

Improved Drainage and Frost Action Criteria for
New Jersey Pavement Design - Road Surface Drainage

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in cooperation with
United States Department of Transportation
Federal Highway Administration

Supplemented by: Road Surface Drainage Design,
Construction and Maintenance
Guide for Pavements

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16. Abstract This report with a supplement describes the state-of-the-art of road surface drainage conditions in New Jersey and a general approach to the solution of the road drainage problem. The fundamental objective of this work is to improve the pavement surface drainage design, construction and maintenance processes used by the New Jersey Department of Transportation. The report encompasses the major facets of hydrologic and hydraulic principles necessary to promote disposal of all water on the surface of pavements and nearby grounds.					
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The intent of this report is to describe the state-of-the-art of road surface drainage conditions in New Jersey and a general approach to the solution of the road drainage problem. Since such an approach concerns basic engineering principles and since there is no need to re-invent the wheel, this report is heavily based on available drainage engineering literature. In a number of instances the information in a particular reference is considered directly applicable to the Department's needs and verbatim excerpts are used. However, for practical reasons quotes are often omitted. Permission for such use of reference documents has been solicited and secured from the authors of the sources mentioned below.

In presenting this report with a supplement then an expression of appreciation goes to the following organizations and individuals:

1. FHWA, formerly BPR, Mr. James K. Searcy, Drainage of Highway Pavement⁽²¹⁾ and Design of Roadside Drainage Channels⁽⁷⁾, Highway Drainage Manual⁽⁶⁾, authors not indicated.

2. U.S. Department of Agriculture, Soil Conservation Service, authors again not indicated, Technical Release No.55⁽⁴⁾, and National Engineering Handbook, Section 4, Hydrology⁽⁵⁾.

3. New Jersey Department of Environmental Protection, Authors Eugene Colub, Thomas Plenik, Robert Dresnack and Su Ling Cheng, Flood Plain Manual⁽¹¹⁾.

4. Three publications by Professor Lynne H. Irwin, J. L. Nieber and Associates were extensively used: Drainage Design Manual⁽¹³⁾, Basis for Drainage Manual⁽¹⁴⁾ and Drainage Design for Secondary Roads⁽¹⁵⁾.

5. The Asphalt Institute, author not indicated, Drainage of Asphalt Pavement Structures (MS-15)⁽⁹⁾.

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A. SUMMARY AND CONCLUSIONS

In general, it must be concluded that there is a real necessity for systematic hydraulic engineering manuals for road design and construction with direct participation of hydraulic engineering specialists in the process of designing, building and maintaining roads. As shown herein, the planning and design of a drainage system requires an experienced hydraulic engineer who is also familiar with both the construction and the maintenance problems involved. It is quite apparent that the scope of the work for which a highway drainage engineer is responsible covers anything from road ditches to river crossings involving from a few hundred square feet to thousands of square miles of runoff area. Thus, his endeavors are very extensive both in the amount of necessary knowledge and the work quantity. Furthermore, his responsibility does not end with the design and construction of the road. That is, if maintenance of the system is not achieved all his preceding efforts become just an exercise in futility.

From the many examples cited in this report, it can be said that in New Jersey existing road drainage practices frequently do not provide adequate solutions for the surface drainage of roads.

In estimating runoffs the main concern is the accuracy with which the runoff quantity is determined. Although practically all hydrologic methods are statistically based, in most cases

where they are being applied there are hardly any specific runoff data available. For road design purposes the key problems usually are whether the watershed area should be assumed urban or can be considered rural and to what extent it is grassy, wooded or a farm land. In many instances when roads are being contemplated the terrain is undeveloped. Normally, however, the roads are built either to develop a particular stretch of land or to connect urban areas. Thus, it is normal to expect the development of land to move along such arteries. In fact, it would probably be safe to assume that such a development would be accomplished within a ten year period. Under such circumstances it seems pointless to consider the undeveloped condition of watersheds without regard to relatively near future changes in their runoff characteristics. In fact, it probably would be much more engineeringly and economically prudent, based say, on population projections, to include such development in the original road design. In cases of substantial structures, such as waterway crossings and major water diversion ditches, the provisions for such development should be included at the time of road construction. Other drainage elements in these instances might be designed to accommodate future modifications should increased runoff quantities occur.

The principle that must be followed in road drainage design is that all surface water has to be removed from the pavement by the shortest and quickest way possible. All water to be transported

along the roadway should be managed by means located outside the roadway proper (ditches and the like). Water should be on the roadway's surface for the shortest time possible. Additionally, all such drainage elements must be designed for the worse conditions that can be reasonably expected particularly with regard to maintenance levels. If grass-lined ditches are used, uncut grass and weeds should be expected; debris might be left in the ditches and damage caused by vehicles might not be repaired for a long time.

From many field observations it is concluded that due to their limited capacity and unattainable maintenance requirements inlet structures frequently do not function adequately. They should therefore be avoided when other means of drainage can be provided. Curb drainage should as well be avoided. In general, everything that would permit water to remain on a pavement must be avoided.

To put it as strongly as possible, the procedures provided in this report and in the guide which supplements it are not merely an alternate solution to roadway drainage problems. Instead, they are presently, in the author's opinion, the optimum design approach to surface drainage of roads. Whether this guide is used or any other similar approach is applied, the hydrologic and hydraulic principles aired herein are a must if roads, including railroads are to be functionally adequate from a drainage standpoint and to possess reasonable durability.

A few concluding words concerning traffic-safe hydraulic structures are in order. It is true that some highway drainage structures are potentially hazardous. This does not have to be so if prudent judgment is used to avoid or minimize said hazards without, however, seriously interfering with the effectiveness of drainage facilities. One way this can be achieved is to always have a hydraulic engineer experienced in road drainage included in the design process.

B. RECOMMENDATIONS

To insure that the Department's design process yields appropriate solutions to roadway drainage problems a number of recommendations are evident.

1. A Bureau of Road (highway and railroad) Drainage Hydraulics Engineering should be established in the Department. The number of hydraulic specialists to be employed by said unit should be commensurate with the necessary amount of work to be performed in connection with highway and railroad design, construction and maintenance. The Bureau should supervise closely and, if necessary, perform the hydraulic engineering (design, construction and maintenance) of highways and railroads. Its staff should additionally be available to troubleshoot problems in the field.

2. Furthermore, the range of responsibilities of such a hydraulics engineering bureau should include both the surface and subsurface drainage of all roads (highways and railroads).

3. The third proposal is to require consultants to have adequate hydraulic engineering staff and to prepare for each project properly developed hydrologic and hydraulic designs. This requirement should be a mandatory prerequisite for the design consultants of all Departments of Transportation.

4. The Department of Transportation of all states should have and use Road Surface and Subsurface Drainage Design Construction and Maintenance Guides. The road surface drainage guide should

be divided into three parts along the lines suggested in this report to facilitate its use. However, to achieve uniformity of application and most importantly to avoid duplication of efforts each individual Department of Transportation should not have to develop its own separate manual. Instead, general guides should be developed through an organization such as AASHTO which then could be amended as required for individual use by the states.

In the meantime, it is recommended that for surface drainage the New Jersey Department of Transportation utilize the guide which supplements this report when drainage areas are less than 200 acres. Tentative guidelines for larger area are provided in Section 2.2.5 of this report. A subsurface drainage guide is presently being prepared by the Department's research unit.

C. INTRODUCTION AND BACKGROUND

C.1 GENERAL

For many years, the problem of water on pavement structures has been recognized but too often improperly dealt with. And yet probably no other feature plays as an important role in determining the ability of a pavement to withstand the effects of weather and traffic and in providing trouble-free service over long periods of time. Most states have solutions for road drainage, especially surface drainage which are based on the correct hydrologic and hydraulic principles. However, rarely are hydraulic engineers employed to properly apply these principles. Frequently, roads are designed and built by individuals having little understanding of drainage requirements and often even without adequate civil engineering background.

In the last fifty or so years soils, at last, became recognized as an engineering material and the new sciences of soil-mechanics and geotechnical engineering came into being. Although the science of the hydraulic engineering by itself is an ancient discipline and although waterways were mankind's first roads, when humanity began building land-roads, hydraulic engineering did not become part of this new development. And yet on this planet nothing can and does exist without being in some way affected by water energies. Furthermore, since in road building

the problem of load bearing is most important, it is to be realized that the science of structural engineering should be intricately involved as well.

While the soil-mechanics discipline is finally a participant in construction of roads and structural engineering, even though barely, at last begins to get involved, it is time to recognize the need for hydraulic engineers to join in the solution of road building problems. Without their help jointly with other disciplines of the civil engineering science, no further progress in building better, more economical and longer lasting road systems can be expected. It is precisely this approach that is being suggested herein.

C.2 STATE-OF-THE-ART

In the field of surface drainage, required hydraulic engineering principles are undoubtedly very well explored. However, as simple as highway drainage principles appear to be, the actual layout and design of a drainage system requires a well developed systematic hydraulic design manual to assist an experienced hydraulic engineer who is familiar with both the construction and the maintenance problems involved. Nevertheless, there is no need to reinvent the wheel, therefore, works already provided by others, especially that of the Bureau of Public Roads, presently FHWA, should be utilized in a way and form that is best suited to a practically applicable guide for road surface drainage engineering.

C.2.1 Existing New Jersey Approach

To obtain details on the New Jersey Department of Transportation's design approach to road drainage, several recent and past engineers responsible for overseeing such work were consulted. From that effort it is evident that drainage design is mostly accomplished by standardization which is exemplified by the following criteria:

Drainage Criteria

New Jersey Department of Transportation

1. Storm Frequency

Interstate Design

15 years for the system
25 years at low points
50 years for cross drains

State Design

10 years for the system
15 years at low points
25 years for cross drains

2. Runoff Coefficient

Rural areas	0.2 - 0.4	
Urban areas	0.4 - 0.6	
Pavement areas	0.7 - 0.9	(depends on type of pavement)

3. Friction Factor

Concrete Pipe	0.013
Corrugated Metal Sewer Pipe	0.013
Corrugated Metal Culvert Pipe	0.024
Earth Ditch	0.030

4. General Guidelines Showing Typical Calculations -

The rational method $Q = CIA$ will be used. Equivalent areas and runoff time of concentrations will be computed using various charts at your disposal.

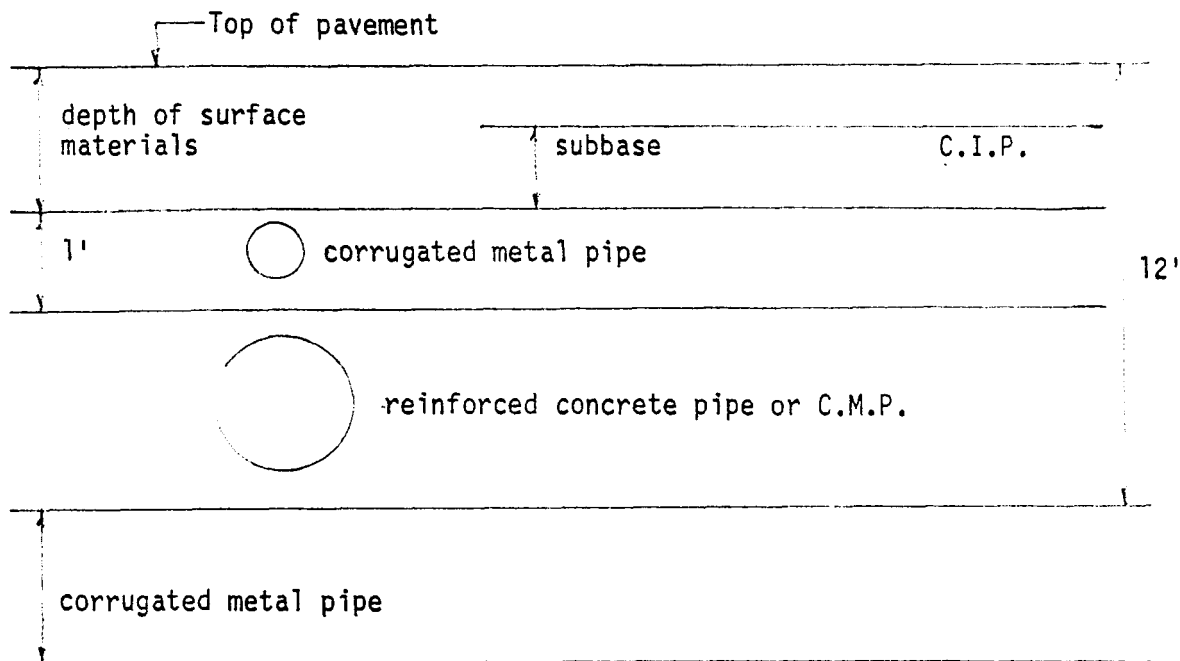
5. Any drainage basin over 1/2 square mile in area must be submitted to the New Jersey Department of Transportation with a stream encroachment application (enclosed) to be submitted to the Division of Water Resources, Department of Environmental Protection.
6. Minimum pipe size on state highways = 15"
At low point, minimum pipe size = 18"
7. Distance between inlets, manholes = 350' - 400'
8. Minimum velocity in storm sewer = 3 F.P.S.
Desirable velocity in storm sewer = 5-8 F.P.S.

Open Channel Flow

Slope protection required when velocity is greater than 8'/sec.

Energy dissipators required when velocity is greater than 15'/sec.

9. FHWA (formerly BPR) circulars will be used when computing headwater on pipes, i.e., inlet control, outlet control, velocity, etc.
10. Criteria Used for Specifying Type of Pipe, Catch Basin, etc. -
Economic costs along with the following chart will indicate the type of pipe to be used on any one job.



The FHWA circulars⁽¹⁾ mentioned in these criteria provide solutions for most of the hydraulic engineering problems dealing with existing streams and large quantities of runoff provided by large runoff areas. Another manual "Design Manual for Elements of Drainage and Culvert Design"⁽²⁾, which ostensibly covers the same areas as the FHWA circulars is also used as a guide.

C.2.2 Field Investigation

To determine the actual functional characteristics of the New Jersey Department of Transportation's road drainage and thus, the consequence of its current drainage design, construction and maintenance practices, a limited field investigation was undertaken. However, it is to be noted that a considerable number of New Jersey roads were surveyed in the performance of this effort. A photographic documentation of the most representative conditions were made and some of this information is provided herein. Figures 1 thru 20 were photographed on Routes 287 and 78, in the majority of cases representing concrete pavement. However, the examples of road construction, maintenance and design shown by these photographs obviously have nothing to do either with the type of pavement, concrete or bituminous, or the age of said roads. The photographs simply depict the most glaring examples of the prevailing terrain and drainage conditions. The age of these roads, whether they are recent or a few years old, has not and cannot have an effect on the drainage situation portrayed herein. That is, a properly designed and adequately constructed

road drainage system simply could not and would not be in the state shown in Figures 1 thru 20 even with poor maintenance. This is especially true in those instances where seemingly no provisions whatsoever had been made for drainage.

Figures 1,2,5 & 10 show the conditions of roads located in rather flat terrain where run-off apparently collects on the paved areas. The same phenomena was observed in cut terrain as is shown in Figures 3,4,6,9 & 11. Figures 7,8,12,13 & 14 portray the consequences: water under pressure in a bituminous pavement, erosion of slopes, failure of the roadway shoulder and the poor condition of what appears to be drainage ditches. Figures 15 thru 20, however, show what appears to be makeshift solutions by maintenance people to drainage problems on a fill. Figures 15 thru 18 are examples of bituminous surfaced spillway entrances which open steep grass and weed lined channels that are now mostly eroded. Figure 18 shows an inaccessible drainage inlet that could be maintained only by hand labor. Figures 19 and 20 portray a closed chute or flume, apparently a makeshift application which is rarely used in New Jersey. Judging by the appearance, it looks functional. In hydraulic engineering practices a flume approach for the steep slope spillways is generally preferred because the control of water flow is better and erosion of slopes is less likely.

Figure 2: The same location as above showing the runoff drainage.

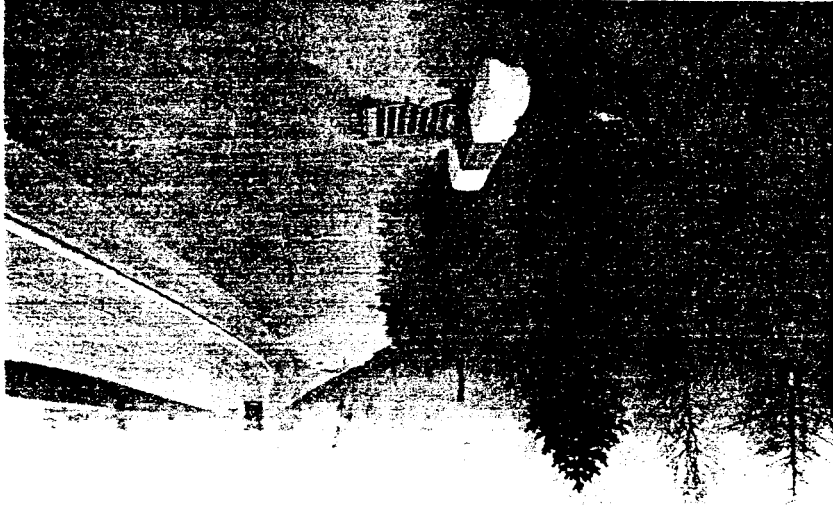
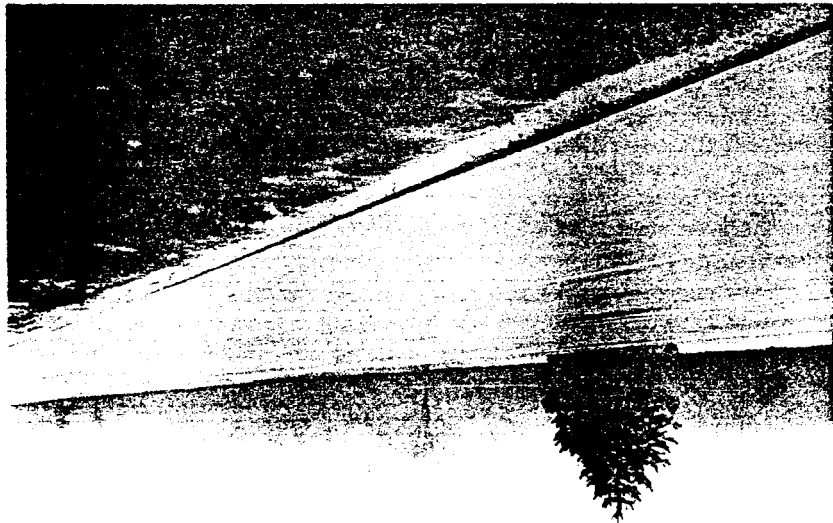


Figure 1: Route 287 northbound @ M.P. 5-1/2 Example of surface "Drainage"



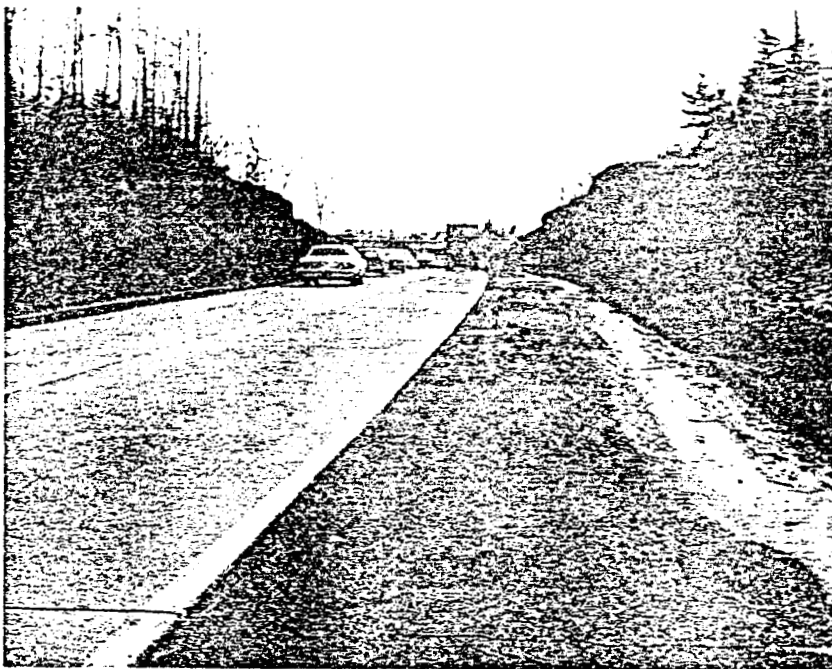


Figure 3: Route 287 northbound @ M.P. 24
Runoff drainage in a cut section.



Figure 4: Route 287 northbound @ M.P. 26
Another example of runoff
drainage in a cut.

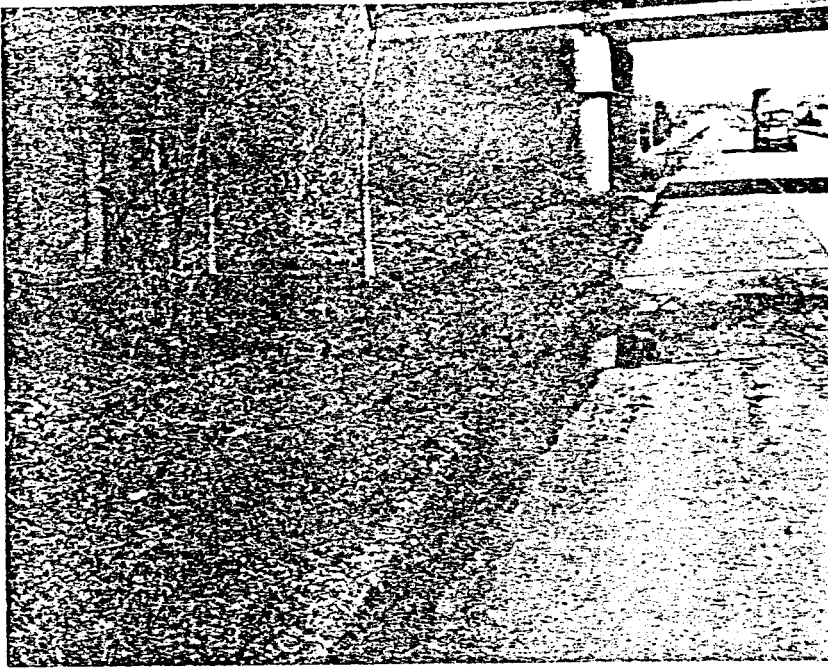


Figure 5: Route 287 southbound @ M.P. 25-1/2
Another example of surface drainage
condition; water in adjacent field
and therefore on the shoulder.

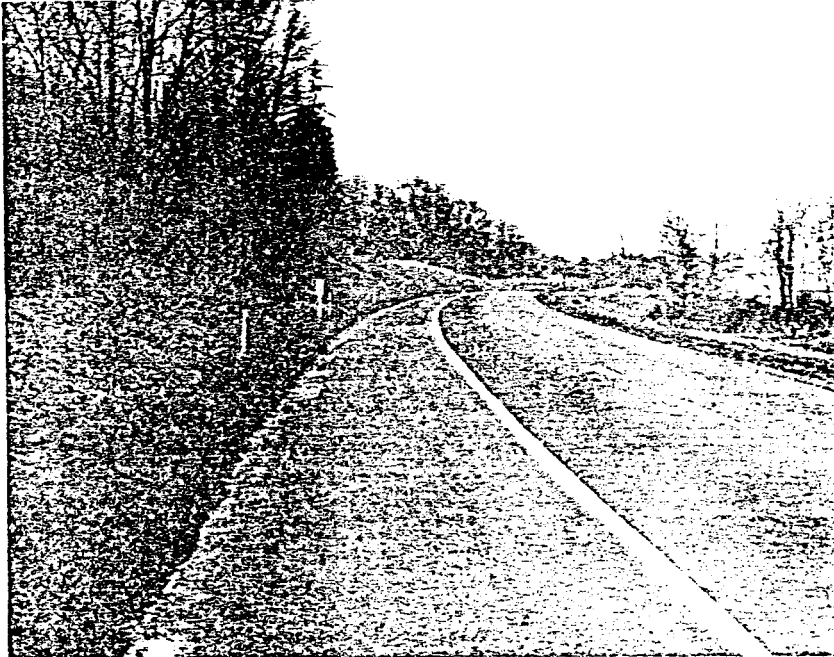


Figure 6: Route 287 southbound @ M.P. 31-1/2
This type of drainage in a cut section
resulted in subsurface drainage
condition shown in Figures 9 and 10.

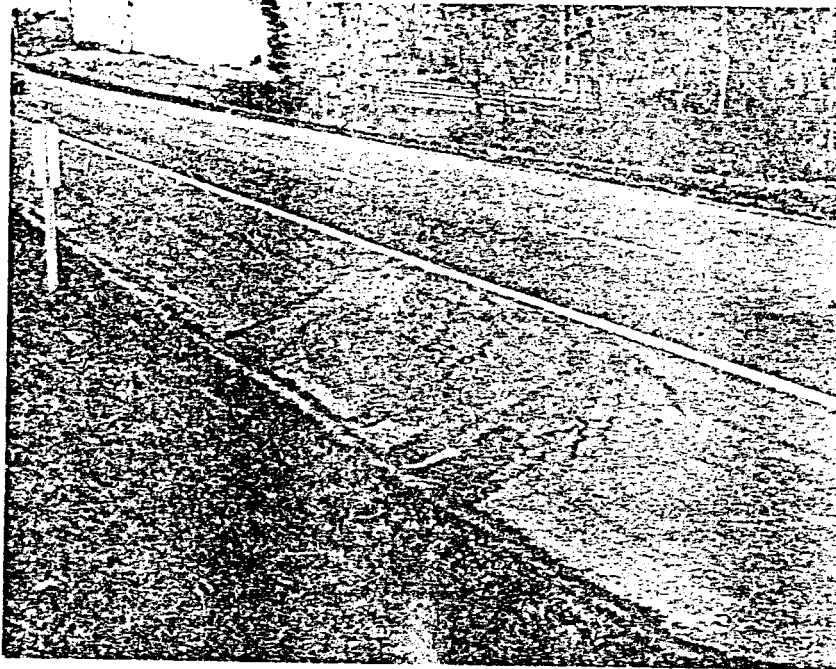


Figure 7: Route 287 southbound @ M.P. 31-1/2. Inadequate surface drainage can cause such a failure.



Figure 8:
Close-up view
of the same
location
shown above.

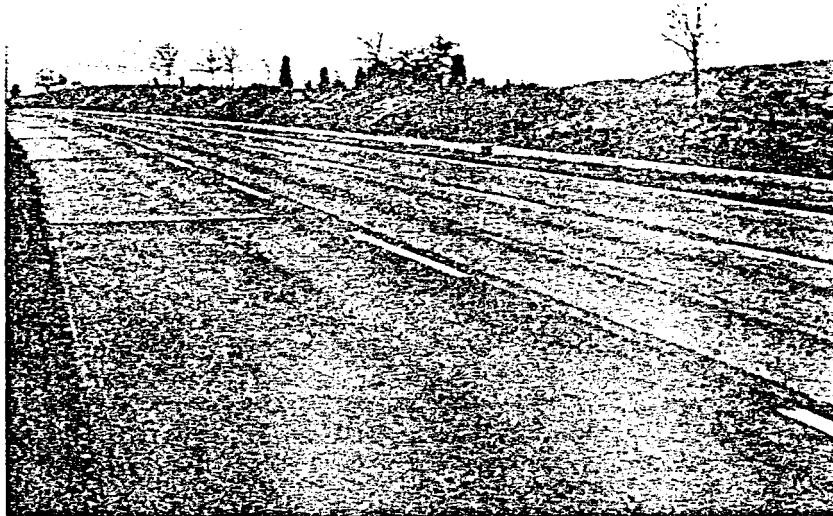


Figure 9: Route 78 westbound @ M.P. 22-1/2
Runoff in a cut section apparently
has contributed to this shoulder failure.

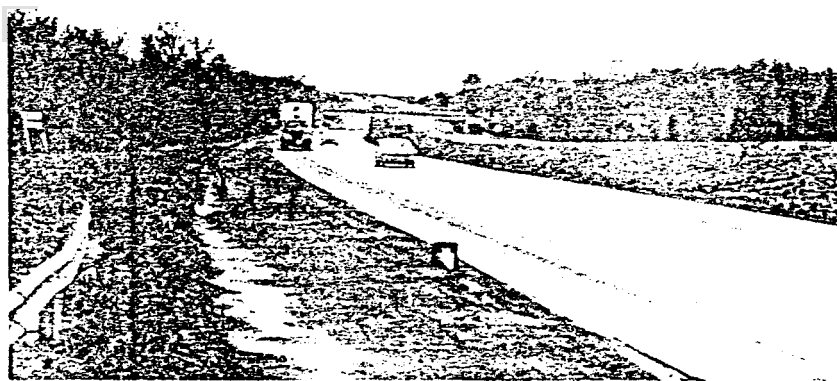


Figure 10: Route 78 eastbound @ Oldwick-Whitehorse
exit. Drainage ditch construction
apparently caused the depicted condition.

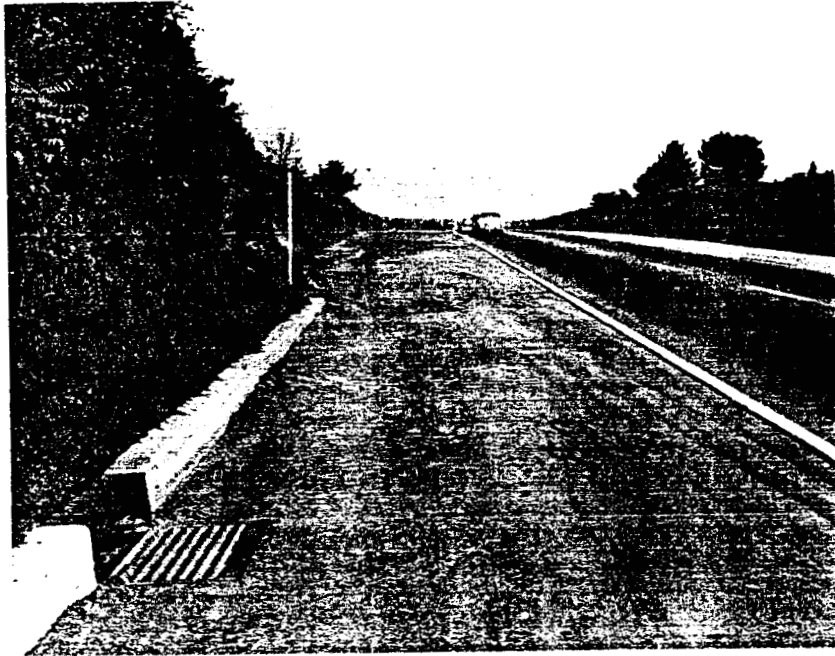


Figure 11: Route 78 westbound @ M.P. 22-23. Condition of a road's shoulder sloping toward an inlet in a cut section.

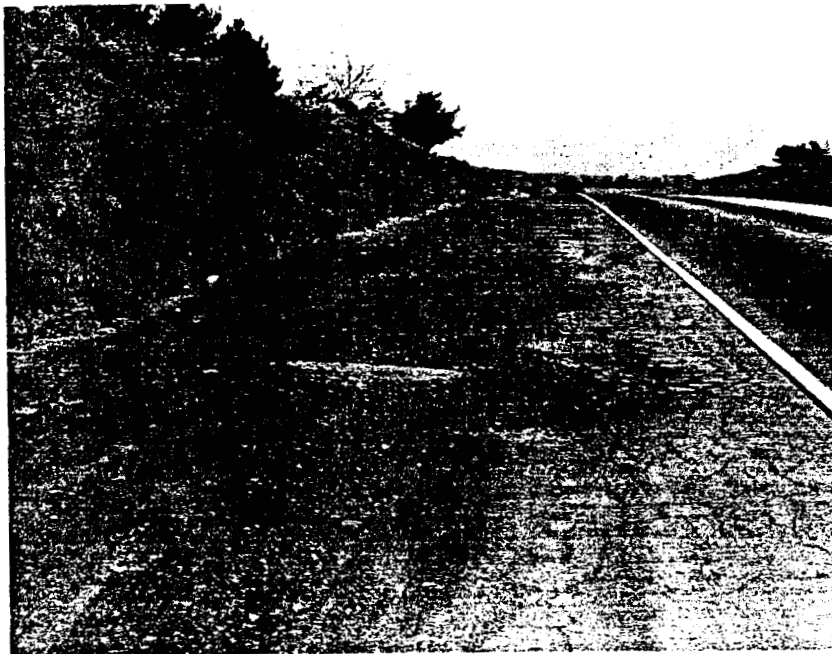


Figure 12: Close-up view of the same section shown above. Shoulder condition after weeks of near drought.



Figure 13: Route 78 eastbound @ M.P. 25-1/2. When no drainage is provided runoff makes provision on its own.



Figure 14:
Different
view of
same
location
shown
above.
Note
failure
of a
drainage
ditch at
the bottom
of the cut.

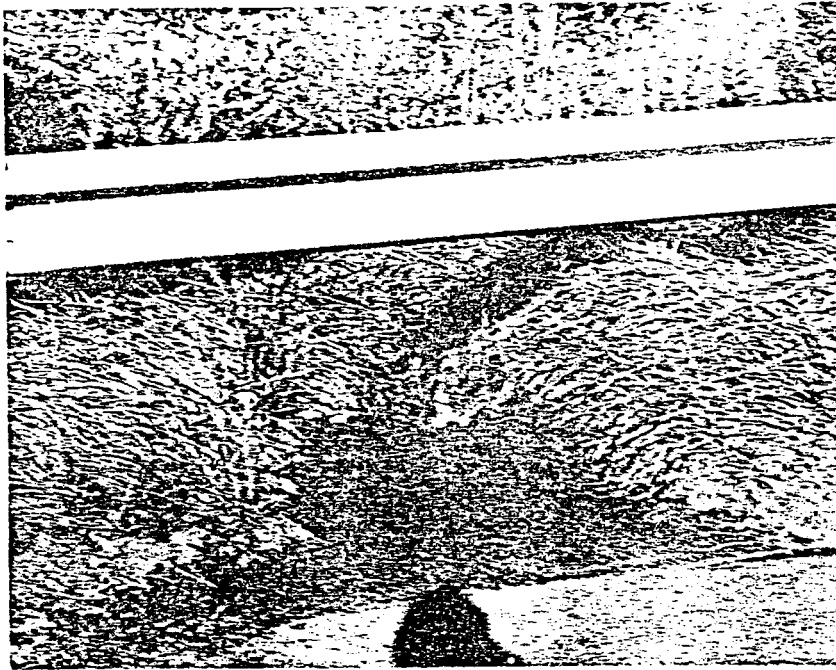


Figure 15: Route 78 westbound @ M.P. 27-28 Evidently a makeshift chute (spillway) has been constructed as a solution to existing drainage condition.

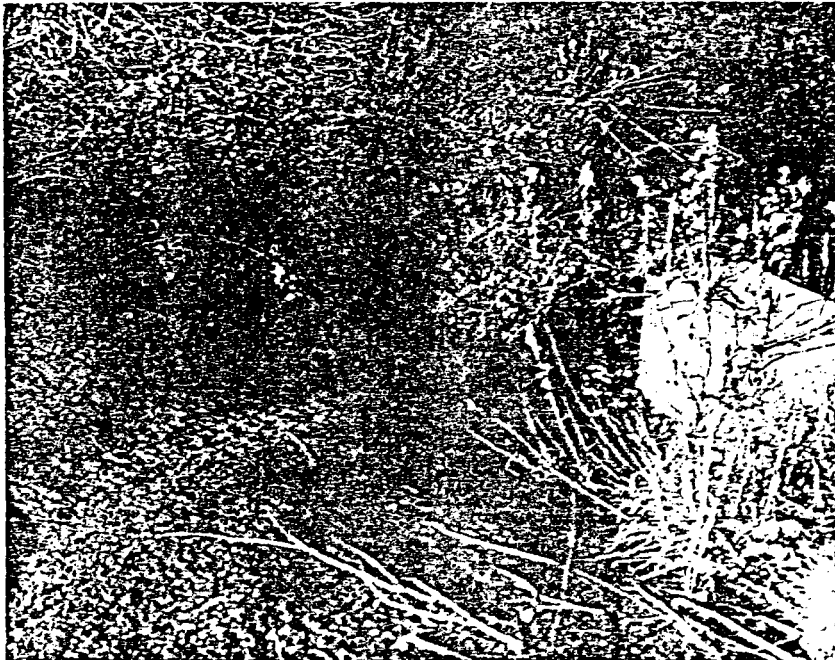


Figure 16: Route 78 westbound @ M.P. 26-27 and bridge structure. Another makeshift chute; improper construction caused erosion.

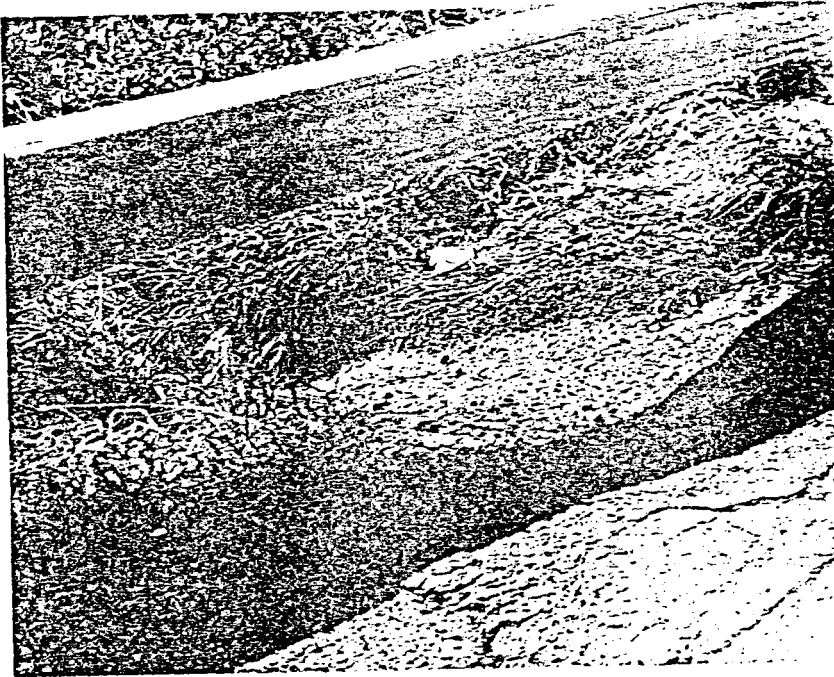


Figure 17: Route 78 eastbound @ M.P. 28-29. Still another makeshift chute has been used.

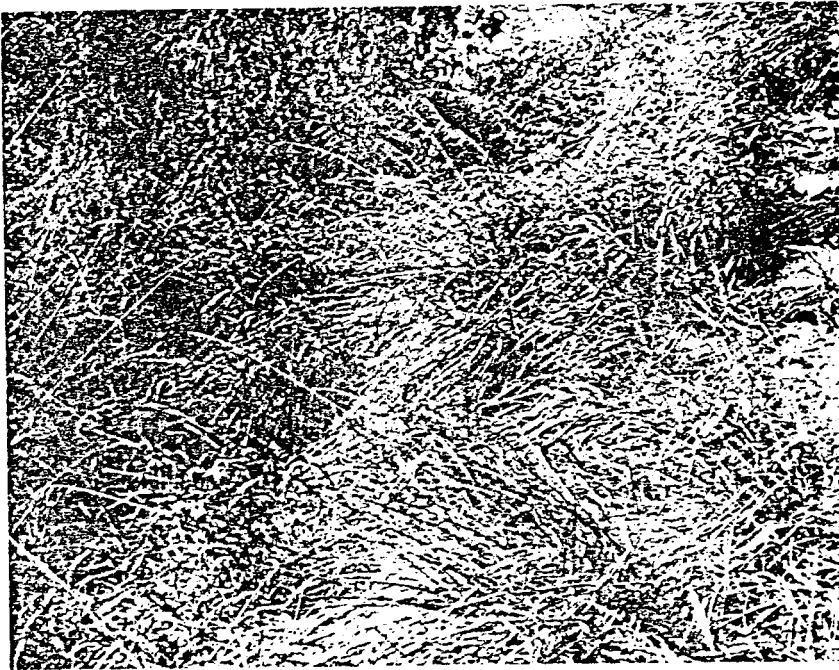


Figure 18: Different view of the same location shown above. Chute drains into, hard to maintain, drainage area.

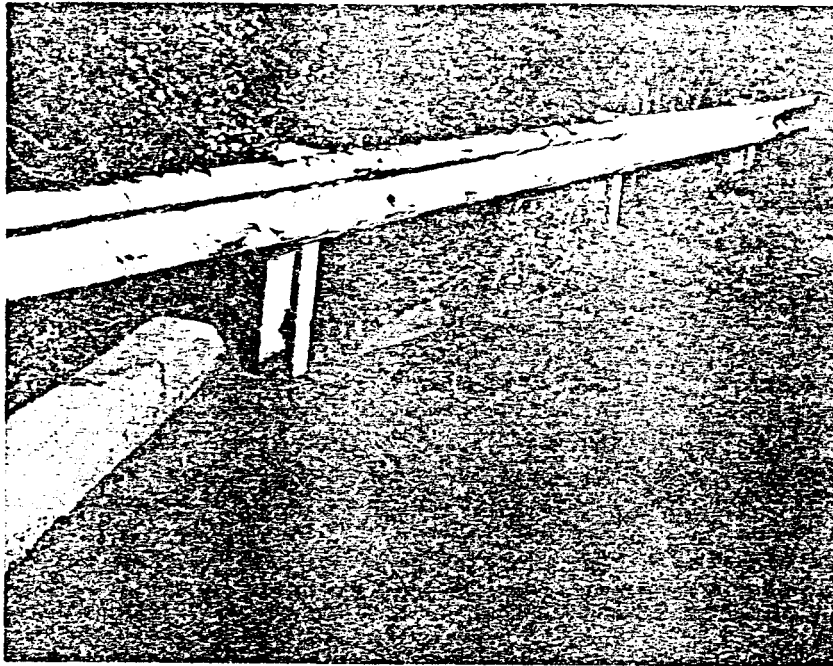


Figure 19: Route 78 westbound @ M.P. 15-16 and bridge. Closed chute (flume) application rarely used in New Jersey.

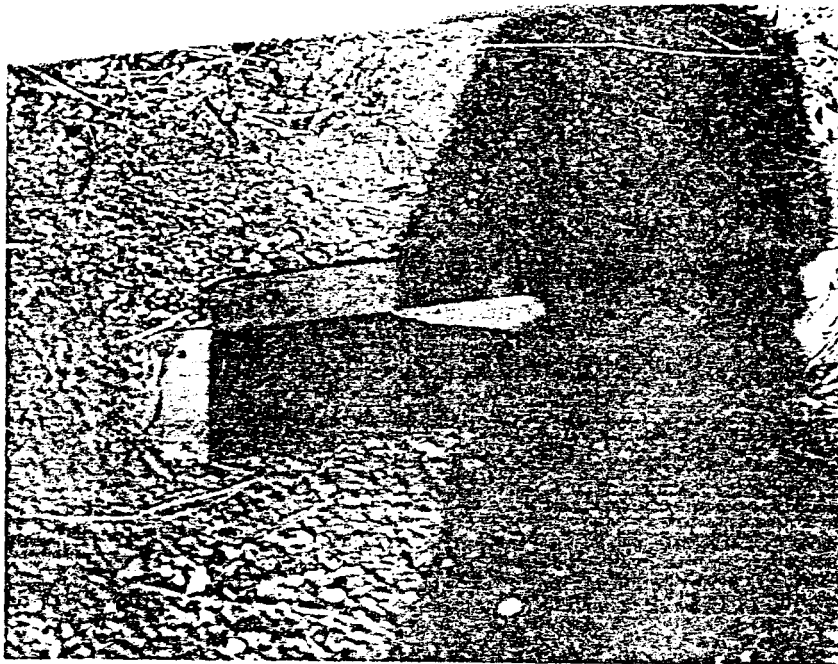


Figure 20: Close-up view of the same location shown above. Condition of the flume indicates it is apparently functional.

D. SCOPE OF WORK COVERED BY THIS REPORT

The fundamental objective of the research efforts described herein was to improve the pavement design process used by the Department in the area of road surface drainage. To achieve the above goal, it was considered necessary to formulate improved design methods and construction procedures for surface drainage systems as a first step in controlling water and/or moisture within New Jersey pavements. This led to the development of a road surface drainage guide which is offered as a supplement to this report and is designed to supplement New Jersey Department of Transportation's present drainage criteria.

The described research is one part of an overall study to formulate means for reducing water damage to New Jersey pavements. Figure 21, a CPM diagram for the Department's drainage and frost action research illustrates the planning of this study; the surface drainage investigations are delineated in Phase I, Subphase I of the diagram. It can be seen that the brunt of this drainage subphase was the performance of exhaustive studies of the state-of-the-art. While other study efforts, frost action, structural strength of pavement and model slab testing have been performed to a large degree by contracts with well qualified institutions, the development of solutions for drainage was accomplished almost entirely in-house.

Surface drainage includes disposal of all water on the surface of the pavement and nearby grounds by applying basic hydrologic and hydraulic principles to the design of all surface drainage structures. To the extent that is practical, surface water should not be allowed to enter the subsurface drainage system.

Although a need for a complete surface drainage guide became obvious, the scope of this research dictated that consideration only be given to conditions where the runoff area does not exceed 200 acres. In instances where larger areas are involved, existing literature available from Soil Conservation Service⁽⁴⁾, U. S. Geological Survey and New Jersey Department of Environmental Protection^(11,12), and discussed in Section 2.2.5 of this report, can provide adequate guidance.

E. RESEARCH APPROACH - ROAD DRAINAGE HYDROLOGY AND HYDRAULICS

E.1 GENERAL

In a multitude of investigations over the years the Department's research unit has gathered evidence that pavement failures on the highway system often stem from the presence of excessive amounts of water within the pavement section. The subsequent study of the state-of-the-art of the road drainage practices substantiated the universality of such findings.

If the problem of water induced deterioration was to be resolved, the necessity of adequate subsurface drainage techniques became apparent. Unfortunately, subsurface drainage could not be looked at separately. Such underdrain system could impinge on the structural components of a pavement and pavement's resistance to frost action could be drastically affected. These problems were investigated congruously under the Phase II and III of main research study. However, there are limits to the amount of water an underdrain should be required to handle. Thus, it became evident that there was a need for a detailed consideration of surface drainage.

For surface drainage an exhaustive study of the state-of-the-art provided for the development of a design guide. Within the scope of this research, it sufficed to limit the road surface drainage guide to conditions where the runoff area is up to 200 acres. This report serves as a vehicle for recounting why specific design criteria were chosen for inclusion in the guide, as well as, explaining some of the basic principles underlying those criteria.

E.2 SURFACE DRAINAGE

E.2.1 General

Knowledge and a thorough understanding of basic hydrologic and hydraulic principles are necessary to design adequate surface drainage for roads. A number of guides which contain various documentation on the principles have been offered. Some of them attempt to cover the subject completely, making it, at best, cumbersome because such an effort has to encompass all there is in both disciplines. Some others divide the subject by hydraulic specialties, such as roadside drainage channels and the like. Only a few, however, attempt to limit the guide by the size of the runoff areas. When it concerns the drainage of the road site itself, a relatively small runoff area and thus a small quantity of water is involved. Nevertheless, it is precisely this area where providing and maintaining good drainage is absolutely essential for a long lasting, trouble free road system. Since the drainage of a road and its immediate surroundings is the scope of this research, the limit of 200 acres of runoff area serves the purpose well. Under such a runoff area limitation most natural streams will be automatically excluded from such a manual. However, part of the ground water problem, i.e., underground streams or springs daylighted by excavation, could be addressed by using such a manual, if the quantity of water flow requires diversion by piping or conduits.

The existing literature sources utilized for development of the desired surface drainage manual are: an article by Z.P. Kirpich⁽³⁾, several publications by the Soil Conservation Service, U. S. Department of Agriculture^(4,5) and by the BPR, presently the Federal Highway Administration^(6,7,8), a publication of the Asphalt Institute⁽⁹⁾, the Handbook of Hydraulics by King⁽¹⁰⁾, and two New Jersey Department of Environmental Protection reports^(11,12).

Three publications by Professor L.H. Irvin, et al^(13,14,15) are used for solution of hydraulic problems, such as open channel and pipe flow. Another useful source is the publication by Ven Te Chow, Ph.D.⁽¹⁶⁾.

As just illustrated by the numerous references cited, to use most of the existing drainage design manuals requires a library of other resources as is regrettably, the case with the pending New Jersey Department of Environmental Protection Flood Plain Manual⁽¹¹⁾. The drainage manual whose development is described in this report is for the most part self contained and there is little need for other references.

E.2.2 Hydrology

E.2.2.1 General

In hydrology there seems to be as many methods for determining runoffs as there are investigations of this problem. All these methods, in essence, amount to variations of the same statistical

approach. Sometimes they are based on existing experimentally established data or just on the study of parameters that control runoffs such as the rational method. In one way or another such a multitude of methods is rather confusing, and their accuracy must be judged in a specific context. It is, however, important to deal with real conditions and quantities, based on facts presenting true situations so as to provide adequate and lasting remedies.

E.2.2.2 The Parameters

Hydrology is the science that deals with the properties, phenomena, and distribution of water on the surface of the land, in the ground and in the atmosphere. There is a hydrologic circle which consists of water falling to the ground in the form of rain, snow, etc., and then that water returned to the atmosphere in the form of vapor from the ground surface and from the precipitation itself. Since in drainage studies all forms of precipitation are measured on the basis of equivalent depth of water which remains and would accumulate on the surface, in hydrologic terms all forms of precipitation are referred to as "rainfall".

The three main aspects of rainfall for the engineer to consider are intensity (the rate of fall), duration (the length of time of intensity) and frequency, i.e., the probable period of time for repetitions of combinations of intensity and duration. To determine a basis for reasonable estimates of intensities,

durations, and frequencies of rainfall for a specific location, records compiled by the U.S. Weather Bureau from their network of automatic rainfall recording devices are available. Also, the New Jersey Department of Environmental Protection⁽¹¹⁾ provides Rainfall Intensity Curves for such purposes.

After losses of evaporation, transpiration, infiltration and the like, some portion of the rainfall remaining on the surface moves away as surface runoff.

The first problem is to determine what portion of rainfall becomes surface runoff. For any given area during a single rainfall, the runoff rate is seldom constant and there is no method for determining the exact amount of runoff. However, there are several solutions which will provide an experienced engineer with good estimates.

E.2.2.3 Design Methods

Before proposing any hydrologic design methods, their limitations should be identified. This is necessary as even the opinions of experts seem to vary on the subject of drainage area limits.

Rainfall intensity is seldom the same over an area of appreciable size or for any substantial length of time, during the same storm. Should, however, a uniform intensity of rainfall of duration equal to the time of concentration occur (the time required for runoff to arrive from the most remote point of the

drainage area), the non-uniformity of the area and of antecedent conditions would vary the rate of runoff. For these and the like conditions, the error in the runoff estimate increases with the increase of the drainage area. On the other hand, the quantity of experimentally established runoff data also rises with the increase in the drainage area size making the statistical approach worthwhile and more reliable but the methods of analysis more complicated.

In the New Jersey Department of Environmental Protection publications^(11,12), a number of hydrologic design methods are suggested as "techniques for solution". In addition, two "weighted" approaches are offered to fill the gaps between the drainage area limits of said methods. All this just to determine which method or combination of them must be applied. Such techniques for the solution of hydrologic problems are rather typical.

To a hydraulic engineer the need for using different techniques for different size drainage areas is obvious. However, the realities are that not every engineer that designs a road is a hydraulic specialist. Therefore, exercising conservative, yet reasonable judgment the limits as follows are offered:

(1) The Rational Method⁽¹¹⁾ is to be used for determining peak discharges of uniform drainage areas up to 200 acres. Such a limitation is based on C.E. Ramser's⁽¹⁷⁾ experimentation as reported by Z.P. Kirpich⁽³⁾ and BPR publication⁽⁷⁾. It is also suggested in the AASHO "Guidelines for Hydrology"⁽²⁰⁾.

(2) Soil Conservation Service Technical Release No. 55⁽⁴⁾ is to be used for drainage areas exceeding 200 acres but up to 2,000 acres.

(3) Special Report 38⁽¹²⁾ is for drainage areas greater than 2,000 acres and up to 1,000 square miles.

(4) For streams controlled by upstream surface storage "the techniques previously discussed will not apply"⁽¹¹⁾.

The "Federal Highway Administration Method"⁽¹⁹⁾, a revised so-called "Potters Method"⁽¹⁸⁾, covers runoff areas up to 100 square miles and provides design procedures for "runoff estimates for small rural watersheds" including areas with surface storages. While the author, for reasons to be presented later in the report prefers the Rational Method in such instances, this method could be considered as an alternative to some approaches previously listed.

The drainage area limits offered herein take into account limitations indicated by data (nomographs) available in Technical Report 55. Also, such an approach circumvents and simplifies the design flood weighting process suggested in the New Jersey Department of Environmental Protection Flood Plain Manual⁽¹¹⁾.

However, with the selection of a specific hydrologic design method the problems of the engineer have just begun. Every specialized hydraulic reference will tell him that in determining the runoff he must account for the future (at least 20 years) of the road he is going to design. For example, Technical Release #55⁽⁴⁾ advises as follows: "...obtaining basic data for runoff

volume and peak rates of discharge is difficult because conditions are constantly changing during the transition from rural to urban land use". Especially in New Jersey this is an ominous warning as New Jersey Special Report 38⁽¹²⁾ clearly states that "the rapid expansion of these 'two cities' (New York -- northeastern New Jersey and Philadelphia -- nearby southern New Jersey) has made New Jersey the most densely populated state in the nation with an average 1970 population density of over 950 persons per square mile".

The glaring examples of the ominousness of such warnings are New Jersey's Routes 22 and 9. The roadsides of the eastern and northern portions of these routes are built up to such an extent that presently their runoff areas are practically impervious. As a result even a short duration, but high intensity storm causes considerable floods. Since available drainage systems apparently were not designed to match such calamities, considerable damage often occurs. Thus, it seems to be the responsibility of the road designers to foresee such occurrences and for all levels of the administration to enforce recommendations of the specialists.

E.2.2.4 Rational Method

The Rational Method is based on the direct relationship between rainfall and runoff. Rainfall intensity is converted into rate of storm runoff by the formula:

$$Q = C i A$$

where:

- Q = peak rate of runoff in cubic feet per second
- C = weighted runoff coefficient presenting ratio to runoff to rainfall
- i = average rainfall intensity, in inches per hours, for the selected frequency and for duration equal to the time of concentration
- A = drainage area, in acres, tributary to the point under design

Practical details and application of this design method are provided in this report's supplement - "Road Surface Drainage Design, Construction and Maintenance Guide for Pavements".

"The rational formula is based on the thesis that if a uniform rainfall of intensity 'i' were falling on an impervious area of size 'A', the maximum rate of runoff at the outlet to the drainage area would be reached when all portions of the drainage area were contributing; the runoff rate would then become constant. The time required for runoff from the most remote point (point from which the time of flow is greatest) of the drainage area to arrive at the outlet is called the time of concentration".

These are ideal conditions of runoff which is already herein indicated, are seldom encountered in practice, especially in larger areas. For these reasons, it is suggested to restrict the application of this approach to drainage areas of less than 200 acres.

E.2.2.5 Design Methods for Areas Exceeding 200 Acres

Since hydrologic design methods for such larger drainage areas are not within the scope of this research, only the most basic information will be provided here.

For drainage areas exceeding 200 acres but up to 2000 acres, Soil Conservation Service Technical Release 55⁽⁴⁾ is suggested as a tabular hydrograph method⁽¹¹⁾.

The equation for computing the discharge is:

$$q = qp (D.A.) (Q);$$

where:

- q = Hydrograph coordinate discharge in cubic feet per second
- qp = Cu.ft. per second per sq.mile per inch of runoff (csm/in).
- D.A. = Drainage area in square miles
- Q = Depth of runoff in inches

The procedure is adequate for determining volumes, peak rates and hydrographs of runoff from urban areas.

Design flood determinations for a drainage area greater than 2000 acres, but up to 1000 square miles can be made using the empirical formulae provided in Special Report 38⁽¹²⁾ prepared by the U.S. Geological Survey in cooperation with the State of New Jersey Department of Environmental Protection. In this manual mathematical

and graphical relations are presented to estimate flood peak magnitudes having selected recurrence intervals ranging from 2 to 100 years for drainage basins with various degrees of existing or projected urban and suburban development. Four parameters are required for use of the relations. Three of these, basin size, channel slope and surface storage within the basin may be measured from topographic maps. The fourth, an index of man-made impervious cover can be determined from existing and future development conditions available from regional, state and local planning agencies. Urban and suburban development are shown to increase flood peaks, as statewide averages, up to three times at the 2-year recurrence interval and up to 1.8 times at the 100 year interval.

Application of and practical details for these design methods should be provided by two separate road surface drainage manuals covering, respectively, basins from 200 to 2,000 acres in size and 2,000 acres and up.

E.2.2.6 Federal Highway Administration Method^(18,19)

This method is somewhat separate from the approaches already discussed herein. While it is just another statistical approach, in its present form it is applicable to all the contiguous United States, Alaska, Hawaii and Puerto Rico. Also, it is apparently designed to cover small rural watersheds of all sizes up to 50 or even 100 square miles and it is developed with the road builders in mind. However, it is meant to provide runoff estimates for rural watersheds and the parameters considered in this design procedure seem not to include the transition from rural to urban

land use. Further, it appears that this method was developed for estimating the runoff and drainage of streams, i.e., for areas larger than one (1.0) square mile. Fortunately, Professor Irwin's design manual⁽¹³⁾ provides on Pages 19 to 22 corrections for urban development and for the discharge from areas smaller than 100 acres. Both corrections, under the circumstances, seem to suit the purpose adequately.

While the FHWA's methods, simplicity, thoroughness and completeness is tempting, its application for road design purposes should be considered with caution. Its suitability for drainage of areas in the immediate vicinity of major highways, roads in urban areas, as well as, road surfaces appear to be somewhat dubious.

Keeping the above admonitions in mind the design procedure offered by this method briefly can be summed up as follows:

The complete procedure consists of nine (9) steps with the probable maximum peak runoff $Q_{p(max.)}$ being determined in Step 2. In this step the only required parameter is the log A, which is the base 10 logarithm of the watershed drainage area measured in square miles. But in the FHWA's "Recommendations for Preparing Design Manuals"⁽¹⁹⁾ it is stated that "Situations where $Q_{p(max.)}$ might be appropriate would be the design inflow for determining the spillway capacity of a dam where failure could cause great loss of life. It probably would not be used on the bulk of the design work involving minor highway drainage structures". To use $Q_{p(max.)}$ in designing a highway drainage structure would undoubtedly result

in some overdesign of the structure. However, if the drainage areas are small, which would be the case if design criteria suggested elsewhere herein are followed, the $Q_p(\text{max.})$ would usually be adequate and use of the FHWA's more complete analysis would not be justified.

Nevertheless, Step 3 of the procedure provides the list of additional parameters -- and means of their determination -- which briefly are:

1. Iso-erodent, R - a precipitation parameter
2. Elevation difference, DH
3. Percent surface water storage area, S
4. Hydrophysiographic zone - a parameter which might help to account for rural to urban land use transition
5. Principal drainage channel length, L
6. 10-year, 60-minute rainfall, P_{60}
7. Cumulative channel lengths, LL
8. 10-year, 10-minute rainfall intensity, P_{10}

The remaining steps provide means for applying these various parameters.

Illustrative examples are given in the FHWA's manual describing this method. However, for a particular area this manual indicates a considerable number of steps that are necessary to resolve each individual problem.

Even though the selection of design methods is the prerogative of each individual designer the above reasoning seems to suggest that, at least for areas less than 200 acres, the Rational design method might be just as adequate and probably simpler to use.

E.2.3 Hydraulics

E.2.3.1 General

Hydraulics deals with the formulation of means for runoff disposal which are engineeringly and economically most efficient. In the case of road drainage design this can be achieved best by a system of ditches, gutters, chutes, median swales and other channels leading to various drainage structures such as culverts, storm sewers, etc. Figure 22 is, pointedly, an idealized rendering of how a properly designed and constructed roadside should function at all times. If, however, such is not the case the makeshift remedies portrayed in Figures 15 to 18 might be forced upon maintenance personnel.

To avoid such a situation all drainage elements should be adequately designed. Also, the need for a systematic maintenance of the elements should be recognized as being essential to any drainage system and taken into consideration in the design of the road drainage. Such an approach, however, must be cognizant of available maintenance resources and capabilities. It is foolhardy to design a drainage system that requires inordinate attention by maintenance or requires maintenance personnel to have considerable knowledge of hydraulic principles.

The subsequent hydraulic design proposals and analyses have been developed with the existing capabilities of New Jersey Department of Transportation's maintenance operations in mind.

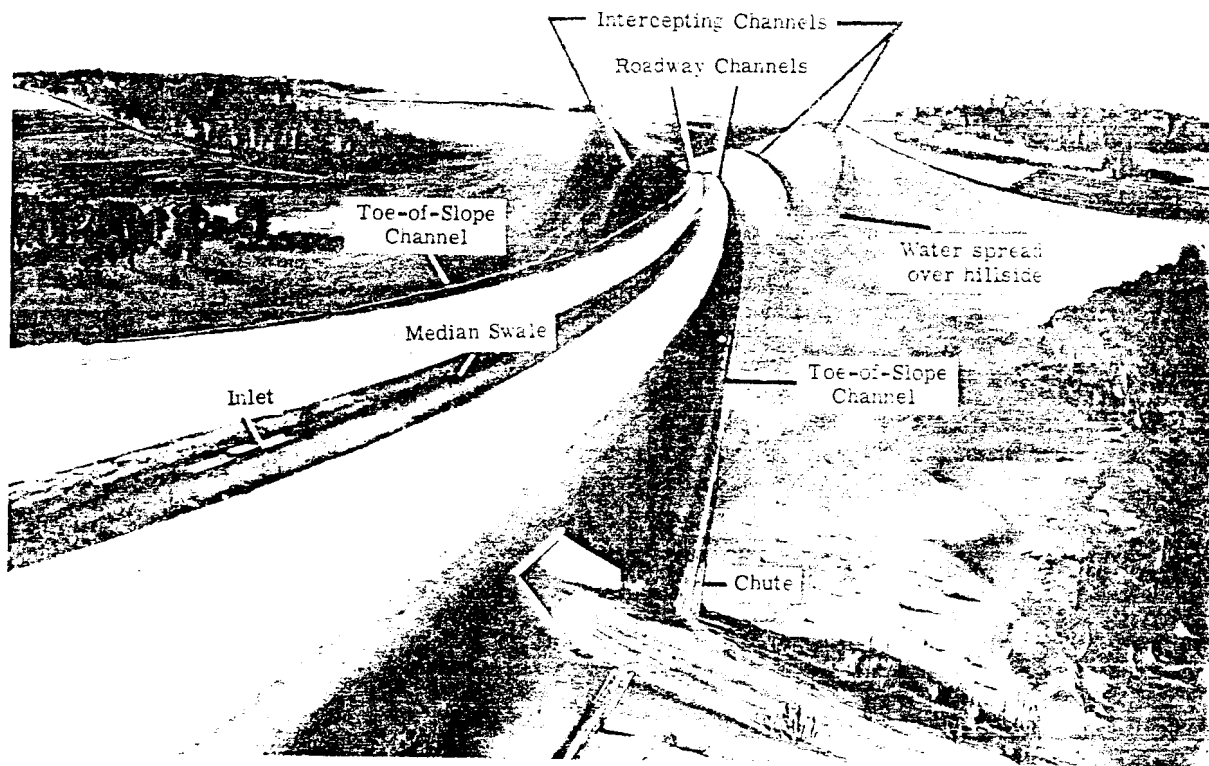


Figure 22.- TYPES OF ROADSIDE DRAINAGE STRUCTURES⁽⁷⁾

E.2.3.2 Open Channel Flow

As defined in King's "Handbook of Hydraulics"⁽¹⁰⁾ the term open channel means any conduit in which water flows with a free surface. All rivers, canals, flumes, etc., as well as, closed conduits and the like when flowing partially full are classified as open channels.

Open channels are constructed on a grade corresponding to that which the water surface is expected to assume, while pressure conduits can be located on any line below the hydraulic gradient.

In this report it is not possible nor is there a need to expand on hydraulic theories; the readily available King's handbook provides such information. However, a few basic terms will be mentioned here in order to better define the scope of concern.

If at any cross-section of a stream the discharge is constant, the flow is said to be steady and if the discharge changes during successive time intervals the flow is unsteady. Further, steady flow in an open channel may be either uniform or nonuniform. If at successive cross-sections in any reach, the mean velocities are the same the flow is uniform but if these velocities are not the same the flow is nonuniform.

As explained in Design of Raodside Drainage Channels⁽⁷⁾, unsteady flow results from variations of the supply such as the runoff flow during a storm period. However, the channels under consideration are designed for and carry a peak flow reoccurring with a selected frequency that can be considered as steady.

Although uniform flow conditions are rarely attained in drainage channels, the error in assuming uniform flow in a channel of fairly constant slope and cross-section is small, especially in comparison to the error in determining the design discharge. In this way, if the channel cross-section, roughness and slope are fairly constant over a sufficient distance to establish essentially uniform flow, equations such as that of Manning give reliable results.

In addition, as already indicated herein, since only relatively small runoff areas are included within the scope of the proposed guide, only small discharges should be expected. Thus, it is mostly open channel flow that need be considered in the proposed Road Surface Drainage Design, Construction and Maintenance Guide. The use of pressure conduits should, however, be a part of suggested manuals covering areas larger than 200 acres.

All these simplifications notwithstanding, no set of rules can be furnished that would apply to all of the many diverse combinations of topography, soil and climate that exist where highways must be built. Therefore, should the necessity for more complex design approaches arise, other reference guides are suggested elsewhere in this report.

Before discussing further the open channel flow a few additional terms and criteria need to be mentioned here. As explained in the BPR highway drainage manual⁽⁶⁾ or for that matter in any hydraulics handbook, for a given discharge and channel (roughness, cross-section and slope) there is a normal depth of flow (d_n) which is given by,

among others, Manning's formula. However, if the slope is relatively flat (e.g. 0.0001^{ft}/ft) the flow will be relatively slow and it will be at any point controlled by conditions downstream. As the slope increases the depth decreases and the velocity increases until the depth will be reached at which the control will change to upstream. This particular depth is called the critical depth (d_c) and the slope is called critical slope for that particular discharge and channel shape. For any other slope the normal depth (d_n) will be greater or less than the critical depth (d_c).

The flow is called subcritical when $d_n > d_c$, and supercritical if $d_n < d_c$.

Flowing water contains potential and kinetic energies. The potential energy at a particular point is represented by the depth of water plus the elevation of the channel bottom above a convenient datum plane. The kinetic energy is represented by the velocity head

$$\left(\frac{v}{2g}\right)^2 \text{ in feet.}$$

Critical depth is the depth of flow at minimum specific energy content. Critical depth occurs and is a control in sections of nonuniform flow whenever it changes from subcritical to supercritical.

Ordinarily, problems in highway drainage seldom require the accurate computation of water surface profiles; however, there should be an awareness of the fact that water depth in a given channel may be influenced by upstream or downstream conditions

depending on whether the slope is steep (supercritical) or mild (subcritical). The following typical conditions of nonuniform flow are often encountered in highway drainage design:

1. A channel on a mild slope discharging into a pool where the depth of flow is changing will result in a nonuniform flow condition.

2. The flow near the break in slope is invariably at critical depth as there is a change from subcritical to supercritical flow. However, downstream as the total energy head for the normal depth drops below the pool elevation (water surface on upstream side of break) above the actual depth quickly approaches the normal depth for the steep channel.

3. Another nonuniform type of flow is the draw down curve to critical depth in the case described in flow Type 2 above. From critical depth at break in grade the depth gradually increases upstream. The water surface curve is long, however, eventually it too approaches normal depth, provided channel characteristics remain reasonably the same.

4. A variation of a steeply sloping channel discharging into a pool involves a hydraulic jump, which is a dynamic transition from supercritical to subcritical flow. The violent turbulence in the jump dissipates energy rapidly. However, normal depth can be assumed to exist on the steep slope upstream up to the toe of the jump.

All the above cases undoubtedly exist no matter how low the discharge is. However, under the discharge conditions considered herein, the energies or flow deviations produced by these phenomena will hardly justify detailed analysis. In those rare cases where such analysis might be necessary the engineer would have to consult the previously cited manuals for larger runoff areas.

E.2.4 Drainage System

E.2.4.1 General

Roadside drainage channels perform the vital function of diverting or removing surface water from the highway right-of-way. They should provide the most efficient disposal system practicable. For such purposes one standard channel will hardly provide a satisfactory drainage for all sections of a highway. Thus appropriate structures must be designed to remove the water before it reaches the highway. These are the hydraulic problems to be dealt with herein.

Erosion control is a necessary part of good drainage design. Unless the side slopes and drainage structures are protected, damage will occur, maintenance costs increase, even resulting in destruction of the roadway. Locations that avoid poorly drained or frequently flooded areas and the like will greatly reduce problems. Field data improves solutions of drainage problems. As already stated herein and elsewhere the design procedures offered here are only tools to aid in solving drainage problems -- there are no standard solutions.

Water standing on the edge of the traveled way for a few minutes during the storm might not cause damage but should water remain for a long period of time on the roadway serious problems are apt to occur.

E.2.4.2 Structures^(7,9,21)

The capacity of a drainage channel carrying uniform flow depends upon its shape, slope and roughness. For a given channel the capacity becomes greater when the grade or the depth of flow is increased, but its capacity decreases as the channel surface becomes rougher. For example, a rubble or stone gutter has only about half the capacity of a concrete gutter of the same size, shape, and slope because of the differences in channel roughness. Often the roughness characteristics are used to the advantage on steep slopes where it is desirable to keep velocities from becoming too high. While a semicircular shape of a channel hydraulically is most efficient, a channel also should be economical to construct, require little maintenance, be safe for vehicles and pleasant in appearance. All these requirements often diminish the hydraulic capacity of said structures.

As already stated and shown in Figure 22 the types of drainage structures can be functionally classified as shown hereinafter.

Pavement Grades: Even uncurbed pavements should have at least 0.5 percent longitudinal slope to prevent undue spread of storm water and its penetration underneath the surface. As already

indicated in this report and elsewhere⁽⁹⁾ a heavy growth of grass at the pavement or shoulder edge in effect provides a condition very much resembling that of curbed pavements. All road edges should therefore be treated in such a manner as to be able to transport water adequately to the properly located outlets. Adequately designed gutters are the best solution of this problem. In any case, near-level grades are most objectionable.

Pavement Cross Slopes: Of necessity the selection of pavement cross slopes is a compromise between requirements for drainage and traffic. For drainage, reasonably steep slopes are needed to minimize water ponding but mainly to remove water from the pavements as fast as possible. Besides the extremely damaging effect of subsurface water penetration, water on pavement surfaces is a major contributor to many dangerous conditions such as hydroplaning or icing.

Table 1. Suggested Transverse Slopes of Pavements, Shoulders and Ditches⁽⁹⁾

Feature	Slope (%)
Pavement	1.5 - 3.0
Shoulder	4.0 - 6.0
Ditch	25.0 - 50.0

The shoulder must be sloped sufficiently to quickly remove surface water from the pavement areas.

Highway Drainage Channels: Starting at the outer edge of the right-of-way there should be intercepting channels on the natural ground outside the cut or fill slope, or on benches breaking the cut slope. Next, there should be roadway channels between the cut slope and the shoulder of the road. Toe-of-slope channels are then used to take the water discharged from the roadway channels and convey it along or near the edge of the roadway embankment to a point of disposal. Out of necessity a shallow depression or a swale is used to drain the median.

Gutters: Gutters should be the channels at the edges of the pavement or the shoulder. They should be paved with concrete, bituminous concrete or the like. They are usually used in lieu of other channels for urban highway drainage or in sections with limited right-of-way. However, preferably shoulders should not be used as gutters because their inadequate design or construction and certainly maintenance often leads to malfunctioning of the drainage system and eventual damage to the roadways.

Curbs: Curbs may be placed either at the edge of the pavement, however, preferably at the outer edge of the shoulder. If used, it must be designed with a gutter section, normally from one (1.0) foot to three (3.0) feet wide having a cross slope steeper than the adjacent surfacing, usually one (1.0) inch per foot. Curbs should be used only to drain the road surface; draining of surrounding roadside should be avoided. Since the curbs confine the storm runoff

to a gutter section with overflow onto the adjacent paved surface and because water is removed from it often by inlets, the malfunctioning of any part of such a system leads invariably to severe road damage.

Inlets: At intervals the water is removed from the gutter section by inlets. The median and gutters in a cut section generally discharge into an underground pipe system, while on the embankment the water collected in the gutter should be discharged down the slope through chutes. Basically, there are two types of inlets, grate and curb-opening inlets and open or closed chutes. Street inlets -- all inlets except possibly open chutes -- are inefficient means for intercepting water and should not be used to intercept the runoff that could have been diverted by more efficient structures, such as open channels. Clogging of grates, blocking of manholes and pipes and insufficient maintenance during and after construction are the realities which make these type of inlets highly inefficient.

The median should slope toward the center swale for drainage. The depressed area is sloped longitudinally to inlets, however, the slope of the swale should not necessarily conform to pavement grade. Since the swale should not be deep, the gutter should be paved and the most efficient type of inlets should be used for removal of runoff. If water does not drain adequately from a median its penetration into the subsurface will eventually result in serious damage to the road.

Chutes: A chute is a steeply inclined open or closed channel which conveys the collected water to a lower level. Chutes are also called flumes and spillways. The most common applications in highway

construction are the chutes used to convey water down cut or fill slopes. Open chutes can be metal or be paved with portland cement concrete, bituminous material, stone, or sod, depending upon the volume and velocity of the water to be removed. On long slopes, closed (pipe) chutes are often used because in an open chute the high velocity water is likely to jump out of the channel, erode the slope, and destroy the chute as is shown in Figures 15 and 16. The inlet of all chutes must be adequately designed to prevent water bypassing the chute and eroding the slope. Frequently, energy dissipators or other types of erosion protection are needed at the chute outlet.

Toe-of-slope channels: These are channels located at or near the toe of a fill when it is necessary to convey water collected by the roadway channel to the point of disposal. On the downhill side of the highway, this channel can often be laid on a mild slope and the lower end flared to spread the water over the hillside. Where this practice would cause erosion or permit water to drain into the highway embankment, the toe-of-slope channel must convey the storm water to a natural watercourse.

In arid and semiarid regions, the water draining out of the roadway cut should be diverted away from the fill far enough so that it does not come back to the highway. The landowner will seldom object to receiving storm water from the highway, provided it is delivered without causing erosion.

Intercepting channels: Channels located on the natural ground near the top edge of a cut slope or along the edge of the right-of-way are termed intercepting channels as their purpose is to intercept the runoff from a hillside before it reaches the roadway. Intercepting the surface flow reduced erosion of cut slopes, lessens silt deposition and infiltration in the roadbed area, and decreases the likelihood of flooding the highway in severe storms.

Intercepting dikes may be built well back from the top of the cut slope and generally on a flat grade until the water can be spread or emptied into a natural watercourse. In most cases, the owners of land will permit highway departments to construct a series of contour furrows beyond the right-of-way in order to recover the water.

An intercepting channel constructed by forming a dike with borrow material is superior to an excavated channel because the latter destroys the natural ground cover and is more likely to erode. Care should be taken to avoid ponding water at the tops of slopes subject to sliding. In slide areas, storm water should be intercepted and removed as rapidly as practicable and sections of the channel crossing highly permeable soil might require lining with impermeable material.

E.2.4.3 Miscellaneous Hydraulic Requirements

As indicated in an old BPR publication⁽⁷⁾ the width of the right-of-way usually allows little choice in the alignment or in the grade of the channel but considering the size of the runoff, applications of inordinate design approaches is improbable and, insofar as practicable, should be avoided.

A sharp change in alignment presents a point of attack for the flowing water, and abrupt changes in grade causes deposition of transported material when the grade is flattened or scour when grade is steepened.

A drainage channel should have a grade that produces velocities that neither erode nor cause deposition in the channel. This optimum velocity also depends upon the size and shape of channel, the quantity of water flowing, the material used to line the channel, and upon the nature of the soil and the type of sediment being transported by the stream. The ideal range for a ditch slope is between about one percent and five percent. For most lining materials, if slope is greater than five percent, the recommended velocity will be exceeded and erosion of the lining may become a problem. If the slope is less than one percent the capability of the ditch will be relatively small, and deposition of sediment may become a problem.

The point of discharge of a drainage channel into the natural watercourse requires particular attention. The alignment of the drainage channel should not cause eddies with attendant scour in the natural watercourse or near drainage structures. In erodible soils, if the flow line of the drainage channel is appreciably higher than that of the watercourse at the point of entry, a spillway or chute should be provided to discharge the water into the watercourse in order to prevent erosion in the drainage channel. The chute should be designed to prevent being undermined and destroyed.

Erosion and maintenance are minimized largely by the use of: flat side slopes, rounded and blended with natural terrain; drainage channels designed with due regard to location, width, depth, slopes, alignment and protective treatment; proper facilities for ground water interception; dikes, berms, and other protective devices; and protective ground covers and planting. Lining as applied to drainage channels includes vegetative coverings. The type of lining should be consistent with the degree of protection required, overall cost, safety requirements, and esthetic considerations.

In general, the lowest cost lining that affords satisfactory protection should be used. This is often sod used alone or in combination with other types of linings. Thus, a channel might be grass lined on the flatter slopes and lined with more resistant material on the steeper slopes. In cross-section, the channel might be lined with a highly resistant material within the depth required to carry floods occurring frequently and lines with grass above that depth for protection from the rare floods. Channels off the roadway can best be protected by laying them on grades which will not produce velocities in excess of those permissible (see Table 2) for the soil of that locality and by spreading the collected water over the hillside as soon as it can be released without reaching the roadway.

Table 2 - Maximum permissible velocities in erodible channels, based on uniform flow in continuously wet, aged channels^(a)

Material	Maximum permissible velocities for		
	Clear Water f.p.s.	Water Carrying Fine Silts f.p.s.	Water Carrying Sand and Gravel f.p.s.
Fine sand (noncolloidal).....	1.5	2.5	1.5
Sandy loam (noncolloidal).....	1.7	2.5	2.0
Silt loam (noncolloidal).....	2.0	3.0	2.0
Ordinary firm loam.....	2.5	3.5	2.2
Volcanic ash.....	2.5	3.5	2.0
Fine gravel.....	2.5	5.0	3.7
Stiff clay (very colloidal).....	3.7	5.0	3.0
Graded, loam to cobbles (noncolloidal).	3.7	5.0	5.0
Graded, silt to cobbles (colloidal)....	4.0	5.5	5.0
Alluvial silts (noncolloidal).....	2.0	3.5	2.0
Alluvial silts (colloidal).....	3.7	5.0	3.0
Coarse gravel (noncolloidal).....	4.0	6.0	6.5
Cobbles and shingles.....	5.0	5.5	6.5
Shales and hard pans.....	6.0	6.0	5.0

(a) From "Design of Roadside Drainage Channels"⁽⁹⁾
 For sinuous channels multiply allowable velocity by 0.95 for slightly sinuous, by 0.9 for moderately sinuous channels, and by 0.8 for highly sinuous channels.

Table 3 - Maximum permissible velocities in channels lined with uniform stands of various grass covers, well maintained^(a)^(b)

Cover	Slope range Percent	Maximum permissible velocity on	
		Erosion-resistant soils f.p.s.	Easily eroded soils f.p.s.
Bermudagrass.....	0-5	8	6
	5-10	7	5
	Over 10	6	4
Buffalograss.....	0-5	7	5
	5-10	6	4
	Over 10	5	3
Kentucky bluegrass.....	0-5(c)	5	4
	5-10(c)	4	3
Smooth brome.....	0-5(d)	3.5	2.5
	Over 10		
Blue grama.....	0-5(d)	3.5	2.5
	Over 10		
Grass mixture.....	0-5(d)	3.5	2.5
	Over 10		
Lespedeza sericea.....			
Weeping lovegrass.....			
Yellow bluestem.....			
Kudzu.....			
Alfalfa.....			
Crabgrass.....			
Common lespedeza ^(e)			
Sudangrass ^(e)			

(a) From "Design of Roadside Drainage Channels"⁽⁹⁾.

(b) Use velocities over 5 f.p.s. only where good covers and proper maintenance can be obtained.

(c) Do not use on slopes steeper than 10 percent.

(d) Use on slopes steeper than 5 percent is not recommended.

(e) Annuals, used on mild slopes or as temporary protection until permanent covers are established.

Table 4 - Maximum Allowable Water Velocities for Different Types of Ditch Linings*

<u>Natural Soil Linings</u>	<u>Maximum velocity, feet per second</u>
Bedrock, or rip-rap sides and bottoms	15-18
Gravel bottom, rip-rap sides	8-10
Clean gravel	6-7
Silty gravel	2-5
Clayey gravel	5-7
Clean sand	1-2
Silty sand	2-3
Clayey sand	3-4
Silt	3-4
Light clay	2-3
Heavy clay	2-3
 <u>Vegetative Linings</u>	
Average turf, erosion resistant soil	4-5
Average turf, easily eroded soil	3-4
Dense turf, erosion resistant soil	6-8
Gravel bottom, brushy sides	4-5
Dense weeds	5-6
Dense brush	4-5
Dense willows	8-9
 <u>Paved Linings</u>	
Gravel bottom, concrete sides	10
Mortared rip-rap	8-10
Concrete or asphalt	18-20

*From "Drainage Design Manual for New York State"(13)

The allowable maximum velocities indicated in Tables 2,3, and 4 should satisfy the prevalent needs to be covered by the proposed surface drainage guide (the supplement to this report). However, it should be noted that the values of Table 3 are designed for well maintained grass covers, which too often is not the condition, especially when roads become routinely operational. Thus in reality smaller velocities are to be expected, especially in areas of minimum slope. Such an occurrence is a typical example of what was earlier described as unattainable maintenance (see Figure 18). This, however, can be foreseen in the design, for example, by lining such channels thusly decreasing the roughness characteristics. The roughness factors of an asphalt lining would double the velocities, while providing a more maintainable installation thus possibly equalizing the increase in initial costs. As a guide for prevention of erosion, while minimizing costs, Table 4 provides comparative values for maximum allowable velocities in open channels.

E.2.4.4 Conduits

As already indicated for most cases within the scope of the proposed guide there will be free surface flow in pipe conduits. Thus, open channel flow design criteria should be considered here. Only on rare occasions, where closed conduits carrying water under pressure are unavoidable, should the more complicated pressure flow approach be considered. For such solutions referenced 1,6, and 10 listed at the end of the report should be used and qualified engineers consulted.

The design approach adapted herein for use in the proposed surface drainage guide was developed by Professor Lynne H. Irwin, et al (13,14,15).

The criteria which must be considered when designing culverts are:

- (1) material of which the culvert is composed,
- (2) inlet and outlet conditions of the culvert barrel,
- (3) allowable headwater at the culvert entrance, and
- (4) culvert barrel slope, length, and diameter

All of these criteria were taken into consideration in the proposed design guide. Three types of culvert materials presently required by the New Jersey Department of Transportation were considered for inclusion in said design guide: corrugated metal, reinforced concrete, and smooth metal pipes.

The type of material composing a culvert is a big factor in determining its hydraulic capacity. The material type affects capacity through the roughness of the walls of the culvert. The rougher the culvert walls, the smaller will be the culvert capacity for a given pipe diameter. A corrugated metal culvert has rougher walls than a smooth metal culvert and therefore provides a greater resistance to flow.

The culvert materials required by the New Jersey Department of Transportation include so-called annularly and helically corrugated metal, reinforced concrete and smooth metal pipes. In general, the lowest cost material that affords satisfactory

protection in any practically feasible circumstances should be used. The material type affects capacity through the roughness of the walls of the conduits.

Factors which affect the choice of a roughness coefficient are Reynolds number, size and shape of conduit, and depth of flow. In addition to these interrelated factors the following should be considered:

- a. rough, opened, or offset joints,
- b. poor alignment and grade due to settlement or lateral soil movement,
- c. deposits in the conduit,
- d. amount and size of solids being transported, and
- e. tree roots, joint compounds, and mortar dams resulting from poor or deteriorated jointing and other protrusions.

Also, it is to be realized that full flow is seldom attained in short pipes, such as culverts, and most short, small pipes are sized for convenience of maintenance rather than based on hydraulic capacity considerations.

In instances where helically corrugated pipes are of 24 inch diameter or less are used as long storm drains and full flow is assured the lower resistance factors may be applied. Extrapolation of the test results to larger pipe sizes is, however, not recommended at this time. Also, for helical conduits of minimal slope and flow velocity, excessive deposition may occur so that use of a higher friction loss allowance approaching that of annular corrugation might be more appropriate.

The inlet and outlet conditions of a culvert also have a great effect on culvert capacity. At the inlet, the water entering the culvert loses energy due to the abrupt contraction in flow areas. Provision of wingwalls and rounding at the culvert entrance improves culvert capacity because it reduces the entrance energy loss. The smaller the energy loss, the larger will be the culvert capacity. Because field construction is required to improve culvert inlet conditions, and because this construction is not done in too many cases, the worst entrance condition (projecting inlet) was assumed in developing the culvert capacity tables offered in the drainage guide.

At the culvert outlet the depth of water in the outlet channel may have an effect on the conditions at the culvert inlet. The range of outlet conditions which are possible for a culvert is so wide, that it was considered impossible to include all of them in the design guide. Therefore, it was assumed in the formulation of the culvert capacity tables that the outlet condition would have no effect on the culvert flow conditions. In making this assumption, the tables would be valid for all situations where the outlet is submerged to a depth no greater than approximately two-thirds of the pipe diameter.

The headwater depth at the culvert inlet is the constraining factor on culvert design. The allowable headwater depth is that depth of water which can be ponded at the inlet culvert without having the pond overtop the roadway or flood valuable property. The greater the headwater depth the greater is the potential energy

available to produce flow through the culvert. It is therefore advantageous to have as high an allowable headwater depth as possible.

The slope and length of a culvert barrel have contrasting effects upon culvert capacity. An increase in culvert slope increases capacity and an increase in length decreases capacity. Culvert length is dictated by the width of the road and the angle of the crossing. Culvert slope is usually the same as that of the approaching stream bed although culvert slope usually should not exceed two percent to avoid erosion problems at the outlet.

Culvert diameter is usually viewed as being the design criteria for which one is designing, that is, culvert diameter is the dependent variable in the design process. In the design process the allowable headwater is given as a constraint and the other variables of slope, length, and material type are usually tried in various combinations. The material type may be more limited than the other variables because of policies set forth by the New Jersey Department of Transportation. Once the parameters of allowable headwater, slope, length, and culvert material are identified, the culvert diameter can be obtained.

The computation of flow through a culvert can be accomplished through considerations of continuity and energy relationships. The flow conditions are assumed to be steady (invariant in time) so that the continuity and energy equations can be written.

There are two types of flow conditions which can occur for a single discharge through a culvert. These conditions are referred

to as inlet control and outlet control. As in the case of channel flow, the inlet control condition exists when the critical depth of flow is greater than the normal depth of flow. The outlet control condition exists when the critical depth of flow is less than the normal depth of flow. Critical depth of flow for a given discharge occurs when the specific energy of flow is a minimum. The normal depth is that depth which occurs for uniform flow conditions. All conditions being equal except for slope, a pipe in inlet control is steeper than one in outlet control.

A culvert flowing with outlet control can flow either full for its entire length, full for a portion of its length, or part-full for its entire length. When the culvert is flowing with inlet control it will flow part-full for its entire length, unless the entrance is sufficiently rounded to allow expansion of the entering flow. For the purpose of the proposed manual, consideration was given only to part-full flowing culverts when in inlet control. The part-full consideration gives a conservative value for headwater when the culvert is operating in inlet control.

To accurately compute the headwater required at the culvert inlet when the culvert is in outlet control, the profile of the water surface within the culvert must be known.

The energy grade line is computed at a cross-section using Manning's equation (or other suitable head-loss formula).

When the culvert is in inlet control the critical depth is assumed to occur at the inlet so that a water surface profile is not necessary.

As mentioned previously there is a loss of energy when water flows through the entrance of the culvert. This energy loss is represented empirically as being proportional to the velocity head ($v^2/2g$) at the culvert entrance.

The outlet velocity of each culvert must be checked to see if it would have erosive effects on the downstream side of the culvert barrel. This check should be done using the critical velocity when the culvert is in outlet control and the velocity at normal depth when the culvert is in inlet control. The use of normal depth is not exactly correct, although it is conservative, since the flow probably does not reach normal depth in the short pipes.

An upper limit of eight feet per second was set on the outlet velocity to protect against soil erosion. Wherever this upper velocity limit is exceeded, the engineer should take measures to prevent erosion at the culvert outlet. A recommended measure is to place rock rip-rap at the outlet.

F. CONSTRUCTION AND MAINTENANCE

F.1 GENERAL

To provide an adequately functioning road system all facets of its engineering must be taken into consideration. This means that in designing roads the realities of their construction and maintenance must be part of the design. Additionally, the construction and maintenance of a road must be executed in such a way as to fully satisfy the design requirements. This then is the only approach that should be followed in designing, building and maintaining of a functional and durable road system. These criteria, of course, apply to the drainage aspects of the system.

F.1.2 Construction and Maintenance of Ditches^(9,13)

The usual order of construction work connected with the drainage system of a highway involves such items as excavation for roadside drainage ditches and structures, trenching and shoring, preparation of pipe bedding, laying, aligning and jointing of pipe, backfilling and compacting, installing structures, and cleaning up.

Drainage work should be scheduled to maintain the roadbed and right-of-way area as dry as possible. Also, measures should be taken to protect roadside drainage channels and slopes from erosion.

Effective drainage during construction frequently eliminates costly delays as well as possible later failures resulting from a saturated subgrade. Drainage channels should be constructed early

in the grading operations beginning at the downstream end, and the necessary channel protection provided before erosion damage occurs. Slopes should be protected from erosion as early as practicable to lessen the risk of eroded soil choking off existing and newly-constructed channels and drainage structures.

One of the most important considerations in ditch construction is the need to protect against erosion of the soil in the ditch. Ditch erosion causes ditches to develop into excessively deep and unsightly channels. It can also undermine cut and fill slopes and cause slope failures.

The sediment picked up by erosion is deposited downstream at a point where the water velocity is slowed. It may clog the ditch or the entrance to a culvert, causing storm water to overflow onto the road. It may also deposit silt in natural stream channels, to the detriment of fish.

Ditch erosion causes maintenance problems at two locations: at the point where the erosion is occurring, and also at the point where sediment is deposited. Once started, ditch erosion can be very difficult to control. Erosion is best handled before it begins, by careful ditch design, construction and maintenance.

Two main factors lead to the problem of erosion in ditches:

- a. excessive water velocity for the type of ditch lining, and
- b. improper maintenance practices which remove the erosion-resistant lining and expose erodible soil.

Means for controlling each of these factors were mentioned earlier and are discussed, in more detail, in the drainage guide supplementing this report.

The inspection program in the maintenance of a drainage system should include inspection of all surface drainage structures, ditches and channels to insure that all are functioning as designed. If channels, pipes, culverts, or outlets are clogged because of silting, debris, brush, snow, ice, or for any other reason, immediate steps should be taken to correct the condition.

All drainage facilities should be well marked and mapped in order that they are not missed when inspection is made.

F.1.3 Construction and Maintenance of Culverts⁽¹³⁾

To choose a culvert which has the capability to pass a specified flood discharge is a very important step in the overall design. Next consideration must be the design of a culvert to stand up to traffic and soil loads. The safety of the design will depend solely upon the care taken in placing the culvert according to design specifications. The following conditions must be satisfied to provide for an adequate culvert placement:

- a. adequate bedding,
- b. proper shaping of bedding,
- c. proper methods to backfill the culvert excavation,
- d. a culvert which is strong enough to stand up to the weight of backfill material and the weight of traffic, and
- e. provide enough backfill cover on the pipe so that the culvert is not crushed by the traffic.

It may cost some extra money to meet all of the above requirements, but the extra cost would be in the initial cost. The extra care taken initially leads to fewer maintenance problems in the future.

These requirements will be somewhat different for pipes made of different materials. The requirements will also be discussed in detail for the different types of pipes in the drainage supplement.

G. TRAFFIC-SAFE AND HYDRAULICALLY EFFICIENT DRAINAGE PRACTICE⁽²²⁾

(This is an exact reprint from NCHRP Report #3)

Some highway drainage structures are potentially hazardous and, if located in the path of an errant vehicle, can substantially increase the probability of an accident. With prudent judgment many of these hazards can be minimized or avoided without seriously interfering with the effectiveness of drainage facilities. No set of rules can be prescribed that would cover every situation. The highway engineer needs a safety consciousness, or awareness, about potential hazards, and the resourcefulness to take countermeasures for their elimination.

Four principal objectives for providing safer roadsides (as applied to drainage structures) have been identified. In order of priority, they are:

1. Unnecessary drainage structures should be eliminated.
2. Necessary drainage structures should be located so that they create the least possible hazard.
3. Structures which cannot be eliminated or redesigned should be designed to inflict minimum damage.
4. Where the first three objectives cannot be feasibly accomplished, guardrail should be installed.

Median inlets should be flush with the ground, or should present no obstacle to a vehicle that is out of control. Such median inlets can be designed to be hydraulically efficient.

End structures for cross drains or culverts should be placed outside the designated recovery area wherever possible. If grates are considered necessary to cover culvert inlets, care must be taken to design the grate so that the inlet will not clog during floods. Where curb inlet systems are used, setbacks should be minimal, and grates should be designed for hydraulic efficiency and safe passage of vehicles. Roadside channels should have flat side slopes. Hazardous channels or energy-dissipating devices should be located outside the designed recovery area or adequate guardrail protection should be provided.

The design and location of drainage structures should receive as much attention from a safety standpoint as other roadway features - such as geometrics, lighting, signing and guardrail.

Excessive use of guardrail to protect traffic from hazardous drainage structures is both a psychological and a physical hazard. Existing structures should be made safer by relocation or modification. Guardrail should be used only as a last resort.

It is necessary to emphasize that liberties should not be taken with the hydraulic design of drainage structures to make them safer unless it is clear that their function and efficiency will not be impaired by the contemplated changes. Engineering judgment should

be used every time grate installation is considered. Even minor changes at culvert inlets can seriously disrupt hydraulic performance.

The key criterion for safety is that potentially dangerous openings to drainage structures should be situated away from the roadways, in locations where they are less likely to be traffic hazards.

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