eroding velocity. They can be constructed to reduce erosion by shortening the length of slope and conveying the runoff water on a nonerosive grade to a stable outlet. Terraces should be used extensively in the valleys, plateau, and mountainous areas of the north and northeastern regions due to the steep slopes and heavy rainfall that cause the high velocity of runoff. Many of these problems can be solved by constructing the terraces to reduce floods.

### 4. Farm Ponds

Farm ponds are needed primarily to provide water supply for livestock, wildlife, recreation, household, fire protection, field and orchard spraying, and fish production. They should be used mainly in the northeastern region. By diverting the runoff through diversions into farm ponds in the wet season, they can be used to serve these purposes during the long dry season.

## Design Criteria

The criteria for designing grass waterways, diversions, terraces, and farm ponds are primarily based on the peak rates of runoff from watersheds. The following scheme can be followed to design each structure individually.

### Estimating Peak Rates of Runoff from Small Watersheds

Based on R. P. Beasley's work (2,6) at the Department of Agricultural Engineering, College of Agriculture, University of Missouri-Columbia, and some data from Thailand, the peak rate of runoff due to the maximum 60 min rainfall, in inches, to be expected once in 10 years can be obtained as shown in Table 4.

For watersheds having conditions differing from those specified in Table 4, the values from Table 4 can be multiplied by an appropriate factor to obtain the peak rate of runoff from the watershed being considered. These factors, as developed by Beasley (2,6) are as follows.

Table 4. Peak Rates of Runoff to be Expected from Watersheds

| Size of Watershed (Acres) | Peak Rate of Runoff (c.f.s.) Beasley's | Factor | In Thailand[1] |
|---|---|---|---|
| 5 | 19 | 2.00 | 38 |
| 10 | 36 | 2.00 | 72 |
| 15 | 52 | 2.00 | 104 |
| 20 | 67 | 2.00 | 134 |
| 25 | 81 | 1.95 | 158 |
| 30 | 94 | 1.90 | 179 |
| 35 | 107 | 1.90 | 204 |
| 40 | 120 | 1.85 | 222 |
| 45 | 132 | 1.80 | 238 |
| 50 | 144 | 1.90 | 260 |
| 55 | 155 | 1.80 | 280 |
| 60 | 166 | 1.75 | 291 |
| 65 | 175 | 1.75 | 306 |
| 70 | 185 | 1.70 | 313 |
| 75 | 195 | 1.70 | 330 |
| 80 | 205 | 1.65 | 338 |
| 85 | 215 | 1.65 | 355 |
| 90 | 225 | 1.65 | 372 |
| 95 | 235 | 1.60 | 376 |
| 100 | 245 | 1.60 | 392 |
| 110 | 265 | 1.55 | 411 |
| 120 | 285 | 1.55 | 442 |
| 130 | 304 | 1.50 | 457 |
| 140 | 322 | 1.50 | 484 |
| 150 | 340 | 1.50 | 510 |
| 160 | 356 | 1.50 | 534 |
| 170 | 372 | 1.47 | 547 |
| 180 | 388 | 1.45 | 563 |
| 190 | 404 | 1.45 | 586 |
| 200 | 420 | 1.40 | 589 |

---

[1] The figures obtained in Table 4 are based on the assumption that:

a) The amount of rainfall in Thailand is about twice as much as in Missouri.

b) The average infiltration rate of the soils are approximately the same.

c) The average slope of the land is approximately the same.

d) The typical watershed shapes are similar.

Location Factor, L: Due to the data of maximum rainfall and based on Beasley's assumption, the value of L in Thailand can be estimated as the maximum depth of rainfall in inches expected during a ten-year period for a rainstorm of thirty-minute duration and dividing this value by 1.9. The value is 2.2.

Soil Infiltration: The values in Table 4 are peak rates of run-off to be expected from a soil with an average infiltration rate. If soil conditions differ from this, multiply the value from Table 4 by an appropriate factor which will be selected from the following:

| Soil Infiltration Rate | Soil Infiltration Factor, I |
|---|---|
| Very high (coarse textured soil throughout such as Ly and Pp) | 0.8 |
| Above average (soil with medium to moderately coarse textured surface soils, well drained as evidenced by bright or non-mottled subsoil, colors such as Lo, Mt) | 0.9 |
| Average (soils with medium textured surface and moderately fine textured subsoils with restricted drainage as evidenced by having gray or mottled subsoil colors, such as Li or Cm) | 1.0 |
| Below average (soils with medium to moderately fine textured surface soils with a claypan | 1.1 |

| | |
|---|---|
| or fragipan subsoil, such as Bo, Bt) | |
| Very low (soil with fine textured surface soils or soils eroded into claypan subsoils, such as Cn, Kn). | 1.2 |

Topography: The values in Table 4 are peak rates of runoff which can be expected from a watershed with an average slope of 8 percent. If the average land slope on a watershed differs from this, the values from Table 4 can be multiplied by factors as shown in Table 5.

Slope of Watershed: The peak rate of runoff will be affected by the maximum distance the runoff travels in reaching the discharge point. The maximum distance that the runoff must travel in reaching the discharge point can be determined. This distance can be found in Table 6. The number of acres in the watershed and the corresponding S factor can be read from the right hand side column of Table 6. The values from Table 4 will be multiplied by S factor.

If different crops are grown on a watershed, the value from Table 4 will be multiplied by the following factor:

| Type of Cover | Vegetative Cover Factor, V |
|---|---|
| Farmstead | 1.2 |
| Row crop | 1.0 |
| Small grain, good quality | 0.8 |
| Small grain, poor quality | 0.9 |
| Pasture, good quality | 0.6 |
| Pasture, poor quality | 0.8 |

Table 5. Topographic Factors T [From Beasley (2,6)].

| Average Land Slope (percent) | Topographic Factor, T |
|---|---|
| 0.5 | 0.50 |
| 1 | 0.65 |
| 2 | 0.72 |
| 3 | 0.78 |
| 4 | 0.83 |
| 5 | 0.88 |
| 6 | 0.92 |
| 7 | 0.96 |
| 8 | 1.00 |
| 9 | 1.04 |
| 10 | 1.07 |
| 12 | 1.14 |
| 14 | 1.20 |
| 16 | 1.26 |
| 18 | 1.32 |
| 20 | 1.37 |

Table 6. Watershed Shape Factors, S [From Beasley (2,6)].

| Size of Watershed, Acres | | | | | | | | | | | | | | | | Shape Factor, S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 | |
| (maximum distance that runoff travels) | | | | | | | | | | | | | | | | |
| | | 600 | 800 | 1000 | 1100 | 1300 | 1400 | 1500 | 1700 | 1800 | 1900 | 2100 | 2300 | 2500 | 2700 | 1.25 |
| | 500 | 700 | 900 | 1100 | 1200 | 1400 | 1600 | 1700 | 1800 | 1900 | 2100 | 2400 | 2600 | 2900 | 3100 | 1.20 |
| | 550 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 | 1900 | 2000 | 2200 | 2400 | 2700 | 3000 | 3300 | 3500 | 1.15 |
| 400 | 600 | 900 | 1200 | 1400 | 1600 | 1800 | 2000 | 2100 | 2300 | 2500 | 2800 | 3100 | 3400 | 3700 | 3900 | 1.10 |
| 500 | 700 | 1000 | 1400 | 1600 | 1800 | 2100 | 2300 | 2500 | 2700 | 2900 | 3200 | 3600 | 3800 | 4100 | 4300 | 1.05 |
| 600 | 850 | 1200 | 1600 | 1900 | 2100 | 2400 | 2700 | 2900 | 3100 | 3300 | 3600 | 4000 | 4300 | 4600 | 4800 | 1.00 |
| 700 | 950 | 1400 | 1900 | 2200 | 2400 | 2700 | 3100 | 3300 | 3600 | 3800 | 4100 | 4500 | 4800 | 5200 | 5500 | 0.35 |
| 800 | 1100 | 1600 | 2200 | 2600 | 2900 | 3200 | 3600 | 3800 | 4100 | 4400 | 4700 | 5100 | 5500 | 5900 | 6200 | 0.20 |
| 900 | 1300 | 1900 | 2600 | 3100 | 3400 | 3700 | 4100 | 4400 | 4600 | 5000 | 5400 | 5900 | 6300 | 6700 | 7000 | 0.85 |
| 1100 | 1600 | 2300 | 3100 | 3600 | 3900 | 4200 | 4600 | 5000 | 5400 | 5700 | 6200 | 6700 | 7100 | 7500 | 7900 | 0.80 |
| 1300 | 1900 | 2800 | 3600 | 4200 | 4600 | 5000 | 5400 | 5800 | 6200 | 6600 | 7100 | 7600 | 8000 | 8400 | 8800 | 0.75 |

| | |
|---|---|
| Meadow, good quality | 0.5 |
| Meadow, poor quality | 0.7 |
| Timber, good quality | 0.5 |
| Timber, poor quality | 0.6 |

If several kinds of cover are present on a watershed, a weighted vegetation factor should be computed. For example, assume that a 100-acre watershed contains 50 acres of small grain, 25 acres of pasture, and 25 acres of timber, all with good quality cover. The weight vegetation factor would be computed as follows:

| | | | | |
|---|---|---|---|---|
| 50 | acres small grain | x factor 0.8 | = | 40 |
| 25 | acres pasture | x factor 0.6 | = | 15 |
| 25 | acres timber | x factor 0.5 | = | 13 |
| 100 | | | | 68 |

$\therefore$ The weighted vegetation factor = $\frac{68}{100}$ =0.68

Contouring: Values in Table 4 are peak rates of runoff to be expected from watersheds with crop rows planted across the slope without terraces or without contour guide lines.

If the entire watershed is farmed parallel to contour guide lines or terraces, the values in Table 4 will be multiplied by an appropriate factor selected from the following:

| Acres in Watershed | Contour Factor, C |
|---|---|
| 0-10 | 0.95 |
| 11-40 | 0.96 |
| 41-100 | 0.97 |
| 101-200 | 0.98 |

If the entire watershed is not farmed on the contour, an appropriate adjustment in the contouring factor can be made.

Storage Factor for Graded Terraces: Water that is in temporary storage such as depression in the channels of graded terraces will reduce the peak rate of runoff from the watershed.

If the entire watershed is terraced, the storage factor P can be chosen from Table 7. If the entire watershed is not terraced, an appropriate adjustment in the storage factor can be made (2,6).

Runoff Frequency: The values in Table 4 are the peak rates of runoff to be expected in an average 10-year period. If the peak rate of runoff for a different design frequency is desired, the values from Table 4 can be multiplied by the following factor.

| Runoff Frequency | Runoff Frequency Factor, F |
|---|---|
| 1/2 year | 0.2 |
| 1 year | 0.3 |
| 2 years | 0.5 |
| 5 years | 0.8 |
| 10 years | 1.0 |
| 25 years | 1.3 |
| 50 years | 1.5 |

## Structure Design Procedures

By using these procedures to estimate the amounts and rates of runoff to be expected in specific areas, the following methods can

Table 7. Storage Factors for Graded Terrace, P [From Beasley (2,6)].

| | Storage Factor P for Graded Terraces (Average length of terraces, ft) | | |
|---|---|---|---|
| Acres in Watershed | 500 | 1000 | 1600 |
| 0- 10 | 0.95 | 0.90 | 0.80 |
| 11- 40 | 0.97 | 0.93 | 0.85 |
| 41-100 | 0.98 | 0.95 | 0.90 |
| 101-200 | 0.99 | 0.97 | 0.95 |

then be used to design the appropriate soil and water conservation structure.

Grassed Waterways

From the conditions in Thailand and the work that has been done by Beasley (2,4) and from the Engineering Field Manual (34), the grassed waterways can generally be designed in Thailand as follows:

a) The designed data, i.e., average land slope, the discharge of runoff to be disposed away, the kind of soil the condition of the vegetation, have to be collected.

b) After the designed data have been collected, the shape, velocity, capacity, width, depth, and the size of the side dikes can be determined by the following procedures.

Shape or Cross-Section: Vegetated waterways can be built to three general shapes, parabolic, trapezoidal, or "v" shaped. Parabolic waterways are the most common and usually found in nature. Typical waterway cross sections are shown in Figures 5, 6, and 7.

Velocity: Maximum permissible velocity for grassed waterways varies with the erodibility of the soil that is in the channel of the waterway, the type and quality of vegetation that can be established and maintained, and the slope of the land. Table 8 gives suggested permissible velocities to be used in the design.

Capacity: Minimum channel capacity is determined by the maximum rate of runoff to be expected in a 10-year period.

Width: When the maximum rate of runoff, Q, and the design velocity

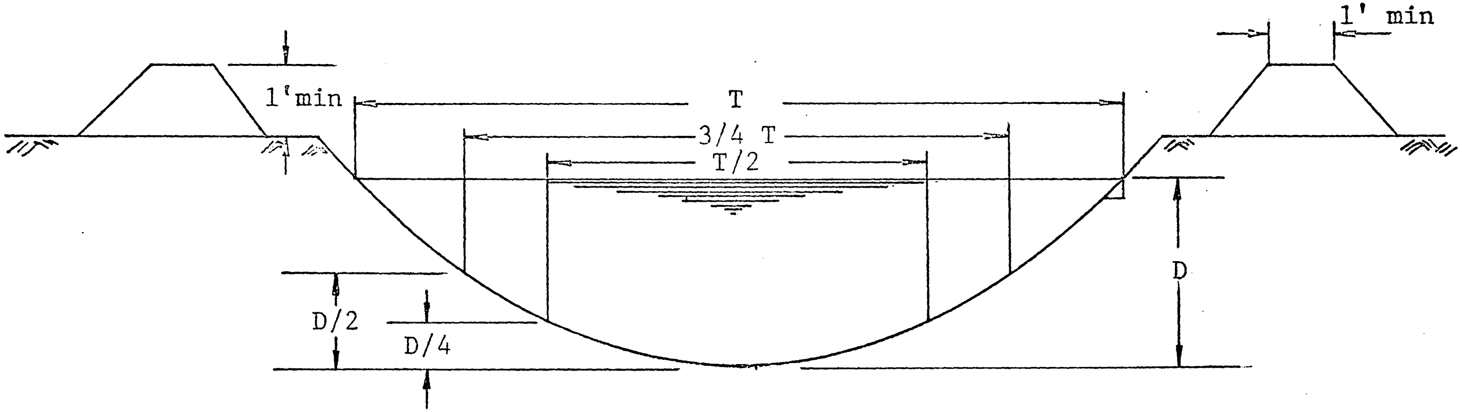

Figure 5. Cross Section of a Parabolic-Shaped Waterway.

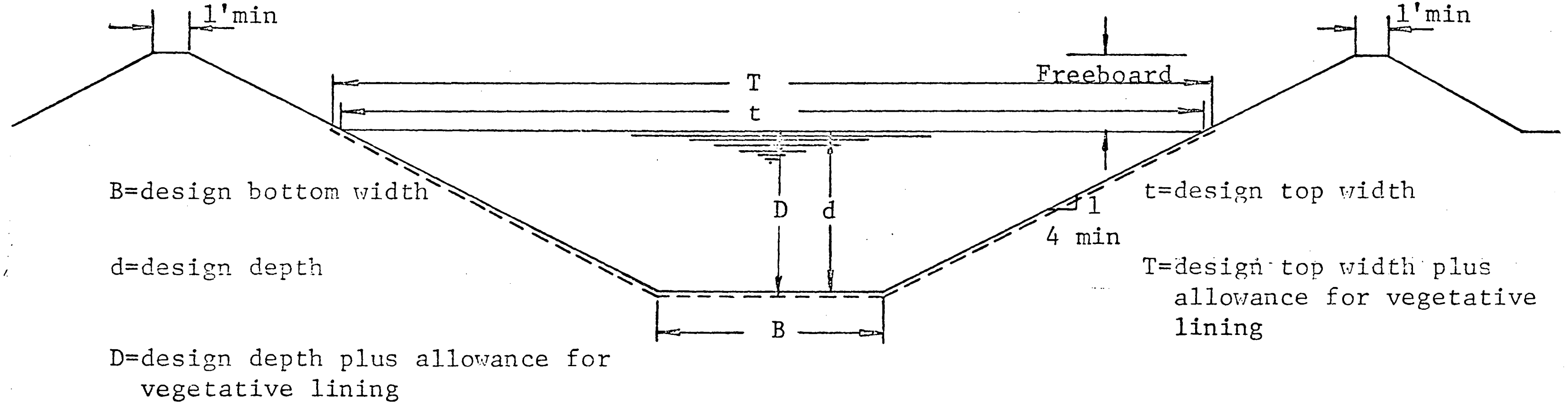

Figure 6. Cross Section of a Trapezoidal-Shaped Waterway, Showing Permanent Side Dikes.

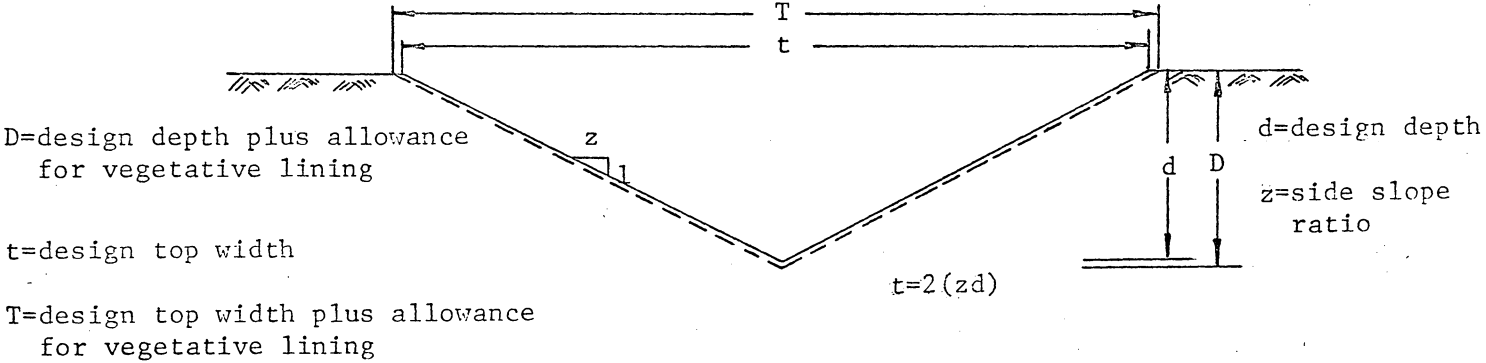

Figure 7. Cross Section of a Triangular-Shaped Waterway.

Table 8. Maximum Permissible Velocities for Open Channels, Feet per Second [From Beasley (2)].

| | Less Erodible Soils[a] Percent of Channel Slope | | | More Erodible Soils[b] Percent of Channel Slope | | |
|---|---|---|---|---|---|---|
| Cover | 0-5 | 6-10 | over 10 | 0-5 | 6-10 | over 10 |
| None | | | | | | |
| Cultivated | 2.0 | - | - | 1.5 | - | - |
| Not cultivated | 2.5 | - | - | 2.0 | - | - |
| Annual Grasses | | | | | | |
| Sparse stand | 3.0 | - | - | 2.5 | - | - |
| Good stand | 3.5 | - | - | 3.0 | - | - |
| Average Density Grasses (blue-grass, fescue, brome) | | | | | | |
| Fair stand | 4.0 | 3.0 | 2.5 | 3.0 | 2.5 | c |
| Good stand | 5.0 | 4.0 | 3.5 | 4.0 | 3.5 | 3.0 |
| Excellent stand | 6.0 | 5.0 | 4.5 | 5.0 | 4.5 | 4.0 |

[a] Less erodible soils are generally those with a higher clay content and higher plasticity. Typical soil textures are silty clay, sandy clay, and clay.

[b] More erodible soils are generally those that have a high content of fine sand or silt and lower plasticity. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

[c] Must have good quality vegetation on these slopes.

(from Table 8) are known, the width of a trapezoidal waterway from Table 10 and the width of a parabolic waterway from Table 11 can be obtained. Widths of the waterways given in Tables 10 and 11 are those required to carry expected runoff at the design velocity when vegetation is short.

The waterway should not be constructed over the design depth, or the velocity will be excessive. The waterway, however, can be made wider than the design width, if it is going to facilitate its construction or maintenance. If the waterway is maintained with farm machinery, a minimum bottom width of 16 ft for trapezoidal waterways, and a minimum top width of 20 ft for parabolic waterways should be used.

If a waterway greater than 60 ft wide is required to be constructed, division into smaller waterways should be considered. If water enters from both sides of a wide waterway, a small dike approximately 0.4 ft high should be constructed in the center of the waterway to divide the flow. If the slope in a waterway is less than 1 percent, the dimensions of the waterway can be obtained from "Design for Diversions."

## Depth

The depth D given in Tables 10 and 11 is the depth of water to be constructed with a rank growth of vegetation in the channel.

Research has shown that in both large and small channels, in channels of different cross sectional shapes and bed slope, and with different vegetal covers, the retardance coefficient in "Manning's coefficient of roughness" varies with VR. The term VR is the product of velocity and the hydraulic radius. This relationship will be called the "n-VR relationship," which is the recommended basis for vegetated channel design.

The five general retardance curves (34), designated as A, B, C, D, and E have been developed for various cover conditions (Figure 8). These cover classifications are based on tests in experimental channels when the leaves were green and generally uniform.

Most of the vegetation used in waterways does not exceed 18 inches in height and may be much shorter at times during the year. Therefore, it is recommended that when designing the channel for safe velocity, a retardance not greater than "D" is to be used. After designing the channel for safe velocity, it must be checked for capacity to accommodate the peak flow under conditions where vegetation gives the highest retardance (Table 9).

The trapezoidal waterway should be constructed with the side slopes 4 to 1 or flatter. The shape of the parabolic waterway below the depth "D" should be shaped to best fit the topography and the maintenance requirements of the waterway. The side slopes should not be steeper than 4 to 1. If permanent side dikes are required to contain the flow, a free board of 0.3 ft should be added in order to allow the material to settle down..

### Side Dikes

Usually permanent side dikes with side slopes no steeper than 4 to 1 are constructed in case they are required for waterway capacity.

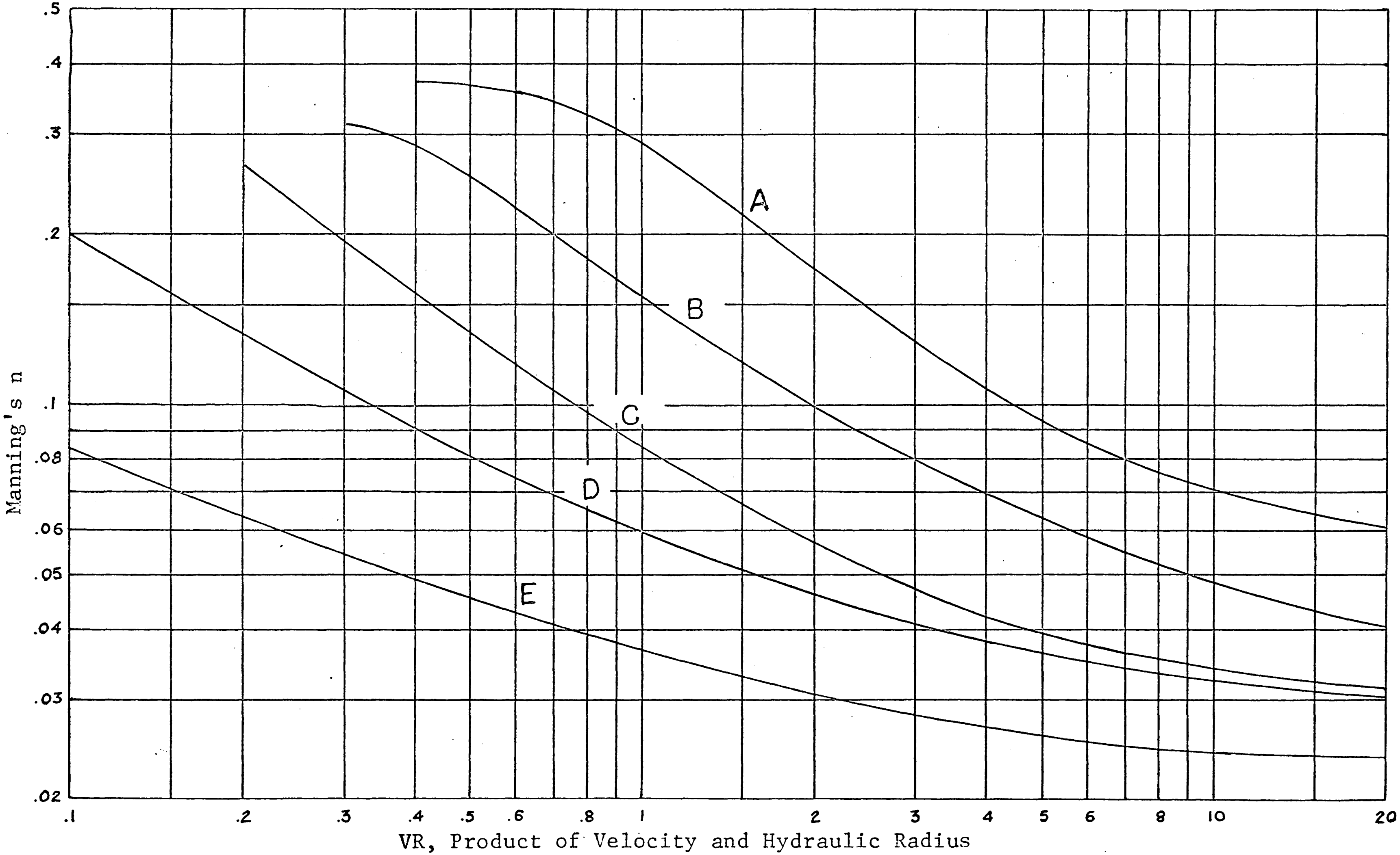

Figure 8. Manning's 'n' Related to Velocity, Hydraulic Radius, and Vegetal Retardance.

Table 9. Classification of Vegetation Cover as to Degree of Retardance [from Engineering Field Manual, 1969 (34)].

| Retardance | Cover | Condition |
|---|---|---|
| A | Reed canarygrass | Excellent stand, tall (average 36") |
| | Yellow bluestem Ischaemum | Excellent stand, tall (average 36") |
| B | Smooth bromegrass | Good stand, mowed (average 12" to 15") |
| | Bermudagrass | Good stand, tall (average 12") |
| | Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses | Good stand, unmowed |
| | Tall fescue | Good stand, unmowed (average 18") |
| | Lespedeza sencea | Good stand, not woody, tall (average 19") |
| | Grass-legume mixture-Timothy, smooth bromegrass, or orchardgrass | |
| | Reed canarygrass | Good stand, mowed (average 12" to 15") |
| | Tall fescue, with bird's foot trefoil or lodino | Good stand, uncut (average 18") |
| | Blue grama | Good stand, uncut (average (13") |
| C | Bahia | Good stand, uncut (6" to 8") |
| | Bermudagrass | Good stand, mowed (average 6") |
| | Red top | Good stand, headed (15" to 20") |
| | Grass-legume mixture, summer (common lespedeza, orchard grass, redtop, Italian ryegrass) | Good stand, uncut (6" to 8") |
| | Centipedegrass | Very dense, cover (average 6") |
| D | Kentucky bluegrass | Good stand, headed (6" to 12") |
| | Bermudagrass | Good stand, cut to 2.5" |
| | Red fescue | Good stand, headed (12" to 18") |

Table 9. Classification of Vegetation Cover as to Degree of Retardance (Continued).

| Retardance | Cover | Condition |
|---|---|---|
| D (cont.) | Buffalograss | Good stand, uncut (3" to 6") |
| | Grass-legume mixture - fall, spring (orchardgrass, redtop, Italian ryegrass, and common Lespedeza | Good stand, uncut (4" to 5") |
| | Lespedeza sericea | After cutting to 2" height |
| | | Very good stand before cutting |
| E | Bermudagrass | Good stand, cut to 1.5" height |
| | Bermudagrass | Burned stubble |

Table 10. Dimensions of Trapezoidal Waterways (Velocity, 3 ft per sec) [from Beasley (4)].

| Slope,% |  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q cfs |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | B* |  |  |  |  |  | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 14 |
|  | D** |  |  |  |  |  | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5*** |
| 15 | B |  |  | 6 | 8 | 10 | 12 | 13 | 14 | 16 | 17 | 18 | 20 | 22 |
|  | D |  |  | 1.1 | 0.9 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 20 | B |  | 5 | 10 | 12 | 15 | 17 | 19 | 20 | 22 | 23 | 25 | 27 | 29 |
|  | D |  | 1.3 | 1.0 | 0.9 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 25 | B |  | 9 | 13 | 17 | 20 | 22 | 24 | 26 | 28 | 29 | 32 | 34 | 36 |
|  | D |  | 1.2 | 1.0 | 0.8 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 30 | B |  | 12 | 17 | 21 | 24 | 27 | 29 | 31 | 33 | 35 | 39 | 42 | 45 |
|  | D |  | 1.1 | 0.9 | 0.8 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| 35 | B | 6 | 15 | 21 | 25 | 29 | 32 | 34 | 37 | 39 | 42 | 45 | 48 | 51 |
|  | D | 1.9 | 1.1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| 40 | B | 8 | 18 | 25 | 29 | 34 | 37 | 40 | 42 | 45 | 48 | 52 | 55 | 58 |
|  | D | 1.8 | 1.1 | 0.9 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| 45 | B | 10 | 22 | 28 | 33 | 39 | 42 | 45 | 48 | 52 | 55 | 59 | 63 | 68 |
|  | D | 1.7 | 1.1 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| 50 | B | 12 | 25 | 32 | 38 | 44 | 47 | 50 | 53 | 58 | 62 | 66 |  |  |
|  | D | 1.7 | 1.0 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 |  |  |
| 55 | B | 14 | 28 | 36 | 42 | 48 | 52 | 56 | 59 | 64 | 68 |  |  |  |
|  | D | ***1.6 | 1.0 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 |  |  |
| 60 | B | 16 | 31 | 39 | 46 | 53 | 57 | 61 | 65 |  |  |  |  |  |
|  | D | 1.6 | 1.0 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 |  |  |  |  |  |
| 65 | B | 19 | 34 | 43 | 50 | 57 | 62 | 67 | 71 |  |  |  |  |  |
|  | D | 1.6 | 1.0 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 |  |  |  |  |  |
| 70 | B | 21 | 37 | 47 | 54 | 61 | 67 |  |  |  |  |  |  |  |
|  | D | 1.6 | 1.0 | 0.8 | 0.7 | 0.7 | 0.6 |  |  |  |  |  |  |  |
| 75 | B | 23 | 40 | 50 | 58 | 66 |  |  |  |  |  |  |  |  |
|  | D | 1.5 | 1.0 | 0.8 | 0.7 | 0.7 |  |  |  |  |  |  |  |  |

Table 10. Dimensions of Trapezoidal Waterways (Velocity, 3 ft per sec) (Continued).

| Slope,% | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | | | | | | | | | | | | | | |
| 80 | B | 25 | 43 | 54 | 62 | | | | | | | | | |
| | D | 1.5 | 1.0 | 0.8 | 0.7 | | | | | | | | | |
| 90 | B | 30 | 49 | 61 | 66 | | | | | | | | | |
| | D | 1.5 | 1.0 | 0.8 | 0.7 | | | | | | | | | |
| 100 | B | 34 | 55 | 68 | | | | | | | | | | |
| | D | 1.4 | 1.0 | 0.8 | | | | | | | | | | |
| 120 | B | 43 | 66 | | | | | | | | | | | |
| | D | 1.4 | 1.0 | | | | | | | | | | | |
| 140 | B | 52 | | | | | | | | | | | | |
| | D | 1.3 | | | | | | | | | | | | |
| 160 | B | 60 | | | | | | | | | | | | |
| | D | 1.3 | | | | | | | | | | | | |

B* = Bottom width of waterway, feet, widths under 5 feet not shown. Bottom width and velocity based on short grass ("D" retardance).

D** = Depth of flow with rank growth, feet ("B" retardance).

*** = Waterways above this line may be difficult to maintain with larger farm machinery.

Table 10. Dimensions of Trapezoidal Waterways (Velocity, 4 ft per sec) (Continued).

| Slope,% | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | | | | | | | | | | | | | | |
| 10 | B* | | | | | | | | | | | 6 | 7 | 8 |
| | D** | | | | | | | | | | | 0.6 | 0.6 | 0.6 |
| 15 | B | | | | | | 5 | 6 | 7 | 8 | 9 | 11 | 12 | 13 |
| | D | | | | | | 0.9 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6*** |
| 20 | B | | | | 5 | 7 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 |
| | D | | | | 1.0 | 0.9 | 0.9 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 25 | B | | | 5 | 8 | 10 | 12 | 14 | 15 | 16 | 17 | 19 | 21 | 23 |
| | D | | | 1.3 | 1.0 | 0.9 | 0.9 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 30 | B | | | 7 | 10 | 13 | 15 | 17 | 19 | 20 | 21 | 24 | 26 | 28 |
| | D | | | 1.2 | 1.0 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 35 | B | | | 9 | 13 | 16 | 18 | 21 | 23 | 24 | 25 | 28 | 31 | 34 |
| | D | | | 1.2 | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| 40 | B | | 6 | 12 | 16 | 19 | 22 | 24 | 26 | 29 | 30 | 33 | 36 | 39 |
| | D | | 1.5 | 1.2 | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 45 | B | | 8 | 14 | 18 | 22 | 25 | 28 | 30 | 32 | 34 | 37 | 41 | 44 |
| | D | | 1.4 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 50 | B | | 10 | 17 | 21 | 25 | 28 | 31 | 33 | 36 | 38 | 41 | 46 | 50 |
| | D | | 1.4 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 55 | B | | 12 | 19 | 24 | 28 | 31 | 34 | 37 | 40 | 42 | 46 | 50 | 55 |
| | D | | 1.3 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 60 | B | | 14 | 21 | 27 | 31 | 34 | 37 | 40 | 43 | 46 | 50 | 54 | 59 |
| | D | | 1.3 | 1.1 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| 65 | B | | 16 | 23 | 29 | 34 | 38 | 41 | 44 | 47 | 50 | 55 | 58 | 63 |
| | D | | 1.3 | 1.0 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 |
| 70 | B | | 18 | 26 | 32 | 37 | 41 | 45 | 48 | 51 | 54 | 59 | 62 | |
| | D | | 1.3 | 1.0 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | |
| 75 | B | 6 | 20 | 28 | 34 | 40 | 44 | 48 | 51 | 55 | 58 | 63 | | |
| | D | 2.2 | 1.3 | 1.0 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0. | 0.5 | 0.5 | |

Table 10. Dimensions of Trapezoidal Waterways (Velocity, 4 ft per sec) (Continued).

| Slope,% | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | | | | | | | | | | | | | | |
| 80 | B | 8 | 22 | 30 | 36 | 43 | 47 | 51 | 55 | 59 | 62 | | | |
| | D | 2.1 | 1.2 | 1.0 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.5 | | | |
| 90 | B | 10 | 26 | 35 | 42 | 48 | 53 | 58 | 62 | 66 | | | | |
| | D | 2.0 | 1.2 | 0.9 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | | | | |
| 100 | B | 13 | 30 | 40 | 48 | 54 | 59 | 64 | 69 | | | | | |
| | D*** | 1.9 | 1.2 | 0.9 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | | | | | |
| 120 | B | 19 | 37 | 49 | 58 | 66 | 72 | | | | | | | |
| | D | 1.8 | 1.2 | 0.3 | 0.8 | 0.7 | 0.7 | | | | | | | |
| 140 | B | 25 | 44 | 58 | 68 | | | | | | | | | |
| | D | 1.7 | 1.2 | 0.9 | 0.8 | | | | | | | | | |
| 160 | B | 30 | 51 | 67 | | | | | | | | | | |
| | D | 1.7 | 1.1 | 0.9 | | | | | | | | | | |
| 180 | B | 35 | 59 | | | | | | | | | | | |
| | D | 1.6 | 1.1 | | | | | | | | | | | |
| 200 | B | 40 | 65 | | | | | | | | | | | |
| | D | 1.6 | 1.1 | | | | | | | | | | | |

B* = Bottom width of waterway, feet. Widths under 5 feet not shown. Bottom width and velocity based on short grass ("D" retardance)

D** = Depth of flow with rank growth, feet ("B" retardance).

*** = Waterways above this line may be difficult to maintain with larger farm machinery.

Table 10. Dimensions of Trapezoidal Waterways (Velocity, 5 ft per sec) (Continued).

| Slope,% | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | | | | | | | | | | | | | | |
| 10 | B* | | | | | | | | | | | | | |
| | D** | | | | | | | | | | | | | |
| 15 | B | | | | | | | | | | | 6 | 8 | 10 |
| | D | | | | | | | | | | | 0.6 | 0.6 | 0.6 |
| 20 | B | | | | | | | | 6 | 7 | 8 | 9 | 11 | 13 |
| | D | | | | | | | | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 |
| 25 | B | | | | | | | 6 | 8 | 10 | 11 | 12 | 13 | 15 |
| | D | | | | | | | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6*** |
| 30 | B | | | | | | 8 | 10 | 11 | 13 | 14 | 15 | 17 | 19 |
| | D | | | | | | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 |
| 35 | B | | | | | 9 | 11 | 13 | 14 | 16 | 17 | 19 | 21 | 23 |
| | D | | | | | 1.0 | 0.9 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 |
| 40 | B | | | | 8 | 11 | 13 | 15 | 17 | 19 | 20 | 22 | 24 | 26 |
| | D | | | | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 45 | B | | | | 10 | 13 | 15 | 17 | 19 | 21 | 22 | 25 | 27 | 29 |
| | D | | | | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 50 | B | | | 7 | 11 | 15 | 17 | 20 | 22 | 24 | 25 | 28 | 30 | 33 |
| | D | | | 1.3 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 55 | B | | | 9 | 13 | 17 | 19 | 22 | 25 | 27 | 28 | 31 | 34 | 37 |
| | D | | | 1.3 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 60 | B | | | 11 | 15 | 19 | 22 | 25 | 27 | 29 | 31 | 34 | 37 | 40 |
| | D | | | 1.3 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 65 | B | | 5 | 12 | 17 | 21 | 24 | 27 | 30 | 32 | 34 | 37 | 40 | 43 |
| | D | | 1.9 | 1.2 | 1.1 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 70 | B | | 6 | 14 | 19 | 23 | 26 | 29 | 32 | 35 | 37 | 40 | 42 | 45 |
| | D | | 1.8 | 1.2 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 75 | B | | 7 | 16 | 20 | 25 | 28 | 32 | 35 | 38 | 40 | 43 | 45 | 48 |
| | D | | 1.8 | 1.2 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |

Table 10. Dimensions of Trapezoidal Waterways (Velocity, 5 ft per sec) (Continued)

| Slope,% | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | | | | | | | | | | | | | | |
| 80 | B | | 9 | 17 | 22 | 27 | 31 | 34 | 37 | 40 | 42 | 47 | 48 | 51 |
| | D | | 1.7 | 1.2 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 90 | B | | 12 | 20 | 26 | 31 | 35 | 39 | 42 | 45 | 48 | 53 | 55 | 57 |
| | D | | 1.7 | 1.2 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 100 | B | | 14 | 23 | 30 | 35 | 39 | 43 | 47 | 51 | 54 | 59 | 63 | 67 |
| | D | | 1.6 | 1.1 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 |
| 120 | B | | 20 | 30 | 37 | 43 | 48 | 53 | 57 | 61 | 65 | | | |
| | D | | 1.5 | 1.1 | 1.0 | 0.8 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | | | |
| 140 | B | 5 | 25 | 36 | 44 | 51 | 57 | 63 | 68 | | | | | |
| | D | 2.8 | 1.4 | 1.1 | 0.9 | 0.8 | 0.7 | 0.7 | 0.7 | | | | | |
| 160 | B | 10 | 30 | 42 | 51 | 59 | 66 | | | | | | | |
| | D | 2.5 | 1.3 | 1.1 | 0.9 | 0.8 | 0.7 | | | | | | | |
| 180 | B | 14 | 35 | 48 | 58 | 67 | | | | | | | | |
| | D | ***2.3 | 1.3 | 1.0 | 0.9 | 0.8 | | | | | | | | |
| 200 | B | 18 | 40 | 54 | 65 | | | | | | | | | |
| | D | 2.1 | 1.3 | 1.0 | 0.9 | | | | | | | | | |

B* = Bottom Width of waterway, feet. Widths under 5 ft not shown. Bottom width and velocity based on short grass ("D" retardance).

D** = Depth of flow with rank growth, feet ("B" retardance).

*** = Waterways above this line may be difficult to maintain with larger farm machinery.

Table 11. Dimensions of Parabolic Waterways (Velocity, 3 ft per sec).

| Slope,% | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D**,ft | 2.0 | 1.4 | 1.2 | 1.1 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 |
| Q,cfs | | | | | | Top Width, Ft* | | | | | | | |
| 10 | 12 | 12 | 12 | 12 | 13 | 14 | 15 | 16 | 16 | 17 | 18 | 19 | 20 |
| 15 | 12 | 14 | 15 | 16 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 20 | 14 | 16 | 19 | 20 | 22 | 24 | 25 | 26 | 28 | 30 | 31 | 33 | 34 |
| 25 | 16 | 19 | 22 | 25 | 27 | 29 | 31 | 32 | 34 | 36 | 38 | 40 | 42 |
| 30 | 19 | 22 | 26 | 29 | 32 | 34 | 36 | 38 | 40 | 42 | 45 | 48 | 51 |
| 35 | 21 | 24 | 30 | 33 | 36 | 39 | 41 | 43 | 45 | 48 | 51 | 54 | 58 |
| 40 | 23 | 27 | 33 | 37 | 41 | 44 | 47 | 49 | 52 | 55 | 57 | 62 | 66 |
| 45 | 25 | 30 | 36 | 41 | 46 | 49 | 52 | 54 | 58 | 62 | 65 | 69 | 73 |
| 50 | 27 | 33 | 40 | 45 | 50 | 54 | 57 | 60 | 64 | 69 | 72 | 76 | |
| 55 | 29 | 36 | 44 | 49 | 55 | 59 | 63 | 66 | 69 | | | | |
| 60 | ***31 | 39 | 48 | 53 | 59 | 64 | 69 | 74 | | | | | |
| 65 | 33 | 42 | 51 | 57 | 63 | 69 | 74 | | | | | | |
| 70 | 35 | 45 | 55 | 61 | 66 | 74 | | | | | | | |
| 75 | 38 | 48 | 60 | 65 | 70 | | | | | | | | |
| 80 | 40 | 51 | 64 | 68 | 74 | | | | | | | | |
| 90 | 44 | 57 | 72 | 76 | | | | | | | | | |
| 100 | 48 | 64 | 78 | | | | | | | | | | |
| 120 | 56 | 75 | | | | | | | | | | | |
| 140 | 64 | | | | | | | | | | | | |
| 160 | 74 | | | | | | | | | | | | |

Table 11. Dimensions of Parabolic Waterways (Velocity, 4 ft per sec) (Continued).

| Slope,% | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D**,ft | 2.3 | 1.6 | 1.4 | 1.2 | 1.1 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 |
| Q,cfs | | | | | | Top Width T, Ft* | | | | | | | |
| 10 | | | | 10 | 10 | 11 | 11 | 12 | 12 | 12 | 13 | 13 | 14 |
| 15 | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 14 | 15 | 16 | 17 | 18 | 19 |
| 20 | 11 | 12 | 13 | 14 | 16 | 17 | 19 | 19 | 19 | 20 | 22 | 23 | 25 |
| 25 | 12 | 14 | 15 | 17 | 19 | 20 | 21 | 22 | 23 | 23 | 26 | 28 | 30 |
| 30 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 26 | 27 | 28 | 30 | 32 | 35 |
| 35 | 14 | 17 | 20 | 22 | 24 | 26 | 28 | 29 | 30 | 31 | 34 | 37 | 40 |
| 40 | 16 | 18 | 22 | 24 | 27 | 29 | 31 | 33 | 34 | 36 | 39 | 42 | 45 |
| 45 | 17 | 20 | 24 | 27 | 30 | 32 | 35 | 36 | 38 | 40 | 43 | 46 | 50 |
| 50 | 18 | 22 | 26 | 30 | 33 | 35 | 38 | 40 | 42 | 44 | 48 | 51 | 55 |
| 55 | 19 | 24 | 29 | 33 | 36 | 39 | 41 | 44 | 46 | 48 | 52 | 56 | 60 |
| 60 | 21 | 25 | 31 | 35 | 39 | 42 | 44 | 48 | 50 | 52 | 57 | 61 | 65 |
| 65 | 22 | 27 | 33 | 37 | 42 | 46 | 48 | 51 | 53 | 56 | 60 | 66 | 70 |
| 70 | 23 | 29 | 34 | 40 | 44 | 49 | 52 | 55 | 57 | 61 | 64 | 72 | |
| 75 | 25 | 31 | 37 | 42 | 47 | 52 | 55 | 58 | 61 | 65 | 68 | | |
| 80 | 26 | 33 | 40 | 45 | 50 | 54 | 58 | 62 | 65 | 69 | | | |
| 90 | 28 | 36 | 44 | 50 | 56 | 59 | 65 | 68 | 72 | | | | |
| 100 | 31 | 40 | 48 | 56 | 61 | 64 | 71 | 75 | | | | | |
| 120 | ***36 | 47 | 58 | 64 | 74 | 76 | | | | | | | |
| 140 | 41 | 54 | 68 | 74 | | | | | | | | | |
| 160 | 46 | 62 | 76 | | | | | | | | | | |
| 180 | 51 | 68 | | | | | | | | | | | |
| 200 | 56 | 75 | | | | | | | | | | | |

Table 11. Dimensions of Parabolic Waterways (Velocity, 5 ft per sec) (Continued)

| Slope,% | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 12 | 14 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D**,ft | 2.7 | 1.9 | 1.5 | 1.3 | 1.2 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.8 |
| Q,cfs | | | | | | Top Width T, Ft* | | | | | | | |
| 10 | | | | | | 10 | 10 | 10 | 10 | 10 | 11 | 11 | 12 |
| 15 | | | | | 10 | 11 | 12 | 12 | 13 | 13 | 14 | 14 | 15 |
| 20 | | | | 11 | 12 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 25 | | | 11 | 13 | 14 | 15 | 15 | 16 | 18 | 19 | 20 | 21 | 22 |
| 30 | | 11 | 13 | 15 | 16 | 17 | 18 | 19 | 21 | 22 | 23 | 24 | 25 |
| 35 | 11 | 12 | 15 | 17 | 19 | 20 | 21 | 22 | 23 | 24 | 26 | 28 | 30 |
| 40 | 12 | 13 | 16 | 18 | 20 | 21 | 23 | 24 | 26 | 27 | 29 | 31 | 34 |
| 45 | 13 | 15 | 18 | 20 | 22 | 23 | 25 | 26 | 28 | 29 | 32 | 34 | 37 |
| 50 | 14 | 16 | 19 | 22 | 24 | 26 | 28 | 29 | 31 | 32 | 35 | 37 | 40 |
| 55 | 14 | 17 | 20 | 23 | 26 | 28 | 30 | 32 | 34 | 35 | 38 | 40 | 43 |
| 60 | 15 | 18 | 22 | 25 | 28 | 30 | 33 | 34 | 36 | 38 | 42 | 44 | 46 |
| 65 | 16 | 20 | 24 | 27 | 30 | 32 | 35 | 37 | 39 | 41 | 44 | 47 | 50 |
| 70 | 17 | 21 | 25 | 29 | 32 | 34 | 37 | 40 | 42 | 44 | 48 | 51 | 54 |
| 75 | 18 | 22 | 27 | 30 | 34 | 36 | 40 | 42 | 45 | 47 | 50 | 53 | 57 |
| 80 | 19 | 23 | 28 | 32 | 36 | 39 | 42 | 44 | 47 | 49 | 53 | 56 | 60 |
| 90 | 20 | 25 | 31 | 36 | 40 | 42 | 47 | 50 | 52 | 54 | 61 | 64 | 68 |
| 100 | 21 | 28 | 34 | 40 | 44 | 46 | 51 | 54 | 58 | 60 | 64 | 72 | |
| 120 | 25 | 32 | 40 | 47 | 51 | 56 | 60 | 64 | 68 | 72 | 76 | | |
| 140 | 28 | 37 | 46 | 54 | 59 | 64 | 70 | 74 | 78 | | | | |
| 160 | 31 | 42 | 52 | 60 | 67 | 74 | | | | | | | |
| 180 | 33 | 47 | 58 | 66 | 75 | | | | | | | | |
| 200 | 37 | 52 | 64 | 72 | | | | | | | | | |

*Top width and velocity based on short grass ("D" retardance).

D**Depth of flow with rank growth ("B" retardance).

***Waterways above this line will have side slopes steeper than 4 to 1 and will be difficult to cross with farm machinery. Waterways less than 20 ft wide may be difficult to maintain with larger farm machinery.

Practically, the waterway should be cut deep enough into the ground to eliminate the need for permanent side dikes.

## Diversions

Based on Beasley's (2,5) work, the diversions in Thailand can be designed by determining capacity, permissible velocity, channel grade, and cross section as follows:

Capacity: The minimum capacity of the diversions should not be less than that required to carry a 10-year frequency runoff. A larger channel that will overflow less frequently can be constructed if the damage from more frequent overflow is greater than the additional cost of construction.

Maximum Permissible Velocity: A velocity which will result in a channel that can be constructed at a minimum cost and which can be easily maintained should be selected. The velocity should not be so high that it would erode the channel. The erodibility of the soil that is exposed in the channel of the diversion and the type and quality of vegetation that can be established and maintained should be determined when the maximum permissible velocity is selected.

Table 12 can be used in selecting the maximum permissible velocity and Table 14 in determining the size of the channel if:

1. The runoff can be diverted from the channel while vegetation is established.
2. Soil conditions are favorable for establishment of a dense stand of grass.

Table 12. Maximum Permissible Velocities, fps (To be used if a stand of erosion resistant grasses can be established and maintained in the channel) [from Beasley (2,5)].

| Vegetative Cover | Less Erodible Soils* | More Erodible Soils** |
|---|---|---|
| Fair | 4.0 | 3.5 |
| Good | 5.0 | 4.0 |
| Excellent | 6.0 | 5.0 |

*Less erodible soils are generally those with a higher clay content and higher plasticity. Typical soil textures are silty clay, sandy clay, and clay.

**More erodible soils are generally those that have a high content of fine sand or silt and lower plasticity. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

3. Good management practices will be followed in establishing and maintaining the grass.
4. The diversion is constructed in rocky soil that is very resistant to erosion.

Table 13 can be used in selecting the maximum permissible velocity and Table 15 in determining the size of the channel if:

1. Runoff cannot be diverted from the channel.
2. Soil conditions are not favorable for establishing dense grass.
3. Good management practices are not likely to be followed.

Channel Grade: If the channel grade does not exceed 0.8 percent, Tables 14 and 15 can be used to select the size of the channel. If the grade in the channel exceeds 0.8 percent, a good stand of erosion resistant grasses in the channel should be established and maintained. The tables for designing grass waterways should be used to select the channel width and depth for grades in excess of 0.8 percent.

Cross Section: A trapezoidal-shaped diversion with a flat bottom and 4 to 1 side slopes should be constructed where possible (Figure 9). The bottom width of the channel and the height of the ridge required to carry a given rate of runoff at or below the maximum permissible velocity can be determined from Tables 14 or 15.

Generally, a number of channels with different bottom widths and heights will carry the given flow at or below the maximum permissible velocity. The size to be selected will depend on the following factors: the land slope on which the diversion is to be constructed, the type of

Table 13. Maximum Permissible Velocities, fps (To be used if a stand of grass cannot be established and maintained) [from Beasley (2,5)].

| Vegetative Cover | Less Erodible Soils* | More Erodible Soils** |
|---|---|---|
| None - cultivated | 2.0 | 1.5 |
| None - not cultivated | 2.5 | 2.0 |
| Sparse annual grasses | 3.0 | 2.5 |
| Fair annual grasses | 3.5 | 3.0 |

*Less erodible soils are generally those with a higher clay content and higher plasticity. Typical soil textures are silty clay, sandy clay, and clay.

**More erodible soils are generally those that have a high content of fine sand or silt and lower plasticity. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

Table 14. Height (H)[1/] of Diversion Ridge with Grass Established and Maintained in Channel [from Beasley (2,5)].

| | Bottom Width (B)[2/] | 6 | | | | | 8 | | | | | 10 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | Grade, percent | 0.2 | 0.4 | 0.6 | 0.8 | | 0.2 | 0.4 | 0.6 | 0.8 | | 0.2 | 0.4 | 0.6 | 0.8 | Q,cfs |
| 5 | | 1.6 | 1.4 | 1.2 | | | 1.5 | 1.3 | 1.2 | | | 1.4 | 1.2 | 1.1 | | 5 |
| 10 | | 1.8 | 1.6 | 1.3 | 1.2 | | 1.7 | 1.5 | 1.3 | 1.1 | | 1.6 | 1.4 | 1.2 | 1.1 | 10 |
| 15 | 1.0* | 2.0 | 1.7 | 1.5 | 1.4 | 1.0* | 1.8 | 1.6 | 1.4 | 1.2 | 1.0* | 1.7 | 1.5 | 1.3 | 1.2 | 15 |
| 20 | | 2.1 | 1.8 | 1.6 | 1.5 | | 1.9 | 1.7 | 1.5 | 1.4 | | 1.8 | 1.6 | 1.4 | 1.3 | 20 |
| 25 | | 2.2 | 1.9 | 1.7 | 1.6 | | 2.0 | 1.8 | 1.6 | 1.5 | | 1.9 | 1.7 | 1.5 | 1.4 | 25 |
| 30 | 1.5* | 2.3 | 2.0 | 1.7 | 1.6 | | 2.1 | 1.8 | 1.6 | 1.5 | | 2.0 | 1.7 | 1.5 | 1.4 | 30 |
| 35 | | 2.4 | 2.1 | 1.8 | 1.7 | 1.5* | 2.2 | 1.9 | 1.7 | 1.6 | | 2.0 | 1.8 | 1.6 | 1.5 | 35 |
| 40 | | 2.5 | 2.1 | 1.9 | 1.8 | | 2.3 | 1.9 | 1.8 | 1.7 | 1.5* | 2.1 | 1.8 | 1.7 | 1.6 | 40 |
| 45 | | 2.6 | 2.2 | 2.0 | 1.8 | | 2.4 | 2.0 | 1.9 | 1.7 | | 2.2 | 1.9 | 1.8 | 1.6 | 45 |
| 50 | | 2.6 | 2.3 | 2.0 | 1.9 | | 2.4 | 2.1 | 1.9 | 1.8 | | 2.3 | 2.0 | 1.8 | 1.7 | 50 |
| 60 | 2.0* | 2.7 | 2.4 | 2.1 | 2.0 | 2.0* | 2.5 | 2.2 | 2.0 | 1.9 | | 2.4 | 2.1 | 1.9 | 1.8 | 60 |
| 70 | | 2.8 | 2.5 | 2.2 | 2.0 | | 2.6 | 2.3 | 2.1 | 1.9 | 2.0* | 2.5 | 2.2 | 2.0 | 1.8 | 70 |
| 80 | | 2.9 | 2.6 | 2.3 | 2.1 | | 2.7 | 2.4 | 2.2 | 2.0 | | 2.6 | 2.3 | 2.1 | 1.9 | 80 |
| 90 | 2.5* | 3.0 | 2.7 | 2.4 | 2.2 | | 2.8 | 2.5 | 2.3 | 2.1 | | 2.7 | 2.4 | 2.1 | 2.0 | 90 |
| 100 | | 3.0* | 2.8 | 2.6 | 2.3 | 2.5* | 2.9 | 2.6 | 2.3 | 2.2 | | 2.8 | 2.5 | 2.2 | 2.1 | 100 |
| 120 | | | 2.9 | 2.7 | 2.5 | | 3.0 | 2.7 | 2.4 | 2.3 | 2.5* | 2.9 | 2.6 | 2.3 | 2.2 | 120 |
| 140 | | | 3.0 | 2.8 | 2.6 | 3.0* | | 2.8 | 2.6 | 2.4 | | 3.0 | 2.7 | 2.4 | 2.3 | 140 |
| 160 | | | | 2.9 | 2.7 | | | 2.9 | 2.7 | 2.5 | 3.0* | | 2.8 | 2.6 | 2.4 | 160 |
| 180 | 4.0* | | | 3.0 | | | | 3.0 | 2.8 | 2.6 | | | 2.9 | 2.7 | 2.5 | 180 |
| 200 | 5.0* | | | | | 4.0* | | | 2.9 | | | | 3.0 | 2.8 | | 200 |
| 220 | | | | | | | | | 3.0 | | 4.0* | | | 2.9 | | 220 |
| 240 | | | | | | 5.0* | | | | | | | | 3.0 | | |
| | | | | | | | | | | | 5.0* | | | | | |

Table 14. Height (H)1/ of Diversion Ridge with Grass Established and Maintained in Channel (Continued)

| | Bottom Width (B)2/ | 12 | | | | | 16 | | | | | 20 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | Grade, percent | 0.2 | 0.4 | 0.6 | 0.8 | | 0.2 | 0.4 | 0.6 | 0.8 | | 0.2 | 0.4 | 0.6 | 0.8 | Q,cfs |
| 5 | | 1.4 | 1.2 | 1.1 | | | 1.3 | 1.2 | | | | 1.3 | 1.2 | | | 5 |
| 10 | | 1.6 | 1.4 | 1.2 | 1.1 | | 1.5 | 1.3 | 1.2 | 1.1 | | 1.4 | 1.2 | 1.1 | | 10 |
| 15 | 1.0* | 1.7 | 1.5 | 1.3 | 1.2 | | 1.6 | 1.4 | 1.3 | 1.2 | | 1.5 | 1.3 | 1.2 | 1.1 | 15 |
| 20 | | 1.7 | 1.5 | 1.3 | 1.2 | 1.0* | 1.6 | 1.4 | 1.3 | 1.2 | 1.0* | 1.5 | 1.3 | 1.2 | 1.1 | 20 |
| 25 | | 1.8 | 1.6 | 1.4 | 1.3 | | 1.7 | 1.5 | 1.4 | 1.3 | | 1.6 | 1.4 | 1.3 | 1.2 | 25 |
| 30 | | 1.9 | 1.6 | 1.5 | 1.4 | | 1.8 | 1.5 | 1.4 | 1.3 | | 1.6 | 1.5 | 1.3 | 1.2 | 30 |
| 35 | | 1.9 | 1.7 | 1.5 | 1.4 | | 1.8 | 1.6 | 1.5 | 1.3 | | 1.7 | 1.5 | 1.4 | 1.3 | 35 |
| 40 | 1.5* | 2.0 | 1.7 | 1.6 | 1.5 | | 1.9 | 1.6 | 1.5 | 1.4 | | 1.8 | 1.6 | 1.4 | 1.3 | 40 |
| 45 | | 2.1 | 1.8 | 1.7 | 1.5 | 1.5* | 2.0 | 1.7 | 1.6 | 1.4 | | 1.9 | 1.6 | 1.5 | 1.4 | 45 |
| 50 | | 2.2 | 1.9 | 1.7 | 1.6 | | 2.0 | 1.8 | 1.6 | 1.5 | 1.5* | 1.9 | 1.7 | 1.5 | 1.4 | 50 |
| 60 | | 2.3 | 2.0 | 1.8 | 1.7 | | 2.1 | 1.8 | 1.7 | 1.6 | | 2.0 | 1.7 | 1.6 | 1.5 | 60 |
| 70 | 2.0* | 2.4 | 2.0 | 1.9 | 1.7 | | 2.2 | 1.9 | 1.8 | 1.6 | | 2.1 | 1.8 | 1.6 | 1.6 | 70 |
| 80 | | 2.5 | 2.1 | 2.0 | 1.8 | 2.0* | 2.3 | 2.0 | 1.9 | 1.7 | | 2.1 | 1.9 | 1.7 | 1.6 | 80 |
| 90 | | 2.6 | 2.2 | 2.0 | 1.9 | | 2.4 | 2.1 | 1.9 | 1.8 | 2.0* | 2.2 | 1.9 | 1.8 | 1.7 | 90 |
| 100 | | 2.7 | 2.3 | 2.1 | 2.0 | | 2.5 | 2.2 | 2.0 | 1.9 | | 2.3 | 2.0 | 1.8 | 1.7 | 100 |
| 120 | 2.5* | 2.8 | 2.4 | 2.2 | 2.1 | | 2.6 | 2.3 | 2.1 | 2.0 | | 2.5 | 2.1 | 1.9 | 1.8 | 120 |
| 140 | | 3.0 | 2.6 | 2.3 | 2.2 | 2.5* | 2.8 | 2.4 | 2.2 | 2.1 | 2.5* | 2.6 | 2.3 | 2.0 | 1.9 | 140 |
| 160 | | | 2.7 | 2.4 | 2.3 | | 2.9 | 2.5 | 2.3 | 2.2 | | 2.7 | 2.4 | 2.1 | 2.0 | 160 |
| 180 | | | 2.8 | 2.5 | 2.3 | | 3.0 | 2.6 | 2.4 | 2.3 | | 2.3 | 2.5 | 2.2 | 2.1 | 180 |
| 200 | 3.0* | | 2.9 | 2.6 | 2.4 | 3.0* | | 2.7 | 2.5 | 2.4 | | 3.0 | 2.6 | 2.3 | 2.2 | 200 |
| 220 | | | 3.0 | 2.7 | | | | 2.8 | 2.6 | | | | 2.7 | 2.4 | 2.3 | 220 |
| 240 | 4.0* | | | 2.8 | | 4.0* | | 2.9 | 2.7 | | 3.0* | | 2.8 | 2.5 | | 240 |
| 260 | | | | 2.9 | | | | 3.0 | 2.8 | | | | 2.9 | 2.6 | | 260 |
| 280 | | | | | | 5.0* | | | | | 4.0* | | 3.0 | 2.6 | | 280 |
| 300 | 5.0* | | | | | | | | | | 5.0* | | | 2.7 | | 300 |

Table 14. Height (H)[1] of Diversion Ridge with Grass Established and Maintained in Channel (Continued)

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[1] Height, feet, required to carry flow with long grass in channel ("C" retardance), including 0.3-ft freeboard, measured from the bottom of the channel to a point 2 ft off the peak of the ridge.

[2] Bottom width required to give desired velocity with short grass in channel ("D" retardance)

*Velocity, in ft per sec, to be expected in channel with short grass ("D" retardance).

Table 15. Height (H)$\underline{1}/$of Diversion Ridge with Sparse Vegetation in Channel [from Beasley (2,5)].

| | Bottom Width (B)$\underline{2}/$ Ft | 6 | | | | | 8 | | | | | 10 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | Grade, percent | 0.2 | 0.4 | 0.6 | 0.8 | | 0.2 | 0.4 | 0.6 | 0.8 | | 0.2 | 0.4 | 0.6 | 0.8 | Q,cfs |
| 5 | 1.0* | 1.3 | 1.1 | 1.0 | 1.0 | 1.0* | 1.2 | 1.0 | 1.0 | 1.0 | | 1.1 | 1.0 | 1.0 | 1.0 | 5 |
| 10 | | 1.5 | 1.3 | 1.1 | 1.1 | | 1.3 | 1.2 | 1.1 | 1.0 | 1.0* | 1.3 | 1.1 | 1.0 | 1.0 | 10 |
| 15 | 1.5* | 1.7 | 1.4 | 1.3 | 1.2 | 1.5* | 1.5 | 1.3 | 1.2 | 1.0 | | 1.4 | 1.2 | 1.1 | 1.0 | 15 |
| 20 | | 1.8 | 1.5 | 1.4 | 1.3 | | 1.6 | 1.4 | 1.3 | 1.1 | 1.5* | 1.5 | 1.3 | 1.2 | 1.1 | 20 |
| 25 | | 1.9 | 1.6 | 1.5 | 1.4 | | 1.7 | 1.5 | 1.4 | 1.2 | | 1.6 | 1.4 | 1.2 | 1.2 | 25 |
| 30 | 2.0* | 2.0 | 1.6 | 1.5 | 1.5 | 2.0* | 1.8 | 1.6 | 1.5 | 1.3 | | 1.7 | 1.5 | 1.3 | 1.3 | 30 |
| 35 | | 2.1 | 1.7 | 1.6 | | | 1.9 | 1.7 | 1.5 | 1.4 | 2.0* | 1.8 | 1.6 | 1.3 | 1.3 | 35 |
| 40 | | 2.2 | 1.8 | 1.7 | | | 2.0 | 1.7 | 1.6 | | | 1.9 | 1.6 | 1.4 | | 40 |
| 45 | | 2.3 | 1.9 | | | | 2.1 | 1.8 | | | | 2.0 | 1.7 | 1.5 | | 45 |
| 50 | 2.5* | 2.3 | 2.0 | | | 2.5* | 2.2 | 1.9 | | | | 2.1 | 1.8 | | | 50 |
| 60 | | 2.4 | | | | | 2.3 | 2.0 | | | 2.5* | 2.2 | 1.9 | | | 60 |
| 70 | | 2.5 | | | | | 2.4 | | | | | 2.3 | | | | 70 |
| 80 | | 2.7 | | | | | 2.5 | | | | | 2.4 | | | | 80 |
| 90 | 3.0* | 2.8 | | | | 3.0* | 2.5 | | | | | 2.5 | | | | 90 |
| 100 | | 2.9 | | | | | 2.6 | | | | 3.0* | 2.6 | | | | 100 |
| 120 | | 3.1 | | | | | 2.8 | | | | | 2.7 | | | | 120 |
| 140 | 3.5* | 3.3 | | | | 3.5* | 3.0 | | | | 3.5* | 2.8 | | | | 140 |

Table 15. Height (H)[1] of Diversion Ridge with Sparse Vegetation in Channel (Continued)

| | Bottom Width (B)[2] Ft | 12 | | | | 16 | | | | 20 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q,cfs | Grade, percent | 0.2 | 0.4 | 0.6 | 0.8 | 0.2 | 0.4 | 0.6 | 0.8 | 0.2 | 0.4 | 0.6 | 0.8 | Q,cfs |
| 5 | | 1.0* 1.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 5 |
| 10 | | 1.3 | 1.1 | 1.0 | 1.0 | 1.0* 1.2 | 1.0 | 1.0 | 1.0 | 1.0* 1.1 | 1.0 | 1.0 | 1.0 | 10 |
| 15 | | 1.4 | 1.2 | 1.0 | 1.0 | 1.3 | 1.1 | 1.0 | 1.0 | 1.2 | 1.1 | 1.0 | 1.0 | 15 |
| 20 | | 1.5 | 1.3 | 1.1 | 1.0 | 1.4 | 1.2 | 1.1 | 1.0 | 1.3 | 1.1 | 1.0 | 1.0 | 20 |
| 25 | | 1.5* 1.6 | 1.4 | 1.2 | 1.1 | 1.5* 1.5 | 1.3 | 1.1 | 1.1 | 1.4 | 1.2 | 1.1 | 1.0 | 25 |
| 30 | | 1.7 | 1.5 | 1.3 | 1.2 | 1.6 | 1.3 | 1.2 | 1.1 | 1.5* 1.4 | 1.3 | 1.1 | 1.0 | 30 |
| 35 | | 1.7 | 1.5 | 1.4 | 1.3 | 1.6 | 1.4 | 1.2 | 1.2 | 1.5 | 1.3 | 1.2 | 1.1 | 35 |
| 40 | | 2.0* 1.8 | 1.6 | 1.4 | 1.3 | 1.7 | 1.4 | 1.3 | 1.2 | 1.6 | 1.4 | 1.2 | 1.1 | 40 |
| 45 | | 1.9 | 1.6 | 1.5 | | 2.0* 1.7 | 1.5 | 1.4 | 1.2 | 1.7 | 1.4 | 1.3 | 1.2 | 45 |
| 50 | | 2.0 | 1.7 | 1.5 | | 1.8 | 1.6 | 1.4 | | 2.0* 1.7 | 1.5 | 1.3 | 1.2 | 50 |
| 60 | | 2.5* 2.1 | 1.8 | | | 1.9 | 1.7 | 1.5 | | 1.8 | 1.5 | 1.4 | | 60 |
| 70 | | 2.2 | 1.9 | | | 2.5* 2.0 | 1.7 | 1.6 | | 1.9 | 1.6 | 1.5 | | 70 |
| 80 | | 2.3 | | | | 2.1 | 1.8 | | | 2.5* 1.9 | 1.7 | | | 80 |
| 90 | | 2.4 | | | | 2.2 | 1.9 | | | 2.0 | 1.7 | | | 90 |
| 100 | | 3.0* 2.5 | | | | 3.0* 2.3 | | | | 2.1 | 1.8 | | | 100 |
| 120 | | 2.7 | | | | 2.5 | | | | 3.0* 2.3 | | | | 120 |
| 140 | | 3.5* 2.8 | | | | 2.6 | | | | 2.4 | | | | 140 |
| 160 | | | | | | 3.5* 2.7 | | | | 3.5* 2.5 | | | | 160 |

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[1] Height, feet, required to carry flow with long grass in channel ("D" retardance), including 0.3-ft freeboard measure from the bottom of channel to a point 2 ft off the peak of the ridge. One foot is considered minimum height.

[2] Bottom width required to give desired velocity with sparse vegetation in channel ("E" retardance).

*Velocity, in feet, per second, to be expected in channel with short, sparse vegetation ("E" retardance).

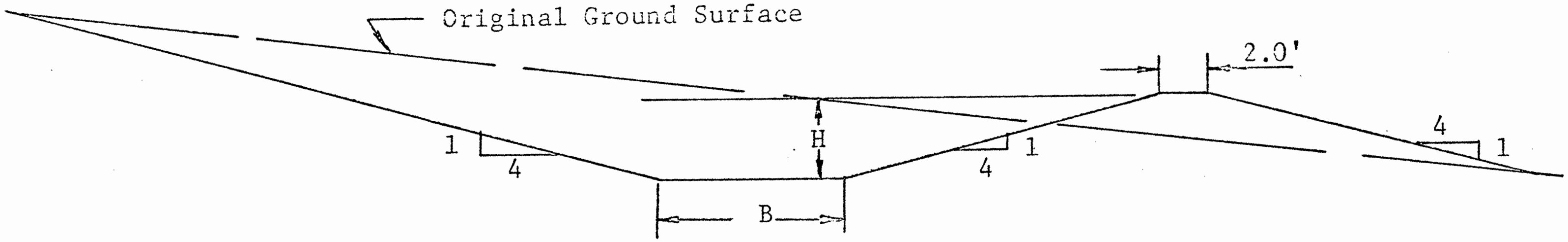


Figure 9. Cross Section of a Diversion.

equipment available for construction, the cost, the location of the channel, and maintenance requirements.

Sometimes the diversion is constructed on steep land or where space is limited. It may be desirable to construct the channel with 3 to 1 side slopes. If this is done, the maximum rate of runoff should be increased by 10 per cent and Tables 14 or 15 should be used to select the bottom width and height of the channel. The heights of ridges are given in Tables 14 and 15.

### Terraces

In Thailand, the terrace can be designed, based on Beasley's (2,3) work at Missouri and The Engineering Field Manual, 1969 (34), by considering the following elements:

Terrace grade: In determining grades for terraces, the factors to be considered are soil type, spacing, and length of terrace. Grades should be sufficient to provide good drainage and develop adequate flow without scouring the channel and washing out crops. A minimum grade of 0.1 to 0.2 is generally used (by S.C.S., U.S.A.). In general, 1,800 to 2,000 ft is the maximum distance that a terrace should drain water in one direction.

Terrace spacing: The equation

$$VI = 0.6S + Y$$

VI = Vertical interval between terraces, ft

S = The average slope of the land draining into the terrace, percent.

Y = A variable depending upon the erodibility of the soil and the irregularity of the slope (1.0-2.0).

The results obtained in Table 16 are computed by this equation.

Practically, these spacings may be varied by 10 percent according to obstacles in the field, adjustments for use of farm machinery, or reaching a satisfactory outlet.

Due to the width of machinery that will be used in farming the terrace, the terraces which are to be parallel from Table 16 can be modified. Table 17 is obtained for determining terrace spacing to best fit a majority of equipment widths. If the size of equipment and row spacing are known, terrace spacing can be obtained from Table 18.

Channel Grades of Level Terraces: Level terraces can be constructed on deep permeable soils that can absorb and store the runoff without crop damage and without serious delay in the farming operations. The permeable and deep loose soils are suitable for level terraces.

Channel Grades of Grade Terraces: The channel grade will depend on the soil type. Usually, the most desirable grades to be used under most conditions are given in Table 19.

It is permissible to vary from the most desirable grade in order to improve alignment of terraces. In a section of a terrace, the grade may be varied as it is between the minimum and maximum grades for that section.

Recommended minimum grades are in Table 20. Maximum permissible grades are shown in Table 21.

Terrace Cross Section: A terrace cross section should contain adequate capacity for the runoff. It should be designed in order to fit the topography, the farm machinery to be used, and the crops to be

Table 16. Spacing for Graded or Level Terraces [from Beasley (2,3)].

| Average Slope of Area Draining into Terrace | Less Erodible Soils Uniform Slopes (k<0.38) | | More Erodible Soils Irregular Slopes (k≥0.40) | |
|---|---|---|---|---|
| | Vertical interval | Horizontal distance | Vertical interval | Horizontal distance |
| % | ft | ft | ft | ft |
| 1 | 2.6 | 260 | 1.9 | 190 |
| 2 | 3.2 | 160 | 2.5 | 125 |
| 3 | 3.8 | 127 | 3.1 | 103 |
| 4 | 4.4 | 110 | 3.7 | 93 |
| 5 | 5.0 | 100 | 4.3 | 86 |
| 6 | 5.6 | 93 | 4.9 | 82 |
| 7 | 6.2 | 89 | 5.5 | 79 |
| 8 | 6.8 | 85 | 6.1 | 76 |
| 9 | 7.4 | 82 | 6.7 | 74 |
| 10 | 8.0 | 80 | 7.3 | 73 |
| 11 | 8.6 | 78 | 7.9 | 72 |
| 12 | 9.2 | 77 | 8.5 | 71 |

Table 17. Suggested Spacings for Parallel Sections of Graded or Level Terraces [from Beasley (2,3)].

| Average Slope of Area Draining into Terrace % | Less Erodible Soils Uniform Slopes, Vertical interval ft | Less Erodible Soils Uniform Slopes, Horizontal distance ft | More Erodible Soils Irregular Slopes, Vertical interval ft | More Erodible Soils Irregular Slopes, Horizontal distance ft |
|---|---|---|---|---|
| 1 | 2.4 | 240 | 2.0 | 200 |
| 2 | 3.2 | 160 | 2.4 | 120 |
| 3 | 3.6 | 120 | 3.2 | 107 |
| 4 | 4.8 | 120 | 3.8 | 94 |
| 5 | 5.3 | 107 | 4.7 | 94 |
| 6 | 5.6 | 94 | 4.8 | 80 |
| 7 | 6.6 | 94 | 5.6 | 80 |
| 8 | 7.5 | 94 | 6.4 | 80 |
| 9 | 7.2 | 80 | 7.2 | 80 |
| 10 | 8.0 | 80 | 8.0 | 80 |
| 11 | 8.8 | 80 | 7.4 | 67 |
| 12 | 9.6 | 80 | 8.0 | 67 |
| Over 12 | | 80 | | 67 |

Table 18. Terrace Spacing Needed for Specific Sizes of Equipment [from Beasley (2,3)].

| Number of Rows | 4 | 6 | 4 | 8 | 6 | | 6 | 8 |
|---|---|---|---|---|---|---|---|---|
| Row Width | 30" | 20" | 40" | 20" | 30" | | 40" | 30" |
| Equipment Width | 10' | | 13-1/3' | | 15' | | 20' | |
| | Trips | spacing, ft | Trips | spacing, ft | Trips | spacing, ft | Trips | spacing, ft |
| | 6 | 60 | 5 | 67 | 4 | 60 | 3 | 60 |
| | 8 | 80 | 6 | 80 | 5 | 75 | 4 | 80 |
| | 9 | 90 | 7 | 94 | 6 | 90 | 5 | 100 |
| | 11 | 110 | 8 | 107 | 7 | 105 | 6 | 120 |
| | 12 | 120 | 9 | 120 | 8 | 120 | 7 | 140 |
| | 14 | 140 | 10 | 133 | 9 | 135 | 8 | 160 |
| | 16 | 160 | 12 | 160 | 11 | 165 | 9 | 180 |
| | 18 | 180 | 14 | 188 | 12 | 180 | 10 | 200 |
| | 20 | 200 | 15 | 200 | 13 | 195 | 12 | 240 |
| | 24 | 240 | 18 | 240 | 16 | 240 | | |

Table 19. Desirable Grades for Terraces [from Beasley (2,3)].

| Soil Permeability | Desirable Grade, Percent |
|---|---|
| Low | 0.4* |
| High | 0.3 |

*For terraces over 1200 ft long observe maximum grade given in Table 21.

Table 20. Minimum Grades for Terraces [from Beasley (2,3)].

| Soil Permeability | Minimum Grade, Percent |
|---|---|
| Low | 0.2 |
| High | 0.0 |

Table 21. Maximum Grades to be Used in a Terrace (from Beasley (2,3)].

| Distance from Upper End of Terrace,*Ft | Maximum Grade, Percent** | Maximum Drop in a 50-ft Interval |
|---|---|---|
| 0 to 50 | 2.4 | 1.20 |
| 50 to 100 | 2.0 | 1.00 |
| 100 to 150 | 1.6 | 0.80 |
| 150 to 200 | 1.2 | 0.60 |
| 200 to 250 | 1.0 | 0.50 |
| 250 to 300 | 0.8 | 0.40 |
| 300 to 350 | 0.7 | 0.35 |
| 350 to 450 | 0.6 | 0.30 |
| 450 to 550 | 0.5 | 0.25 |
| 550 to 1200 | 0.4 | 0.20 |
| 1200 to 1600 | 0.3 | 0.15 |

*Assuming a drainage area equivalent to a normal terrace spacing for this length.

**If the terrace discharges into a grass outlet, the grade in the 50-ft section next to the outlet should not exceed 0.4 percent or 0.3 percent if the length of the terrace > 1200 ft.

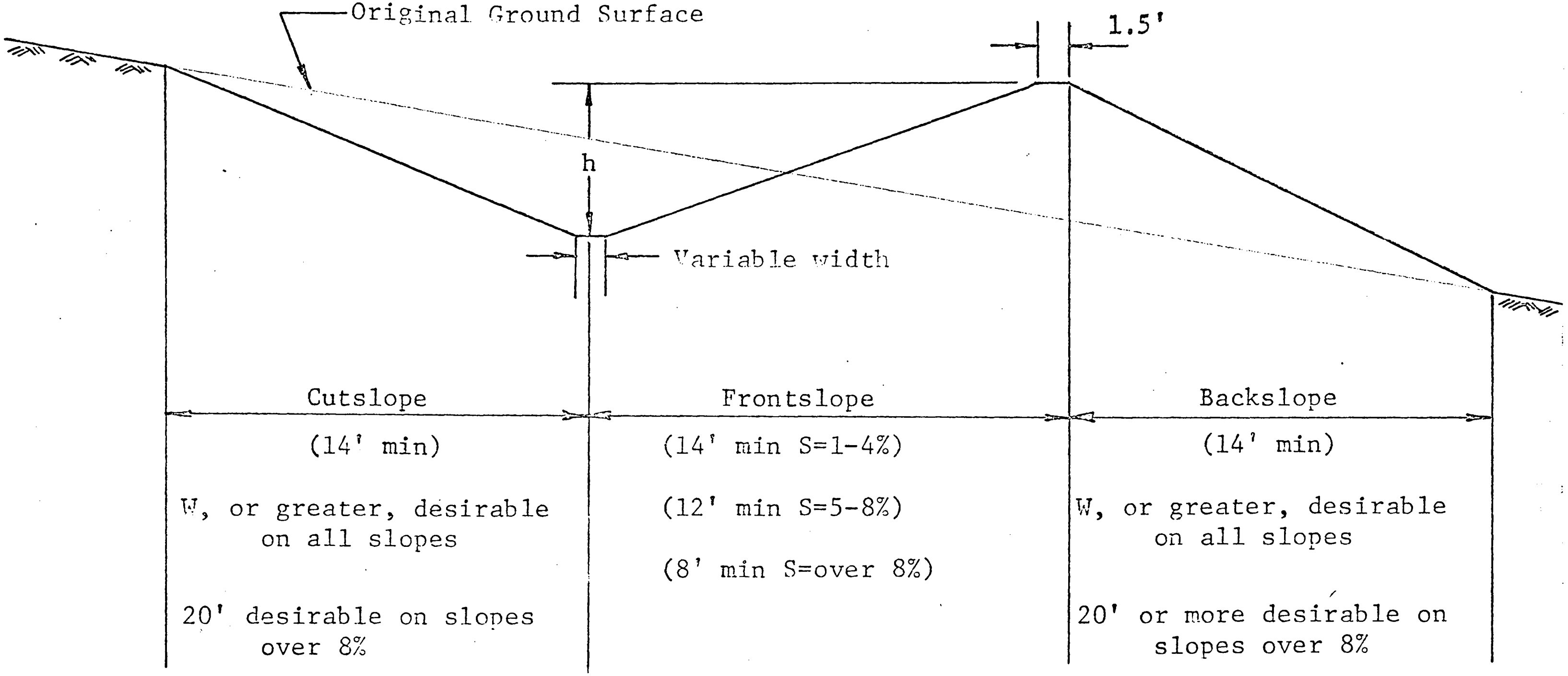
grown. Also it should be economical to construct with the equipment available.

The capacity of graded terraces should be big enough to carry the peak rate of runoff to be expected in a 10-year period. A typical cross section of a broad-base terrace with a v-shaped channel is shown in Figure 10. The dotted line in Figure 10 indicates a terrace that may also be constructed with a flat bottom, if the record from the past experience on certain soils and slopes indicate that the flat bottom channel is easier to construct and to farm. The minimum constructed height of the terrace ridge is shown in Table 22. During construction, if good compaction cannot be established, additional height should be allowed for settling. The depth of cut in the terrace channel can be varied in order to reduce the curvature and improve the alignment of the terrace.

The cross section of level terraces should be the same as the graded terraces except that in all cases the channels must have sufficient capacity to store at least 2 inches of runoff from the area draining into the terrace. As indicated in Table 22, the minimum constructed ridge height of 1.5 ft will take care of this capacity.

Usually, terraces should not exceed 1,600 ft in length. If a longer terrace is to be designed, the portion of terrace greater than 1,600 ft should be designed as a diversion.

Generally, all terraces must have adequate outlets that may be made of a vegetated area or other stable one. The outlet should carry runoff from the terraces to a point where the water will not cause



W=the maximum width of machinery to be used to farm the terrace

S=the slope of the original ground surface

h=the height of the terrace ridge-measured as indicated, minimum values of h are given in Table 22.

Figure 10. A Typical Terrace Cross Section.

Table 22. Minimum Constructed Ridge Heights for Terraces (measured as indicated in Figure 9) [from Beasley (3)].

| Distance from Upper End of Terrace*, Ft | Minimum Constructed Ridge Height, Ft** | | |
|---|---|---|---|
| | Graded Terraces | | Level Terraces |
| | Land Slope over 8% | Land Slope 0 to 8% | All Slopes |
| 0 to 400 | 1.2 | 1.0 | 1.5 |
| 400 to 600 | 1.2 | 1.1 | 1.5 |
| 600 to 800 | 1.3 | 1.2 | 1.5 |
| 800 to 1000 | 1.4 | 1.3 | 1.5 |
| 1000 to 1300 | 1.5 | 1.4 | 1.5 |
| 1300 to 1600 | 1.5 | 1.5 | 1.5 |

*Assuming a drainage area equivalent to a normal terrace spacing for this length.

**If the terrace discharges into a grass outlet, the grade in the 50-ft section next to the outlet should not exceed 0.4 percent or 0.3 percent if the length of the terrace > 1200 ft.

any damage.

Height: The depth of flow in graded terraces can be computed by Manning's formula (10). Beasley suggested using a value of n=0.06. The terrace ridge height, as indicated by h in Figure 10 can be obtained by adding a freeboard of 0.3 to 0.5 ft to the depth of flow.

Table 23 gives the depth of flow and the ridge height for a v-shaped terrace with ten-to-one side slopes, a grade of 0.3 percent, and 0.5 ft freeboard.

## Farm Ponds

Generally, the primary factors that should be studied carefully in order to select the location of farm ponds are:

1. The size of drainage area
2. The kind of soils
3. Condition of the drainage area
4. Pollution from some sources
5. Economics and capacity of storage
6. Convenient for different purposes
7. Avoid locations of buried pipelines, overhead power lines or cables
8. Minimum area of shallow water

The Size of Drainage Area: Where surface runoff is the main source of water supply, the contributing drainage area should be large enough to maintain sufficient water in the pond during all periods of intended use. The drainage area should not be so large, because it

Table 23. Depth of Flow and Terrace Heights [from Beasley (2)].

| Distance from Upper End of Terrace (Ft) | Depth of Flow (Ft) | Height (Ft) |
|---|---|---|
| 100 | 0.3 | 0.8 |
| 200 | 0.4 | 0.9 |
| 400 | 0.5 | 1.0 |
| 600 | 0.6 | 1.1 |
| 800 | 0.7 | 1.2 |
| 1000 | 0.8 | 1.3 |
| 1300 | 0.9 | 1.4 |
| 1600 | 1.0 | 1.5 |

requires a larger and more expensive spillway to drain the surplus water out safely, and may result in excessive siltation and less desirable conditions for fish production.

In estimating the size of drainage area required to maintain a reliable supply of water during the period of intended use, the amount of runoff that will be expected for that period must be determined. The most critical period will be that in which a limited amount of rainfall occurs, and usually this will be a period of high evaporation losses.

The Kind of Soils: The suitable soils for a pond should be able to hold the water and to give a stable embankment. If the permeability and stability of the soil are not known, soil borings should be taken and tested before any farm ponds are built.

Condition of Drainage Area: Permanent grass or timber should be grown throughout the entire drainage area in order to protect the soil from erosion which would fill the pond up with sediment. If sloping land in the drainage area is to be cultivated, terraces should be constructed to reduce erosion losses.

Pollution from Some Sources: Pollution of farm pond water should be avoided by selecting a site where drainage from feedlots, farmsteads, sewage lines, mine dumps, and similar areas will not go down to the ponds. Sometimes diversions should be used to divert undesirable drainage.

Economics and Capacity of Storage: From an economic standpoint, the pond should be located where the largest storage volume can be obtained with the least amount of earth moving or earth fill. This condition generally will occur where a dam is constructed across a narrow valley which has relatively steep side slopes.

Convenient for Different Purposes: Ponds to be used by livestock should be located so that livestock will not have to travel more than one-quarter mile to reach them from the large grazing areas.

If the pond is to be used for fire protection, the pond should be constructed within 500 ft of the farm buildings and near an all weather road.

If it is to be used for the farmstead water supply, it should be located near the farmstead, preferably at a higher elevation. If possible, the pond should be located so as to serve more than one purpose. In addition, most ponds can provide for fishing, recreation, and wildlife.

Avoid Locations with Buried Pipeline, Cables, or O.P.L.: Buried pipelines or cables may be damaged by the excavating equipment during construction. Overhead power lines present a hazard to fishermen and others using farm ponds. Those power lines may be within reach of a fishing rod held by someone fishing from the top of the dam.

Minimum Area of Shallow Water: A site should be selected so that it will not have large areas of shallow water because weed growth is difficult to control in these areas.

## Designing a Pond

Based on Beasley's (2,7) work, a farm pond can be designed by considering the following factors:

1. Storage capacity needed
2. Size of drainage area to be needed to supply the pond
3. Surface area and depth which will provide the desired storage
4. Spillway design
5. Water supply systems

Storage Capacity Needed: The farm pond must have adequate capacity to:

1. Supply the intended uses
2. Provide for evaporation losses
3. Provide for seepage losses
4. Supply a reserve pool
    a) Table 24 shows the amount of water needed for different uses
    b) Evaporation: In a dry year, the amount of water evaporating from the surface of a pond may exceed the amount replaced by the rainfall on the pond. Figure 11 shows the excess of evaporation over rainfall in a dry year in Thailand. The percent reduction in capacity by evaporation from typical farm ponds can be determined from Table 25.
    c) Seepage: Seepage losses vary widely depending upon the kind of the soil and the practices followed during construction. Seepage losses should be negligible for ponds constructed in less permeable soils and should not

Table 24. Amount of Water Required for Different Uses [from Beasley (2,7) and Engineering Field Manual, 1969].

| Use | Amount Gallons per Day |
|---|---|
| Household (amount per person) | 50 per person |
| Beef cattle and horses | 15 per animal |
| Dairy cattle, drinking only | 20 per animal |
| Dairy cattle, drinking, barn, and utensil cleanup | 50 per animal |
| Hog | 5 per animal |
| Sheep | 2 per animal |
| Chickens | 10 per 100 |

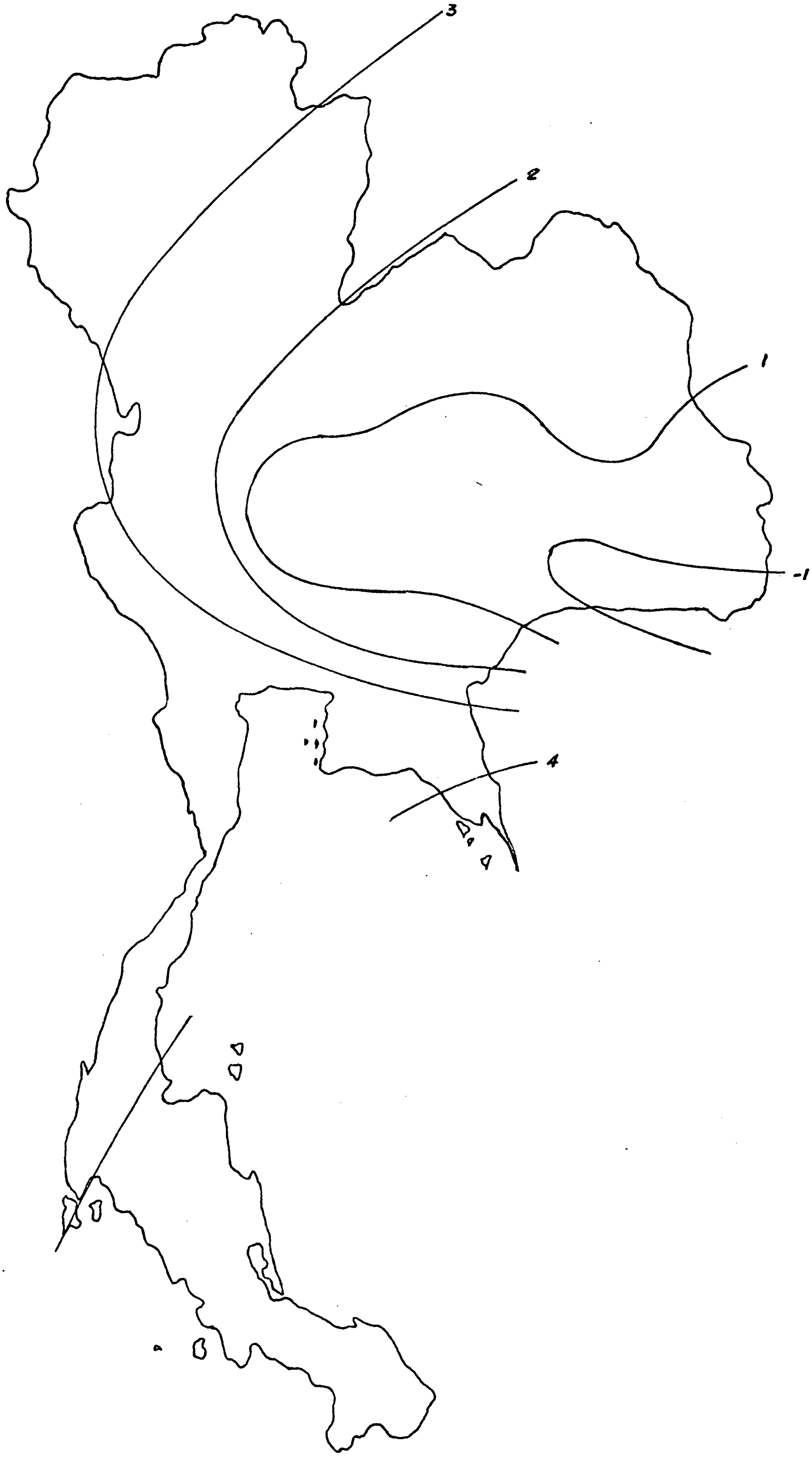


Figure 11. Excessive Evaporation over Rainfall (indicated by-) and Rainfall over Evaporation in a Dry Year in Thailand.

Table 25. Percent Reduction in the Capacity of Typical Farm Ponds for Each 1.0 Ft Net Loss by Evaporation [from Beasley (2,7)].

| Extent to Which Water is Depleted During Period | Maximum Depth of Water in Pond (Ft)<br>8 | 10 | 12 |
|---|---|---|---|
| Water maintained at near full reservoir during the period | 22 | 18 | 15 |
| Entire supply of water depleted during the period | 13 | 10 | 8 |
| One-half the maximum depth used during the period | 18 | 14 | 12 |
| All but 4 ft of water used during the period | 18 | 13 | 11 |

exceed 5 percent of the total volume per year for ponds located on more permeable soils.

d) Reserve Pool: Keeping a certain amount of water in a reserve pool will prevent the pond dam from drying out and cracking and will provide water for wildlife, recreation, and for sediment accumulation. Table 26 indicates how to determine the percent of the total volume of the pond according to varying depths of water in the reserve pool.

Table 27 shows recommended minimum depths of water for farm ponds when seepage and evaporation losses are normal. Where a year-round water supply is essential or where seepage losses exceed three inches per month, greater depths are desirable.

Size of Drainage Area: The amount of runoff from the watershed must be determined in estimating the size of drainage area to supply the water in the pond. The amount of runoff from a watershed depends on many variables: amount, intensity, and duration of rainfall; land slope, soil infiltration, vegetative cover, and surface storage in the watershed.

The values in Figure 12 are developed as a general rule for estimating the size of drainage area in Thailand required per acre-foot of storage in a pond to maintain a normal pool level.based on the similar situation of topography, soil type, and rainfall data.

Surface Area and Depth: In dry seasons, the depth of water evaporated from the surface of the pond is appreciable. The pond

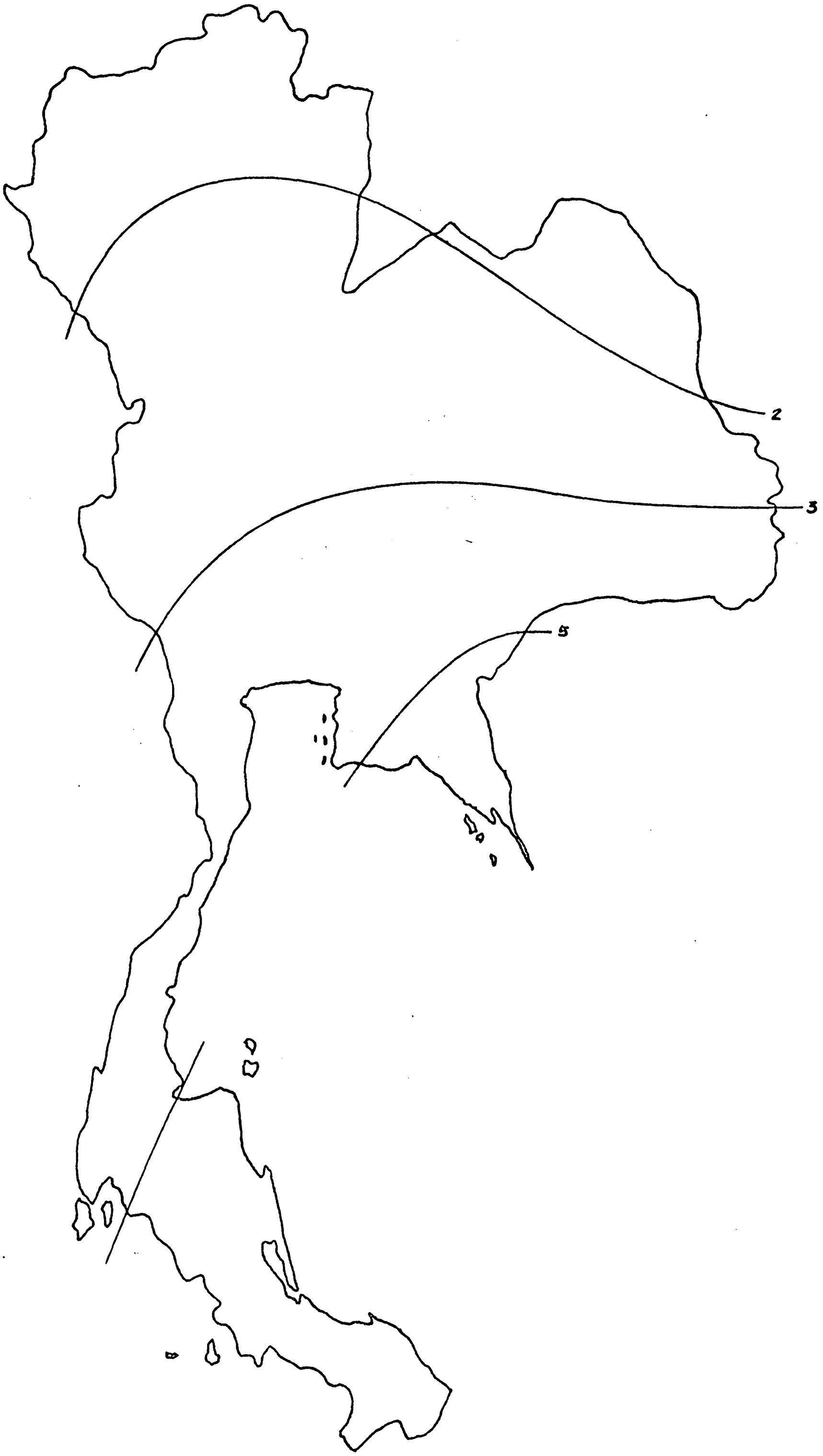


Figure 12. Guide for Estimating Approximate Acres of Drainage Area Required per Acre-Foot of Storage in a Farm Pond in Thailand.

Table 26. Percentage of the Total Volume of Typical Ponds with Varying Depths of Water in the Reserve Pool [from Beasley (2,7)].

| Depth of Water in Reserve Pool (Ft) | Total Depth of Pond (Ft) 8 | 10 | 12 |
|---|---|---|---|
| 12 | | | 100 |
| 11 | | | 85 |
| 10 | | 100 | 71 |
| 9 | | 82 | 58 |
| 8 | 100 | 66 | 47 |
| 7 | 78 | 51 | 37 |
| 6 | 58 | 39 | 28 |
| 5 | 42 | 29 | 21 |
| 4 | 28 | 20 | 15 |
| 3 | 18 | 13 | 11 |
| 2 | 10 | 8 | 7 |
| 1 | 5 | 4 | 3 |

Table 27. Recommended Minimum Depths of Ponds and Reservoirs [from Engineering Field Manual, 1969 (34)].

| Climate | Annual Rainfall (Inches) | Minimum Water Depth Over 25 Percent of the Area (Ft) |
|---|---|---|
| Super humid | Over 60 | 6 |
| Humid | 40-60 | 8 |
| Sub-humid-Moist | 30-40 | 9 |
| Sub-humid-Dry | 20-30 | 10 |
| Semi-arid | 10-20 | 12 |
| Arid | Under 10 | 14 |

should be constructed so that a minimum depth of 8 ft or greater will extend over an area equal to at least one-sixteenth and if possible up to one-fourth of the surface area.

In designing a farm pond, it is essential to select the water surface area and the depth that will give the capacity needed in the pond. The following approximate relationships between surface area, depth, and capacity for typical ponds may be used in making this determination.

1. For small ponds where the excavation is made over the entire area covered by the water

$$\text{Surface area (acres)} = \frac{\text{storage (acre-ft)}}{\text{0.5 times the maximum depth (ft)}}$$

2. For large ponds where the excavation is not made over the entire area covered by the water

$$\text{Surface area (acres)} = \frac{\text{storage (acre-ft)}}{\text{0.4 times the maximum depth (ft)}}$$

If a more accurate determination of the capacity of a pond and its relation to the surface area is desired prior to construction, the following procedure should be followed:

1. Survey an accurate contour map of the area on which the pond is to be constructed. The contour which represents the water level in the pond should be selected.
2. The proposed fill will be drawn on this map, indicating the places where the fill intercepts the contour lines.
3. The volume of water stored above the original ground surface

can be computed by finding the average area of adjacent contours, multiplying each average area by the vertical distance between contours, and determining the sum of these products.

4. The volume of fill material that should be excavated from below the water level contour will be determined and added to the volume of water stored above the original ground surface to get the total capacity of the pond.

Spillway Design: The spillway may consist of a principal spillway, an emergency spillway, or a combination of both. The capacity of combined spillway should be great enough to carry the runoff from the storm without excessive erosion.

A ten-year frequency runoff from the watershed should be used to determine the capacity of the spillways if any of the following conditions exist (2):

1. The ten-year peak rate of runoff from the watershed is 80 c.f.s. or less.
2. The product of reservoir depth (ft) times the storage capacity (acre-ft) is less than 500.
3. The height of the embankment or the total overfall in full-flow structures is 25 ft or less.

Table 28 indicates the maximum permissible velocities in the exit section of emergency spillways.

If the velocities in the emergency spillway are over those specified in Table 21 (a) or if there is the possibility of prolonged

Table 28. Maximum Permissible Velocities in the Exit Section of Emergency Spillways, Ft per Sec (from Beasley (2)].

| Quality of Vegetation | Less Erodible Soils[a] Channel Slope (%) | | | More Erodible Soils[b] Channel Slope (%) | | |
|---|---|---|---|---|---|---|
| | 0-7 | | 8-16[c] | 0-7 | | 8-16[c] |
| (a) All runoff through emergency spillway | | | | | | |
| Fair | 4 | | 3 | 3 | | d |
| Good | 5 | | 4 | 4 | | 3 |
| Excellent | 6 | | 5 | 5 | | 4 |
| | 0-8 | 9-14 | 15-20 | 0-8 | 9-14 | 15-20 |
| (b) Emergency used once a year or more frequently | | | | | | |
| Fair | 6 | 5 | 4 | 5 | 4 | 3 |
| Good | 7 | 6 | 5 | 6 | 5 | 4 |
| Excellent | 8 | 7 | 6 | 7 | 6 | 5 |
| (c) Emergency used once each two years or less frequently | | | | | | |
| Fair | 7 | 6 | 5 | 6 | 5 | 4 |
| Good | 8 | 7 | 6 | 7 | 6 | 5 |
| Excellent | 10 | 8 | 7 | 8 | 7 | 6 |

[a] Less erodible soils are generally those with a higher clay content and higher plasticity. Typical soil textures are silty clay, sandy clay, and clay.

[b] More erodible soils are generally those that have a high content of fine sand or silt and lower plasticity. Typical soil textures are fine sand, silt, sandy loam, silty loam.

[c] For slopes over 16 percent, use a principal spillway.

[d] Use a principal spillway.

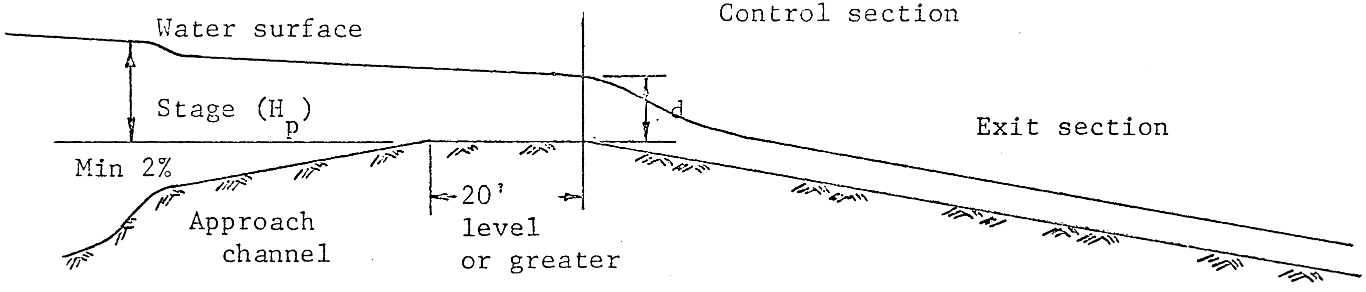
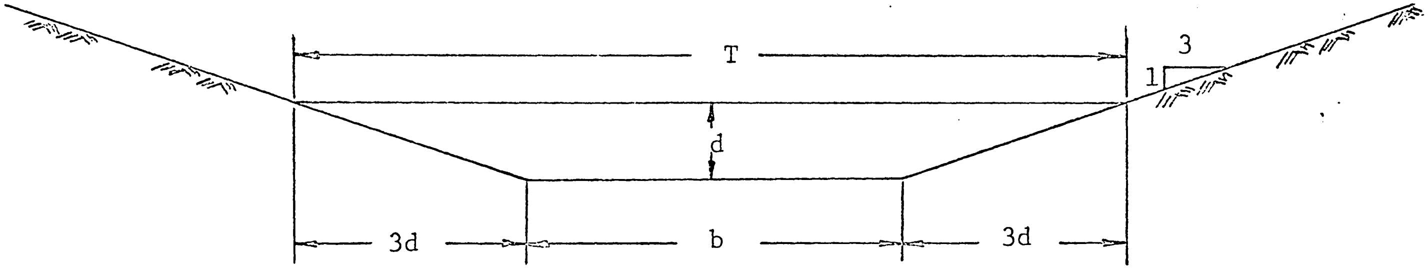


Figure 13. Profile Along Center Line of Excavated Earth Spillway.



Cross Section at Control Section

Figure 14. Cross Section of Excavated Earth Spillway.

runoff through the spillway following a rain, a principal spillway should be constructed. The slope of the exit section of the spillway should fall in between three to ten percent in order to convey the outflow to a point where the water may be released without damage to the fill.

Size of Emergency Spillway: The emergency spillway can be constructed in two ways:

1. Earth Embankment Structures: Usually a trapezoidal shape will be constructed as the control section with three-to-one or flatter side slopes. Ten ft is the minimum width for all control sections. Table 29 shows the minimum width of the control section and depth of flow when the required discharge is known for drainage areas larger than 10 acres.

   The width and depth of the exit section can be determined by the same procedure as designing a grassed waterway, and the velocities may be selected from Table 28.
2. Full-Flow Structures: When the capacity has been determined, the width of the crest and the depth of the flow can be obtained from Table 30. The slope of the emergency spillway crest should be made so that the water will flow over at a uniform depth throughout its length. Usually, the crest should be made level.

The following symbols are used in determining the flow through the spillway:

Table 29. Discharge Through Control Section of Vegetated Spillway, cfs [from Beasley (2)].

| Depth of Flow, Ft | Bottom Width of Control Section, Ft | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 35 | 38 | 40 |
| 0.5 | 6 | 8 | 9 | 11 | 12 | 13 | 14 | 16 | 18 | 20 | 21 | 23 | 25 | 27 | 29 | 29 |
| 0.6 | 10 | 12 | 13 | 15 | 17 | 19 | 20 | 22 | 24 | 27 | 29 | 32 | 34 | 36 | 38 | 40 |
| 0.7 | 13 | 15 | 17 | 20 | 22 | 25 | 27 | 29 | 31 | 34 | 37 | 40 | 43 | 47 | 49 | 51 |
| 0.8 | 17 | 20 | 23 | 26 | 29 | 32 | 34 | 37 | 40 | 43 | 46 | 50 | 54 | 51 | 60 | 63 |
| 0.9 | 20 | 24 | 28 | 32 | 35 | 39 | 42 | 46 | 49 | 52 | 56 | 61 | 66 | 70 | 74 | 77 |
| 1.0 | 25 | 30 | 34 | 38 | 42 | 47 | 51 | 55 | 59 | 63 | 67 | 72 | 77 | 82 | 87 | 92 |
| 1.1 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 96 | 102 | 108 |
| 1.2 | 35 | 41 | 47 | 53 | 59 | 65 | 71 | 76 | 81 | 87 | 92 | 98 | 104 | 110 | 117 | 124 |
| 1.3 | 41 | 48 | 55 | 62 | 68 | 75 | 81 | 87 | 93 | 100 | 107 | 114 | 120 | 126 | 133 | 140 |
| 1.4 | 47 | 55 | 62 | 70 | 77 | 85 | 91 | 98 | 106 | 114 | 122 | 130 | 136 | 143 | 151 | 160 |
| 1.5 | 54 | 62 | 70 | 79 | 87 | 95 | 103 | 111 | 119 | 123 | 137 | 146 | 153 | 161 | 170 | 180 |
| 1.6 | 61 | 70 | 79 | 88 | 97 | 106 | 115 | 125 | 124 | 144 | 153 | 162 | 171 | 180 | 190 | 200 |
| 1.7 | 68 | 78 | 88 | 98 | 108 | 118 | 128 | 138 | 148 | 158 | 168 | 178 | 188 | 200 | 210 | 220 |
| 1.8 | 76 | 86 | 97 | 108 | 119 | 130 | 141 | 153 | 164 | 175 | 185 | 197 | 208 | 220 | 231 | 242 |
| 1.9 | 83 | 95 | 106 | 118 | 130 | 142 | 154 | 167 | 179 | 192 | 203 | 216 | 228 | 240 | 252 | 264 |
| 2.0 | 91 | 104 | 116 | 128 | 141 | 154 | 167 | 181 | 194 | 208 | 221 | 235 | 248 | 261 | 274 | 288 |

Table 30. Discharge Through Emergency Spillways for Full-Flow Structures, cfs [from Beasley (2)].

| Depth of Flow, Ft | Width of Spillway Crest-Ft | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 120 | 140 | 160 | 180 | 200 |
| 0.3 | 4 | 9 | 14 | 18 | 23 | 27 | 32 | 36 | 41 | 45 | 54 | 63 | 72 | 81 | 90 |
| 0.4 | 7 | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 | 83 | 97 | 111 | 125 | 133 |
| 0.5 | 10 | 19 | 29 | 39 | 49 | 58 | 68 | 78 | 88 | 97 | 117 | 136 | 156 | 175 | 194 |
| 0.6 | 13 | 26 | 38 | 51 | 64 | 77 | 89 | 102 | 115 | 128 | 153 | 173 | 205 | 230 | 256 |
| 0.7 | 16 | 32 | 48 | 64 | 81 | 97 | 113 | 129 | 145 | 161 | 193 | 225 | 258 | 230 | 322 |
| 0.8 | 20 | 39 | 59 | 79 | 98 | 118 | 138 | 157 | 177 | 198 | 236 | 275 | 315 | 354 | 394 |
| 0.9 | 23 | 47 | 70 | 94 | 117 | 141 | 164 | 188 | 211 | 235 | 282 | 323 | 376 | 423 | 470 |
| 1.0 | 28 | 55 | 83 | 110 | 138 | 165 | 193 | 220 | 248 | 275 | 330 | 385 | 440 | 495 | |
| 1.1 | 32 | 63 | 95 | 127 | 159 | 190 | 222 | 254 | 286 | 317 | 381 | 444 | | | |
| 1.2 | 36 | 72 | 108 | 145 | 181 | 217 | 253 | 289 | 325 | 361 | 434 | | | | |
| 1.3 | 41 | 82 | 122 | 163 | 204 | 245 | 285 | 326 | 367 | 408 | | | | | |
| 1.4 | 46 | 91 | 137 | 182 | 228 | 273 | 319 | 364 | 410 | 456 | | | | | |
| 1.5 | 51 | 101 | 152 | 202 | 253 | 303 | 354 | 404 | 455 | | | | | | |

$Q_{ip}$ = peak rate of runoff from the watershed used in designing the principal spillway, in c.f.s.

$Q_i$ = peak rate of runoff from the watershed used in designing both spillways (principal and emergency), in c.f.s.

$V_{rp}$ = volume of runoff from the watershed used in designing the principal spillway, in acre-ft.

$V_v$ = volume of runoff from the watershed used in designing both spillways, in acre-ft

$V_{sp}$ = volume of detention storage used in designing the principal spillway, in acre-ft

$V_s$ = total volume of detention storage used in designing both spillways, in acre-ft

$Q_{op}$ = flow through the principal spillway, in c.f.s.

$Q_{ie}$ = flow through the emergency spillway, in c.f.s.

The procedure to determine the principal spillway discharge is as follows:

1. The frequency of storm for which the principal spillway should be designed will first be determined.
2. The peak rate of runoff from the watershed for this frequency storm ($Q_{ip}$) will be computed.
3. The volume of runoff from the watershed ($V_{rp}$) for this frequency storm can be determined by multiplying the value from Table 31 by the number of acres in the watershed. When the watershed has slope of 1 percent or less, the values from Table 31 are reduced by the following amounts: with a

Table 31. Volume of Runoff from a Watershed, Acre-Ft per Acre [from Beasley (2)].

| | Frequency of Storm | | | | | | |
|---|---|---|---|---|---|---|---|
| VxI | 1/2 Year | 1 Year | 2 Years | 5 Years | 10 Years | 25 Years | 50 Years |
| 0.5 | 0.02 | 0.03 | 0.03 | 0.05 | 0.07 | 0.10 | 0.12 |
| 0.6 | 0.02 | 0.03 | 0.04 | 0.07 | 0.09 | 0.12 | 0.14 |
| 0.7 | 0.03 | 0.04 | 0.05 | 0.08 | 0.10 | 0.14 | 0.17 |
| 0.8 | 0.04 | 0.05 | 0.06 | 0.09 | 0.12 | 0.16 | 0.19 |
| 0.9 | 0.05 | 0.06 | 0.07 | 0.11 | 0.14 | 0.18 | 0.21 |
| 1.0 | 0.05 | 0.07 | 0.08 | 0.12 | 0.16 | 0.20 | 0.23 |
| 1.1 | 0.06 | 0.08 | 0.09 | 0.14 | 0.17 | 0.22 | 0.26 |
| 1.2 | 0.07 | 0.09 | 0.10 | 0.15 | 0.19 | 0.24 | 0.28 |
| 1.3 | 0.08 | 0.10 | 0.12 | 0.17 | 0.21 | 0.27 | 0.31 |

slope of 0.-0.5 percent, reduce by 0.04 acre-ft per acre, and with a slope of 0.51-1.0 percent, reduce by 0.02 acre-ft per acre.

4. The amount of detention storage ($V_{sp}$) between the water level at the point when flow starts through the principal spillway and the water level at the point when flow starts through the emergency spillway will be determined.
5. $V_{sp}/V_{rp}$ can be computed
6. The value of $Q_{op}/Q_{ip}$ can be determined from Table 32 when the value of $V_{sp}/V_{rp}$ are known.
7. The expected flow through the principal spillway $Q_{op}$ can be solved.

The procedure to determine the peak rate of flow through the emergency spillway is as follows:

1. The frequency of storm for which the total structure should be designed are determined.
2. The peak rate of runoff from the watershed for this frequency storm ($Q_i$) can be computed.
3. The volume of runoff from the watershed ($V_r$) can be determined by multiplying the value from Table 31 by the number of acres in the watershed together with watershed location and slope.
4. The total detention storage ($V_s$) can be determined by computing the detention storage between the water level at the point where the emergency spillway starts to flow and the

Table 32. Relationship of $Q_{op}/Q_{ip}$ to $V_{sp}/V_{rp}$ for Principal Spillway Design [from Beasley (2)].

| $V_{sp}/V_{rp}$ | $Q_{op}/Q_{ip}$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| 0.0 | 1.00 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.88 |
| 0.1 | 0.87 | 0.85 | 0.84 | 0.82 | 0.81 | 0.79 | 0.78 | 0.76 | 0.74 | 0.73 |
| 0.2 | 0.72 | 0.70 | 0.68 | 0.67 | 0.65 | 0.64 | 0.62 | 0.61 | 0.60 | 0.58 |
| 0.3 | 0.57 | 0.55 | 0.54 | 0.52 | 0.51 | 0.50 | 0.49 | 0.47 | 0.46 | 0.45 |
| 0.4 | 0.44 | 0.43 | 0.42 | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 | 0.36 | 0.35 |
| 0.5 | 0.34 | 0.33 | 0.32 | 0.31 | 0.30 | 0.29 | 0.28 | 0.27 | 0.27 | 0.26 |
| 0.6 | 0.25 | 0.24 | 0.23 | 0.22 | 0.22 | 0.21 | 0.20 | 0.20 | 0.19 | 0.18 |
| 0.7 | 0.18 | 0.17 | 0.16 | 0.15 | 0.15 | 0.14 | 0.14 | 0.13 | 0.12 | 0.12 |
| 0.8 | 0.11 | 0.11 | 0.10 | 0.09 | 0.09 | 0.08 | 0.08 | 0.07 | 0.07 | 0.06 |
| 0.9 | 0.05 | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 |

water level when the emergency spillway is flowing at the design depth together with the detention storage from the principal spillway.

5. $V_s/V_r$ are computed.
6. The value of $Q_{oe}/Q_i$ can be determined from Table 33.
7. The flow through the emergency spillway $Q_{oe}$ will be obtained.

## Water Supply System

Embankment Ponds: Beasley (7) points out that a pipe can be installed under the dam in cases where water is needed at some points below the dam, and that a 1-1/4 inch pipe will supply sufficient water for most uses.

Excavated Ponds: Water cannot be withdrawn from the pond by gravity. A ramp with a slope of four to one or flater can be constructed for livestock access. If the water is required for other kinds of uses, the pump system can be installed.

Table 33. Relationship of $Q_{oe}/Q_i$ to $V_s/V_r$ for Emergency Spillway Design [from Beasley (2)].

| $V_s/V_r$ | $Q_{oe}/Q_i$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| (a) All flow carried by emergency spillway | | | | | | | | | | |
| 0.2 | 0.91 | 0.90 | 0.89 | 0.87 | 0.86 | 0.85 | 0.83 | 0.82 | 0.80 | 0.79 |
| 0.3 | 0.77 | 0.76 | 0.75 | 0.73 | 0.72 | 0.71 | 0.69 | 0.68 | 0.66 | 0.65 |
| 0.4 | 0.64 | 0.62 | 0.61 | 0.59 | 0.58 | 0.57 | 0.55 | 0.54 | 0.53 | 0.52 |
| 0.5 | 0.51 | 0.49 | 0.48 | 0.47 | 0.46 | 0.44 | 0.43 | 0.41 | 0.40 | 0.39 |
| 0.6 | 0.39 | 0.37 | 0.36 | 0.35 | 0.34 | 0.32 | 0.31 | 0.29 | 0.28 | 0.27 |
| 0.7 | 0.28 | 0.26 | 0.25 | 0.24 | 0.23 | 0.21 | 0.20 | 0.18 | 0.17 | 0.16 |
| 0.8 | 0.17 | 0.16 | 0.15 | 0.14 | 0.13 | 0.11 | 0.10 | 0.09 | 0.08 | 0.07 |
| 0.9 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 |
| (b) $Q_{op}/Q_i$ = 0.10 (capacity of principal equals 10% of peak rate of inflow | | | | | | | | | | |
| 0.2 | 0.83 | 0.81 | 0.80 | 0.78 | 0.77 | 0.76 | 0.74 | 0.73 | 0.72 | 0.70 |
| 0.3 | 0.69 | 0.68 | 0.67 | 0.65 | 0.64 | 0.63 | 0.61 | 0.60 | 0.59 | 0.57 |
| 0.4 | 0.56 | 0.54 | 0.53 | 0.51 | 0.50 | 0.49 | 0.47 | 0.46 | 0.45 | 0.44 |
| 0.5 | 0.43 | 0.41 | 0.40 | 0.39 | 0.37 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 |
| 0.6 | 0.31 | 0.29 | 0.28 | 0.27 | 0.26 | 0.24 | 0.23 | 0.22 | 0.21 | 0.20 |
| 0.7 | 0.19 | 0.18 | 0.17 | 0.16 | 0.15 | 0.14 | 0.13 | 0.12 | 0.11 | 0.10 |
| 0.8 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.01 | 0.00 |
| (c) $Q_{op}/Q_i$ = 0.20 (capacity of principal equals 20% of peak rate of inflow | | | | | | | | | | |
| 0.2 | 0.75 | 0.74 | 0.72 | 0.71 | 0.69 | 0.68 | 0.66 | 0.65 | 0.63 | 0.62 |
| 0.3 | 0.61 | 0.60 | 0.58 | 0.57 | 0.55 | 0.54 | 0.52 | 0.51 | 0.50 | 0.49 |
| 0.4 | 0.48 | 0.47 | 0.45 | 0.44 | 0.42 | 0.41 | 0.39 | 0.38 | 0.37 | 0.36 |
| 0.5 | 0.35 | 0.34 | 0.32 | 0.31 | 0.30 | 0.29 | 0.27 | 0.26 | 0.25 | 0.24 |

Table 33. Relationship of $Q_{oe}/Q_i$ to $V_s/V_r$ for Emergency Spillway Design (Continued)

| $V_s/V_r$ | $Q_{oe}/Q_i$ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| 0.6 | 0.23 | 0.22 | 0.20 | 0.19 | 0.18 | 0.17 | 0.15 | 0.14 | 0.13 | 0.12 |
| 0.7 | 0.11 | 0.10 | 0.08 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.01 |
| (d) $Q_{op}/Q_i$ = 0.30 (capacity of principal equal 30% of peak rate of inflow | | | | | | | | | | |
| 0.2 | 0.67 | 0.66 | 0.64 | 0.63 | 0.61 | 0.60 | 0.58 | 0.57 | 0.55 | 0.54 |
| 0.3 | 0.53 | 0.52 | 0.50 | 0.49 | 0.47 | 0.46 | 0.44 | 0.43 | 0.41 | 0.40 |
| 0.4 | 0.39 | 0.38 | 0.36 | 0.35 | 0.33 | 0.32 | 0.31 | 0.30 | 0.28 | 0.27 |
| 0.5 | 0.26 | 0.25 | 0.23 | 0.22 | 0.20 | 0.19 | 0.18 | 0.17 | 0.15 | 0.14 |
| 0.6 | 0.13 | 0.12 | 0.11 | 0.10 | 0.09 | 0.08 | 0.07 | 0.06 | 0.05 | 0.04 |
| 0.7 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |

Table 34. Capacities of Canopy, Hood, Morning Glory, and Drop Inlet Spillways with Smooth Metal Conduits, cfs [from Beasley (2)].

| Length of Conduit, Ft | Total Head, Ft | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 6-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 1.7 | 2.1 | 2.4 | 2.6 | | | | | | | |
| 30 | 1.5 | 1.8 | 2.1 | 2.4 | 2.6 | 2.8 | | | | | |
| 40 | 1.4 | 1.7 | 2.0 | 2.2 | 2.4 | 2.6 | 2.9 | 3.1 | | | |
| 50 | 1.3 | 1.6 | 1.8 | 2.0 | 2.2 | 2.4 | 2.5 | 2.7 | 2.9 | 3.0 | 3.2 |
| 60 | 1.2 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.4 | 2.6 | 2.7 | 2.8 | 3.0 |
| 70 | 1.1 | 1.4 | 1.6 | 1.8 | 2.0 | 2.1 | 2.3 | 2.4 | 2.6 | 2.7 | 2.8 |
| 80 | 1.1 | 1.3 | 1.5 | 1.7 | 1.9 | 2.0 | 2.2 | 2.3 | 2.4 | 2.6 | 2.7 |
| 90 | 1.0 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 | 2.1 | 2.2 | 2.3 | 2.4 | 2.6 |
| 100 | 1.0 | 1.2 | 1.4 | 1.6 | 1.7 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.5 |
| 8-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 3.2 | 3.9 | 4.5 | 5.1 | | | | | | | |
| 30 | 3.0 | 3.6 | 4.2 | 4.7 | 5.1 | 5.5 | | | | | |
| 40 | 2.8 | 3.4 | 3.9 | 4.3 | 4.8 | 5.2 | 5.5 | 5.9 | 6.2 | | |
| 50 | 2.6 | 3.2 | 3.7 | 4.1 | 4.5 | 4.8 | 5.2 | 5.5 | 5.8 | 6.1 | 6.3 |
| 60 | 2.4 | 3.0 | 3.5 | 3.9 | 4.3 | 4.6 | 4.9 | 5.2 | 5.5 | 5.8 | 6.0 |
| 70 | 2.3 | 2.9 | 3.3 | 3.7 | 4.0 | 4.4 | 4.6 | 5.0 | 5.2 | 5.5 | 5.7 |
| 80 | 2.2 | 2.7 | 3.2 | 3.5 | 3.9 | 4.2 | 4.5 | 4.7 | 6.0 | 5.2 | 5.5 |
| 90 | 2.1 | 2.6 | 3.0 | 3.4 | 3.7 | 4.0 | 4.3 | 4.5 | 4.8 | 5.0 | 5.3 |
| 100 | 2.0 | 2.5 | 2.9 | 3.2 | 3.6 | 3.9 | 4.1 | 4.4 | 4.6 | 4.8 | 5.0 |
| 10-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 5.2 | 6.4 | 7.3 | 8.2 | | | | | | | |
| 30 | 4.9 | 6.9 | 7.7 | 8.5 | 9.1 | | | | | | |

Table 34. Capacities of Canopy, Hood, Morning Glory, and Drop Inlet Spillways with Smooth Metal Conduits, cfs (Continued).

| Length of | Total Head, Ft | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Conduit, Ft | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 40 | 4.6 | 5.6 | 6.5 | 7.3 | 8.0 | 8.6 | 9.2 | 9.8 | 10.3 | | |
| 50 | 4.3 | 5.3 | 6.2 | 6.9 | 7.6 | 8.2 | 8.7 | 9.3 | 9.8 | 10.3 | 10.7 |
| 60 | 4.1 | 5.0 | 5.9 | 6.6 | 7.2 | 7.8 | 8.3 | 8.8 | 9.3 | 9.8 | 10.2 |
| 70 | 4.0 | 4.8 | 5.6 | 6.3 | 6.9 | 7.5 | 8.0 | 8.5 | 8.9 | 9.4 | 9.8 |
| 80 | 3.8 | 4.7 | 5.4 | 6.1 | 6.6 | 7.2 | 7.7 | 8.1 | 8.6 | 9.0 | 9.4 |
| 90 | 3.7 | 4.5 | 5.2 | 5.8 | 6.4 | 6.9 | 7.4 | 7.8 | 8.3 | 8.7 | 9.0 |
| 100 | 3.6 | 4.4 | 5.0 | 5.6 | 6.2 | 6.7 | 7.1 | 7.6 | 8.0 | 8.4 | 8.7 |
| | 12-inch Diameter Conduit | | | | | | | | | | |
| 20 | 7.8 | 9.5 | 11 | 12 | | | | | | | |
| 30 | 7.3 | 9.0 | 10 | 12 | 13 | 14 | | | | | |
| 40 | 7.0 | 8.5 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | | |
| 50 | 6.7 | 8.1 | 9.4 | 11 | 12 | 13 | 13 | 14 | 15 | 16 | 16 |
| 60 | 6.4 | 7.8 | 9.0 | 10 | 11 | 12 | 13 | 14 | 14 | 15 | 16 |
| 70 | 6.1 | 7.5 | 8.7 | 10 | 11 | 12 | 12 | 13 | 14 | 14 | 15 |
| 80 | 5.9 | 7.3 | 8.4 | 9.4 | 10 | 11 | 12 | 13 | 13 | 14 | 15 |
| 90 | 5.7 | 7.0 | 8.1 | 9.1 | 10 | 11 | 12 | 12 | 13 | 14 | 14 |
| 100 | 5.6 | 6.8 | 7.9 | 8.8 | 9.7 | 10 | 11 | 12 | 12 | 13 | 14 |
| | 14-inch Diameter Conduit | | | | | | | | | | |
| 20 | 10 | 12 | 14 | 16 | | | | | | | |
| 30 | 9.6 | 12 | 14 | 15 | 17 | 18 | | | | | |
| 40 | 9.2 | 11 | 13 | 14 | 16 | 17 | 18 | 19 | 20 | | |
| 50 | 8.8 | 11 | 12 | 14 | 15 | 17 | 18 | 19 | 20 | 21 | 21 |
| 60 | 8.4 | 10 | 12 | 13 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 70 | 8.2 | 10 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 80 | 8.0 | 10 | 11 | 12 | 14 | 15 | 16 | 17 | 18 | 19 | 19 |
| 90 | 7.7 | 9 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 100 | 7.5 | 9 | 10 | 12 | 13 | 14 | 15 | 16 | 17 | 17 | 18 |

Table 34. Capacities of Canopy, Hood, Morning Glory, and Drop Inlet Spillways with Smooth Metal Conduits, cfs (Continued)

| Length of Conduit, Ft | Total Head, Ft. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| | 16-inch Diameter Conduit | | | | | | | | | | |
| 20 | 14 | 17 | 19 | 21 | | | | | | | |
| 30 | 13 | 16 | 18 | 20 | 22 | 24 | | | | | |
| 40 | 12 | 15 | 18 | 20 | 22 | 23 | 25 | 26 | 28 | | |
| 50 | 12 | 15 | 17 | 19 | 21 | 22 | 24 | 25 | 27 | 28 | 29 |
| 60 | 12 | 14 | 16 | 18 | 20 | 22 | 23 | 25 | 26 | 27 | 28 |
| 70 | 11 | 14 | 16 | 18 | 19 | 21 | 22 | 24 | 25 | 26 | 27 |
| 80 | 11 | 13 | 15 | 17 | 19 | 20 | 22 | 23 | 24 | 26 | 27 |
| 90 | 11 | 13 | 15 | 17 | 18 | 20 | 21 | 22 | 24 | 25 | 26 |
| 100 | 10 | 13 | 15 | 16 | 19 | 19 | 21 | 22 | 23 | 24 | 25 |
| | 18-inch Diameter Conduit | | | | | | | | | | |
| 20 | 17 | 21 | 25 | 28 | | | | | | | |
| 30 | 17 | 20 | 24 | 27 | 29 | 31 | | | | | |
| 40 | 16 | 20 | 23 | 26 | 28 | 30 | 32 | 34 | 36 | | |
| 50 | 16 | 19 | 22 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 38 |
| 60 | 15 | 19 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 37 |
| 70 | 15 | 18 | 21 | 23 | 26 | 28 | 30 | 31 | 33 | 35 | 36 |
| 80 | 14 | 18 | 20 | 23 | 25 | 27 | 29 | 30 | 32 | 34 | 35 |
| 90 | 14 | 17 | 20 | 22 | 24 | 26 | 28 | 30 | 31 | 33 | 34 |
| 100 | 14 | 17 | 19 | 22 | 24 | 26 | 27 | 29 | 31 | 32 | 33 |
| | 20-inch Diameter Conduit | | | | | | | | | | |
| 20 | 22 | 27 | 31 | 34 | | | | | | | |
| 30 | 21 | 26 | 30 | 33 | 36 | 39 | | | | | |
| 40 | 20 | 25 | 29 | 32 | 35 | 38 | 41 | 43 | 45 | | |
| 50 | 20 | 24 | 28 | 31 | 34 | 37 | 40 | 42 | 44 | 46 | 49 |

Table 34. Capacities of Canopy, Hood, Morning Glory, and Drop Inlet Spillways with Smooth Metal Conduits, cfs (Continued).

| Length of Conduit, Ft | Total Head, Ft | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 60 | 19 | 24 | 27 | 30 | 33 | 36 | 38 | 41 | 43 | 45 | 47 |
| 70 | 19 | 23 | 26 | 30 | 32 | 35 | 37 | 40 | 42 | 44 | 46 |
| 80 | 18 | 22 | 26 | 29 | 32 | 34 | 36 | 39 | 41 | 43 | 45 |
| 90 | 18 | 22 | 25 | 28 | 31 | 33 | 36 | 38 | 40 | 42 | 44 |
| 100 | 17 | 21 | 25 | 28 | 30 | 32 | 35 | 37 | 39 | 41 | 43 |
| 24-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 32 | 39 | 45 | 51 | | | | | | | |
| 30 | 31 | 38 | 44 | 50 | 54 | 59 | | | | | |
| 40 | 30 | 37 | 43 | 48 | 53 | 57 | 61 | 65 | 68 | | |
| 50 | 30 | 36 | 42 | 47 | 52 | 56 | 60 | 63 | 67 | 70 | 73 |
| 60 | 29 | 36 | 41 | 46 | 51 | 55 | 59 | 62 | 65 | 68 | 72 |
| 70 | 28 | 35 | 40 | 45 | 49 | 53 | 57 | 60 | 64 | 67 | 70 |
| 80 | 28 | 34 | 40 | 44 | 48 | 52 | 56 | 59 | 62 | 65 | 68 |
| 90 | 27 | 34 | 39 | 43 | 47 | 51 | 55 | 58 | 61 | 64 | 67 |
| 100 | 27 | 33 | 38 | 42 | 46 | 50 | 54 | 57 | 60 | 63 | 66 |
| 26-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 36 | 44 | 51 | 57 | | | | | | | |
| 30 | 35 | 43 | 49 | 55 | 60 | 65 | | | | | |
| 40 | 34 | 42 | 48 | 54 | 59 | 64 | 68 | 72 | 76 | | |
| 50 | 33 | 41 | 47 | 53 | 58 | 62 | 67 | 71 | 74 | 78 | 81 |
| 60 | 33 | 40 | 46 | 52 | 56 | 61 | 65 | 69 | 73 | 76 | 80 |
| 70 | 32 | 39 | 45 | 50 | 55 | 59 | 64 | 68 | 71 | 75 | 78 |
| 80 | 31 | 38 | 44 | 49 | 54 | 58 | 62 | 66 | 70 | 73 | 76 |
| 90 | 31 | 37 | 43 | 48 | 53 | 57 | 61 | 65 | 69 | 72 | 75 |
| 100 | 30 | 36 | 42 | 47 | 52 | 56 | 60 | 64 | 67 | 71 | 74 |

Table 34. Capacities of Canopy, Hood, Morning Glory, and Drop Inlet Spillways with Smooth Metal Conduits, cfs (Continued).

| Length of Conduit, Ft | Total Head, Ft | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 30-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 51 | 62 | 72 | 80 | | | | | | | |
| 30 | 50 | 61 | 70 | 78 | 86 | 93 | | | | | |
| 40 | 49 | 60 | 69 | 77 | 84 | 91 | 97 | 103 | 109 | | |
| 50 | 48 | 58 | 68 | 75 | 83 | 89 | 96 | 101 | 107 | 112 | 117 |
| 60 | 47 | 57 | 66 | 74 | 81 | 88 | 94 | 99 | 105 | 110 | 115 |
| 70 | 46 | 56 | 65 | 73 | 80 | 86 | 92 | 98 | 103 | 108 | 113 |
| 80 | 45 | 55 | 64 | 72 | 78 | 85 | 91 | 96 | 101 | 106 | 111 |
| 90 | 44 | 54 | 63 | 70 | 77 | 83 | 89 | 94 | 99 | 104 | 109 |
| 100 | 44 | 53 | 62 | 69 | 76 | 82 | 88 | 93 | 98 | 103 | 107 |
| 36-inch Diameter Conduit | | | | | | | | | | | |
| 20 | 75 | 91 | 105 | 117 | | | | | | | |
| 30 | 73 | 89 | 103 | 115 | 126 | 136 | | | | | |
| 40 | 72 | 88 | 102 | 114 | 124 | 134 | 144 | 152 | 161 | | |
| 50 | 71 | 87 | 100 | 112 | 123 | 131 | 142 | 150 | 158 | 166 | 173 |
| 60 | 70 | 86 | 98 | 110 | 121 | 130 | 140 | 148 | 156 | 163 | 171 |
| 70 | 69 | 84 | 97 | 109 | 119 | 129 | 138 | 146 | 154 | 161 | 168 |
| 80 | 68 | 83 | 96 | 107 | 117 | 127 | 135 | 144 | 151 | 159 | 166 |
| 90 | 67 | 82 | 95 | 106 | 116 | 125 | 134 | 142 | 149 | 157 | 164 |
| 100 | 66 | 81 | 93 | 104 | 114 | 123 | 132 | 140 | 147 | 155 | 162 |

## MODEL PROBLEM SOLUTIONS

The techniques previously described for designing certain selected soil and water conservation structures are modified to fit Thailand's conditions and used in the following designs.

1. Peak Rates of Runoff: The problem is to determine the peak rates of runoff to be expected once in ten years from a ten-acre watershed located near Bangkok, Thailand, having the following characteristics:

   (1) Chainat soil series

   (2) Land slope average of 1 percent

   (3) The runoff has to travel a maximum distance of 1600 ft in reaching the discharge point

   (4) Six acres of row crop land in the upper half of the watershed is terraced. The terraces average 1300 ft in length. The crop rows are planted parallel to the terraces.

   (5) Four acres of good quality meadow in the lower half of the watershed are not terraced.

   (6) There are no impoundments, except terraces, on this watershed

Beasley's (2,6) procedure, as modified earlier in this report for Thailand conditions, can be used to estimate peak flows. The formula is:

$$Q = Q_T \text{ x } L \text{ x } I \text{ x } T \text{ x } S \text{ x } V \text{ x } C \text{ x } P \text{ x } F.$$

where

| Condition | Factor |
|---|---|
| $Q_T$, the peak rate of runoff for a ten acre watershed from Table 4 is 72 c.f.s. | |
| L, Location in Bangkok | 2.20 |
| I, Soil infiltration factor of chainat series | 1.20 |
| T, Topographic factor when land slope is one percent | 0.65 |
| S, Watershed shape factor when the maximum distance of water flow is 1600 ft | 0.80 |
| V, Vegetative cover factor;<br>6 acres row crop (1.0)<br>4 acres meadow (0.5) | 0.80 |
| C, Contouring | 0.99 |
| P, Surface storage factor | 0.89 |
| F, Ten-year frequency runoff | 1.00 |

The peak rate of runoff from this ten acre watershed near Bangkok can then be estimated by substituting the factor values in the formula

$$
\begin{aligned}
Q &= Q_T \text{ x } L \text{ x } I \text{ x } T \text{ x } S \text{ x } V \text{ x } C \text{ x } P \text{ x } F \\
&= 72 \text{ x } 2.2 \text{ x } 1.2 \text{ x } 0.65 \text{ x } 0.80 \text{ x } 0.80 \text{ x } 0.99 \text{ x } 0.89 \text{ x } 1.0 \\
&= 69.7 \text{ c.f.s.}
\end{aligned}
$$

2. Grassed Waterways: The problem is to design a grassed

waterway to take care of the surplus water from a five-acre field of corn located near Ubon-ratchathani, Thailand, having the following characteristics:

(1) Phon Phi Say series

(2) Land slopes average 8 percent

(3) The runoff must travel a maximum distance of 900 ft in reaching the discharge point

(4) Corn is grown on the entire field which is terraced. The terraces average 500 ft in length. The corn is planted parallel to the terraces.

(5) There are no impoundments, except terraces, in the field

(6) The soil is erodible but is covered with a good stand of bluegrass

Using Beasley's (2,6) procedure, the peak flow expected once in ten years from this five acres of corn is:

$$Q = Q_T \times L \times I \times T \times S \times V \times C \times P \times F$$

$$= 38 \times 2.2 \times 0.8 \times 1.00 \times 0.85 \times 1.0 \times 0.95 \times 0.95 \times 1.00$$

$$= 51 \quad \text{c.f.s.}$$

To design grassed waterways with minimum capacity of 51 c.f.s. the design characteristics from Beasley (34) are:

Average land slope = 8 percent

Discharge, Q = 51 c.f.s.

The soil is erodible and good stand of bluegrass is established

Maximum permissible velocity for grassed waterway (from Table 8) = 3.5 ft per sec

From Table 10, the dimension of a trapezoidal waterway is

Bottom width B = 37 ft; Depth of flow,
D = 0.6 ft

From Table 11, the dimensions of a parabolic waterway is

Top width T = 44 ft; Depth of flow
D = 0.9 ft

3. Diversions: The problem is to design a diversion to convey the runoff from a ten-acre field of cotton and peanuts located near Udon thani, Thailand, having the following characteristics:

   (1) Loei Series

   (2) Land slopes average 8 percent

   (3) The runoff must travel a maximum distance of 1,600 ft in reaching the discharge point

   (4) Cotton and peanuts are cultivated as the row crops in the entire watershed which is terraced. The terraces average 1000 ft in length. The peanuts and cotton are planted parallel to the terraces.

   (5) There are no impoundments, except terraces, on the watershed

   (6) The soil is less erodible with fair stand of bermuda grass.

   (7) The channel grade is 0.8 percent

By using Beasley's (2,5) procedure, the peak rate of runoff expecting once in ten years from this ten acres of cotton and peanuts is:

$Q = Q_T \times L \times I \times T \times S \times V \times C \times P \times F$

$= 72 \times 2.2 \times 0.9 \times 1.00 \times 0.80 \times 1.0 \times 0.95 \times 0.90 \times 1.00$

$= 97.5$ c.f.s.

To design diversions with minimum capacity of 97.5 c.f.s., the the design procedure from Beasley (2,5) is as follows:

Discharge, Q = 97.5 c.f.s.

The soil is less erodible and fair stand of bermuda grass is established.

$\therefore$ Maximum permissible velocity in the channel

= 4.0 ft per sec

The channel grade is = 0.8 percent

From Table 14, the dimension of diversion can be obtained:

Bottom width (B) = 10 ft

The height of diversion ridge (H) = 2.1 ft

4. Diversion Terraces: The problem is to design a diversion terrace to transport the runoff from a five acre field of peanuts located near Chiangmai, Thailand, having the following characteristics:

(1) Chiangmai Series

(2) Land slopes average 5 percent

(3) The runoff has to travel a maximum distance of 1,100 ft in reaching the discharge point

(4) One acre of this five-acre watershed is farmed on the contour, and the other four acres of peanuts are planted across the slope without terraces.

(5) There are no impoundments in the field

(6) The soil is less erodible with uniform slopes

Using Beasley's (2,5) procedure, the peak rate of runoff expected once in ten years from this five acres of peanuts is:

$Q = Q_T \times L \times I \times T \times S \times V \times C \times P \times F$

$= 38 \times 2.2 \times 1.0 \times 0.88 \times 0.80 \times 1.0 \times 0.99 \times 1.00 \times 1.00$

$= 58.3$ c.f.s.

To design the terrace with a minimum capacity of 58.3 c.f.s., the design characteristics from Beasley (2,3) are:

The soil is chiengmai series

Average slope of the land = 5 percent

The soil is less erodible with uniform slopes

From Table 17, the vertical interval = 5.3 ft

The horizontal distance = 107 ft

Discharge of runoff, Q = 58.3 c.f.s.

The soil is low permeable, then from Table 19 the grade of the terrace = 0.3 percent

Cut slope and front slope of terrace = 10:1

The graded terrace is 1,300 ft long

Depth of flow in the v-shaped terrace is 0.9 ft at the distance 1,300 ft from the upper end of terrace (Table 23)

D = 0.9 ft; S = 0.3 percent

Cross-sectional area of v-shaped channel, A

$= 1/2(9+9)0.9 = 8.1$ sq ft

Velocity in the channel, $V = \frac{1.49}{n} R^{2/3} S^{1/2}$

$= \frac{1.49}{0.06} (\frac{8.1}{18.08})^{2/3} (0.3)^{1/2}$

$= 24.85\ (0.448)^{2/3} (0.548)$

$= 24.85 \times 0.586 \times 0.548$

$= 7.98$ ft per sec

$\therefore$ Discharge $Q = AV$

$= 8.1 \times 7.98$

$= 64.7$ c.f.s.

The v-shaped graded terrace with ten-to-one side slopes, a grade of 0.3 percent, 0.5 ft free board with the ridge heights 1.4 ft and 1,300 ft long are required to carry the discharge of runoff from this area (Table 23).

5. Farmpond: The problem is to design a pond to be constructed in Nakhon-ratchasima to provide
   (1) Drinking water and water for barn and utensil cleanup for 40 dairy cows in production
   (2) Drinking water for 30 beef cows
   (3) Household water for a family of 6 people
   (4) A reserve pool 5 feet deep
   (5) Maximum depth limited to 12 ft

Then water requirements for intended uses:

40 producing cows @ 50 gallons (Table 24) = 2,000 gallons per day

30 beef cows @ 15 gallons (Table 24) = 450 gallons per day

6 people @ 50 gallons (Table 24) = 300 gallons per day

Total 2,750 gallons per day

The pond will be built large enough to provide sufficient water to supply the above uses for a 1-year period. The yearly use will be 365 x 2,750 = 1,003,750 gallons. Since an acre-ft contains 326,000 gallons,

The yearly use expressed in acre-ft will be

$$= \frac{1,003,750}{326,000} = 3.08 \text{ acre-ft}$$

Total losses from the pond include evaporation losses, seepage, and reserve pool and can be determined as follows:

Evaporation losses: In Nakhon-ratchasima, evaporation from the pond surface in a dry year will exceed precipitation by 0.9 ft. Assuming a ten-ft maximum depth, the evaporation losses as shown in Table 25 will equal to 0.9 x 14

= 12.6 percent of the total volume if the water is not withdrawn below the 5-ft level.

Seepage: Assume the seepage losses to be 3 percent

Reserve Pool: The 5 ft of water retained in the reserve pool will amount to 29 percent of the total volume (Table 26).

Then total losses:

Evaporation = 13 percent of the total volume

Seepage = 3 percent of the total volume

Reserve pool = 29 percent of the total volume

Total = 45 percent of the total volume

Total Storage Capacity: Since the losses amount to 45 percent of the total volume, the amount of water needed for intended uses (3.08 acre-ft) equals 55 percent of the total capacity.

55 percent = 3.08 acre-ft
100 percent = 5.6 acre-ft
= total capacity of the pond

The size of drainage area can be computed as follows: From the previous situation, a storage capacity of 5.6 acre-ft was required of which,

55 percent was for the intended use
13 percent was for evaporation losses
3 percent was for seepage losses
29 percent was in the reserve pool

The amount of water needed to replace that which is used, lost by evaporation, and seepage is 71 percent of the total volume.

Seventy-one percent of 5.6 equal to 3.97 acre-ft

From Figure 12, the pond located in Nakhon-ratchersima, 3 acres of drainage area will be required per acre foot of water to be replaced during one-year period of intended use.

Then the minimum size of the drainage area is

3 x 3.97 = 11.9 acres

Assuming that the actual drainage area into the pond is 15 acres, then the following example illustrates how to calculate the dimensions of the principal spillway and the emergency spillway:

The watershed has the following characteristics:

a) Drainage area - 15 acres

b) Location - Nakhon ratchasima; L - 2.2

c) Soil - Bun trick series; I = 1.1

d) Average landslope on watershed - 6 percent; T = 0.92 (Table 5)

e) Maximum distance that runoff travels in reaching the structure - 1600 ft; S = 0.8 (Table 6).

f) 5 acres of row crop land are terraced, and 10 acres of good quality meadow are not terraced;

$$V = \frac{5 \times 1.0 + 10 \times 0.5}{15} = 0.66, \; C = 0.99$$

g) The average length of terraces is 1,600 ft; P - 0.85 (Table 7)

h) There is no appreciable surface detention storage on the watershed above the proposed structure

i) The conditions of emergency spillway are such that it may be used once each two years. A two-year frequency storm will be used in the design of the principal spillway; then runoff-frequency factor F = 0.5

j) A twenty-five year frequency storm should be used in the design of the total structure; so runoff frequency factor, F = 1.3

k) The reservoir pool will cover $= \frac{5.6 \text{ acre-ft}}{0.45 \times 10 \text{ ft}} - 1.2$ acres when flow starts through the principal spillway

l) The emergency spillway will be located at an elevation

1 ft above the level of the principal spillway

m) When the flow starts through the emergency spillway, the reservoir pool will cover 1.5 acres

n) The depth of flow through the emergency spillway should not exceed 1.5 ft.

o) When the depth of flow in the emergency spillway is 1.5 ft, the reservoir pool will cover 2 acres

p) The conduit for the principal spillway will be smooth iron pipe 60 ft long with a drop inlet. The total head causing flow 14 ft.

The size of the principal spillway can be determined step by step as follows:

1. The principal spillway is designed for a two-year frequency storm

2. The peak rate of runoff from the watershed for this two-year frequency storm is

$$Q_{ip} = Q_T \text{ x } L \text{ x } L \text{ x } I \text{ x } T \text{ x } S \text{ x } V \text{ x } C \text{ x } P \text{ x } F$$

$$Q_{ip} = 104 \text{ x } 2.2 \text{ x } 1.1 \text{ x } 0.92 \text{ x } 0.8 \text{ x } 0.66 \text{ x } 0.99 \text{ x } 0.85 \text{ x } 0.5$$

$$= 51.2 \text{ c.f.s.}$$

3. VxI = 0.66 x 1.1 = 0.726

From Table 31 the volume of runoff in acre-ft per acre = 0.0526

Location factor = 2.2

Then the volume of runoff will be

$= 0.0526 \times 2.2 = 0.1125$ acre ft per acre

The total volume of runoff

$V_{rp} = 0.1125 \times 15 = 1.69$ acre-ft

4. The amount of detention storage between the principal and emergency spillways is equal to the average pool area times the depth

$$V_{sp} = \frac{1.2 + 1.5}{2} \times 1 = 1.35 \text{ acre-ft}$$

5. $\frac{V_{sp}}{V_{rp}} = \frac{1.35}{1.69} = 0.8$

6. From Table 32 $\frac{Q_{op}}{Q_{ip}} = 0.11$

7. $Q_{op} = 0.11 \times 51.2 = 5.62$ c.f.s.

8. From Table 34, 10-inch smooth pipe having a capacity of 7.8 c.f.s. will be required

The size of the emergency spillway can be determined as follows:

1. The total structure is designed for a twenty-five year frequency storm

2. The peak rate of runoff from the watershed for this twenty-five year frequency storm is

$Q_i = Q_t \times L \times I \times T \times S \times V \times C \times P \times F$

$= 104 \times 2.2 \times 1.1 \times 0.92 \times 0.8 \times 0.66 \times 0.99 \times 0.85 \times 1.3$

$= 133.12$ c.f.s.

3. $V \times I = 0.66 \times 1.1 = 0.726$

From Table 31 the volume of runoff in acre-ft per acre = 0.144

Location factor = 2.2

Then the volume of runoff will be

$$= 0.144 \times 2.2 = 0.3168 \text{ acre-ft per acre}$$

The total volume of runoff

$$V_r = 0.3168 \times 15 = 4.752 \text{ acre-ft}$$

4. The amount of detention storage above the emergency spillway level is equal to the average pool area times the depth

$$\frac{1.5 \text{ acres} + 2 \text{ acres}}{2} = 2.62 \text{ acre-ft}$$

The detention storage for the principal spillway, 1.35 acre-ft will be added to obtain the total detention storage $V_s$.

$$V_s = 2.62 + 1.35 = 3.97 \text{ acre-ft}$$

5. $\frac{V_s}{V_r} = \frac{3.97}{4.752} = 0.835$

6. and $\frac{Q_{op}}{Q_i} = \frac{5.62}{133.12} = 0.04225$

From Table 32 (a) $\frac{Q_{oe}}{Q_i}$ will be obtained equal to 0.135

7. $Q_{oe} = 0.135 \times 133.12 = 17.9$ c.f.s.

8. From Table 24, when the emergency spillway has the capacity to carry 17.9 c.f.s. at a depth of flow of 1.5 ft, the control section of the emergency spillway should be 10 ft wide.

# CONCLUSIONS

Model problem solutions for peak rate of rainfall, grass waterways, diversions, diversion terraces, and farm ponds for Thailand application have been developed in this study. These solutions were based on previous research conducted in the United States with modifications made based on the different conditions existing in Thailand. However, due to limited records relating to climatic factors, land use, and soil characteristics in Thailand, further modifications most likely will be necessary as more data in these areas are collected and analyzed.

The models developed in this study, however, can serve as definite guides for implementing soil and water engineering in field applications. Evaluations can then be made as to their effectiveness. This experience will also serve to determine what additional modifications need to be made.

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# ADAPTING SELECTED SOIL AND WATER ENGINEERING TECHNOLOGY TO THAILAND CONDITIONS

by

Kraisorn Weerasopone

## (ABSTRACT)

Techniques were developed for the purpose of applying soil and water conservation structure designs utilized in the United States for use in Thailand. Design parameters currently being used in the United States were first studied and evaluated as to their development and application. The range of application of the various soil and water conservation structures were determined. This process included an evaluation of the soil types, land use, topography, and climatic factors in terms of their effect on the types of soil and water conservation structure designs to be utilized. Since the parameters may act separately or in various combinations, design limits are essential for each one.

In the second step of the study, all available survey data applicable in characterizing these same parameters in Thailand were assembled and analyzed for each region. From this analysis, design ranges and the limits for each factor were estimated, based on the research and experience in the United States. Particular attention focused on the research of Beasley and the research compiled in the Engineering Field Manual.

Finally, these estimated design values for Thailand's conditions were substituted in United States formulae. From these substitutions,

other design procedures for model designs of several major engineering soil and water conservation structures were developed.