# THE DESIGN OF ROADSIDE DRAINAGE CHANNELS

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## SYNOPSIS

Good surface drainage is an important element in the safe, convenient and economical use of a highway. In this paper, the author presents a simple method of analysis which indicates how to design channels to avoid future difficulty and abnormal expense in maintaining the surface drainage system. This analysis consists of first estimating the peak rate of runoff from each drainage area contributing to channels on the highway; second, checking the ability of these channels to carry the estimated discharge without eroding or overflowing; and third, designing protection against erosion or designing modified channel sections for increased capacity where necessary.

This discussion is limited to consideration of the problem in the humid sections of the country where sod can be readily established since space does not permit discussing the radically different treatments necessary in arid regions. The 'thatching' action of sod in protecting the soil against erosion increases manyfold the depth of water which may be satisfactorily carried in a given channel and also the maximum gradient permissible for such a channel. The cost of providing sod is usually substantially less than the cost of paved gutters, the design of which is also discussed.

## INTRODUCTION

The scope of this study is the design of roadside drainage channels with respect to erosion control, adequate capacity for normal peak rates of runoff, landscape considerations, efficient maintenance, ultimate economy and traffic safety. Because climatic conditions greatly affect methods which may be successfully employed for erosion control, the scope is limited geographically to the humid regions where rainfall is sufficient in amount and seasonal distribution to support native grasses forming a good sod.

## Fundamental Considerations

The primary purpose of the roadside drainage channel is to provide for efficient removal of surface runoff from the roadway so that traffic may move safely, and park clear of the paved roadway in rainy weather when necessity requires. The channel, therefore, should have adequate capacity to carry the normal peak rate of run-off without overflowing. For ultimate economy, the channel should retain this capacity for the life of the road without excessive maintenance costs; this means that the channel should not erode or silt up. In the snow belt, the channel may be designed for snow storage. Since safety is one of the paramount considerations in highway design, the drainage channel should have gently-sloping sides and a flat-rounded bottom so that a vehicle forced off the roadway may run down into the channel without overturning. In hilly or mountainous country, practical considerations of economy in first cost will limit the extent to which this ideal cross-section may be attained. Prevailing or obsolete standards of right-of-way width should not be permitted to restrict the width of channel necessary for hydraulic capacity or traffic safety.

The modern highway cross-sections in use in most of the State highway departments are in accord with these design principles in varying degrees. The emphasis on traffic safety together with the increasing appreciation of good landscape design has resulted in wide-spread acceptance of the wide shallow roadside drainage channel in place of the deep narrow ditch carried over from railroad design. The practice of seeding or otherwise artificially establishing sod on shoulders, slopes and drainage channels where feasible has developed as the necessity for controlling erosion became apparent. The principal object of this study is to present a simple method of determining in advance of construction the portions of drainage channel which are likely to erode unless treatment other than ordinary seeding is provided.

## Predetermining Erosion Hazard in Drainage Channels

Control of erosion is fundamentally a matter of controlling velocity or of treating the material so that it will withstand the velocity likely to occur. The velocity at which water will flow in a given channel depends on the inter-related factors of grade, shape of cross-section, roughness of channel lining and the rate at which water is being delivered to the channel. Figure 1 is a simple diagram which takes all these factors into consideration.

This diagram is to be used for investigating the erosion hazard in the typical roadside channel and is applicable only to the cross-section for which it is computed. Since simplicity in design and construction requires the use of a standardized cross-section as much as possible this limitation is not a serious drawback, particularly since similar diagrams for other shapes of channel commonly used can be readily prepared. Figures 2 and 3 are diagrams for two other cross-sections. The curves ate computed by the Manning formula.

## TABLE I, ALLOWABLE VELOCITIES

| Type of lining | Allowable Velocity (ft. per sec.) |
|---|---|
| Well-established grass on any good soil | |
| Bermuda grass | 6 |
| Bluegrass | 5 |
| Smooth brome grass | 5 |
| Western wheat grass | 4 |
| Buffalo grass | 4 |
| Sudan grass (annual, temporary cover) | 3 |
| Common lespedeza (annual, reseeding) | 3 |
| Lespedeza Sericea | 3 |
| Earth without any vegetation | |
| Fine sand or silt, non-colloidal | 1 to 2 |
| Ordinary firm loam | 2 to 3 |
| Stiff clay, very colloidal | 4 |
| Clay and gravel | 4 |
| Coarse gravel | 4 |
| Shale | 5 |

Data for vegetal channels from Roadside Development Report, Part II, Appendix IV, April 1940.
Data for other materials adapted from recommendations of Special Committee on Irrigation Research, Am. Soc. Civil Eng. 1926.

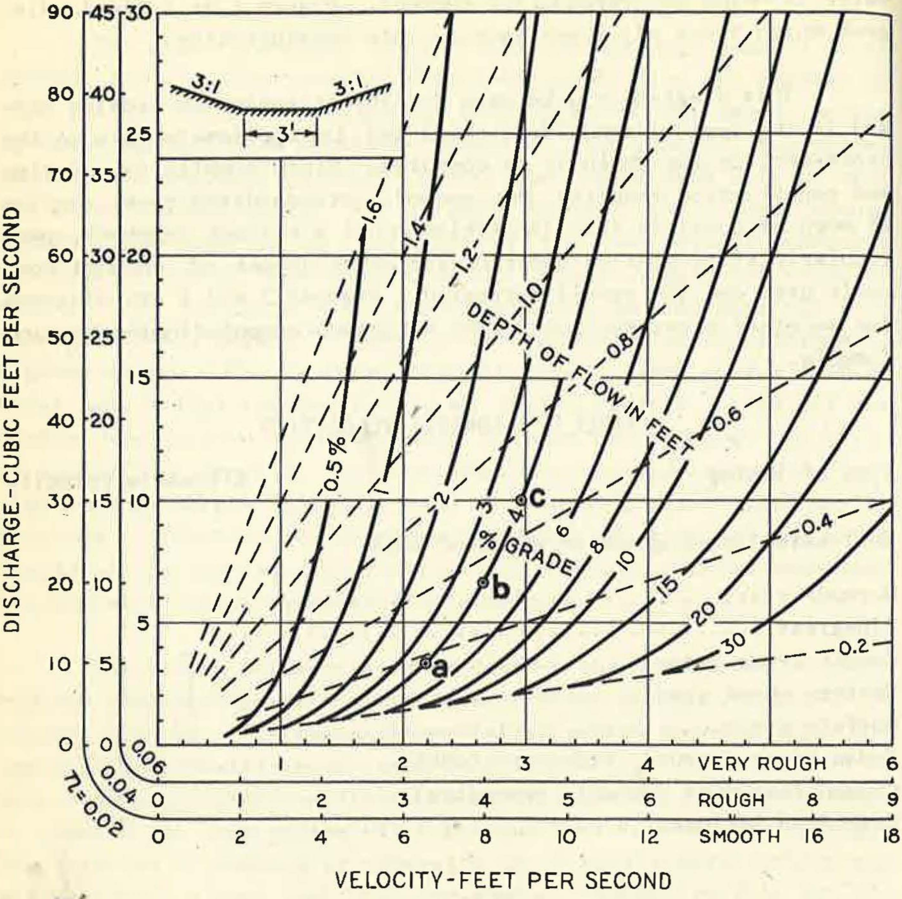


FIGURE I. RELATIONS BETWEEN GRADE, DEPTH, DISCHARGE, AND VELOCITY FOR A CHANNEL 3 FEET WIDE AT THE BOTTOM AND HAVING 3:1 SIDE SLOPES, FOR VARIOUS LININGS

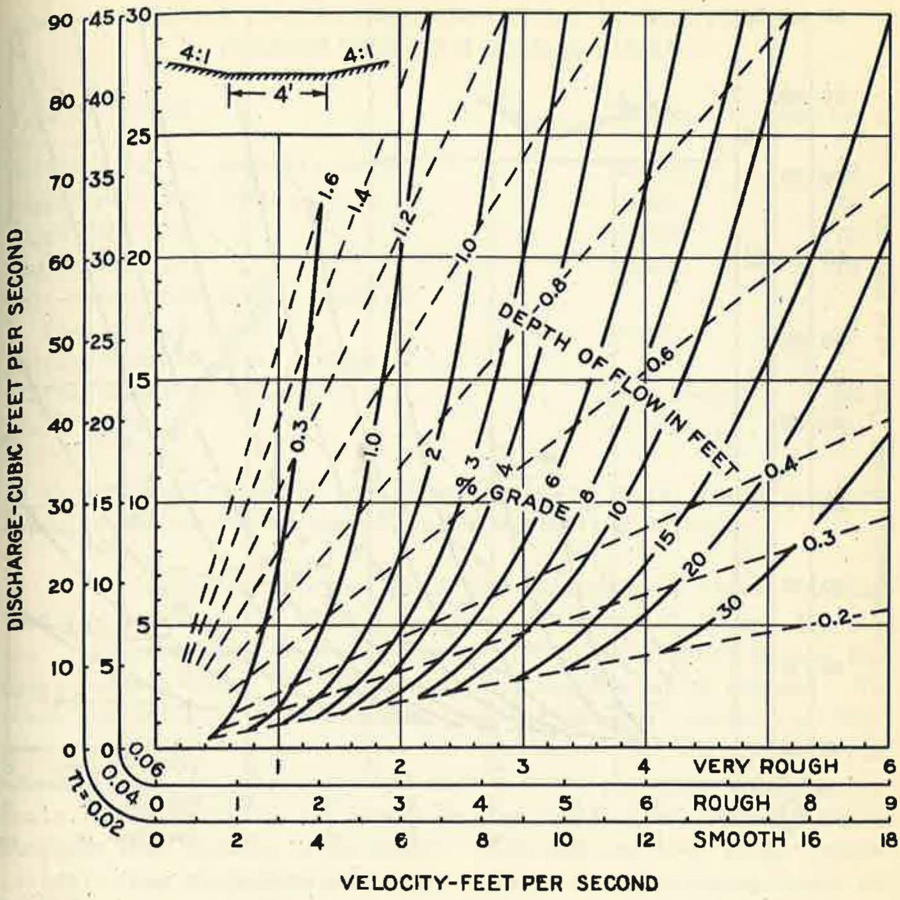


FIGURE 2.-RELATIONS BETWEEN GRADE, DEPTH, DISCHARGE AND VELOCITY FOR A CHANNEL 4 FEET WIDE AT THE BOTTOM AND HAVING 4:1 SIDE SLOPES, FOR VARIOUS LININGS.

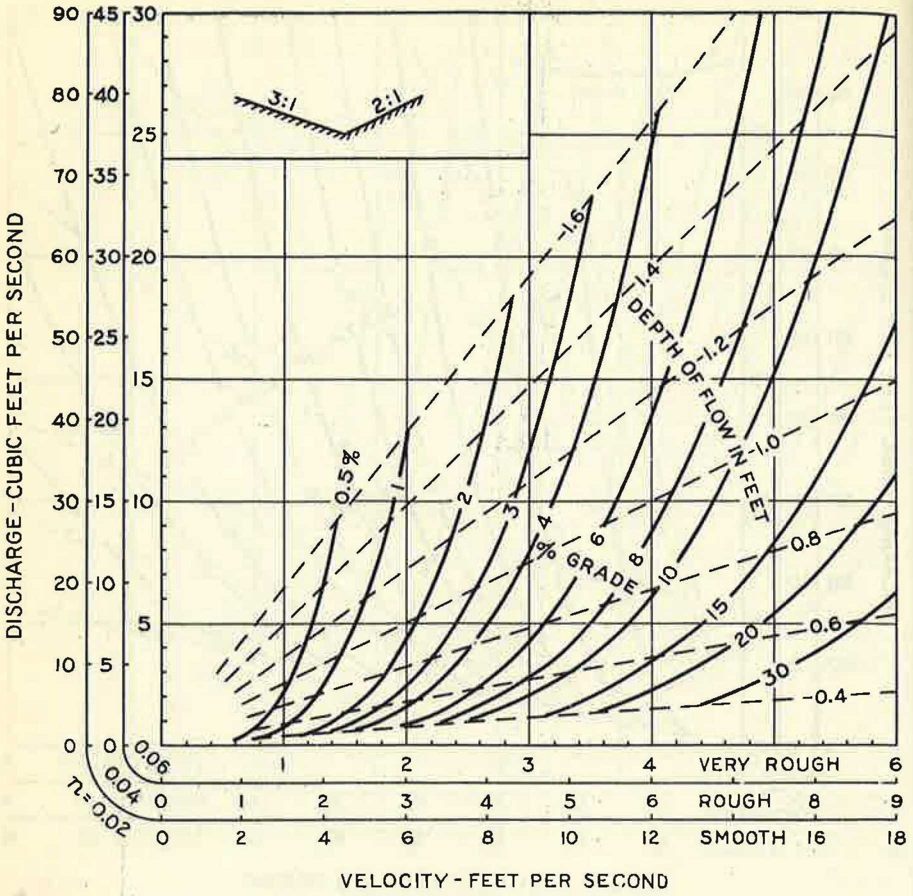


FIGURE 3.- RELATIONS BETWEEN GRADE, DEPTH, DISCHARGE, AND VELOCITY FOR A V-SHAPED CHANNEL HAVING 3:1 AND 2:1 SIDE SLOPES, FOR VARIOUS LININGS

## TABLE 2, CHANNEL ROUGHNESS FOR USE IN SELECTING SCALES ON VELOCITY-DISCHARGE DIAGRAM

| Type of lining | Scale | Manning n |
|---|---|---|
| Ordinary earth, smoothly graded | smooth | 0.02 |
| Jagged rock, or rough rubble | rough | .04 |
| Rough concrete | smooth | .02 |
| Smooth rubble | smooth | .02 |
| Well-maintained grass, depth of flow over 6-inches | rough | .04 |
| Well-maintained grass, depth of flow under 6-inches | very rough | .06 |
| Heavy grass | very rough | .06 |

In general, use roughest condition likely to exist for estimating capacity and smoothest condition for estimating velocity.

The use of the diagram may be illustrated as follows: Assume that the peak rate of runoff has been estimated at 10 cu. ft. per sec. (see paragraph on estimating runoff) for a channel having the cross-section shown in the diagram and a grade of 4 percent. To check the velocity on bare earth, use the 'Smooth' scale. (n=.02); move along the 4 percent curve to the point 'a' where discharge equals 10 cu. ft. per sec. and read 6.8 ft. per sec. on velocity scale. This velocity is excessive for earth (see Table 1) so we conclude that sodding is necessary. With sod use the 'Rough' scale (n=.04); from the 4 percent curve at 'b' we read velocity equal to 4 ft. per sec. This velocity is allowable for a good sod.

If grasses are allowed to grow rank the resistance to flow is increased and the velocity is still further decreased. Since a decrease in velocity must result in an increase in cross-sectional area of flow if the given peak rate of discharge is to be obtained, the channel may be overflowed. To check on this condition the depth of flow should be investigated as follows:

### Checking Capacity of Channel.

The dotted lines are drawn through points of equal depth of flow on the discharge curves. Thus in the preceding example water would flow about 0.4 ft. deep in a bare earth channel (point a), or about 0.55 ft. feep in the sodded channel (point b). If the grasses are allowed to grow rank the flow will be approximately as shown on 'Very Rough' scale (n=.06), point 'c' on curve, which lies about 1/3 of the distance from the 0.6 to the 0.8 ft. depth. The depth of flow is thus approximately 0.67 ft. with rank sod. This illustrates why the required depth of a channel should be based on the roughest condition of the channel likely to exist. A freeboard of at least 0.3 ft. should be provided above this maximum depth of flow to allow for silting, for wave action, and for a factor of safety against too low an estimate of peak runoff.

In channels with comparatively flat side slopes the discharge capacity increases rapidly with small increases in depth, and consequently the allowance of 0.3 ft. freeboard is usually adequate. In the example, increasing the depth to 1.0 ft. more than doubles the discharge capacity at a depth of 0.67 ft. The resulting velocity is about 5.7 ft. per sec. on the 'Rough Scale' which is above the recommended limit for bluegrass sod, but since this limit is in itself conservative, no appreciable damage need be anticipated by an abnormal runoff double that for which the channel was designed. Silting in the bottom of the channel, while reducing the depth of flow, will reduce discharge capacity only a small amount since the major increments of discharge are contained in the top layers of water and not at the bottom of the channel. For the same reason the rounding of the bottom of the channel usually shown on typical cross-sections does not significantly affect the discharge capacity computed for a strictly trapezoidal section.

## Designing for Increased Capacity

In any channel with fixed side slopes the discharge capacity may be increased by increasing (1) grade, (2) bottom width, (3) depth, or through decreasing resistance to flow by providing a smoother lining. Increasing the grade is frequently impractical. Increasing the bottom width has the least effect on the velocity and is therefore desirable where velocity is close to the limit. On the other hand, increasing the depth, while increasing velocity slightly more than that with increased bottom width, is the simplest procedure and also requires less overall width. The latter consideration is important where right of way is restricted or expensive. The smoothing of the channel lining provides increased capacity without increased width (or may even reduce width) but since this must be accomplished by some kind of paving the cost may become excessive.

The effect of channel cross-section upon depth of flow, velocity, and required width of channel is demonstrated in Table 3, based on Figures 1, 2 and 3. Note that the V-shaped channel has an excessive depth of flow and requires nearly as much width as the section with a 3 ft. flat bottom. The discharge flowing full indicates the reserve capacity afforded by the allowance of 0.3 ft. freeboard.

TABLE 3, EXAMPLES OF EFFECT OF CHANNEL SHAPE

Taken from Figures 1, 2 and 3 with Discharge of 10 cu. ft. per sec. flowing in Sodded Channels on a 1 percent grade (n=.06)

| | 3-ft. bottom 3:1 slopes | 4-ft. bottom 4:1 slopes | V-bottom 3:1 & 2:1 Slopes |
|---|---|---|---|
| Depth of flow (ft.) | 0.95 | 0.80 | 1.45 |
| Depth plus 0.3 ft. freeboard | 1.25 | 1.10 | 1.75 |
| Velocity (ft. per sec.) | 1.8 | 1.6 | 1.9 |
| Width (including freeboard)(ft.) | 10.5 | 12.8 | 8.8 |
| Discharge flowing full (cu. ft. per sec.) | 17 | 18 | 16 |

Instead of providing additional capacity in a given channel it is sometimes possible to divert part of the runoff into another channel as by the construction of an intercepting ditch on top of the cut slope. Treatment of the drainage area to increase infiltration, by mulching or other means, will also reduce the peak rate of runoff.

On grades less than 2 percent the design of a sodded channel is likely to be determined by capacity requirements. As the grade steepens the velocity increases and a point is reached beyond which the maximum allowable velocity for sod becomes the determining factor. For a given rate of discharge and a fixed grade the velocity may be kept under control by increasing the bottom width of the channel, or by flattening the channel slopes. Both of these methods require a substantial increase in the overall width of the channel. Where it is not feasible to design a sodded channel, it may be paved, in which case velocity is no longer the governing factor. The capacity of a channel of given shape and depth may be doubled by changing the lining from well-maintained sod to concrete or masonry, or tripled if the initial condition was a rank grass.

## Increasing Bottom Width on Steep Grades

Outfall channels carrying water discharged from cut sections frequently involve steep grades on which the standard cross-section would develop excessive velocities. The solution of this problem is to pave the channel or to increase the bottom width. The required bottom width of a sodded channel may be approximated by the following rule:

$$b_2 = b_1 \times \frac{S_2}{S_1}$$

in which $b_2$ is the required bottom width, $b_1$ is the width of the standard section, $S_2$ is the proposed grade and $S_1$ is the grade on the standard section at which the given discharge produces the maximum allowable velocity. The use of this rule eliminates the necessity of preparing diagrams for channels with increased bottom width.

## Paved Channel

For safety side slopes of a paved channel should be flat in locations where vehicles might be forced into the channel. In other locations, as at the top of a cut slope, or the toe of a fill slope protected by guard rail, economy dictates the use of a more efficient hydraulic section. The most efficient section is a semi-circle but difficulties in construction make a semi-hexagonal section preferable. High velocities developed in paved channels may require provision for checking this velocity at the outlet unless the channel is discharging into a pool of water of appreciable depth. Velocity may be checked by a wide apron with projections or baffle walls on the surface or a low sill at the end creating a stilling pool. Current research on this problem, which exists at culvert outlets also, should provide more definite principles for the design of energy dissipating structures.

## Desirable Cross-section for Roadside Channels in Earth

The ideal roadside channel cross-section to be built in earth adjacent to an earth or stabilized shoulder should have a slope from the shoulder of at least 4:1 (which is the steepest slope permitting a driver in the outside lane to see the entire length of the slope), a rounded bottom at least 4 ft. wide and a back slope not steeper than 4:1. The depth should vary from a minimum of about 1 ft. below the edge of shoulder in regions of low rainfall intensities to a minimum of 1½ ft. in the southern and gulf coast states. Depths and widths should be increased to provide additional capacity where the runoff analysis indicates peak runoff rates from the tributary drainage areas of such magnitude that the water is likely to rise during peak flow above an elevation 0.3 ft. below the shoulder line. When the ideal cross-section results in an excessive amount of excavation which cannot profitably be used for embankment construction (as in flattening embankment slopes) the width of the bottom may be reduced and the back slope steepened to not more than 2:1 provided the discharge capacity remains adequate. The slope from the shoulder may also be steepened to a maximum of 3:1. The resulting cross-section, however, will have very limited capacity and may require closely-spaced culverts or auxiliary channels (intercepting channels, or storm sewers) to avoid overflow onto the shoulder during time sof peak runoff.

The ideal cross-section is based first of all upon obtaining a channel which a vehicle can cross at any angle with a reasonable chance of not overturning. But this section is also favorable to establishing and maintaining a good sod (it is flat enough to mow mechanically), provides space for snow storage and lessens the chances of snow drifts accumulating (because the 'stream-lining' carries the wind across without eddies). Finally, the gentle slopes covered with sod can be easily merged into the landscape. The spaciousness of the entire roadway cross-section tends to relieve the tension of driving because the driver feels that he has a chance of survival if he has to dodge off the roadway in an emergency. Any departure from this ideal cross-section tending to narrow down the roadway is usually a compromise between safety and economy or expediency.

## Roadside Channels In Rock

In solid rock cuts, the back slope will necessarily be very steep, approaching vertical in the extreme case. In such instances the drainage channel may have a narrow rounded, V-shaped cross-section just large enough to concentrate the peak runoff without overflowing on the shoulder. Another design which has considerable merit is to pave the entire shoulder and to provide for drainage in a monolithic curb and gutter with catch basins closely spaced emptying accumulated drainage into cross culverts or into storm sewers. Such a design balances the cost of additional excavation in a wider cut against the cost of more expensive drainage facilities and at the same time affords a maximum of all-weather traffic safety. It is difficult to maintain narrow sodded shoulders between a paved gutter and the paved roadway; in such cases the shoulder should be stabilized and surface-treated.

Obviously erosion is not a problem in roadside channels cut in solid rock. However, since it is seldom practical to finish the channel smoothly, it may be advisable to pave the channel with concrete or rubble masonry in order to maintain sufficient velocity so that extra cross-sectional area is not needed for the required capacity. Furthermore, in rock cuts there is usually a continual accumulation of spalled rock, cinders or sand from ice-treatment, and loosened earth which will be more readily removed by flowing water in a smooth-lined channel than in a jagged rock-lined channel.

## Ditch Checks and Drop Structures

Another method of controlling velocity in channels is to flatten the grade in a series of steps, with abrupt drops built out of concrete, stone, timber or other available material constructed at each step. The channel between drops is designed for a non-eroding velocity in the channel at the peak discharge rate. The structures are designed for the peak discharge through a weir notch, which may have the same shape as the channel above, but is more frequently a constriction in the channel. In order to prevent under-scour an apron with wingwalls must be provided below the drop. The spacing of the drop structures will depend on the general gradient of the channel, the intervening gradient and the vertical drop at the structure.

If the channel between structures is designed for a non-eroding velocity of about 2 ft. per sec. in bare earth the intervening gradient will be less than 0.5 percent and the number of structures per 100-ft. station will be approximately equal to the general gradient in percent divided by the drop in feet at each structure. Thus on a 5 percent grade, structures having a 0.5 ft. drop, would be spaced ten to the station. The cost per structure would depend on the material and the size of the notch necessary for the peak discharge. Properly designed concrete structures will cost from $5.00 to $10.00 or more each, or on a 5 percent grade, from $50 to $100 or more per station. For the same cost per station it would be possible in most cases to construct a smoothly paved, continuous gutter 3 to 5 ft. wide, or a continuous sodded gutter 9 ft. wide, either of which would adequately carry the discharge. The cost per station for drop structures will be less for higher drops but safety considerations limit the height of drop in roadside channels.

Where sod is used between drop structures the intervening grade may be increased to as much as 5 percent (determined by reference to velocity discharge diagram, Fig. 2) and in most cases the need for stepping the grade line is eliminated.

One of the main objections to any drop structures in channels parallel and close to the roadway is the hazard to traffic. The structures also interfere with mowing operations and are always unsightly. In some soils they are difficult to maintain because of water washing out the soil below or around the structure. Drop structures are useful, however, in channels normally inaccessible to vehicles on the roadway, where the channel drops off suddenly into a creek bed. In such cases the drop should be designed as an engineering structure with ample notch capacity and protection against scour at the downstream end.

## Estimating Peak Rate of Run-off

Any method of designing a channel for a limited velocity and adequate capacity necessitates an estimate of the peak rate of discharge which the channel will be expected to carry. This factor is very important but has received relatively little attention. The grade of the channel is usually thought of as being the criterion upon which the occurrence of erosion must be based, but a glance at Figure 1 shows that velocity, which is the principal factor causing erosion, changes rapidly with the rate of discharge, particularly for low flows, regardless of the grade.

The peak rate of runoff may be estimated by several methods: the Burkli-Ziegler and the so-called rational formulas, and runoff curves developed by the U. S. Department of Agriculture. The rational formula is preferred to the Burkli-Ziegler because the slope factor introduced in the latter is of questionable value. The slope should be considered in estimating the time of concentration used in the rational formula by a rough approximation of the probable velocity in the channels through which the water flows from the most remote part of the drainage area. This may be accomplished with velocity-discharge diagrams, using an assumed discharge. The velocity of overland flow on grass may be roughly approximated by the rule of thumb that the velocity in feet per second is approximately equal to one-tenth the square root of the total fall in feet, provided the grade is not more than 20 percent.

The simplest method, probably as reliable as any other, is the use of runoff curves of the type published by the Highway Research Board in April 1940, in Appendix IV of the Roadside Development Report, Part II. By selecting a curve representing the topographic, soil, vegetal cover and surface storage characteristics of the drainage area, the peak rate of discharge may be read directly in cubic feet per second from the size of the area in acres.

In dealing with runoff problems it may be helpful to visualize in simplified form the physical phenomena which take place. To begin with, rain never falls at a uniform rate for long intervals. The rain falling at low intensities may be completely soaked up in the soil, this infiltration taking place rapidly at first and then at a mimimum sustained rate regardless of how long rain may have been falling. This infiltration rate depends on the size and compaction of soil particles, presence of organic material in the soil and on the surface in the form of vegetation or mulches and other factors. Rain falling on bare soil beats the soil into a muddy suspension which tends to clog the surface pores, thus decreasing infiltration. A mulch protects the soil from this action. During the time that the rate of rainfall exceeds the rate of infiltration, runoff takes place, the small depressions filling up first, and overflowing until finally a sheet of water of appreciable depth is creeping slowly over the surface. From that point on the rapidity with which the water concentrates depends upon the number and kind of collecting channels. As the rain builds up to its maximum intensity the volume of water in transit over the surface of the ground becomes greater, and the more this temporary surface storage increases the greater becomes the dampening effect on the peak rate at which the rain is falling. Since a smoothly paved surface permits little or no infiltration, and offers little resistance to flow, the volume of water detained on the surface at any time is very small and the peak rate of runoff is very nearly equal to the peak rate of rainfall. On the other hand, a gently sloping bluegrass pasture has a high rate of infiltration, affords much resistance to surface flow and can store up a large volume of water with the result that the peak rate of runoff may be only one-tenth of the peak rate of rainfall. The stored-up water will flow out gradually over a long period of time, perhaps an hour or two after runoff has ceased from a paved area.

The frequency with which any peak rate of rainfall occurs in a given region can be determined from intensity frequency data such as that contained in USDA Misc. Pub. No. 204. A given intensity of rainfall will seldom produce the same peak rate of runoff in successive occurrences because the characteristics of the drainage area affecting runoff will vary within a wide range. Consequently a two or five-year rainfall frequency may be safely used as equivalent to a longer runoff frequency. In attempting to evaluate the damage which may have been done by runoff rates exceeding that for which a channel may have been designed, it may be noted that on a given drainage area, the higher the peak rate, the shorter is the duration of that rate. The principal effect is to superimpose a sharper and higher peak on the runoff curve. The greater the opportunity for temporary surface storage, the less this peak will exceed the normal peak.

## Application of Suggested Method of Designing Roadside Channels

Due to the uncertainties necessarily involved in estimating runoff from small drainage areas the simple calculations should not be carried out to more than one or two significant figures. Drainage area divides may be spotted by field parties taking preliminary cross-sections, and plotted on a drainage area map preferably drawn to a fairly large scale. The estimation of runoff coefficients or the selection of runoff curves should not be done in the office by a draftsman, but should be done in the field by an engineer familiar with factors influencing runoff, and able to visualise conditions as they are likely to exist after the construction is completed.

After peak rates of runoff have been estimated, a diagram of the type shown in Figure 1 may be used to check up the velocity developed in, and capacity of, the standard channel section ordinarily used. In the great majority of cases the standard section will be found adequate for capacity. In a few cases the velocity developed will indicate the need for sodding. Infrequently, critical conditions will necessitate special study to develop economic designs.

The purpose of introducing this method of analysis is not to disrupt procedures of preparing plans developed through long years of experience but to add a simple check on channel design which will reveal, during the plan stage, the points at which extra care should be taken to avoid future difficulty and expense in maintaining the completed highway.

## Construction and Maintenance of Vegetated Channels

Detailed discussion on the construction and maintenance of vegetated channels is beyond the scope of this paper, but there are several points which are worth noting. In the first place the kind of grass selected for seeding or sodding a channel should preferably be a short-bladed variety with a deep root system forming a dense turf and not a bunch grass around which the water will wash, or a stiff-stemmed grass which will not bend flat under the pressure of the current. The efficacy of sod for controlling erosion results largely from the 'shingling' or 'thatching' action which protects the soil from the high velocity in the stream. Experiments with Bermuda grass indicate that resistance to erosion is practically as good when the grass is dormant as when it is green. Another favorable circumstance is the fact that in most regions the highest intensity rains which cause the most erosion damage normally occur during the summer months and not when the grasses are dormant.

When seeding can be done at the right season of the year to establish a reasonably good turf in a short period of time channels from very small drainage areas may be seeded instead of sodded, taking the chance that a damaging rain will not occur during that period. Any necessary reseeding will still involve less total cost than an initial installation of sod. Mulching of the seeded areas, now rather common practice, greatly increases the chances of avoiding damage by intense rains. Local circumstances and individual judgment will determine the extent to which chances may be taken on seeding in drainage channels. (In some regions grass is normally established by sprigging or planting stolons and roots, relying on the natural spreading habit of the particular species to secure complete cover in a short period of time. In such regions the remarks about seeding will apply with equal significance to these other inexpensive methods of establishing grass.)

A compromise solution is to sod only the bottom of the channel, (assuming this bottom to be rounded) gambling that a rate of runoff sufficient to rise above the sodded area will not occur until grass has become established by other cheaper methods on the rest of the channel. To play safe, however, sod should be placed to an elevation slightly above the depth of the peak discharge for which the channel is designed; this procedure is recommended where sod is plentiful and relatively inexpensive.

Vegetated channels can be completely successful only if they are adequately maintained. Channels should be mowed regularly to avoid excessive restriction to flow and to keep down weeds. Bare spots should be repaired by sodding immediately upon discovery as small breaks in the sod enlarge rapidly when subjected to heavy flows. Silting of the channel is a troublesome problem which can be permanently solved only by tracing the silt back to its source and eliminating erosion at that point. Since silt is deposited only when the carrying capacity of the stream is reduced by checking the velocity channels should be designed, insofar as practical, so that the gradient is always increased, and never flattened, in the direction of flow.