HIGHWAY RESEARCH RECORD

Number 58

Drainage Law

4 Reports

Flood Plain Planning

6 Reports

Depressed Curb-Opening Inlets

1 Report

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Part I

DRAINAGE LAW

Better Drainage Facilities for Less Tax Dollars by Cooperative Agreements

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•DRAINAGE DESIGNS for State highways can be generally divided into two groups; one group comprising designs where a satisfactory solution can be worked out within the right-of-way area, and a second group where a satisfactory solution requires something to be done beyond the normal right-of-way limits. While both require interagency cooperation, this latter group brings into sharp focus the necessity for coordinated planning and construction of drainage facilities in areas under the jurisdiction of two or more governmental agencies, plus, in some cases, private property owners. This group of highway drainage designs presents problems that warrant special consideration and includes the fields of engineering, law, economics, governmental economy, and public relations. Typically, once it is necessary for the State to go beyond the normal right-of-way, it is encroaching into areas under some other governmental jurisdiction. These areas may be urbanized, rural, or in a transitional stage. They may be city, county, or both, and further, may be a portion of a special assessment district legally organized to solve a particular localized flood control or other problem.

The State highway is usually only a long narrow strip with occasional expanded areas at interchanges. Its drainage problems are the disposal of precipitation falling within its own bounds and the passing across the right-of-way property of water coming to it; all without any unnecessary changes in the existing or natural drainage pattern and with no uncompensated damage to property.

In the early transition from rural area to urban, poor drainage and flooding may not be too serious as far as it concerns property damage and public inconvenience, and the drainage problem that is developing is not widely noticed. It is dramatically spotlighted when flooding, State highway closures or serious traffic hazards, property damage followed by claims and suits against the State, and possibly injury or death to motorists or other persons occur with the sequence of events during or following seasonal storms.

The usual natural sequence is precipitation to surface water to stream water to flood water, thence back to stream water and to final disposal usually in an ocean, bay, or inland lake. Legal concepts generally tend to follow this sequence, and legal definitions support the descriptive words used.

At some point in this sequence the works of the hydraulic engineer are needed to prevent the hazards, damage, and injury caused by uncontrolled water after it ceases to be termed precipitation. The sooner these works, generally called drainage facilities, intrude into the sequence as controlling factors, the better for all especially the taxpayer, who eventually pays all the bills, no matter what their nature or origin.

Paper sponsored by Special Committee on Highway Laws.

The detrimental effects of uncontrolled storm water disposal can be prevented by proper planning and construction of drainage facilities. If these effects cannot be entirely prevented due to prior inadequate construction or complete lack of facilities, they can be prevented from recurring by construction of supplemental or new works.

The adverse effects of poor drainage with or without attendant flooding on highways and adjacent properties may be listed to include:

1. Delays, interruption, and inconvenience to traffic due to floods or roadway failures. When expressed in dollars, these delays and interruptions may be quite large.
2. Injuries and hazards to vehicles and persons caused by floods or roadway failures. These also can be large if expressed in dollars, and certainly should be considered large if expressed in terms of human suffering and anguish.
3. Damage to State highway drainage facilities with resulting repair and maintenance costs.
4. Damage to private and public property. These may also be quite large, as witnessed by one claim for alleged damages in this District (California Division of Highways District IV) for $2,100,000. This claim was not paid, although it cost the taxpayers about $20,000 to amass the data necessary to resist the allegations. However, the probable net savings to taxpayers due to good engineering and careful attention to the drainage laws of the State of California as well as the laws of nature, in the original design, could be said to be $2,100,000 less $20,000, or $2,080,000.
5. Pavement or subgrade failure with resultant costly repairs and maintenance.
6. Damage to public utilities in urban areas.
7. Contamination of public water supplies and sewerage systems with the attendant detriments to public health.
8. Public impression that the taxpayer is getting inferior engineering while paying for top grade service.
9. Lessening of the public's esteem for their governmental agencies, officials, and employees.

In California, the State is responsible for passing across the right-of-way, drainage flowing to its State highway and is also responsible for disposal of storm water falling on its property. In accordance with constitutional and statutory provisions, California Highway Users Tax funds can be expended for highway purposes only. These provisions prohibit the State from using highway funds to finance comprehensive storm drain projects or any other flood control works in excess of minimum facilities necessary for protection of the State highway system. However, there is nothing to prevent the State from contributing the estimated amount needed for its minimum drainage facilities to any agency that has developed a comprehensive drainage plan that would satisfy all the State's drainage obligations in as good or better manner than the State could provide by unilateral action. The basic requirement is that any contribution by the State must be a direct tangible benefit that can be computed by a rational method. This insures that highway funds be used for highway uses only. In some cases, it is evident that the State highway is a contributor to the drainage problem and also suffers from it along with its adjacent neighbors. Yet, it is not feasible or lawful for any one agency or owner to finance an overall system adequate to solve even its own problems, let alone those of the other agencies.

Given these circumstances, the logical solution is a scheme of cooperation among the various jurisdictions for complete solution to a specific drainage problem and to provide an equitable means for financing and following through on such a scheme.

A policy of continual contact with the nine counties of California State Highway District IV and especially with those counties having organized Countywide Flood Control Districts has been worked out. All State highway drainage facilities embodied in new construction are planned to conform to County Master Drainage and Flood Control Plans regarding capacity and location. Where master plans are not applicable, individual solutions are worked out and a separate joint agreement is obtained.

When there is a distinct line of separation between jointly planned facilities, no formal agreement is needed because the bearer of design, construction, and maintenance costs is evident. Generally speaking, the State Division of Highways accepts these burdens within its right-of-way, and the other agency retains or accepts the burden of all facilities outside the right-of-way. In cases where the lines of demarcation are not so evident, a written cooperative agreement is required to finance, construct, maintain, and accept liability for jointly needed facilities where both agencies have tangible benefits, the duty of providing drainage facilities, or both.

This agreement might as a minimum recite the names of the agencies, the reason or need for the agreement, the benefits to be derived by each party, the amounts to be contributed by each, a statement of which agency will plan and which will construct the facility, the date construction must be completed, who is to maintain the completed system, and which party assumes liability for changes in the existing drainage pattern caused by construction of the new or improved system.

By these methods of providing proper drainage facilities during original construction, both State Highway Users Tax funds and local tax funds are conserved and the taxpayers money saved because the increased cost of installing drainage structures under completed and heavily traveled State highways is well established.

Where jointly needed facilities are required in connection with an existing State highway, a written cooperative agreement is almost always required. Many of these involve upgrading the capacity of structures due to collection of storm water by the local agency and concentrating it at a particular State highway culvert to the benefit of both parties and in accordance with their master plans. The financing, construction, liability, and maintenance must be equitably allocated and set forth to the satisfaction of both public agencies.

In rather rare instances, it is necessary for a private owner or developer to enter into an interagency cooperative project. This may be monetary in nature or the owner or developer may construct a portion of the project or cause it to be constructed. In cases like this and particularly where the local agency will take over the completed facility for maintenance, a two party agreement with the permanent local agency allowing them to make a temporary agreement with the private owner is preferred. This is also the case where there are two or more local agencies involved along with the State. Here it is also preferable to write a two party agreement between the State and the local agency that will take over the burden of future maintenance and let this agency make the necessary agreements with the other local agencies. All of these activities progress more expeditiously where directed by a special group within a public agency.

In 1948, District IV of the California Division of Highways, recognizing the growing complexity and importance of its drainage problems, set up a small crew of specialized engineers whose primary duty concerns State highway drainage as it is affected by engineering hydraulics, legal aspects of highway drainage, and disposal of storm runoff with the least detrimental effect to the State highway and to adjacent property, be it public or private. This unit has at present 31 engineers and is headed by a Senior Highway Engineer with title of District Hydraulics Engineer. District IV, served by this Hydraulics Section, comprises the nine counties immediately surrounding San Francisco Bay.

The functions of this section are to design major drainage facilities for State highway projects; advise highway designers concerning general surface drainage, and check drainage designs prepared by others; to furnish hydrology for all parts of the district; to make continuous checks of changes in land use for alterations in drainage patterns as they may affect the State highway system; to establish and maintain liaison with other agencies concerned with drainage; to make special studies for other district departments as requested; and to analyze and make recommendations for disposition of claims and complaints involving drainage damage allegedly caused by State highway drainage facilities or the lack of these facilities.

In the exercise of its functions, the Hydraulics Section frequently encounters unsatisfactory drainage conditions that cannot be properly corrected by the design of new facilities without assistance from agencies having jurisdiction over areas outside the normal limits of highway right-of-way. These problems are usually solved as previously described.

Drainage law attempts to follow the laws of nature, and drainage must in general be disposed of without damage to adjacent property. Even if the laws of some States are not clear regarding damage due to drainage, good engineering on the part of any public agency does not dispose of storm runoff in such a manner as to unnecessarily damage private property. If there is no solution that does not cause some damage to property, then the owner should receive just compensation for the damage. Cooperatives generally result in solutions that cause no damage or at least much less than would occur if any one agency acted alone.

Since District IV of the California Division of Highways has had a fully organized and operating Hydraulics Section, it has not been required to pay a single claim for alleged damage due to recently completed State highway drainage installations where such a claim was based solely on allegedly improper engineering or violation of drainage law. In some few cases where claims have been fully or partially allowed, the awards were based on public interest and the eventual savings to the taxpaying public rather than on poor engineering or violations of drainage law.

The filing of claims or suits against the State cannot be prevented. Their cost to the taxpayers, however, can be reduced to the time and effort required to refute them if drainage facilities are so designed that there are no good engineering or drainage law violations, no uncompensated damage to properties beyond the right-of-way, and if all necessary safety devices are installed to prevent injury to persons or animals.

All of District IV's Cooperative Agreements resulted in better overall drainage facilities than any of the interested agencies could have constructed without aid from the others and resulted in taxpayers' savings either in original cost, maintenance expenditures, damage repair costs, or some combination of these.

As illustrations of drainage Cooperative Agreements in California Highway District IV, the following cooperative projects were selected as examples of good overall engineering; adherence to drainage law, and the laws of nature. They resulted in substantial direct savings to the taxpaying public and indirect savings to local citizens in the form of relief from flooding, with attendant increase in property and human values. One of these examples is in San Mateo County and the other in Sonoma County.

Bella Vista Avenue Drainage Outfall

At Bella Vista Avenue in the Sharp Park area of the City of Pacifica, design studies indicated a depressed section to be the best and most economical for proposed freeway (Fig. 1). However, surface drainage crosses the State highway at this point, and the depressed design had to provide for transporting this terrain drainage across the right-of-way and also to dispose of roadway drainage collecting in the depressed section. There was no adequate outfall between the right-of-way and the Pacific Ocean, about 1,200 feet westerly.

Under conditions existing at the time of design, runoff from the uplands east of the State highway was passed across the right-of-way in a 78-in. corrugated metal pipe that discharges into a completely inadequate ditch and pipe system under the jurisdiction of the city. Urbanization of the areas, above and below the highway, is in progress and the area above includes development of a community high school with large areas from which runoff will be considerably increased. Flood conditions have occurred almost every rainy season in the area below the highway and between it and the ocean.

Drainage studies by the State developed the best plan for drainage facilities, considering freeway completion and ultimate urbanization development.

This plan provides a 72-in. reinforced concrete pipe passing under the freeway depressed section, along Bella Vista Avenue, and discharging into the Pacific Ocean. This drainage system has a total length of 1,400 ft and is within two governmental jurisdictions; the State's, due to its freeway right-of-way, and the city's, due to incorporation of the area. Runoff from within the highway right-of-way, collecting in the depressed section, will discharge by gravity through the system, thereby eliminating the necessity for an expensive pumping plant with its continual operating expense. This plan was by far the superior solution to this drainage problem.

The City of Pacifica had developed a Master Drainage Plan, that proposed a major storm drain outfall along this same route. This indicated interest on the part of the city. Discussions with the city brought out that cooperation was justified and very desirable, as it would provide the best facility with minimum cost to both public agencies.

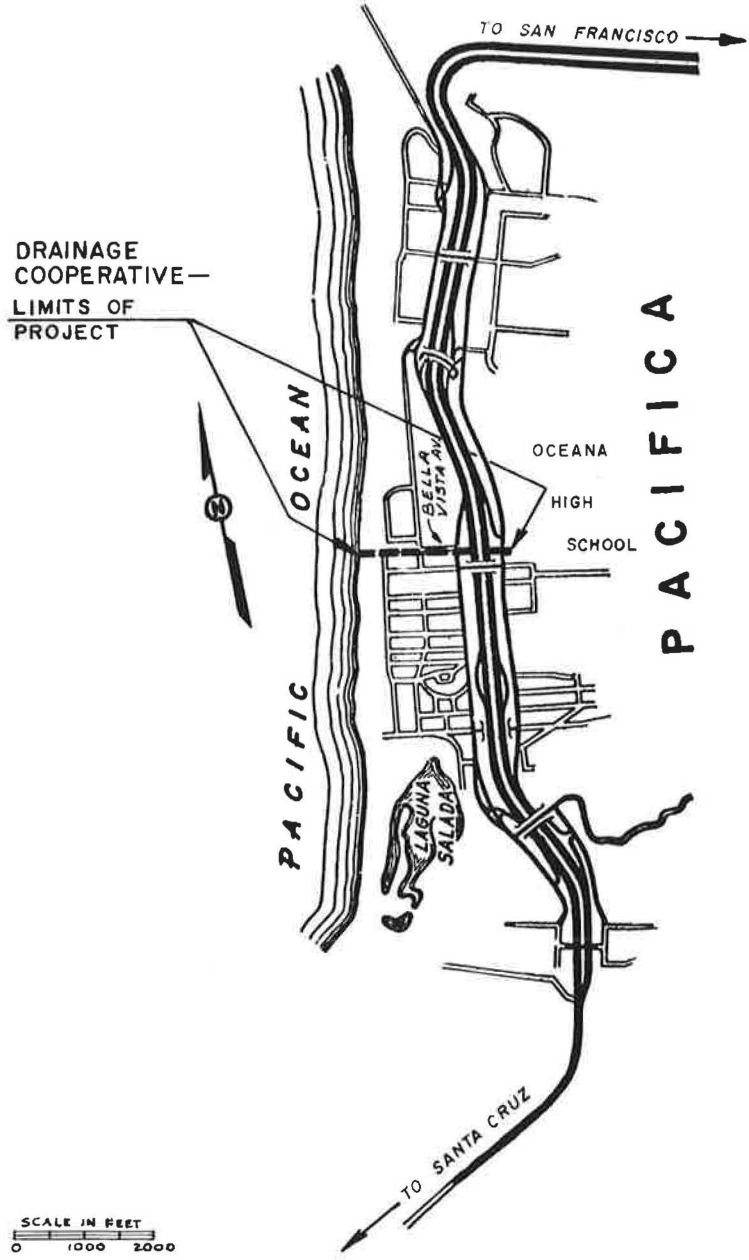

Figure 1. Bella Vista Avenue Drainage Outfall, City of Pacifica, San Mateo County, Calif.

An agreement was negotiated, and the completed cooperative agreement set forth that the city would provide the necessary right-of-way for the drainage outfall, clear and free of all obstructions, and would maintain all portions of the drainage facilitiy lying outside the State right-of-way. The State agreed to design, construct, and finance these two items.

This project is now under construction. The State is saving right-of-way costs for the outfall, estimated at about $22,000, and considerable maintenance costs. The city is saving about $100,000, the cost of the outfall paid for by the State in lieu of a more costly pumping plant, less right-of-way and right-of-way clearance costs paid by the city.

Willow Brook Channel Improvement

In December 1956, a new freeway in Sonoma County, locally called the Petaluma Bypass, was completed and opened to traffic. This freeway crosses an area north of Petaluma known as Denman Flat, which is historically a flood plain (Fig. 2). Design

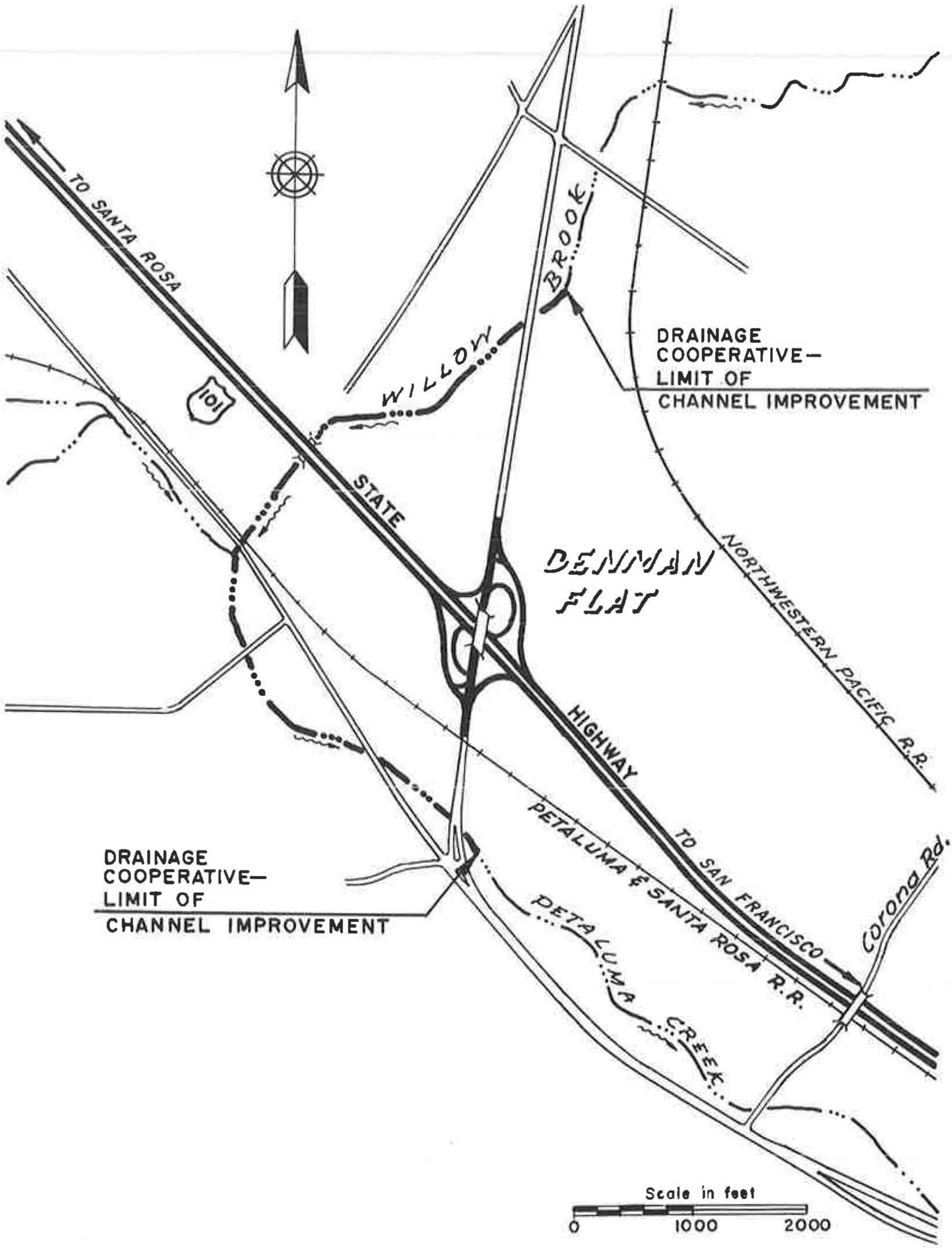

Figure 2. Willow Brook Channel Improvement, Denman Flat, Sonoma County, Calif.

and construction of freeway drainage facilities was in conformity with the historical drainage and flooding pattern; but in 1958, the seasonal rainfall was unusually heavy and portions of the freeway and some of the interchange loops were flooded eight times with considerable delay and hazard to traffic. Investigation revealed changes in the flood pattern due to changes in the channel characteristics of the upper reaches of Petaluma Creek, locally termed Willow Brook. This freeway flood caused adverse public reaction and cost $1,800 in excess maintenance costs for this one season alone. In addition, owners of flooded private property complained bitterly and demanded action from county agencies. Investigation clearly showed that the progressively decreasing capacity of Willow Brook was the cause of the changes in drainage and flood patterns, and that improvement of about 4,000 ft of this channel was the superior engineering solution and, at the same time, the best for taxpayers and private owners.

Accordingly, a Cooperative Agreement was negotiated with the newly formed Sonoma County Flood Control District. The agreement provided for rectification of about 4,000 ft of Willow Brook Channel to improve drainage in the Denman Flat area. The project was subsequently completed and has been in operation for 4 years.

The main provisions of the agreement were that the State agreed to construct about 4,000 ft of realigned and rectified channel to replace existing Willow Brook, and the county agency agreed to acquire all necessary rights-of-way and to assume all maintenance responsibilities on satisfactory mutual inspection of the completed work. It further agreed to preserve the normal capacity of the channel as constructed.

The cost to the State was about one-half the estimated cost of an inferior alternate consisting of a series of equalizing culverts under the freeway. In addition, it was an engineering solution that permanently eliminated the flood problem instead of merely alleviating it. The cost to the county agency was only the right-of-way and maintenance costs, wihch it would have eventually incurred. Thus, there was a considerable saving to all taxpaying segments—the sector paying to Highway Users Tax funds via fuel use taxes and the sector paying property and other taxes for the operation of local agencies.

In conclusion, the following personal opinions are made:

1. In any highway district and especially those in some stage of transition to urbanization, the formation of a hydraulics or drainage section is well worth consideration, even if this unit is initially limited to one engineer. This unit should devote its entire time and effort to the specialized work of drainage and become thoroughly familiar with drainage structure design and have a working knowledge of the drainage laws of the State and locality. It should establish and maintain a system of communication with other governmental agencies and private interests regarding drainage matters.

2. Better overall handling of drainage will result from continued liaison with other agencies and with private interests such as land developers.

3. When drainage problems are too far reaching to be handled by an individual highway agency, negotiations with other interested agencies will nearly always result in superior facilities with less overall expenditure of tax funds. This cooperation should, however, be limited to amounts directly proportioned to tangible benefits or to legal obligations, and attempts by one agency to dip into the funds of another, under guise of a drainage cooperative, should not be permitted.

4. The methods and procedures herein described result in superior handling and solving of drainage problems and generally enhance public esteem for the governmental official and employee. The engineer in public service is thus giving his employers, the taxpayers, the highest type of professional engineering service.

ACKNOWLEDGMENT

Appreciation is expressed to H. C. Suenderman, District Hydraulic Engineer, District IV, California Division of Highways, for his assistance in the preparation of this paper.

Legal Aspects of Backwater from Culverts

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This paper deals with the effects of ponding immediately upstream of culverts and examines the problem of liability for damages to private property. It does this by citing several actual and hypothetical cases that illustrate at least three special conditions: (1) flooding caused only by natural runoff in excess of the design flood for the structure; (2) a progressive increase in runoff caused by urbanization of the watershed; (3) increased runoff caused by physical changes within the watershed, such as drainage improvements or diversion of flow from outside drainage areas. The legal responsibility for flood damages in each case is examined in the light of case histories. Finally, some guidelines are developed to assist the highway drainage engineer in coping with these problems.

•AN UNDERSTANDING of backwater from culverts and its legal implications involves, first, an elemental knowledge of the hydraulics of culverts and, second, a definition of backwater in relation to culvert operation.

Culverts are conduits for carrying natural and artificial watercourses through a roadbed. They are usually smaller in cross-section than the watercourses for which they substitute. This constriction in channel cross-section causes the water at the inlet of the culvert to rise, imparting sufficient energy to force the water into the culvert at the same rate that it approaches the inlet. The incremental rise in water level at the inlet of the culvert, above the level which would have prevailed if the watercourse were not influenced by the culvert, is called "backwater." A more common term is "ponding" or "ponding effect."

The depth of the backwater and the configuration of the terrain upstream of the culvert determine the areal extent of the ponding effect. Backwater depth depends on the hydraulic performance of the culvert and the amount of runoff, or flow, to which it is subjected; configuration of the terrain, whether the topographic relief is broad and flat or narrow and steep, establishes the relative magnitude of the ponding effect. The two factors are closely associated. Obviously, a small amount of backwater could have a widespread ponding effect, and, conversely, a large amount of backwater could have a limited ponding effect.

Backwater depth as a function of the hydraulic performance of a culvert is often a composite of several effects, some of which are not readily understood or precisely definable. The two most common influences, however, are (1) the size and shape of the culvert and (2) the amount of runoff relative to the capacity of the culvert.

The size of the culvert is an obvious factor; but, size for size, the shape has a more pronounced effect on backwater depth. For example, a box culvert which is high and narrow produces more backwater than a low and wide box culvert of the same cross-sectional area. Thus, the degree to which the watercourse is constricted at the culvert inlet is related to backwater depth.

The capacity of a culvert depends on the hydraulic conditions under which it must operate. Normally, a culvert is designed so that the expected runoff will not submerge the inlet. If the inlet becomes submerged, the backwater effect increases sharply with little increase in culvert capacity. Runoff, therefore, which exceeds the design capacity of a culvert causes a significant increase in backwater.

Paper sponsored by Special Committee on Highway Laws.

In the field, backwater effect is readily measured either by observed high water levels during a runoff period or from identifiable high water marks following a runoff event. The high water elevation on the upstream side of a culvert is known as the "headwater" level. The corresponding elevation on the downstream side is the "tailwater" level. The "head differential," or the difference between the headwater and tailwater levels, less any unsubmerged fall in the culvert, is the backwater effect. This would not be true for a culvert with a "free" outfall unaffected by tailwater. The backwater in such a case would be the headwater depth at the inlet less the normal depth of flow in the watercourse. The normal depth must be computed from the channel geometry assuming no highway culvert is in place.

The extent of backwater damage, obviously, is related to land use within the backwater area. A designer must weigh the cost of minimizing backwater effect against the probability of incurring damage claims. Sometimes it is more prudent to bear the cost of more capacity than to run the risk of extensive damage. For most installations, however, the damages are likely to be light; and it is more economical to take a calculated risk. (It should be added that backwater flooding is not the only risk evaluated by the culvert designer. The danger of building up a head against a highway embankment, possibly causing a washout of the roadway, interruption of traffic, and flood damages downstream, merits equal consideration.)

Standard practice requires that culverts be designed for floods that occur on the average of once in a given number of years. For major highways and freeways the criterion is once in 50 years, or higher if the risks warrant. The difficulty is predicting the magnitude of the 50-yr flood with accuracy because the science of hydrology, subject to the whims of Mother Nature, has not kept pace with advancements in hydraulics. More important are problems associated with runoff that exceeds design capacity. Such runoff might be caused by (1) "Act-of-God" rainfall, (2) developments within the watershed, or (3) diversion of runoff from one watershed to another.

In this discussion it should be noted that the law governing watercourses is substantially different from the law governing surface waters. Generally speaking, a riparian owner has a right to have a natural watercourse flow unimpaired in both quality and quantity. The common law regarded surface waters as a common enemy and one could rid himself of them in any manner without liability. The common law rule regarding surface waters has been modified in most jurisdictions. (See 24 Minnesota Law Review 891 for a discussion of the various holdings.) Minnesota follows the reasonable-use rule as laid down in the leading case of Sheehan v. Flynn, 59 Minn. 436, 61 N.W. 462. In the three cases which follow, Case I deals with a fact situation involving a watercourse, though legal cases involving surface waters are used also; Case II is assumed to relate to surface waters; and in Case III the facts involve both a watercourse and surface waters. In all three cases it is assumed that the immunity of the State was waived, thereby placing the State in the same position as a private party.

CASE I

Engineering Details

During September 1957, a heavy rainfall produced a small flood at a highway stream crossing. Subsequently, a farmer residing immediately upstream of the highway brought a claim against the State contending that the flooding was caused by insufficient culvert capacity. His claim amounted to $8,475 and included losses to 123 acres of cropland, 90 acres of meadow, 40 acres of pasture, and damages to farm buildings and livestock.

An investigation revealed that the offending structure was a concrete box culvert 10 ft wide and 4 ft high. Newspaper accounts and pictures led to the conclusion that the maximum headwater level peaked 1 ft below the highway's profile grade and that the maximum head differential between headwater and tailwater was 1.3 ft. The runoff was generated by a rainfall of 5.8 in. as recorded at a nearby weather station. Weather Bureau records disclosed that the rainfall was the heaviest in 49 yr. Because the rainfall exceeded the previously recorded 24-hr maximum by 2 in. and the culvert had not been overtaxed since its construction in 1932, it was concluded that the runoff probably exceeded the 50-yr flood for the stream.

The terrain upstream of the culvert site is a slightly undulating, ancient lake bed, and the watercourse lies only about 4 ft below the level of the farmstead. It was apparent that widespread flooding would have occurred regardless of the highway backwater effect. Engineers investigating the claim approached the problem on the basis that the only responsibility attributable to the State was damage in excess of that which would have occurred without the highway influence. Accordingly, two contours were defined by survey, one at the backwater level and the other 1.3 ft lower. The area between the two contours defined the fringe area affected by backwater. Through the presentation of this evidence and other engineering details at the claim hearing, the State was successful in reducing the allowed damages to $2,200.

Legal Comments

The manner of handling the claim and apportioning the damages attributable to the highway influence is in accord with a number of decisions in this country, provided the State was in some measure negligent in constructing or maintaining the highway and its drainage facilities. The theory of those cases providing for apportionment of damages is that the defendant should only be liable for the damages attributable to his negligence and not be liable for the damages which would have occurred without his negligence from a so-called "Act of God."

Minnesota does not follow the attributable-damages rule. In Bibb Broom Corn Co. v. Atchison, Topeka and Santa Fe Ry. 94 Minn. 269, 102 N.W. 709, the defendant railroad company delayed forwarding a carload of the plaintiff's broom corn; and because of the delay, the boxcar stood in the path of an unusual flood that destroyed the broom corn. The defendant claimed the damage was from an unforeseeable cause, namely an "Act of God." The court stated:

> No wrongdoer should be allowed to apportion or qualify his own wrong; and, if a loss occurs while his wrongful act is in operation and force, and which is attributable thereto, he should be held liable.

Inasmuch as the defendant was negligent by reason of delaying the shipment, he was held liable.

In the case of National Weeklies Inc. v. Jensen and Another 183 Minn. 150, 235 N.W. 905, action was brought against the City of Winona and its contractor for negligent flooding of the plaintiff's basement while installing a storm sewer. The rule in the Bibb Broom Corn Company case was followed. Again there was an unusual storm that the defendants claimed to be an "Act of God" and therefore denied liability. The jury found the defendants negligent and, as a result, liable, even though the damages would not have occurred were it not for the so-called "Act of God." The court stated:

> If the damage done was solely the result of an Act of God the city was not liable. If the negligence of the city proximately contributing and an act of God combined to produce the result, the city is liable.

The court does indicate that if all the damages would have occurred in any event without the concurrence of defendant's negligence, by reason of the "Act of God," then the defendant would not have been liable. The Minnesota Supreme Court had previously stated in Van Wilgren v. Albert Lea Farms Co. 176 Minn. 339, 223 N.W. 301, that:

> If the rainfall was of such a character that the damage to plaintiff's crops would have been equally as great if defendant had made no change in conditions, the acts of defendant could not be said to be the proximate cause of the damage and it could not be held liable therefor.

In Case I, the State denied any negligence. The final payment of $2,200 was a good compromise because the question would have been a fact question for the jury had the case been tried. Had the jury found negligence by reason of inadequate culvert capacity, the State would have been liable for the entire damages.

What is the rule where there is no negligence on the part of the State in constructing and maintaining roadway and drainage facilities, and damages to property are caused by an unprecedented rainfall?

In the Van Wilgren case, the court held:

> ...If defendant provided a reasonably sufficient outlet for the water from such rainfalls as in the exercise of ordinary prudence and foresight it ought to have anticipated as likely to occur, and the damage resulted from a downpour so unprecedented that defendant could not reasonably be expected to have anticipated and provided for it, defendant is not liable therefor.

In Poynter v. County of Otter Tail, 223 Minn. 121, 25 N.W.2d 708, the court was concerned with a stream or watercourse. It cited the Van Wilgren case with approval and held the county not liable because there was no negligence shown.

The rule, therefore, in Minnesota is that the State is not liable for damages caused by unprecedented rainfall when the State was not negligent in constructing and maintaining its roadway and drainage facilities. This is true in matters involving either watercourses or surface waters. As stated in Poynter v. County of Otter Tail:

> If defendant provided a proper outlet for the water from such rainfalls as it reasonably ought to have anticipated, it is not liable; but if it failed to provide a proper outlet for the water from such rainfalls as it ought to have expected, it is liable and is not relieved from liability by the fact the rainfall in question happened to be of unprecedented character, for in that case its negligence added to the overflow.

The Poynter case cited and quoted from 2 Farnham, Waters and Water Rights, Section 577, as follows:

> The one about to erect a structure over a watercourse is entitled to act upon the assumption that natural conditions will continue as they have existed within a reasonable time prior to that at which he proceeds with his undertaking. He is not bound to anticipate convulsions of nature, nor floods which have not previously been known to occur. Therefore, where his structure becomes injurious to his neighbor because of an unprecedented flood, he must be shown to have been guilty of negligence in the manner of constructing it, in order to be held liable for the injury.

It is important to point out that the Minnesota Supreme Court, in the Poynter case, held it was an error for the trial court to charge the jury that:

> ...If the defendant, Otter Tail County constructed the embankment and culverts so as to interfere with the natural flow of the water and by reason of it the waters backed up on the land occupied by the plaintiff and did it damage, the defendant county would be liable irrespective of negligence.

In closing Case I, it should be borne in mind that the question of negligence and what could be reasonably foreseen is a jury question.

CASE II

Engineering Details

A small highway culvert was installed near a city at a time when the drainage area of the culvert was rural in character. The culvert served adequately for many years until gradual urbanization increased storm water runoff. The upper reaches of the watershed became a housing project with paved streets, and a toy distributing company built a warehouse in the lower reaches adjacent to the highway. During July 1957, a high-intensity, short-duration rainfall measuring 0.8 in. at an airport two miles away produced flooding at the culvert site. Water backed up to a depth of 20 in. on the floor of the toy warehouse causing extensive damage to packaged merchandise. Ultimately, the owners of the toy firm brought a claim against the State and the city alleging flood damages to the building and contents in the amount of $12,000.

Engineers investigating the claim in cooperation with the attorney general's office approached the problem on the premise that flooding was caused by urbanization of the watershed and that the State was not negligent in failing to provide sufficient culvert capacity. Through surveys of highwater marks and culvert geometry, the engineers were able to estimate the maximum runoff occuring from the storm. Using accepted design procedures, the probable maximum runoff was also estimated for the same storm with the watershed in its original rural state. By hydraulic computation, it was shown that the backwater effect for rural conditions was more than 20 in. less than that for urban conditions.

The State legislative claims commission on hearing the evidence of both parties declined to render a judgment and recommended that the State legislature by legislative action waive the State's immunity from suit in the matter. The legislature ultimately granted the claimant the right to sue the city and State jointly. After thorough investigation by the attorney general's office and the city attorney, it was determined that the applicable law was not sufficiently conclusive to warrant the risk of an unfavorable verdict. The plaintiff agreed to an out-of-court damage settlement in the amount of $3,500. The State's share was $2,333.33.

Legal Comment

There are only a few cases in the country that have actually considered the legal questions raised by Case II. Most of these cases involve municipalities rather than the State itself. Even in cases involving municipalities, the authorities are divided. Some authorities hold that a municipality is not liable when, by reason of increased improvements and general urbanization of the area, a storm sewer becomes inadequate and results in flooding. Reasons for the rule are immunity of suit and statutory provisions and holdings that municipalities are not liable for defective plans. Therefore, the problem does not arise in most jurisdictions. There are a few cases that have held a municipality liable for damages occasioned by an inadequate storm sewer, although the storm sewer was adequate when constructed and the inadequacy was the result of the city's growth (See Louisville v. Leezer, 143 Ky. 244, 136 S.W. 223). It was held that the city's obligation extended to making such changes as the changed conditions made necessary.

It is apparent that there is a difference in the fact situation between the State constructing a highway and a municipality constructing a street and providing storm sewer service. The municipality grants building permits and actually authorizes the growth that causes the drainage facilities to become inadequate. It, of course, has notice of the growth because it is a party to that growth. The State of Minnesota, on the other hand, does not control the growth of the municipality. If areas surrounding truck highways become urbanized, the highway department has little means, if any, at its disposal to control the growth. It usually does not have much notice of impending urbanization until it is largely an accomplished fact. For that reason, it is not believed that the State is legally in the same position as a municipality under the fact situation stated in Case II. In no event should it be an insurer of the adequacy of its facilities under changing conditions.

This does not mean, however, that the State has only to provide drainage facilities adequate to meet present needs. As stated by the Minnesota Supreme Court in the Van Wilgren case and the Poynter case (both cited and quoted from in Case I), a defendant in a drainage action involving the adequacy of a drainage structure must provide a outlet for the water from rainfalls as reasonably anticipated. The Poynter case involved a watercourse; the Van Wilgren case, surface waters. The Van Wilgren case seemed to follow the law of watercourses. Yet it could be the authority for future decisions involving surface waters. If so, it would not be stretching the legal principle involved to conclude that the State, in constructing its highways and the drainage facilities appurtenant thereto, is required to construct drainage facilities adequate to handle surface water from such area development as can be reasonably foreseen.

There are no Minnesota Supreme Court cases directly in point. However, the language in other cases as well as the Van Wilgren case may serve as a guideline.

As mentioned previously, with reference to surface waters, Minnesota is committed to the reasonable-use rule. A landowner may rid his land of surface waters and cast them on the lands of others, together with waters that otherwise would not have gone there, if:

> (a) There is a reasonable necessity for such drainage;
> (b) If reasonable care is taken to avoid unnecessary injury to the land receiving the burden;
> (c) If the utility or benefit accuring to the land drained reasonably outweights the gravity of the harm resulting to the land receiving the burden; and
> (d) If when practicable, it is accomplished by reasonably improving and aiding the normal and natural system of drainage according to its reasonable carrying capacity, or if, if the absence of a practicable natural drain, a reasonable and feasible artificial drainage system is adopted....What is a reasonable use is a question of fact to be resolved according to the special circumstances of each particular case. Enderson v. Kelehan (1948) 226 M. 163, 32 N.W. 2d 286.

In Bush v. City of Rochester (1934), 191 Minn. 591, 255 N.W. 256, the city was held liable for damage by reason of not reasonably providing for the disposal of surface water when it constructed a city street. The court held that the disposition of surface waters must be "reasonable under all the circumstances."

In Greenwood v. Evergreen Mines Company (1945), 220 Minn. 296, 19 N.W.2d 726, the plaintiff brought action against the Evergreen Mines Co. and the Village of Crosby. The Evergreen Mines Co. was dismissed out. The facts were that the village had placed a 42-in. culvert under a road at Serpent Creek that was the natural outlet from Serpent Lake. Thereafter, and during the dry years of the 1930's, additional culverts were placed downstream to handle the flow in Serpent Creek at locations where additional roads were built. These culverts varied in size from 9 to 36 in. They were adequate for the flow at the time of construction. When the dry spell was over and rainfall increased, the level of Serpent Lake rose and the culverts were no longer adequate. Some of the culverts were plugged up, some intentionally so. The result was flooding of the plaintiff's property. The court quoted "McQuillan on Municipal Corporations," Section 2877, with approval:

> ...The duty of a municipality with respect to culverts to take care of surface water coming through a natural drain does not end with the original installation, but is a continuing one, to be exercised with due regard to changed conditions affecting the flow of water to be accommodated by the culverts.

The Greenwood case involved a natural watercourse. Nevertheless, it gives an indication of the court's thinking; and, together with the other cases, it would appear that the State in constructing its highways must make reasonable provision for disposing of surface waters. In making such provision, reasonable care to prevent unnecessary injury to others may require that it take into consideration changing conditions that are reasonably foreseeable. If, considering all the factors of a particular location, it can be reasonably foreseen that the area will develop, provisions should be made in constructing the highway to provide drainage facilities reasonably adequate to handle the anticipated increase in runoff due to the anticipated urbanization of the area. The test is reasonableness. Consideration probably can be given to anticipation of the probable construction of storm sewers to handle much or all of the increased surface waters. Agreements can sometimes be worked out with municipalities for sharing the costs of larger culverts when development within the municipality is imminent. Each case must be decided on the basis of its individual facts. Few, if any, contemplated in the 1940's the vast commercial and residential expansion into suburban and rural areas that is taking place in the 1960's. This should be taken into consideration in exercising reasonable prudence.

A problem suggests itself: Assume that the State could not reasonably have anticipated the increase in surface waters caused by the urbanization of the area and assume no negligence in maintenance. The urbanization of the area becomes an accomplished fact. Would the State then be legally required to make changes to accommodate the increased flow of surface waters? The answer would be in the negative. However, more often than not, the increased surface waters adversely affect the highway; and to protect the highway, the road authority makes the necessary changes. In many instances the municipality or political subdivision takes the necessary steps to provide other means of surface-water disposal. And there are instances where the property owners themselves have provided the means of carrying the water away.

In settling Case II the State and the city avoided the possibility of a much greater liability than the actual settlement. There was evidence too, not mentioned in the engineering details, that the culvert in question had become partly plugged with mud and silt and that weeds and reeds had grown up adjacent to both its inlet and outlet, thereby decreasing its efficiency and raising the question of negligence. The actual fact situation, from which hypothetical Case II is taken, was more complicated than the facts stated in this paper. It should further be borne in mind that what consitutes a watercourse and what is merely surface water is sometimes difficult to determine. These comments in Case II are limited to surface waters. A stricter rule of law applies to watercourses.

CASE III

Engineering Details

Two major highways are joined above the mouth of an intermittently flowing stream at the outskirts of a small city. The watershed covers 4,350 acres and is rural in character. The terrain is undulating in the upper reaches but falls sharply in a deepening valley at the highway junction. A box culvert 10 ft high and 10 ft wide constructed in 1924 carries runoff through the junction to a riprapped channel parallel to the highway and another box culvert of equal size under an intersecting street. The capacity of these culverts was overtaxed in 1953, and in an effort to control the backwater effect of future floods, the road authority constructed retaining walls over the inlets and along the approach channels to contain the backwater.

On Memorial Day, 1959, a sudden storm broke over the watershed and, according to available reports, 5.1 in. of rain fell within a 2-hr period. The swiftly concentrating runoff overtaxed the box culverts, and the rapidly rising backwater quickly overflowed the retaining walls and highway. A greenhouse, drive-in business, veterinarian's quarters, and a number of houses were damaged by the sudden flood. Claims totaling more than $40,000 were ultimately filed against the State.

The engineering investigation revealed that while the rainfall causing the flood was virtually unprecedented, the culverts were in fact too small for a flood of much less magnitude. A contributory fact, bearing on the responsibility for the inadequacy of the structures, however, was brought out. A few years preceding the flood, a farmer had ditched an extensive slough into the watershed. The slough had a drainage area of 830 acres, roughly 20 percent of the total watershed. Runoff from this drainage overtaxed a 4-ft square box culvert at a township road intersection and overflowed the road to a depth of several feet. The ditch had been constructed as a private project and there was no evidence that any public authority had granted permission for the outlet.

In hearings before a legislative committee on claims, the State denied total liability on the basis that the rainfall was an "Act of God" and the illegally diverted drainage contributed to the damages. The committee ultimately recommended a substantial reduction in the payment of alleged claims, but the question of illegal diversion of drainage was never pursued.

Legal Comment

Case III involves a watercourse. The recited facts would indicate that the State in placing the culvert in 1924 did not provide a reasonably sufficient outlet for the water from rainfalls as ought to have been reasonably anticipated. Assuming the facts as indicated, the State would be liable unless all of the damage would have occurred irrespective of the State's negligence (See comments in Case I and cases cited therein).

The State also claimed that another and intervening cause was responsible, at least in part, for the damages; namely, the diversion of surface waters from the slough into the watercourse.

Case II cited and quoted from the Poynter v. Otter Tail County case when the Minnesota Supreme Court cited "2 Farnham on Waters and Water Rights" to the effect that "one about to erect a structure over a watercourse is entitled to act on the assumption that natural conditions will continue as they have existed within a reasonable time prior to that at which he proceeds with his undertaking."

The State could not have foreseen the drainage of the slough in 1924. Had the culvert been adequate, when installed, for reasonably anticipated waters that the State could have foreseen, the State would not have been legally liable for flooding caused solely by the overtaxing of its culvert due to the increased flow of water from the slough.

The claims committee of the legislature allowed a part of the claims presented. The damage award was not pursued because there is no statutory appeal provided for the allowance of a legislative claim; and even if there were, the failure of the State to provide an adequate opening would have weighed heavily in determining whether to appeal or not.

CONCLUSION

The lesson to be learned from Cases I and II is that there is no substitute for the adequate design of culverts if the road authority is to escape or mitigate its liability for damage from backwater. From a legal standpoint "adequate design" would mean that there could be no finding of negligence if the adequacy of a culvert became a matter for litigation.

The engineering approach to "adequate design" of culverts involves professional judgment and skill in the application of the principles of hydrology and hydraulics. Certainly an engineer should determine the design runoff on the basis of rare past runoff events, increased, if warranted, to allow for such developments as can be reasonably foreseen. Equally important for all major culvert structures is the need to analyze the hydraulic performance with respect to the design runoff and to determine the probable backwater effect. If the risk of backwater damage is high, the engineer might well weigh the cost of increasing the size of the culvert against gaining control of the backwater area through a flowage easement or other means.

There are many culverts on public highways throughout the country that have not had the benefit of a through hydrologic and hydraulic analysis. Many of these are likely to be sources of future damage claims. Likewise, urbanization will affect many of the watersheds and problems like Case II will arise. Each situation will call for presentation of the facts by an engineer-lawyer team. Gathering the evidence is the engineer's job, but it requires close liaison with the lawyer to obtain the facts pertinent to a defense of each case. Local jurisdictions may well determine what evidence is admissable, but the lawyer will attempt to have admitted all facts pertinent to the defense.

This paper emphasizes that liability for damaging backwater at culverts is a question of negligence, either wholly or in part. It further emphasizes that if runoff occurs that could not be reasonably foreseen at the time the culvert was installed, the road authority should not be held liable. Runoff that cannot be reasonably foreseen, assuming no manmade interference such as covered by Cass III, is given expression by the phrase "Act of God." There is nothing magical about it that automatically relieves the road authority of responsiblity. What is needed to escape liability is evidence to prove that the storm, flood, or other convulsion of nature could not have been reasonably anticipated.

Inverse Condemnation and the Law of Waters

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This paper deals with research on recent trends of legislation and court decisions pertaining to actions of inverse condemnation and relates them specifically to factual situations involving land damage due to interference with or rearrangement of drainage. Rules of liability between adjacent private owners for damage due to interference with the flow of surface water or disruption of percolating water can be traced back into the common law. In the present era of highway construction, courts have tried to apply this body of private law to drainage claims against public agencies. Results have not always been successful as attested to by recent efforts to clarify and codify in statute law the legal responsibilities of public agencies in regard to drainage damage, and by the continued existence of uncertainty in doctrines developed through judicial decisions on inverse condemnation claims. Analysis of these trends suggests that the police power dimension to this problem has not been fully explored or appreciated either by legislatures or courts, and that strong reasons exist for assigning a greater role to this concept in the development of inverse condemnation doctrine for claims against public highway agencies.

•MODERN HIGHWAY CONSTRUCTION is massive, and in spite of the most careful attention to elements of design the construction of a new highway may alter existing drainage patterns. A property owner in the vicinity of the highway may then suspect, at the time of condemnation, that he will be flooded out, water-soaked, or injured in some other way because he may have reason to know that the highway will alter existing drainage patterns. If he goes into the initial condemnation action, however, and asks compensation for this type of damage, he will be told that he is too early, that his damage at this time is merely speculative, and that he must wait until the damage has occurred before he can sue.

He may suffer damage later, however, and if he goes to court at this time he will find again that he faces several hurdles to recovery, the most important of which is the doctrine that the sovereign is immune from liability in tort. Under this doctrine, the State is not liable in circumstances in which private parties normally are compelled by law to pay for their wrongdoing. But sovereign immunity has often been misconceived, and it never was as absolute as it often appears. Indeed, the immunity principle can best be described as an exception to the imposition of governmental liability for a variety of specific damagings that never were protected on immunity grounds. For example, liability was imposed from earliest times when a nuisance created by a governmental agency caused damage to another property owner. Highway embankments are frequently treated as nuisances in drainage cases, enabling injured landowners to sue the highway agency directly on a "nuisance-tort" theory. The governing doctrine of drainage law grew up not in a tort context even though the principles sound tortious, but as a branch of property law. This fact led to the characterization of the right to interfere with drainage as a property right, as easements, and servitudes that will allow the highway department to send water on to the land of another. These property

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rights may be acquired by the highway agency when it builds the highway, thereby purchasing the right to flood without incurring liability.

Because the courts grew used to talking about interests in drainage as property rights, another door to recovery was opened to the injured landowner, inverse condemnation. Essentially, inverse condemnation is a suit brought by a landowner for damage attributable to the highway improvement that was not compensated in the original condemnation proceeding. The inverse suit circumvents the sovereign immunity barrier because it is based on the eminent domain clause of the constitution, which commands that property that is taken or damaged by a governmental agency must be compensated. The inverse remedy has a position in law that is as high as or higher than the immunity principle because it is derived from the eminent domain clause, which is set forth as part of the basic law of the land.

If the State chooses to say—and practically all the states have said so—that the eminent domain clause is self-executing, then the property owner is able to sue in inverse condemnation for his property damage and not worry about sovereign immunity. This self-executing aspect of the inverse condemnation action is of considerable assistance to the landowner because it means that he may proceed to bring a suit in court for his damage without the benefit of enabling legislation. In about half the States this suit may take the form of a direct action at common law.

Additional perspective can be gained by looking at some of the history that surrounds the compensation problem in eminent domain, particularly at the so-called "consequential damage" issue. Beginning in the nineteenth century, consequential damage (i.e., damage not involving the physical taking of property) was not compensable. The cases that laid down this rule, however, arose in situations where the injury was nonphysical; such as a denial of access, or a change in street grade unaccompanied by loss of lateral support. In Illinois, where nonphysical consequential damage was at first noncompensable, the State Constitution was amended in the late nineteenth century to provide for compensation of the damaged property as well as for its taking. Illinois was the first State to make this change, and its constitution became a prototype for other States that similarly amended their constitutions on the theory that the damaging amendment would extend the basis of compensation in eminent domain cases. Before adoption of the damaging amendment, the Illinois court had found for the landowner in water damage cases even though the constitution at that time only required that takings be compensated. History shows then that the eminent domain clause began to move in the direction of allowing landowner recovery for water damage even before the language of State constitutions was amended to add the word "damage" to its guarantee of property rights. Landowners discovered early that the eminent domain clause could be used as grounds for an independent cause of action when water damage occurred.

At the Federal level the classic decision on this point is Pumpelly v. Green Bay Co.[1] This case employed a very simple analysis of the Federal eminent domain provision, which only contains a taking clause. Here, the plaintiff's land was permanently flooded when a dam blocked a watercourse. As he was totally deprived of the use of his land, the court merely had to resort to a constructive taking theory to allow recovery even though title had not been formally appropriated. Since the Pumpelly decision the Federal cases have been fairly conservative in allowing recovery, but damages have been allowed if the flooding was sufficiently permanent and sufficiently attributable to the public improvement. Procedural problems are eliminated at the Federal level by the Tucker Act (28 U.S.C. § 1491) which gives consent to sue for cases arising under the Federal Constitution.

In addition to relying directly on the eminent domain clause as a basis for recovery in the inverse cases, the courts have also turned to private water law concepts. First, the principles of water law have been worked out in a context of private litigation and the background has been that one of the parties to the lawsuit has wished to make a developmental use either of the water in dispute, or of property that affects the drainage system in the area. Second, the decisional law in these cases has been worked out as a series of rules that have been somewhat mechanically applied. For example, it has been indicated that liability may be incurred in many States for stopping up a water-

[1] 80 U. S. (13 Wall.) 166 (1871).

course, but not for interfering with surface drainage even though the landowner is equally damaged in both cases.

Private water law doctrine came into inverse condemnation cases because of an early court applied limitation to these actions. They recognized, of course, that to allow without limit suits under inverse condemnation—eminent domain theory might broaden the responsibilities of public agencies too far. Hence many courts said, especially in the early cases, that the public agency would be liable in inverse condemnation cases in which a private defendant would have been liable. Obviously, if this approach is taken, and the court applies to the highway agency the very same doctrines of water use that apply to private defendants, highway agencies will be held liable with the same artificial results as indicated earlier.

Because these categories of private water use are not airtight, and because many States have modified their absolute water law principles to adopt more flexible doctrines based on reasonable use, the scope of inverse liability is confused in many States. From case to case, it is difficult to tell how the decision will come out, partly because of the fuzziness of the doctrine relied on by the court. In addition, the characterization of the affected water resource is critical, but the distinctions are factual, and until a case is tried it may not be possible to determine with certainty whether the highway has increased surface runoff or has blocked a watercourse.

A solution of the highway agency's liability which is not as dependent on the nature of the affected water resource has been suggested. Some jurisdictions have enacted statutes trying to codify the common law rules governing drainage, and in some instances have pushed the responsibility of the public agency even a little further. It is felt that these statutes have not succeeded in clarifying the basis of liability, because they have had to work against a fairly mechanical, fairly chaotic, common law pattern. In one instance, a statute applicable to municipalities and counties requires that the public agency provide sufficient surface drainage to take care of surface waters whenever the provision of drainage is "necessary or desirable."

In addition, two trends that are beginning to affect the more orthodox private water law principles that are used in the inverse cases have been detected. First, several States have now abolished sovereign immunity. To some extent, of course, drainage cases were always triable under tort principles. Apart from nuisance doctrine, municipal liability has always been imposed for building inadequate culverts that caused flooding. As sovereign immunity is abolished, however, the question of whether all the cases that are now brought under inverse water law principles will be shifted over to a tort theory must be asked.

There are some interesting clues that should be noticed. One is the Federal Tort Claims Act (28 U.S.C. § 1291) that waives sovereign immunity in tort. This statute contains an exception to liability that is stricter than recovery under inverse condemnation. Federal agencies are therefore better off under the statute waiving sovereign immunity than they were before. Another clue is provided by a recent North Carolina case[2] that without abolishing sovereign immunity in that State shifts the substantive context of water cases from a property to a tort setting. In this case, sea waters that had previously flowed over the plaintiff's property were backed up by a highway and caused flood damage. Liability was indicated, but most interesting was that the North Carolina court started by analyzing this case on water law property principles. They pointed out that they followed the civil law rule not the common enemy rule. It was noted that all of these concepts are beginning to merge into the reasonable-use doctrine.

Another question is whether private water law doctrine can be applied to a public agency as applied to a private defendant who interferes with drainage resources. A more open recognition of the eminent domain clause as an allocator of loss is suggested. The more explicit use of the eminent domain clause to shift the burden of loss when property owners suffer undue injury due to highway improvements is also suggested. As an early Wisconsin case pointed out, the highway does not use water, it intercepts water. A distinction should be made between private cases in which there is a joint use of water resources by private individuals, and an interference with these resources by a superior public agency.

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[2]Midgett v. North Carolina State Highway Comm'n, 132 S.E.2d 599 (N.C. 1963).

Another problem in the handling of damage claims under eminent domain provisions has been overlooked. The converse to the imposition of public liability under the eminent domain clause is public "nonliability" under police power principles. In highway access cases, the courts have frequently used police power analysis to hold that a public agency is not liable for deprivation of access. Similarly, police power analysis should be available to solve some of the water damage cases.

Two recent cases that move in this direction are briefly mentioned. One is a California case, Beckley v. Reclamation Bd.[3] In this case, the plaintiff's land had been inundated following the construction of levees by the board. California had previously followed the common enemy rule, and as these were flood waters, liability would not previously have been imposed. However, the court held that the common enemy rule was inapplicable, and found for the plaintiff because, they said, he could not protect himself. In private cases, the lower landowner could always take protective measures when his neighbor shifted flood waters to him, and his neighbor who received the waters was able to take remedial measures in turn. In the Beckley case, however, the defendant was a flood control agency that was entitled by law to make the improvement, and then prohibit the plaintiff from making any changes in his own land that would have interfered with its scheme. The California court used police power analysis to find that the flood control agency had cast too great a burden on the plaintiff, and held that his damage was compensable in eminent domain.

Another case in this vein is Dudley v. Orange County.[4] Here a temporary dam built by the county to deal with flood conditions had inflicted water damage on the plaintiff. The temporary nature of the dam was not the decisive factor, however. The court compared the construction of the dam to any other instance of government action to remedy emergency conditions, making an analogy to cases in which a city tears down buildings to control the spread of fire. Building the dam became an action in aid of the county's police power. The fact that one or two property owners were damaged is not important, the court held, because the purpose of the dam was to prevent even greater damage to the rest of the community.

The discussion raises this question: if water law is put aside as the basis of settling inverse claims, as some of the courts are beginning to do, what should be put in its place? It is suggested, first of all, that a distinction be made between physical injuries occurring after construction of the highway and nonphysical injuries that can be discerned at the time of construction. Damage claims in the second category raise special problems. However, when physical injury has occurred to property following construction of a highway improvement, an examination of the eminent domain clause points to recognition of an absolute liability on the part of the highway agency. This conclusion is reached by looking at what the highway authority can do at the time of initial construction. They can, of course, take all precautions found necessary to avoid all possible risks to surrounding landowners. Precautionary steps at this time might include the building of culverts with more excess capacity, the taking of flowage easements on an overly extensive scale, etc. In the normal case, the highway agency stops short of full precautions and by so doing, it insures itself. That is, by avoiding the expense of complete protection, the highway agency effectively purchases its own insurance; and on this basis, absolute liability should be imposed in cases of physical injury.

It is then necessary to examine some way of limiting the liability of the highway agency. It is not suggested that the highway agency should become an insurer of all damage occuring in the vicinity of the highway improvement. Two limitations on absolute liability can be suggested; and when these limitations are applied to a range of factual situations, the results closely approximate those that are reached by the courts on other grounds. One such limitation is the "cause in fact" test. If the damage was not in fact caused by the highway improvement, the highway department should not be liable; and many of the cases that have been troublesome to highway lawyers are cases in which it is impossible to tell why flood damage occurred. Some highway agencies

[3] 205 Cal. App 2d 734, 23 Cal. Rptr. 428 (1962).

[4] 137 So. 2d 859 (Fla. App.), appeal dismissed, 146 So. 2d 379 (Fla. 1962), Cert. denied, 372 U. S. 959 (1963).

collect data on water cycles and conduct aerial surveys before construction, in order to have the necessary data to show (if damage occurs) that the damage would have happened even if the highway had not been built. Second, some policy limits will have to be imposed on public liability. Certainly one such limitation is the "Act of God" rule that is applicable to hurricanes and floods that no one could have expected. In those cases, no one would suggest that liability should be imposed on the highway agency.

In conclusion, the rules governing the liability of State highway agencies for water damage are in a period of transition, as the courts abandon mechanical rules of liability for a more flexible and fairer approach. Equity and clarity in the doctrinal law governing liability for water damage will come, but only as the loss-distribution function of the eminent domain clause is recognized as the starting point for analysis, and as doctrines developed in a nonpublic setting are gradually put aside.

Illinois Study of Highway and Agricultural Drainage Laws

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•NATURE'S elaborate system of drainage is constantly changing in response to changes in the face of the earth. Where these latter changes are man-made, the need for adjustment of the drainage system may be sudden, and the adjustment that is needed may be of extensive proportions. Modern methods of agriculture and construction of highway improvements present examples of man-made changes which frequently call for substantial relocation and reconstruction of drainage systems. The effects of these agricultural and highway improvements raise questions which involve not only physical engineering, but the legal relationships and responsiblities of landowners among themselves and between landowners and the public, represented by various agencies of government. An orderly, coordinated, and realistic body of agricultural and highway laws relating to drainage greatly facilitates achievement of prompt and satisfactory adjustment of highway and drainage facilities where their reconciliation is needed.

Historically the laws relating to highways and drainage have grown up separately. As a result, the developments in relatively recent years which have sharpened the need for closer coordination of programs and drainage improvements have, at the same time, presented particular difficulties for both lawmakers and engineers in working to achieve this coordination. There is particular need to study highway and drainage laws in a way that permits comparisons and highlights their points of contact with each other. The benefits of such study accrue both to those who are responsible for formulating policies and procedures, or interpreting the law in its application to controversies, and to those who are responsible for designing or administering programs of drainage and highway improvements.

Recognizing the need for a coordinated approach to dealing with drainage and highway laws, the Agricultural Engineering Department of the University of Illinois submitted a proposal to the Illinois Research Council to compile and assemble into a single study the laws relating to agricultural drainage and highway drainage in Illinois, and to investigate the practices and procedures of highway authorities and others in handling drainage problems. A research project prospectus was approved by the Illinois Highway Research Council and submitted for Illinois' Cooperative Highway Research Program. The project, as approved for this program, was activated in February 1959 with funds supplied by the U. S. Bureau of Public Roads, the Illinois Division of Highways, and the Illinois Agricultural Experiment Station.

One major objective of this project was to compile and analyze existing Illinois drainage laws applicable to highway and agricultural activities, and to present this information in a single source. Another objective was to analyze the drainage policies and practices of highway and engineering agencies. The entire project was, therefore, divided into two phases: one, a study of the law as it is written, and the other a study of the law in action, as reflected by administrative and engineering practices.

The first phase has now been completed.[1] It is the objective of this paper to indicate

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[1] A full report of the first phase of this project has been published in the University of Illinois Bulletin. See Drablos, C.J.W., and Jones, B.A., Jr., "Illinois Highway and Agricultural Drainage Laws", Univ. of Illinois Engineering Experiment Station Circular No. 76, (Urbana, 1963), 70 pp.

briefly the major substantive areas of the subject matter dealt with in the Illinois law, and which are likely to be found in the law of other States, and to describe the framework used for organizing and carrying on this study of related laws.

COMMON LAW RULES OF DRAINAGE

Laws relating to drainage are derived from two sources: common law and statutory law. The common law is found in court decisions declaring principles, practices and customs which have evolved and are commonly accepted without the formality of legislative enactment. Because the common law is based on experience, it is natural that new factual situations due to advances in highway and agricultural technology have, from time to time, revealed gaps for which no precedent exists or for which public policy calls for a change in the law. Thus statute law, enacted, by the State legislatures, has built up a substantial body of rules supplementing, and sometimes supplanting, the common law. From these two sources a comprehensive, but not always explicit, set of rules has developed to provide for the establishment of rights regarding drainage and to settle disputes arising over these rights.

Three common law rules regarding drainage of surface waters are found in the laws of the several States. They are known as the civil law rule, the common enemy rule, and the reasonable use rule. The historical roots and rationale of these rules may be described with relative clarity; however, identification of these rules with the law of particular States is risky because of judge-made modifications in applying these rules to factual situations.

In its strictest form, the civil law rule recognizes the existence of natural drainage between adjoining lands: The owner of the lower land must accept the surface water that naturally drains onto it. On the other hand, the owner of the upper land can do nothing to change the natural system of drainage to increase the natural flow. In other words, those acquiring land must expect and are required to accept it subject to the conditions of nature. The civil law rule has the advantage of making the rights readily predictable, and it tends to avoid the contests in hydraulic engineering that are likely to occur under other doctrines.

Diametrically opposed to the civil law rule is the common enemy rule, which recognizes an owner's right to use his property as he pleases. It gives each landowner an unqualified right, by means of operations on his own land, to fend off surface waters as he sees fit, without being required to take into account the effect on other landowners, who have the duty and right to protect themselves as best they can.

The reasonable use rule differs from both the civil law and the common enemy rule in that a possessor of land is not unqualifiedly privileged to deal with the natural flow of surface waters to the detriment of others. A landowner incurs liability only when his interference with the flow of surface water is unreasonable. The issue of reasonableness is determined in each case by considering all relevant circumstances, such as the amount of harm that is caused, the foreseeable harm caused by the person who alters the flow, the motive by which he acted, etc. The rule of reasonable use differs from the other two rules in that it leaves the whole matter of legal liability for injury to be determined upon the facts of each case in accordance with the general principles of fairness and necessity.[2]

Many additions, qualifications, and restrictions in both the civil law and the common enemy rule have been made by the courts and legislatures. In fact, both rules have been so modified that there now may seem to be no valid distinction betweem them and and the rule of reasonable use. However, the conclusion that the three rules are now one and the same is not justified. A leading drainage attorney in Illinois[3] draws the following conclusion regarding the use of the three types of drainage rules:

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[2] S.V. Kinyon and R.C. McClure. "Interferences With Surface Waters," Minnesota Law Review, Vol. 24, No. 7, p. 891 (1940).

[3] D. V. Dobbins. "Surface Water Drainage," Notre Dame Lawyer, Vol. 36, p. 518 (August 1961).

The civil law rule in its unmodified form creates an implied easement of natural flow in favor of the higher land across the lower land. This easement concept remains as the basic element of the civil law rule, which is not to be found in the common enemy rule (either in its original or modified form) or in the reasonable use rule. The rule has been modified in some jurisdictions to permit the owner of the dominant estate to improve the drainage upon his land in any manner that he pleases so long as he does so in the general course of natural drainage. This modification is a grant of an additional right to the upper owner and is an enlargement of, not a restriction upon, the burden which the lower land must bear. In other jurisdictions the rule has been less drastically modified in that the improvement of the drainage on the upper lands must be reasonable and not cause undue hardship to the lower lands. Again the easement element of the rule remains and the reasonable use limitation is placed only upon the upper landowner. Thus, the rule, in both its original and modified forms, grants a right to the owner of the dominant estate and places a corresponding duty upon the owner of the servient estate.

The common enemy rule in its inception granted unqualified rights to both the upper and the lower landowners but placed no corresponding duty on either. The modifications of this rule have all had the result of limiting the rights originally granted under the rule. Thus the rights still remain—although they must be exercised in a reasonable manner so as not to cause undue hardships upon the land of a neighbor.

The reasonable use rule is essentially a tort rule involving both intentional and unintentional invasions of another's interest in the use and enjoyment of his land. The rule is negative in its concept. It does not grant any rights, but attempts to define the circumstances under which an owner of land will be held liable in damages for the use which he makes of his land. It puts the law of surface water drainage in the category of a private nuisance. No one has the right to create or maintain a nuisance, but not every nuisance is an actionable one. So it is with surface waters under this rule. No owner is given any right to improve the drainage of his land under this rule, but if he does so he may or may not be liable for any injury which results.

Types of Drainage Water Movement

Four types of drainage water movement are generally recognized: (1) channel, (2) surface, (3) flood, and (4) percolating. The courts have indicated that the civil law rules of natural drainage are applicable to channel, surface,[4] and flood waters.[5] These rules do not apply to percolating waters, which are generally considered to be part of the land and therefore belong to the owner of the land.

Surface water has been defined as water derived from falling rain or melting snow or which rises to the surface in springs and is diffused over the surface of the ground.[6] Water is considered surface water until it reaches a well-defined channel and becomes part of the running water of a stream.[7] However, this difference is of little consequence in Illinois, since the courts have stated that they can perceive no reason why the same drainage rule should not apply to surface waters, running streams, and watercourses.[8]

[4] Gormely v. Sanford, 52 Ill. 158 (1869).
[5] Pinkstaff v. Steffy, 216 Ill. 406, 75 N.E. 163 (1905).
[6] 56 Am. Jur., "Waters," Sec. 65 (1947).
[7] Crawford v. Rombo, 44 Ohio St. 279, 7 N.E. 429 (1886).
[8] Pinkstaff v. Steffy, 216 Ill. 406, 75 N.E. 163 (1905).

Natural Flow of Surface Water

The civil law rule is traceable to the continental European civil law, where in the 17th century the civil law of France had been adapted from the old Roman law.[9] At that time the natural drainage rule indicated no servitude unless water was flowing in a regulated watercourse. Therefore, it seems that a possessor of lower land was privileged to obstruct the natural flow of surface water from adjoining land if it flowed naturally in a diffused state over a wide area. This interpretation raises the question whether the rules of natural drainage apply to surface water flowing in a diffused state. The American courts, in States committed to the civil law rule, generally took their statement of the rule from sources that did not include the regulated course requirement.[10] Therefore, it may be argued that a possessor of lower land is not privileged to obstruct the natural flow of surface water either where the flow is through natural drainways or where it is diffused over a wide area.[11]

The civil law rule has been illustrated as follows:

> ... as between the owners of higher and lower ground, the upper proprietor has an easement to have surface water flow naturally from his land onto the land of the lower proprietor, and that the lower proprietor has not the right to obstruct its flow and cast the water back on the land above.[12]

Acceleration

Where natural drainage exists, the question arises whether the upper owners may make improvements upon their land which increase or accelerate the flow upon the lower land. Such improvements may be in the form of increased areas of cultivation, increased land use, improvement of drainage channels, drainage of ponded areas, or changes in land use (such as urbanization of agricultural land). Another might be the placing of a culvert in a natural channel intercepted by the roadway. At the time of its installation, the culvert may be adequate to handle the natural flow from the upper watershed. However, as time goes by, various improvements in the upper watershed may cause the flow to increase. As a result, the culvert occasionally may not be able to handle the increase, causing water to back up on the upper land. In such event who is responsible for increasing the size of culvert to adequately handle the increase in flow?

Under the rules of natural drainage in Illinois, the owner of the upper, or dominant, land has the right to pass off surface waters through natural drains upon and over the lower, or servient lands. In addition, the courts have said that the owner of the dominant land has the right to drain water by artificial means into natural channels on his own land even if the quantity deposited upon the adjoining servient lands is thereby increased and the flow accelerated.[13] This ruling, however, is limited by the condition that all of the land drained either naturally or artifically must lie within the natural basin that drains into the tributary watercourse.

The owner of the dominant land has no right to collect and discharge water onto lower land if the water would not naturally flow in that direction. Furthermore, he has

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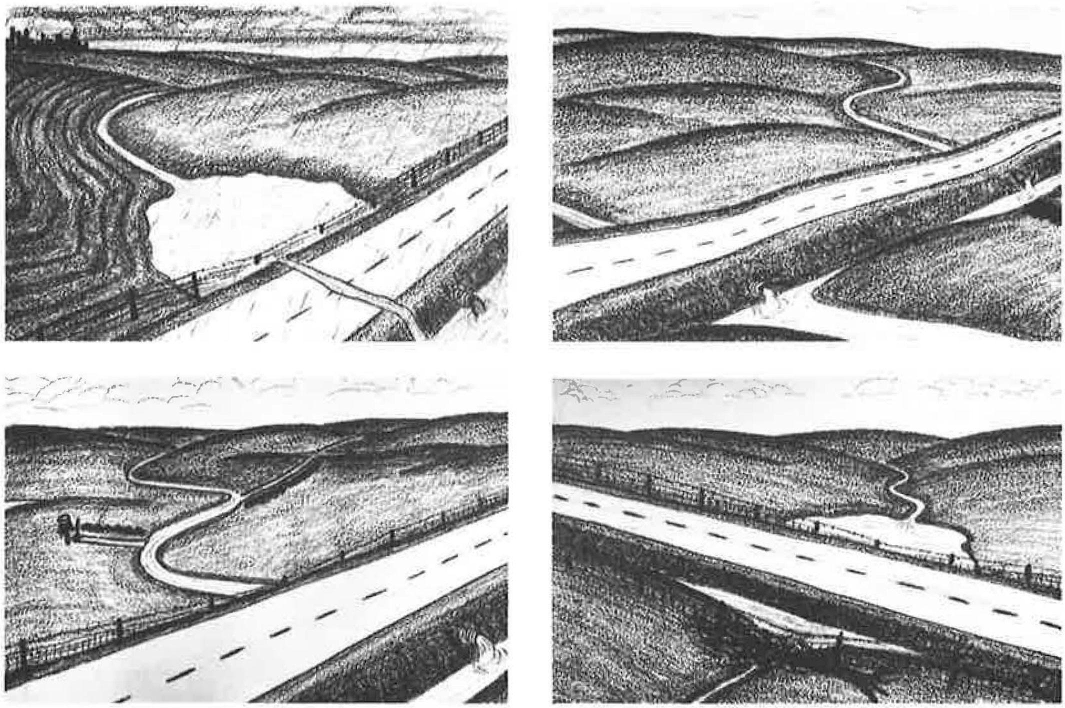
[9] Jean Domat. "The Civil Law in Its Natural Order," Vol. 1, Book 2. (Boston:1853).

[10] H.P. Farnham. "The Law of Waters and Water Rights," Vol. 3, Sec. 889a. (Rochester, 1904).

[11] S. V. Kinyon and R. C. McClure. "Interference With Surface Waters," Minnesota Law Review, Vol. 24, No. 7, p. 891 (1940); Johnson v. Marcum, 152 Ky. 629, 153 S. W. 959 (1913).

[12] 93 C. J. S., "Waters," Sec. 114 (1956). See also "Surface Water Law in Virginia," Virginia Law Review, Vol. 44, No. 1, p. 135 (1958).

[13] Dayton v. Drainage Commissioners, 128 Ill. 271, 21 N.E. 198 (1889); Peck v. Herrington, 109 Ill. 611 (1884); Town of Saratoga v. Jacobson, 193 Ill. App. 110 (1914); Fenton and Thompson R. R. v. Adams, 221 Ill. 201, 77 N. E. 531 (1906).



Interference with the flow of natural drainage by (upper left) acceleration due to upstream improvements, (upper right) diversion, (lower left) drainage of ponded areas, and (lower right) obstruction of natural flow path.

no right to collect even the water that would naturally flow toward the servient land and discharge it in a body except in a natural channel or watercourse.[14] Although no court seems to have considered the question, it is probable that the right to accelerate the flow of water on the dominant land by means of artificial ditches is limited to the requirements of good husbandry. If the acceleration is done wantonly, with the purpose of injuring the lower owner, it is probable that a court would enjoin the dominant owner from continuing.[15]

There seems to be little concern about the increase of flow in established streams caused by accelerating the flow on the upper land, probably because any increase in volume would be almost negligible in comparison with the total natural flow. It is generally considered, also, that any overflow of an established stream is usually caused by waters draining naturally into the streams, and artificial works on the dominant land do not make any appreciable difference.[16]

Diversion

Water is considered diverted either when a channel is changed wholly within the premises of one landowner or when it is changed so that the water flows onto the servient land at a location other than the point of natural entry.

Diversion of water wholly within the premises of an individual owner has been held to be permissible provided new artificial channels are not created on lower lands, and the channel is restored to its original location before the water reaches the land of

[14] Throop v. Griffin, 77 Ill. App. 505 (1898).
[15] G.W. Pickels and F.B. Leonard. "Engineering and Legal Aspects of Land Drainage in Illinois, Illinois State Geological Survey Bulletin 42, Urbana, Ill., p. 282 (1929).
[16] F.B. Leonard, Jr. "Common Law Drainage of Surface Waters and the Illinois Drainage Statutes," Doctoral Thesis, Univ. of Illinois College of Law, p. 14 (1916).

others.[17] Therefore, the privilege of diverting water wholly within the premises of an individual owner depends on having the water pass from the higher to the lower owner at the precise point of natural entry.[18]

If a diversion allows water to enter the premises of a lower owner at a point other than natural flow, the courts have held the upper owner liable. The owners of higher ground are not authorized by law to remove natural barriers and thereby allow water to flow out of its natural course onto adjoining and lower lands.[19] Nor do the dominant landowners have the privilege of collecting water usually flowing onto the lower fields by several channels into one channel and thereby cause it to flow in undue and unnatural quantities to the injury of the lower owner.[20]

The principles of diversion apply to highway authorities as well as to individual landowners. Adjoining landowners have a right to drain their lands across or along highways provided they follow the path of natural drainage. And, in turn, highway authorities may prevent landowners from diverting and casting water on the highway out of its natural course.[21] Likewise, highway authorities have the right to drain roads under the natural drainage rules, but in so doing they generally are not permitted to collect and divert a quantity of water along the highway that would drain naturally in another direction except under certain statutory provisions when it can be shown that it is for the public benefit.[22]

Ponded Areas

The easement for the discharge of surface waters is not confined to water flowing from the dominant estate where the natural surface of the ground remains undisturbed. It extends also to waters collected in natural ponds and low and marshy areas located in the path of natural flow.[23] This is an exception to the restriction on removing natural barriers. A landowner may remove natural barriers surrounding a pond or a series of ponds formed by the collection of surface water on the dominant land, provided the ponds are situated on a grade descending toward the lower land, and the removal of such barriers will allow the water from the ponds to drain into a natural watercourse.[24]

Ponds are generally surrounded by a rim, and at some point on the circumference of the rim there is usually a slight depression that allows overflow. This point is considered the natural outlet of the ponded area,[25] and a landowner may cut the rim or deepen the depression at this point of lowest elevation to drain the basin. However, no authority permits the dominant owner to cut through the rim at a location other than the lowest point and thereby allow the water to drain on the land of another.[26]

How large a pond may be drained on and over the adjoining owner has not been completely answered. It is clear that small ponds located on the dominant estate may be drained in the course of natural drainage, and that the dominant owner may drain a pond that collects surface water from rain and melting snow. The owner of the higher land may not, however, drain a natural lake or large body of water on the land of an adjoining owner.[27] In this matter the question of when the lower land has in fact been overburdened may be an important consideration.

Obstruction

The servient landowner may not interrupt or prevent the natural flow or passage of

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[17] Dettmer v. Illinois Term. R.R., 287 Ill. 513, 125 N.E. 37 (1919); Daum v. Cooper, 208 Ill. 391, 70 N.E. 339 (1904).
[18] Fenton and Thompson R.R. v. Adams, supra, note 13.
[19] Dayton v. Drainage Commissioners, supra, note 13; Anderson v. Henderson, 124 Ill. 164, 16 N.E. 232 (1888).
[20] Gillham v. Madison County R.R., 49 Ill. 484 (1869).
[21] Davis v. Commissioners of Highways, 143 Ill. 9, 33 N.E. 58 (1892).
[22] Ill. Rev. Stat., Ch. 121, Sec. 4-502, 5-802, and 6-802 (1961); Young v. Commissioners of Highways, 134 Ill. 569, 25 N.E. 689 (1890).
[23] Fenton & Thompson R.R. v. Adams, supra, note 13.
[24] Commissioners of Highways of Pre-Emption v. Whitsitt, 15 Ill. App. 318 (1884).
[25] Anderson v. Henderson, supra, note 19.
[26] Fenton & Thompson R.R. v. Adams, supra, note 13.
[27] Peck v. Herrington, supra, note 13.

water across his land to the detriment or injury of the dominant proprietor.[28] This rule is often applied to acts causing obstruction of a natural watercourse. Here the important point is not whether the force of the water flowing from one tract to another has been sufficient to make a channel with definite and well-marked sides or banks but, rather, whether it moves uniformly or habitually over a given course having reasonable limits in width.[29]

Many of the cases concerning obstruction of natural flow have involved highways constructed across agricultural land. Thus, in one case, the lower landowner obstructed a natural watercourse at a point where it crossed a public highway. The upper landowner (the highway agency) petitioned the court to have the lower landowner remove the obstruction. The court sought to determine that the watercourse was natural, and then held that the highway agency had the right to have water falling on the highway flow off into the natural watercourse. It held further that, if the water falling on land on one side of a highway flowed naturally across the highway through a swale or depression onto lands on the other side, a natural watercourse existed even though it did not have well-defined banks and bed, and did not flow at all times of the year.[30] The same principles apply to both highway authorities and private landowners.[31]

The party erecting an embankment across a natural watercourse is generally considered responsible for providing openings adequate to allow water from the land above to flow as it has in the past. However, whether rainfall is so heavy and unprecedented that the damage it causes may be considered "an act of God," which thereby may relieve the defendant from liability, is a question to be determined by a jury.[32]

When an upper owner has wrongfully diverted water from his land onto the land of a lower owner at a point where it would not flow naturally, Illinois courts hold that the latter may lawfully obstruct the flow of such waters upon his premises.[33] In addition, a natural obstruction on the servient land, such as shrubs, weeds, brushwood, cornstalks, or other crop residues may accumulate and impair natural drainage, and the owner of the higher land cannot compel the owner of the lower land to remove it.[34]

Overflow

In Illinois, water overflowing the banks of a small stream comes within the rules governing natural drainage. Where the natural slope of the land makes one side of a small stream the dominant land and the other side the servient land, the servient landowner has no right, by use of embankments or other artificial means, to stop the natural flow of flood waters over his land and thus force them on the dominant land.[35] Even the interest of good husbandry does not justify construction of a levee to protect land from overflow in times of flood if it interferes with the natural flow of water and thus injures the owner of a dominant estate.[36] If, however, the position of the land is such that water does not flow naturally from one side of the stream to the other, adjacent landowners have the right to build levees or embankments to prevent overflow so long as no injury is caused to others.[37]

On occasion, landowners adjacent to the highway have contended that highway agencies are obligated to drain their land and protect it from overflow. However, Illinois courts have held that these agencies are not responsible for providing drainage to protect adjacent land from natural overflow of water.[38] Also, highway agencies cannot bind them-

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[28] Mellor v. Pilgrim, 7 Ill. App. 306 (1880); Gillham v. Madison County R.R. supra, note 20.
[29] Lambert v. Alcorn, 144 Ill. 313, 33 N.E. 53 (1893).
[30] Town of Bois D'Arc v. Convery, 255 Ill. 511, 99 N.E. 666 (1912).
[31] Younggreen v. Shelton, 101 Ill. App. 89 (1901).
[32] Chicago, P. & St. L. Ry. v. Reuter, 223 Ill. 387, 79 N.E. 166 (1906).
[33] Schmitz v. Ort, 92 Ill. App. 407 (1900).
[34] H.W. Hannah. "Illinois Farm Drainage Law," Circular 751, University of Illinois College of Agriculture," p. 7 (1956).
[35] Mauvaisterre Drainage & Levee Dist. v. Wabash Ry., 299 Ill. 299, 132 N.E. 559 (1921).
[36] Pinkstaff v. Steffy, supra, note 8.
[37] Shontz v. Metzger, 186 Ill. App. 436 (1911).
[38] Padfield v. Frey, 133 Ill. App. 232 (1907).

selves by agreement to furnish drainage for areas not being overflowed to a greater extent than they originally were, unless drainage is made necessary by their acts.

Easements and Licenses

Various types of easements may be employed in conjunction with common law rights to deal with drainage problems. Easements may be acquired based on uninterrupted use of land, for a period of 20 years, contrary to the rights of the owner or person with primary rights. Rights of drainage by prescription release the servient estate from the burden of the original easement.[39]

The State and Federal governments are generally considered immune to the application of prescriptive rights. However, the exemption of counties, cities, towns, and other minor municipalities from the operation of the statute of limitations extends only to matters affecting their public rights (as distinguished from private and local rights). Public rights are considered those in which the people as a whole have an interest in common, whereas private rights are those enjoyed exclusively by the inhabitants of a local district.[40]

In various situations licenses may be useful legal devices for creating temporary or special drainage arrangements between adjacent landowners. A license is an authorization to perform a particular act on or affecting the land of another, and differs from an easement in that it confers on the licensee no possessory interest in the property subject to his act. Licenses may be granted informally, by oral agreement, and are generally revocable at the will of the licensor. However, study of the law relating to licenses and easements discloses troublesome areas where distinctions are not clearly maintained, and where agreements purporting to be licenses are treated as creating vested rights in the nature of easements.[41]

STATUTE LAW RELATING TO DRAINAGE

Supplementation of common law rules by statute law has resulted in clarifying the rights and duties of private landowners to each other and in relation to the public. Additionally it has performed the important function of providing a framework of procedure for performing various acts needed to establish and operate coordinated drainage systems. As presently codified, the statutory law relating to drainage is found in connection with various powers and functions of government. Some deal with the relationship between landowners and highway agencies; others deal with the relationship needed to coordinate the activities of public agencies; still others deal with remedies and procedures.

Relationship Between Highway Authority and Individual Landowners

Eminent Domain.—Generally, the drainage of highways across adjoining lands is governed by the same rules as apply to drainage of private lands. One exception is that a highway agency may use the eminent domain laws to acquire property or rights to perform necessary functions of drainage.[42]

The highway agency must, however, respect certain limitations as to its use of eminent domain laws. It may not use the right for the purpose of carrying off sewage deposited on the highway.[43] If land is acquired by eminent domain for highway purposes, injuries to the landowner are to be expected and the landowner is to be reimbursed for them in the eminent domain award. However, condemnation does not bar the landowner

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39 Zerban v. Eidmann, 258 Ill. 486, 101 N.E. 925 (1913).

40 Phillips v. Leininger, 280 Ill. 132, 117 N.E. 497 (1917); Savoie v. Town of Bourbonnais, 339 Ill. App. 551, 90 N.E. 2d 645 (1950); Brown v. Trustees of Schools, 224 Ill. 184, 79 N.E. 579 (1906).

41 Wessels v. Colebank, 174 Ill. 618, 51 N.E. 639 (1906); Van Ohlen v. Van Ohlen, 50 Ill. 528 (1870).

42 Ill. Rev. Stat., Ch. 121, Sec. 4-502, 5-802, and 6-802 (1963).

43 Dierks v. Commissioners of Highways of Twp. of Addison, 142 Ill. 197, 31 N.E. 496 (1892).

from filing suit for a subsequent injury growing out of the negligence or unskillfulness of the public authorities in constructing drains in the highway.[44]

Contracts with Owners or Occupants of Adjoining Lands.—Where highway agencies are about to lay a tile drain along any public highway, they may contract with the owners or occupants of adjoining lands to lay larger tile than necessary to drain the highway and permit the contracting landowner to connect to it. However, the adjoining landowner must pay the cost of enlarging the tile to carry off the additional draining from his land, and the drain must be a part of the highway drainage system.[45]

Illinois statutes further provide that a landowner through or along whose land a public highway passes may, if he so desires, drain onto the right-of-way after notifying the proper highway authority and receiving written permission for any ditching, excavating, or other work he proposes to do within the limits of the highway.[46] If, however, he constructs a ditch or drain within the limits of the highway right-of-way without first getting the required permission, his construction may subject him to a penalty under the Highway Code. Also, such private facilities may be considered an obstruction even if they only render the highway less safe, useful, or convenient to the public.[47]

Maintenance.—The Highway Code imposes on the respective highway authorities the duty to construct, maintain, and repair highways within their jurisdiction.[48] Whether the highway agency has the duty to maintain and repair drainage systems along the highway after adjoining landowners, with permission, have constructed private drains is not clear from the statute. However, it is not likely that drains constructed for private purposes in the highway right-of-way are included within the statutory definition of highways.

Relationship Between Highway Authority and Drainage District

Legislation has removed many of the limitations of the common law and made it possible for the majority of landowners within a given area to organize a drainage district to provide new drainage outlets, and to force the minority of landowners to join in the project.[49] The relationship between such drainage districts and the public highway authorities is an extremely important aspect of any study of laws relating to highway and agricultural drainage.

Assessment of Highways.—The Illinois Drainage Code authorizes the inclusion of highways in the assessment rolls of a drainage district.[50] However, the Illinois Constitution and the Revenue Act exempt the State government from taxation.[51] The Constitution also prevents the State from ever being made a defendant in a court of law or equity.[52] The courts have relied on these provisions in holding that State property is not subject to special assessment or taxation.[53] The section of the Drainage Code providing for assessment of highways appears to be confined to the State's political subdivisions, such as counties and townships. The courts have held that cities, villages, and counties are mere agencies of the State through which local government is conveniently administered, and that the general assembly may authorize property held by one of its agencies to be burdened with a charge for the benefit of another of its agencies to the extent of benefits received. The benefits conferred on the lands by improved drainage must be shown, and the assessment must not exceed the benefits.[54]

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44 Tearney v. Smith, 86 Ill. 391 (1879).
45 Ill. Rev. Stat., Ch. 121, Sec. 9-107 (1963); Davis v. Commissioners of Highways, supra, note 21; Township of Whitley v. Linville, 174 Ill. 579, 51 N.E. 832 (1898).
46 Ill. Rev. Stat., Ch. 121, Sec. 9-117 (1963).
47 Nelson v. Fehd, 203 Ill. 120, 67 N.E. 828 (1903). See also Town of Hudson v. Carrithers, 201 Ill. App. 153 (1916).
48 Ill. Rev. Stat., Ch. 121, Sec. 4-405, 5-40, and 6-201.7 (1963).
49 G.W. Pickels. "Drainage and Flood Control Engineering," (New York, N.Y., 2nd 3d., 1941) p. 435.
50 Ill. Rev. Stat., Ch. 42, Sec. 5-2 (1963).
51 Ill. Const., Art. IX, Sec. 3 (1870); Ill. Rev. Stat., Ch. 120, Sec. 500 (5) (1963).
52 Ill. Const., Art. IV, Sec. 26 (1870).
53 In re City of Mt. Vernon, 147 Ill. 359, 35 N.E. 533 (1893).
54 Ill. Rev. Stat., Ch. 42, Sec. 3-23, 5-1 (1963).

Use of Highways by Drainage Districts.—Drainage commissioners are empowered by statute to use any part of a public highway for doing necessary work, provided such use will not permanently destroy or materially impair the highway for public use.[55] Reported cases indicate it is permissible for a drainage district ditch to cut across a highway, but are not clear as to the right of a drainage district to drain into highway ditches or to construct a drain along the highway within the right-of-way. There are no Illinois cases on this question. In cases involving construction of a ditch within the highway right-of-way, the problem has not been whether the drainage district is within its rights with regard to the highway agency, but whether it has obtained the consent of the fee owner.[56] However, in present-day land acquisition proceedings, the consent of a fee owner is not of great concern, inasmuch as the highway agency usually acquires the fee simple title. Therefore a more important point would seem to be whether the drainage district creates an obstruction by constructing a drain in the highway right-of-way. It is arguable that the rules covering an individual landowner also apply to the drainage district.

Bridges and Culverts.—Enactment of the Illinois Drainage Code in 1955 helped clarify who was responsible for maintaining bridges and culverts. The code stated that whenever a district drain crosses a public highway other than in the course of natural drainage, the district is liable to the highway agency for the cost of constructing any bridge or culvert made necessary by such crossing. The district is also liable for the cost of repairing and maintaining such bridge or culvert.[57]

On the other hand, when a drain constructed in the course of natural drainage crosses a public highway, the highway agency must construct and maintain a bridge or culvert to serve the needs of the public for drainage of land within the natural watershed. This provision applies not only to needs at the time of construction, but for all future time.

However, if a district, by deepening, widening, or straightening a natural drain, or by changing the established grade, width, or alignment of a ditch, removes or threatens to remove a supporting member of the bridge, the district is liable to the highway agency for the cost of protecting or underpinning such supporting member.

REMEDIES

The remedies of damages and injunction are available to the Illinois landowner who is injured by disturbance of drainage. Where damages are sought recovery depends on proof of causation as in similar types of injury to real property. Jury trials are customary, and awards range from the traditional $1 nominal damages for a technical invasion of property rights to substantial damages to compensate actual injury. Permanent damages are measured by the difference between fair market value before and after the injury.[58] Where the cause of injury can be corrected, damages may be recovered only for injuries up to the time of the lawsuit. However, recurrence of injury creates a new cause of action.[59]

Injunctive relief against highway agencies is normally allowed only with extreme caution due to its effect on essential public functions. The use of injunctions to deal with destructive injuries not capable of being compensated by damages is common among private parties. Among the situations which Illinois courts have allowed to be dealt with by injunctions are: prevention of diversion of water, removal of obstructions to natural flow of water, deposition of sewage, and unlawful connection to drainage facilities.[60]

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[55] Ill. Rev. Stat., Ch. 42, Sec. 4-14 (1963).
[56] Moore v. Gar Creek Drainage Dist., 266 Ill. 399, 107 N.E. 642 (1915).
[57] Ill. Rev. Stat., Ch. 42, Sec. 12-4 (1963).
[58] Cromwell v. Allen, 151 Ill. App. 404 (1909); Reinke v. Sanitary District of Chicago, 260 Ill. 380, 103 N.E. 236 (1913).
[59] Mellor v. Pilgrim, 7 Ill. App. 306 (1880); Allen v. Michel, 38 Ill. App. 313 (1890).
[60] Dayton v. Drainage Commissioners, 128 Ill. 271, 21 N.E. 198 (1889); Town of Nameoki v. Buenger, 275 Ill. 423, 114 N.E. 129 (1916); Dierks v. Commissioners of Highways of Addison Township, 142 Ill. 197, 31 N.E. 496 (1892); King v. Manning, 305 Ill. 31, 136 N.E. 730 (1922).

TECHNIQUES FOR STUDY OF RELATED HIGHWAY AND AGRICULTURAL DRAINAGE LAWS

The cooperative project of the University of Illinois, the Illinois Division of Highways, and the U. S. Bureau of Public Roads for the study of highway and agricultural drainage laws offered a unique opportunity to obtain a comparative view of two bodies of law and of two related aspects—legal and engineering—of highway drainage problems. In the first phase of this project, now completed, the researcher's work was, to a great extent, facilitated by the fact that lawyers have developed an effective methodology for the compilation and analysis of statute law and court decisions. Thus, identification and extraction of pertinent information from the total accumulated body of legal materials were accomplished satisfactorily through use of the reference aids normally relied on in legal research; namely, digests, citators, annotations, and index lists of legal periodicals.

In developing the research plan for a study of agricultural and highway drainage law, two problems not encountered in normal day-to-day legal research were recognized. One of these, the fact that laws relating to drainage had a long history, has already been noted. Because legislation and, to an even greater extent, case law on drainage rights, are found throughout the records of the nineteenth century, the researcher should be prepared to review a substantial amount of historical material in the process of compiling the present law. Much of this nineteenth century and early-twentieth century law has lost its validity for current conditions and practices of highway engineering and agricultural land use, but some still retains its vitality and some is pertinent for developing necessary historical perspectives for modern practices. Thus the researcher should plan to review the law relating to drainage in terms of its history and indicate its evolution as he selects for his compilation those statutes and cases which may be considered as currently controlling.

A second major problem encountered in developing a research plan concerns organization of the subject matter so that the research report will have comprehensive and coordinated coverage. In this matter the varying circumstances and legislative history of the States must be considered. However, it is submitted that many features of general applicability are present in the outline for organization of the research report for the first phase of the Illinois drainage law study. This outline is as follows:

- I. Objective of the Study
- II. Historical Review
  - A. Common Law Drainage
  - B. Theory of the Common Law Drainage Rules
  - C. Illinois Adoption of Natural Drainage Rule
  - D. Early Attempts at Collective Action
  - E. Statutory Enlargement of Natural Drainage Rule
  - F. Statutory Drainage Law
  - G. Summary
- III. Natural Drainage
  - A. Basic Principles of Natural Drainage
  - B. Legal Classification of Water
  - C. Watercourse
  - D. Water Movements
  - E. Acceleration
  - F. Diversion
  - G. Drainage of Ponded Areas
  - H. Obstruction
  - I. Overflow
  - J. Easement
- IV. Statutory Drainage
  - A. Highway Authority
  - B. Drainage Districts
  - C. Individual Landowner
  - D. Extension of Covered Drain Through Land of Others
  - E. Drains and Levees for Mutual Benefit
- V. Bridges and Culverts
  - A. Construction
  - B. Maintenance
  - C. Liabilities
  - D. Private Bridges and Culverts
- VI. Sewage and Pollution
  - A. Equitable Jurisdiction in Pollution Cases
  - B. Criminal Jurisdiction in Pollution Cases
- VII. Legal Remedies
  - A. Damages
  - B. Injunction
  - C. Limitations on Granting of Damages and Injunction
- VIII. References Cited
- IX. Index

SUMMARY

Drainage laws provide a basis for determining the duties and responsibilities of all affected parties, including highway authorities. They also provide the necessary framework for carrying out various essential functions involving engineering, administering and financing drainage systems. They indicate where it is permissible to drain, under what conditions drainage may take place, what rights the landowner (including the highway authority) has, under what conditions the movement of water can be increased without causing liability, under what limitations water can be forced to flow in a direction other than natural flow, what rights group drainage enterprises have in relation to the highway authority, etc.

The laws relating to drainage and the principles and practices followed in the treatment of interrelated highway and agricultural drainage have developed over many years. Therefore the pertinent information is so dispersed that it is not always readily available. Consequently, a compilation of the laws, together with a resume of the practices that have been followed, is an important tool to provide the highway administrators with a basis for extablishing sound drainage policies. This information will also provide other interested groups with a better understanding of the drainage problems that are encountered and a greater appreciation of the need to find satisfactory solutions. If this information is properly used some of the conflict that has previously existed in this field should be resolved.

Common law differs from State to State. Inasmuch as Illinois has adopted the civil law rule, this report has followed this rule in outlining the rights and duties of the various parties. However, the problems encountered under this rule may give some insight into what to expect in other States that follow other rules. The statutory provisions are also those in effect in Illinois. Although they may not be directly applicable elsewhere, again they may offer some useful suggestions.

Part II

FLOOD PLAIN PLANNING

Flood Mapping Program of the U. S. Geological Survey

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•THE ACT of March 3, 1879, creating the Geological Survey, did not specifically define its responsibilities in the water resources field. Annual appropriation acts, beginning with 1888, have authorized the use of appropriated funds for water resources investigations. Beginning with the fiscal year ending June 30, 1895, successive appropriation bills passed by Congress carried the following items: For gaging the streams and determining the water supply of the United States, and for the investigation of underground currents and artesian wells, and for the preparation of reports on the best methods of utilizing the water resources.

Successive appropriation acts have continued to define further the authorization for the water resource functions of the Survey. The current programs and any presently contemplated future recommendations are fully authorized in the language of the present appropriation act.

For more than 50 yr the mutual interests of the State and Federal governments in water resource problems have been implemented in the Geological Survey by cooperative investigations. These cooperative activities have been a major part of the work of the Survey. The current trend is for increased participation by States in cooperative water resources investigations. The present appropriation bill provides, "That no part of this appropriation shall be used to pay more than one-half the cost of any topographic mapping or water resources investigations carried on in cooperation with any State or municipality." The size and scope of the cooperative program clearly reflect the interest of State and local agencies in being "partners" in this nationwide water-resources appraisal task. All of the States plus American Samoa, Guam, Puerto Rico, the Virgin Islands, and the District of Columbia contribute to the Survey's water resources investigations through financial cooperation. More than 300 individual State and local agencies participate.

For many years the water resources problems of the country were such that the primary emphasis in the Geological Survey's program was the collection of basic water resources data. The increasing demand for solutions of increasingly complex water problems now necessitates greater attention to analytical, interpretative, and research phases of water resources investigations. One problem demanding attention is caused by man's occupancy of flood plains.

The natural function of a flood plain is to carry away excess water in time of flood. Failure to recognize this function has led to rapid and haphazard development on flood plains with a consequent increase in flood hazards. The average annual flood damage in the United States in dollars has increased from less than $100,000,000 at the begin-

Paper sponsored by Committee on Surface Drainage of Highways.

ning of the century to almost $300,000,000 today, even though about $5 billion has been spent for flood protection works. The increased damage is apparently not due to greater floods, but to increased encroachment on flood plains. It is reported that for every $6 spent by the Federal Government for flood control, $5 is spent by the public expanding onto the flood plain. The average annual flood protection expenditure, for 1937-60 period, was $288,000,000, whereas the average annual loss was $284,000,000; both figures adjusted to 1960 values. The problems of flood-plain development have been discussed in several excellent papers published by the University of Chicago, Department of Geography (1-5).

> It is economically infeasible and often physically impossible to provide adequate flood-control measures for every locality subject to flood damage. Hence, corrective and preventive measures must be taken in order to adjust man's activities on flood plains to the regimen of streams. Such measures, generally known as flood-plain zoning or planning, can help solve or ease many flood problems.
>
> Fundamental to effective flood-plain planning is the recognition of the flood potential of streams and the hazards involved in flood-plain occupation. When necessary restrictions are imposed on communities in their flood-plain development, a marked reduction in flood damage is possible. Basic data on the regimen of the streams, particularly the magnitude of floods to be expected, the frequency of their occurrence, and the areas they will overflow, are essential to flood-plain planning. (6)

The Senate Select Committee on National Water Resources has recommended that the Federal Government in cooperation with the States should:

> Regulate flood plain use as a means of reducing flood damages whenever such regulation provides greater net benefits to the national economy than would be provided through other methods of preventing flood losses. Additional steps should be taken to delineate flood hazard areas so that the public will be aware of the risks involved in occupying flood plains. (7)

The documentation of flood events has long been an activity of the Geological Survey, acting through the Water Resources Division, Surface Water Branch. Descriptions of several hundred floods have been published in the water-supply paper series. Beginning in 1950, annual water-supply papers (WSP) have been published reporting on floods of each year. The first of this series was "Floods of 1950"; a similar title designates reports for subsequent years. Separate water-supply papers have been prepared for outstanding floods, as for the 1951 flood in Kansas, 1955 floods in northeastern States, and 1955-56 floods in farwestern States. It is interesting to note that the first Survey flood report, describing a flood on the Passaic River, Water-Supply Paper 88 (8) includes a topographic map of an area in the central basin of New Jersey that was inundated by floods of February-March 1902. Other water-supply papers showing flood inundated areas are:

1. WSP's 96, 147, and 162 (9-11) contain planimetric maps showing flooded areas at Kansas City (1903 and 1904); Trinidad, Colorado (1904); and Ithaca, New York (1905).
2. WSP 488 (12) shows on a 20-ft-interval contour map the area in San Antonio, Texas, flooded in September 1921.
3. WSP 838 (13) contains a sketch map showing overflow channels and areas in the vicinity of the mouth of the Ohio River, January-February 1937 flood.
4. WSP 843 (14) contains a sketch map showing areas flooded in the lower Sacramento River Basin, California, December 11-14, 1937.
5. WSP 1139 (15) shows areas inundated by July 1951 floods on Mississippi River in vicinity of St. Louis; along Kansas River from Junction City to the mouth; along Missouri River from Kansas City to the mouth; along Marais des Cygnes and Osage River above Lake of the Ozarks; along Neosho River and tributaries in Kansas; Kansas River at Kansas City; and in Kansas at towns of Lawrence, Manhattan, Ottawa, Salina, and Topeka.

6. WSP 1260-B (16) shows areas flooded by April 1952 floods; along Missouri River from Yankton, S. D., to Kansas City, Mo., between Bismarck and Mandan, N. D., at Pierre, S. D., at South Sioux City, Neb., and Sioux City, Iowa and at St. Joseph, Mo.; and flooding at Sioux Falls, S. D., by Big Sioux River.

7. WSP 1260-C (17) shows areas flooded by April 1952 floods on various streams; in Rock Island and Moline, Ill.; and Davenport and Bettendorf, Iowa; at Clinton, Dubuque and Muscatine, Iowa; at Carver, Chaska, Granite Falls, Mankato, Marshall, Montevideo, Moorhead, St. Paul, and Winona, Minn.; at Fargo, N. D.; and at La Crosse and Prairie du Chien, Wis.

8. WSP 1320-A (18) shows area flooded in June 1953 by Floyd River and major tributaries upstream from Sioux City, Iowa.

9. WSP 1420 (19) shows area inundated at Stroudsburg, Pa., on August 18, 1955.

Thus, it is noted that preparation of flood inundation maps is nothing new to the Survey. However, maps that just outline flooded areas are inadequate for modern needs. Engineering data are needed to evaluate the problem and to plan wise development of flood plains.

When man occupies a flood plain, he assumes a risk, and this risk must be evaluated if sound development is achieved. What is the chance of a flood reaching a particular location? The decision as to the kind of development and where to locate it will be governed by the chance of flooding. This chance can be evaluated by a knowledge of the frequency of floods of selected heights; thus, flood-frequency information is pertinent engineering data. Problems arising from the occupation of flood plains are economically important, and they make the development of sound flood-frequency methods imperative.

The subject of flood frequency has attracted many students of hydrology (20), but as yet there is no agreement that any one method is best. In view of this lack of agreement and of the fact that several methods appear to be of equal merit, the Survey has adopted and described (21) a method that has the practical advantage of simplicity. Significant features of the Survey method are as follows:

1. It is concerned with momentary peak discharges.
2. Recurrence intervals, T, are computed as $(n+1)/m$, where n is length of record and m is order number, the greatest being 1.
3. Curves are fitted graphically.
4. The mean annual flood is defined as the flood having a recurrence interval of 2.33 years.
5. A means is provided for computing flood frequencies of natural flow on any stream, gaged or ungaged.

Following standard Survey methods, regional flood-frequency reports have been prepared, mostly in cooperation with State highway departments, for 31 States and the Delaware River Basin (22); these processed reports are available from the Washington, D. C. office or from the Survey Surface Water office in the appropriate State.

Regional flood-frequency reports are being prepared or are in process of publication in a series of water-supply papers that will cover conterminous United States. Each volume will be for a part, each covering an area as now used for publication of gaging station records. These reports will contain regional flood-frequency curves plus a tabulation of flood peaks for gaging stations in the area. The first of these should be released soon and the others will follow at intervals over the next two or three years. The reports will be titled "Magnitude and Frequency of Floods in the United States" with a further designation, for example, "Part 4, St. Lawrence River Basin." A complete list is as follows:

1.	WSP 1671.	Part 1-A.	North Atlantic Slope Basins, Maine to Connecticut.
2.	WSP 1672.	Part 1-B.	North Atlantic Slope Basins, New York to York River.
3.	WSP 1673.	Part 2-A.	South Atlantic Slope Basins, James River to Savannah River.

4. WSP 1674. Part 2-B. South Atlantic Slope and Eastern Gulf of Mexico Basins, Ogeechee River to Pearl River.
5. WSP 1675. Part 3-A. Ohio River Basin except Cumberland and Tennessee River Basins.
6. WSP 1676. Part 3-B. Cumberland and Tennessee River Basins.
7. WSP 1677. Part 4. St. Lawrence River Basin.
8. WSP 1678. Part 5. Hudson Bay and Upper Mississippi River Basins.
9. WSP 1679. Part 6-A. Missouri River Basin above Sioux City, Iowa.
10. WSP 1680. Part 6-B. Missouri River Basin below Sioux City, Iowa.
11. WSP 1681. Part 7. Lower Mississippi River Basin.
12. WSP 1682. Part 8. Western Gulf of Mexico Basins.
13. WSP 1683. Part 9. Colorado River Basin.
14. WSP 1684. Part 10. The Great Basin.
15. WSP 1685. Part 11-A. Pacific Slope Basins in California except Central Valley.
16. WSP 1686. Part 11-B. Central Valley of California.
17. WSP 1687. Part 12. Pacific Slope Basins in Washington and Upper Columbia River Basin.
18. WSP 1688. Part 13. Snake River Basin.
19. WSP 1689. Part 14. Pacific Slope Basins in Oregon and Lower Columbia River Basin.

A flood-frequency curve applies to a specific location; to be useful, it must be transferred along a stream to all locations in the study area. This transfer is achieved by developing flood profiles through the reach of the channel being investigated. These profiles may be defined by a survey made soon after a flood or by a flood routing process.

The task force on Flood Plain Regulations, Committee on Flood Control, Hydraulics Division, ASCE, states, in reference to data to be developed:

> The information to be collected and developed falls generally into two categories. First, topographic; and second, hydrologic....As a minimum, the report should incorporate a typical flood hydrograph, typical stream and valley cross sections, water surface profiles and overflow maps for selected floods, a tabulation and chart giving information on known floods, and typical flood photographs. (23)

Damage and destruction caused by the severe floods of August 1955 in the Northeastern States and of December 1955-January 1956 in the far Western States revived interest in flood problems. The Federal Flood Insurance Act of 1956, Public Law 1016, gave encouragement to the establishment of zoning restrictions. A manual for the guidance of those engaged in flood-plain planning, titled "Hydraulic and Hydrologic Aspects of Flood-Plain Planning," was prepared through a cooperative arrangement between the Geological Survey and the Commonwealth of Pennsylvania and was published as Survey Water-Supply Paper 1526 (6).

As an illustration of how flood information can be presented on a map, and to develop techniques, the Survey made pilot studies in several areas and published the results as map reports. These were published as Hydrologic Investigations Atlases, as have been all such Survey reports (24). These reports, usually on one sheet, show on a topographic map base the area inundated by a flood. In addition, there is shown a histogram of floods, a flood-frequency curve, flood profiles, photograph of area during flood, and a short text. The variety of conditions covered are as follows:

1. A large, single area covered by specific flood (HA-14).
2. Several separate areas on flat terrain covered by a specific flood (HA-39).
3. Flooded area shown on a photomosaic (HA-40).

4. Areas in a city covered by floods of selected frequency (HA-41).
5. Foothill and tidewater inundation (HA-54).
6. Inundation by ocean tides (HA-65).

COOPERATIVE PROJECTS

State and local interest in flood inundation problems is evidenced by the fact that 13 States, local agencies, and the Commonwealth of Puerto Rico have contributed funds for cooperative projects with the Survey.

Project Descriptions

General Description.—A report for an area consists of a map showing the area inundated by a specific flood, plus a histogram of flood peaks, a flood-frequency curve, and flood profiles. A short text explains the exhibits.

Some projects involved reporting on a specific event, whereas other projects have added a program for obtaining field data to provide information for making a more accurate report at a later time. Several projects have been for one or two maps, whereas others provide a series of maps covering large areas.

Colorado.—Boulder County cooperates in a continuing project to outline areas probably inundated by floods of selected frequency. The first study was of the City of Boulder, the second was an adjacent area in the county, and other studies are being made at population centers.

Illinois.—A five-year program is being conducted in cooperation with the Northeastern Illinois Metropolitan Area Planning Commission. The program provides for completion of forty-four 7½-min quadrangle sheets in six counties in the Chicago area. Work is being conducted from an office at Oak Park, Ill. As work is completed in each quadrangle, an open-file report is prepared for the cooperator, pending publication of data as an Hydrologic Investigations Atlas. These maps are used by local governmental agencies to help plan development of a rapidly growing suburban area. The reports have been found useful to county and city officials concerned with zoning, forests, parks, streets and roads, and other activities.

New Jersey.—A continuing program provides for progressive mapping in the Raritan River Basin. Open-file reports are made pending atlas publication.

Ohio.—Immediately after the great January 1959 floods, the State of Ohio, acting through the Department of Natural Resources, provided funds for mapping flooded areas in 12 cities. Publication of the last map of the project is imminent.

Puerto Rico.—Following the August 1961 floods, the Commonwealth provided cooperative funds to prepare flood studies of six areas. Considerable work was done by Commonwealth officials surveying flood boundaries at many locations. The main interest appears to be in problems related to flood zoning and flood protection works.

Tennessee.—The City of Chattanooga provides cooperative funds for a continuing study on Chattanooga Creek. Gages have been installed and cross-sections determined for obtaining field data in a very complex area. Part of the study consists of flood routing by electronic computer.

Texas.—The City of Dallas provides cooperative funds for a continuing study on White Rock Creek and its tributaries. Field data are being obtained at selected sites to aid in the study.

Virginia.—An extensive, almost county-wide, program is being conducted in cooperation with Faixfax County, in an area rapidly changing from rural to suburban and urban. Many stage and precipitation gages have been installed. A 1- or 2-ft-interval contour map was made of about 80 miles of stream channels; stream cross-sections are taken from these maps. Extensive flood routing by electronic computer is involved. The newly tried features of this program make it a "pilot project."

Project Reports

California.—Floods in Almeda Creek Basin at Fremont: report published as Hydrologic Investigations Atlas-54, shows areas between foothills and San Francisco Bay that were flooded in December 1955 and April 1958.

Floods near Fortuna: HA-78 shows area along lower Eel River that was flooded in December 1955.

Floods on San Dieguito River and its tributaries, Santa Ysabel Creek and Santa Maria Creek, in San Diego County. (Report to be published by State Cooperator.)

Colorado.—Floods at Bounder: HA-41 shows areas in Boulder that would be inundated by floods of 25- 50- and 100-yr recurrence intervals.

Floods on Boulder Creek below Boulder (U. S. Geological Survey open-file report).

Floods on St. Vrain and Lefthand Creeks at Longmont (open-file report).

Florida.—Map showing area along Hillsborough River at Tampa flooded in March 1960 (HA-66).

Illinois.—To date six Hydrologic Investigations Atlases have been published for the Chicago area: (1) Arlington Heights Quadrangle (HA-67), (2) Aurora North Quadrangle (HA-70), (3) Near Chicago Heights (HA-39) financed by Federal funds, (4) Elmhurst Quadrangle (HA-68), (5) Highland Park Quadrangle (HA-69), and (6) Wheeling Quadrangle (HA-71).

In the process of publication are maps for nine other quadrangles: (1) Harvey (HA-90), (2) Hinsdale (HA-86), (3) Joliet (HA-89), (4) Libertyville (HA-88), (5) Palatine (HA-87), (6) Park Ridge (HA-85), (7) Geneva (HA-142), (8) Lombard (HA-143), and (9) Wadsworth (HA-144).

As work is completed in each quadrangle, an open-file report is prepared for the cooperator pending publication of the atlas.

Iowa.—Floods on Des Moines River, Raccoon River, Walnut Creek, and Fourmile Creek at Des Moines, in 1947, 1954, and 1960 (HA-53).

Kansas.—Floods in the Arkansas River Basin at Wichita in 1942, 1944, 1951, 1955, 1957, and 1960 (HA-63).

Floods of the Kansas River, Topeka, in 1935 and 1951 (HA-14).

Louisiana.—Floods of 1962 near Baton Rouge (HA-126).

Michigan.—Floods on Clinton River, North Branch and Middle Branch of Clinton River and Harrington Drain, Mount Clemens (HA-59).

Mississippi.—Floods on Pearl River at Jackson in 1961 (HA-127). An open-file report was prepared June 1963.

New Jersey.—Atlantic Ocean tidal floods of 1960 and 1962 on Absecon Island and Atlantic City (HA-65).

Extent and frequency of inundation of flood plain in the vicinity of Bound Brook in Somerset and Middlesex Counties (open-file report).

Extent and frequency of inundation of Millstone River Flood Plain in Somerset County (open-file report).

Extent and frequency of inundation of flood plain near Raritan (open-file report).

Extent and frequency of inundation of flood plain in the vicinity of Somerville and Manville (open-file report).

Ohio.—Floods on Tuscarawas River and Wolf Creek at Barberton (HA-49).

Floods on Middle Branch and East Branch Nimishillen Creek at Canton (HA-50).

Floods at Chillicothe (HA-45).

Floods at Circleville (HA-48).

Floods on Scioto River, Olentangy River, and Alum Creek at Columbus in January 1959 (HA-52).

Floods on Sandusky River at Fremont in 1959 (HA-47).

Floods on the Kokosing River, Dry Creek, and Center Run at Mount Vernon in 1959 (HA-40). Flooded area shown on photomosaic, pending completion of topographic map.

Floods on Licking River, North Fork and South Fork of Licking River, and Raccoon Creek at Newark in 1959 (HA-44). Flooded area shown on photomosaic, pending completion of topographic map.

Floods at Springfield in 1913 and 1959 (HA-43).

Floods on Mahoning River at Warren in 1959 (HA-51).

Floods on Crab Creek at Yongstown in 1959 (HA-56).

Floods at Zanesville (HA-46).

Pennsylvania.—Floods on the Susquehanna River at Harrisburg in 1936 (HA-57).

Puerto Rico.—Floods at Bayamón and Cataño (HA-77).

Floods at Toa Alta, Toa Baja, and Dorado (HA-128).

Reports are in preparation for Río Cibuco, Río Grande de Arecibo, Río Grande de Manití, and Humacao.

Tennessee.—Floods on Chattanooga Creek at Chattanooga (open-file report) (25).

Texas.—Floods on White Rock Creek above White Rock Lake at Dallas (open-file report).

Two flood-map reports prepared for areas in New Jersey were put to immediate use. (1) Data in the Millstone River report were used by the State to position flood-marker signs. These show the level of the 1938 flood, one of the highest known on this stream. The program of sign erection is one part of a comprehensive plan authorized by the 1962 New Jersey Legislature to "avoid pressure for increased governmental expenditures for the construction of flood control structures to protect property unwisely located in flood-hazard areas." (2) Atlantic City flood-map information was used in a study of design criteria for an expressway into Atlantic City. Minimum grade elevations across four miles of tidal marsh were determined primarily on data and frequency relations of the flood-map report (26).

In another State, the design of a highway crossing was influenced by a flood-inundation study. On a contour map, the Survey report showed the areas of a town that would be inundated by a flood of selected frequency: (a) with no bridge and approach fills in place, and (b) for several different bridge designs. The differences between the two showed areas in the town that would be inundated due to construction of bridge and approaches.

Projects of the type described here are conducted by district offices of the Surface Water Branch, Water Resources Division of the Geological Survey. Consultative service is provided by the Washington, D. C. office staff. District offices are located in almost every State, usually at the State Capitol. Office staffs remain relatively permanent, thus, they become familiar with local problems and acquire knowledge needed for consideration of peculiar local situations.

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Some Problems in Flood Mapping in Illinois

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•DURING the past $2\frac{1}{2}$ yr, inundation mapping in northeastern Illinois has been an interesting, informative, and reasonably successful venture. The cooperator (Northeastern Illinois Metropolitan Area Planning Commission), local governmental agencies, and the general public appear to be content with the form and context of the reports, making good use of the reports, and are favorably disposed toward the project, respectively.

The problems in this venture have been many and varied. In addition to the more common ones, such as preparation of cost estimates and procurement of adequate staff, there have been more unusual ones, such as form and context of the reports, the proper interpretation of data, and even the admissibility of the reports as evidence in legal proceedings.

In 1959, at the request of the Planning Commission, the first flood map for the Metropolitan Area was prepared. It was published as Hydrologic Atlas No. 39. The outstanding floods in this area occurring in1954 and in 1957 are shown as a blue overprint on the already available $7\frac{1}{2}$ min topographic map of the Calumet City quadrangle. Three problems were particularly troublesome. First, there was the difficulty of finding, at that time, adequate field information concerning floods that had occurred as much as five years ago. This area, however, contained several gaging stations, and several profiles that had been developed shortly after the floods were available. By 1959, most of the actual flood marks were gone, however. Interviews with many local residents, yielded varying information. One variation came from those who were hoping for relief by governmental action; they had had frequent severe floods. Different stories came from those who were trying to sell their property; they never had been bothered with floods.

Another problem was the definition of what constitutes a flooded area. In this region, due to recent glaciation, stream nets are poorly developed. There are many swamps, ponds, and miscellaneous areas for which there are no drainage outlets. These areas may be flooded, but with elevations and frequencies entirely unrelated to those for flowing streams nearby. For the first map, this problem was not entirely resolved. Since then, a policy of mapping only those areas directly connected to flowing streams has been adhered to. A statement has been inserted in the accompanying text to the effect that there may be other areas that are unmapped that may be flooded by local precipitation.

The third problem was a delay in publication. More than a year passed between the completion of field work and release of the printed atlas. For work currently in progress, this delay has been shortened, but is still undesirably long. This problem is now being circumvented by use of an open-file release. As soon as a manuscript has been prepared and approved, preliminary black and white reproductions are distributed to interested local agencies, usually within a month after the completion of field work.

After the completion of HA-39, discussions with the Planning Commission resulted in a proposal to map and additional forty-three $7\frac{1}{2}$ min quadrangles. The Commission first proposed that the work be completed in two years, but a compromise of five years was finally agreed on. The first year would be devoted, largely, to the establishment of a suboffice, recruitment of staff, installation of 225 crest-stage gages, and initiation of a flood-frequency study. This would leave time to complete only three or four maps, and would require about ten maps per year for the remainder of the five-year period.

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At this point, an estimate of cost for the entire project presented a problem. The estimate was needed by the Commission to make appropriate contractual arrangements with the local agencies involved. Due to limited experience, only a rough estimate could be made. It appeared that, on the average, each quadrangle would have 25 linear miles of channels to be mapped, and experience suggested $200 per mile for the cost of mapping. Twenty-five percent was added for crest-stage gages, flood-frequency studies, and contingencies. The Commission was then advised that, although any map for any fixed sum could not be guaranteed, the best estimate was an average cost of $6,250 per quadrangle. This is the basis on which all the original agreements were prepared. Since then, some minor extras have been added, and it now appears that the total cost of the project will be about $300,000.

Flood mapping has its legal aspects as shown in the following discussion. The Highland Park map was involved in a legal action almost immediately after its release to the open file. A park board undertook to acquire a portion of the floodplain, and offered to buy at the going rate for flood-plain property. This land, however, was already controlled by a real estate speculator, who claimed the property was suitable for higher uses, and demanded a correspondingly higher price. The park board resorted to a condemnation suit and attempted to introduce the flood map as evidence of fair value. The realtor opposed introduction of the map on the grounds that it was hearsay evidence—the man who made the map did not personally witness the flood. The court was about to uphold the realtor's position until the park board produced a witness who had personally observed the flood. The witness stated that he stood on this manhole cover and that the water was up to here on his legs; this elevation did, in fact, correspond to the information shown on the map. The map then was admitted as evidence, and the park board saved enough money to pay a substantial part of the whole mapping project.

This situation, of course, leaves much to be desired. Not always will an eye witness be available to testify to the validity of the maps.

The problems herein described are by no means a complete catalogue; but they are typical of the problems in flood mapping in Illinois.

The Use of Flood Maps in Northeastern Illinois

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•FLOOD MAPPING can be considered a multipurpose program from which a wide range of benefits can accrue to both public and private interests. The multipurpose aspects of a flood mapping program can be illustrated by examining the uses made of flood maps in Northeastern Illinois. In general, flood maps are used to establish the hydrologic basis for flood-plain regulations to guide the location of residential, commercial, and industrial structures. The 17 maps that have been prepared for Northeastern Illinois have been presented at public meetings and were discussed with officials from 97 municipalities having a total population of 1, 100, 000. Additionally, officials from the six counties of Northeastern Illinois (Cook, DuPage, Kane, Lake, McHenry, and Will) have been presented with maps and advised on their potential use. The purpose of the meetings with the municipal and county officials was to familiarize them with the flood-plain information, and to guide the use of the data when they are formulating land use plans.

The use of flood maps is not limited to guiding new development, however, for the maps can be used to preserve the natural recharge potential of the shallow aquifers, guide the purchase of open space, aid the location of sewage treatment plants and refuse disposal sites, and help in the selection of sites for storage reservoirs.

All levels of government (Federal, State, local, and special district) have had occasion to use the flood maps for Northeastern Illinois. These run the gamut from building and zoning, health, and highway departments to school boards and sanitary districts.

Additionally, private users ranging from the individual homeowner seeking a house "that doesn't flood" to the large land development corporation that is planning a 2,000 unit subdivision and wants to avoid the problems associated with marketing houses in a subdivision that has a reputation for flooding.

FLOOD MAPPING BENEFITS

Flood mapping has proved to be a significant tool that can aid in avoiding the uneconomic development of flood plains. This is of particular significance in rapidly expanding metropolitan areas. In Northeastern Illinois, for example, it is estimated that the population is increasing at a rate of 75,000 per year and this increase normally will require a yearly addition of 25,000 housing units (1).

It is conceivable that this growth and development can be accommodated without increasing flood damages or foreclosing other potential benefits because only 11 percent of Northeastern Illinois has been subject to inundation. Table 1 gives the percent of area that has been flooded in three drainage subbasins.

TABLE 1

Basin	Drainage Area	Percent of Area Inundated
Skokie River	11	18
Weller Creek	13	3
Salt Creek	10	14

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The average for these three basins is 11 percent and this percentage appears to be representative of the entire area. Flood maps, if properly used, can produce the following benefits.

Reduced Demands for Flood Control Works

If the areal limits of the flood plains are not well defined, it is reasonable to assume that 11 percent of the new houses each year or 2,750 will be located on sites subject to inundation, and that ultimately public expenditures will be required to mitigate the flood losses associated with such sites.

Recent experience has shown that the cost of flood control for residential areas amounts to approximately $3,400 per house (2). (The cost of a low levee to protect a 150 house subdivision is estimated at $513,000.) This represents the cost of flood control prorated per house for a wholly residential area. Other flood control surveys show a higher prorated cost per house ($7,000 per house on the Little Calumet River) for protection, but these areas contain vacant land where additional development can be located. In this study the cost of flood control per house is estimated to be $3,400. For Northeastern Illinois, the annual cost of flood control could conceivably average $9,350,000 per year (2,750 houses × $3,400). Of course, this amount would not be spent every year because expenditures for flood control generally take place shortly after major floods, and major floods are assumed to be randomly distributed in time.

If the flood maps are successful in steering new development away from flood-plain areas, an annual benefit of $9,350,000 per year will accrue to Northeastern Illinois. This is an annual benefit because it is reasonable to assume that unless adequate definition of flood-plain areas is available, 11 percent of the new houses each year will be located on flood plains.

Availability of Ground Water

During normal and low water levels, the streams of Northeastern Illinois are effluent—the base flow of the stream is a discharge from the ground water reservoir to the surface. This process is reversed, however, during periods of high flow when the streams become influent—there is a discharge from the surface waters to the ground water reservoir. This recharge takes place because of the differential in head; the surface water levels rise very rapidly following runoff from precipitation, whereas the ground water levels rise slowly because of the slow infiltration through the overlying materials.

A detailed analysis of a shallow aquifer in Northeastern Illinois concluded that 33 percent or 100,000 gallons per day per square mile of the potential yield was from stream flow (3). The figure for the entire region would not be that high but conceivably could be 10 percent of the potential yield from the shallow aquifer—based on analysis of location of shallow aquifer in relation to pumpage cones and drainage ways. This would amount to 50,700,000 gallons per day (10 percent of 507,000,000 gallons per day estimated for all of Northeastern Illinois).

The natural recharge associated with floods can be preserved only if flood plains are kept free of development, for when development takes place it is generally followed by programs of engineering works (channel deepening, reservoirs, levees) designed to reduce flood damages by keeping the water away from the development. This in turn reduces the natural recharge associated with flooding.

Flooding gives rise to an estimated annual water supply benefit of $3,700,000. This figure is computed on the basis that the ground water has a value of $0.22 per thousand gallons (the price of Lake Michigan water at the Chicago corporate limits the most considered alternative) less the $0.02 per thousand gallons estimated cost for development (4). Unless adequate definition of flood plains is available and properly used, development of the flood plains will trigger flood control programs that will eliminate the recharge associated with flooding.

PURCHASE OF OPEN SPACE

Standards for public recreational open space recommend 17-25 acres per 1,000 population in 1960, and 29-35 acres per 1,000 population by 1980 (5). If these standards are to be met in the next 20 yr, an average of 1,950 acres of open space will be required each year to keep up with population growth (75,000 per year population increase × 26 acres per 1,000—the average of the recommended standard).

The value of flood-plain land should be less than land not subject to inundation. This reduction in value reflects the losses that will be suffered from flooding. However, when flood plains are not well defined, this reduction in value is not always perceived. In a recent condemnation suit, a park board realized a substantial reduction in price for a parcel of land that was shown to be a flood plain by the introduction of a flood map in the court case (6). In a similar case, a highway department paid the regular land price for a parcel of flood plain when it was not shown that the land was subject to floods.

A reasonable difference in price between flood-plain land and flood-free land is $1,000 per acre. At this rate the use of flood maps to guide open space purchases will result in an annual benefit of $1,950,000.

Water Pollution Abatement

By locating sewage treatment plants above flood heights, it is possible to avoid shutdown and bypassing when the receiving streams flood. Flood-free refuse disposal sites are safeguards against refuse saturation by flood water that in turn would mobilize the contaminants. Also, they avoid the channel encroachments and subsequent raised flood stages associated with refuse disposal sites on flood plains.

ECONOMIC FEASIBILITY OF FLOOD MAPPING

All of the benefits discussed above will not automatically evolve from a flood mapping program and therefore cannot be wholly attributed to it. Flood mapping is an effective and dramatic means of communicating the flood situation to property managers. Thus, it is reasonable to ascribe ten percent of the benefits to the data (the flood maps) and reserve the remaining 90 percent of the benefits for the administration and effectuation of flood damage reduction programs.

The average annual benefits of the flood mapping program are ten percent of the following: reduced demand for flood control—$9,350,000; availability of ground water—$3,700,000; purchase of open space—$1,950,000; or $1,500,000 per year.

The cost of preparing 53 flood maps for Northeastern Illinois is $375,000. Assuming that the flood maps will need to be redone every ten years because of new developments, changed channel conditions, and unusual hydrologic events, the average annual cost would be $37,500.

When the benefits and costs are compared for flood mapping, the benefits exceed the costs by a 40 to 1 ratio ($1,500,000: $37,500). The average annual benefits also exceed the average annual cost by $1,462,500 ($1,500,000 - $37,500).

The economic feasibility of flood mapping in Northeastern Illinois demonstrates the justification for the program. The flow of benefits generated by the program greatly exceeds the costs and is far superior to some recent actions that encouraged new development on flood plains so that the increased flood damages would make a flood control project economically feasible.

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Cooperative Planning in Use of Flood Plains

Corps of Engineers Information Studies Program

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•THE FLOOD PLAINS of this country are an important part of the land resource. There has been some discussion as to whether the best use is being made of it. Areas where additional effort will contribute to the best use of this resource include: awareness of the hazards concomitant to the use of flood plains; technical information that can be used to determine the degree of risk of using the flood plain; and cooperative planning of the use of the flood plain.

IMPORTANCE OF FLOOD PLAINS

The Corps of Engineers has estimated that there are about 109 million acres of land in the 48 contiguous States that are in the flood plains of rivers and streams (approximately five percent of the land area). In addition, there is the land that is subject to lake and ocean overflow that probably amounts to another one percent.

It is safe to assume, however, that flood-plain land represents more than six percent of the value of all land in the United States because it has natural advantages which include fertility, levelness, and closeness to centers of activity. Its nearness to water attracts men who want to use the water for human consumption, industrial processing, waste disposal, and often as a base for transportation.

Flood-plain land will be even more important as the demand for land in the United States increases. Landsburg, Fischman, and Fisher (1) made a projection of land requirements for the 48 States, wherein each use was considered separately. For the year 2000, the requirements add up to 50 million acres more than the 1,900 million acre area total of the 48 contiguous States. This projection shows that increasing attention will need to be given to multiple land use. It does suggest, however, that flood-plain land will become even more significant. The same projection showed an increase in urban land (including city parks) from 21 million acres in 1960 to 45 million in 2000.

As with any other resource, maximum contribution from flood-plain land can only be achieved through proper use. Certain uses are more adaptable for unprotected land than others. For example, automobile parking areas, ball parks and other recreational areas are less subject to damage than others. Of course, in many cases, the land need for certain developments even though subject to damage is so great that the cost of protective works is justified.

However, the water that created the flood plains puts a burden on those who use them and too often it appears as a hidden enemy. Man should not develop the flood plain until he understands this natural opponent and has determined how to cope with it.

CONSEQUENCES OF IMPROPER USE OF FLOOD PLAINS

When improvements, which are subject to damage when inundated or washed away, are placed on flood plains, losses must be expected. These losses may consist of physical damage to property such as furnishings, buildings, equipment, communication and transportation facilities, and crops. Property classes include agricultural, residential, commercial, industrial, communication and utilities, transportation, and waterways and waterway facilities. The resultants include the necessity to repair and

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replace the property, and also the interruption of normal activities such as industrial production, business, and movement of people and goods. Concurrent problems appear in the form of flood fighting, disaster relief, and emergency services such as increased police and fire patrol. The losses may also be in the form of lives and human suffering. The present average rate of damages from floods in the United States that can be measured in monetary terms is estimated to be over 900 million dollars annually (2) or over 5 dollars per year per person living in this country.

The consequences of using the flood plain are (1) to suffer the flood losses or (2) build flood control works. In this country prior to 1936 most flood control consisted of individuals' work protecting only their own property; most often, however, a more economical solution is a joint effort protecting many properties.

Congress, in 1936, saw the need for and authorized countrywide Federal participation in flood control works. Since then about six billion dollars have been expended, mainly by the Corps of Engineers, to reduce flood damages and make flood-plain land available for higher use. Corps of Engineers' projects by 1963 had prevented damages totaling nearly 12 billion dollars, including 553 million dollars during fiscal year 1963. The annual rate of expenditure for flood control by all agencies, Federal and non-Federal, is now approaching 500 million dollars; and because of the rapid development in unprotected flood plains it must be augmented if flood damages are to be decreased.

It has been estimated that another 11.5 billion dollars worth of flood control works will be required to protect developments now in unprotected flood plains or expected by 1980 (2). Many of these will be developments that could be put on nonflood-plain sites at less cost than for building flood protective works. The flood plains are usually ideal for other desirable uses that are not subject to much damage. Open spaces, in demand for urban areas, recreational parks and automobile parking areas are examples.

Much flood plain development has been and will be through ignorance. Because people move on the average of once every five years, they are not likely to be aware that the home they are about to buy or the commercial site on which they are about to build is a flood plain. Community planners often do not know the full extent and frequency of flooding expected on land. The awareness of the need for a reexamination of attitudes toward the use of flood plains is growing. It started as early as 1936 when Gilbert White wrote that

> Land planning has additional importance as it relates to the feasibility of reducing flood wastage by means other than protection. It seems entirely possible that in some flood plains change in location and structure of buildings or modification of farming system may yield net gains greater than those from control or preventive works. (3)

CORPS OF ENGINEERS FLOOD PLAIN INFORMATION PROGRAM

In 1960, the Congress in recognition of the need for more widespread knowledge of flood hazards authorized the Corps of Engineers in Section 206, of PL 86-645, to compile and disseminate information about flood problems, damages, and measures for their amelioration. The program has been under way since October 1961.

The specific objectives of the Corps of Engineers' program, as stated in the manual for the program are as follows:

1. To compile in a clear and useful form and to disseminate to States and local governmental agencies specific information on floods and potential flood hazards, including identification of areas subject to inundation by floods of various magnitudes and frequencies.
2. To encourage optimum and prudent use of the Nation's river valleys by providing to State and local governmental agencies a factual basis for:
   (a) Reducing future flood damages and hazards through carefully considered and well-planned State and local regulation and use of the flood plains;
   (b) Developing land use plans, which may include consideration of justifiable flood protective works;
   (c) Preserving adequate floodway and channel rights-of-way and channel clearances.

3. To publicize available information for the guidance of private citizens and interests on use of and hazards of using the flood plains.

4. To reduce future expenditures for Federal projects to protect developments which, in the absence of the information program, would have taken place, or for alleviation of flood problems arising from improper flood plain development.

The Corps of Engineers has for many years been collecting flood-plain information for use in its study program for determining the advisability of flood control work. Essentially the same information is required to determine the economic feasibility of a flood control project. However, the information collected has not always been in a form readily usable by others.

Because the States are in the best position to encourage proper use of flood plains, the Corps of Engineers work with them closely on this program. At the request of the Corps of Engineers each State also has designated a coordinating agency to work with it on this program.

Application for a Study

Although a State may apply, usually the local governmental agency (a city or a county) prepares an application for a study and submits it to the State for approval. Any responsible local governmental agency including properly authorized planning agencies are eligible. The most important requirement for local cooperation is that the study information will be publicized and used. Also information and data in the hands of the applicant are to be furnished the Corps of Engineers. If requested, a representative of the Corps of Engineers will discuss the program with the prospective applicant and assist in preparing the application. After the State coordinating agency reviews the application, it is forwarded to the appropriate District Office of the Corps of Engineers. A recommendation for its priority within the State is included in the State's letter to the Corps of Engineers.

When the application is received by the Corps, the information already available is reviewed and a plan for the study is outlined. At this time a Corps representative may call on the applicant to discuss the technical data to be included in the report enabling optimum results to be obtained with the manpower and funds available. When possible a representative of the State will participate. At times, information in the files can be made available for later use as the study progresses.

The application is forwarded to the Office of Chief of Engineers where it is reviewed, and if approved, a study fund allotment is made when available.

The Study

The work involved in making flood-plain information studies is aimed at providing technical data such as the extent of inundation, depths, velocities, and duration of floods of various magnitudes and frequencies.

First, of course, a review of the existing data is made. For some studies, most of the information needed is already available. This is usually true where studies have been made to examine the feasibility of flood control works. It was observed that most of the study applications were for areas where the least information was available.

Where most of the data must be collected, the following work is performed: (1) Ground surveys to determine existing cross-sections and profiles of stream beds. (2) A search for information about past floods including location and determination of elevation of high water marks. (3) Determination of the size of potential floods based on watershed characteristics, taking into account information on past floods. This generally includes the estimating of the size of the standard project flood (the largest flood considered for land use planning). (4) Estimate the frequency of floods of various sizes. (5) Estimate the profile of the floods chosen for depicting the flood hazard. This step also provides estimates of velocities. (6) Preparation of maps showing the information. Maps with the largest scale and smallest contour interval practicable are desirable. However, existing maps must be used, where practicable. Sometimes aerial mosaics will serve the purpose. Where the applicant desires the information on larger scale maps than can be prepared under the law authorizing this program, he is encouraged to arrange for the maps through some other means. (7) Locating the outlines of the inundation which would be experienced for each of these floods. From the profiles and the topography shown on the maps, depths can be determined.

The Report

The reports are prepared in two parts: (1) a technical report that may include appendices for engineers, planners, and the like; and (2) a summary report, written in laymen's language, for distribution to the public. The technical report presents the findings of the study and details that may be of value to the technical people.

The contents of the typical report include: (1) introduction; (2) flood history; (3) flood control improvements, existing or authorized, if any; (4) existing flood plain management controls, if any; (5) flood problem (present and future); and (6) guidelines for reducing future flood damages. The "flood problem" section deals with channel and flood-plain conditions that aggravate flood damages and describes floods of three sizes (small, intermediate, and great) that may be expected in the future. Where practical, these are tied to the recurrence of floods of record under present and future conditions, but they may be hypothetical floods such as the standard project flood.

The reports also set forth "guidelines for reducing future flood damages" emphasizing the need for planning the best use of flood plains, and include descriptions of the various methods of regulating and managing their use. Possibilities of flood control works are not omitted.

The summary reports cover the flood history, a word picture of potential future flooding, what can be done to reduce future flood damages, and the maps showing the area that would be inundated by floods of various sizes.

The Follow-Up

When the reports have been delivered, representatives of the Corps of Engineers will be available to explain the information and to provide supplemental data that may be needed. For example, an additional profile might be computed where the planning showed that a flood, different from any furnished with the report, should be the basis for regulation.

Status of Program

Status of the program as of January 1, 1964 is as follows: applications approved—90, States involved (includes Puerto Rico)—32, studies covered by approved applications—183, reports completed—9, studies under way—77, and approved studies not started—97.

The reports that have been completed are American River, Morrison Creek, and Snodgrass Slough, all in the vicinity of Sacramento, Calif.; South Platte River at Denver, Colo.; Chicopee and Conant Brooks, Monson, Mass.; Farmington, Mich.; West Fork of Trinity River, Tarrant County, Tex.; and Yakima River near Richland, Wash., and Stillaguamish River. About 50 more are scheduled for completion by June 1964, 14 of these by February 1964.

PROGRAMS OF OTHER FEDERAL AGENCIES

In addition to the Corps of Engineers and U. S. Geological Survey, the Tennessee Valley Authority explicitly provides flood-plain information in the form of "local flood reports." The procedures used and the data furnished are essentially the same as for Corps of Engineers' studies.

The Tennessee Valley Authority has been furnishing these reports for communities within its geographical area since 1953, 108 have been delivered. All of them have been used to guide the development of flood plains, and 36 communities have adopted flood-plain regulations.

USING FLOOD-PLAIN INFORMATION TO CHOOSE THE BEST USE OF THE FLOOD PLAIN

The best use of the flood plain cannot be determined without taking into account other land that is available and the future needs of the many interests in the community or region involved. Therefore, the study should begin with the preparation of a land-use plan that takes into account both the social and economic needs of the people. Inasmuch as monetary values cannot be assigned to social advantages or disadvantages, the best choice will be made when a primary plan is prepared that optimizes monetary values, and is then modified if judgment indicates that the social values would be worth the additional cost.

The steps which the planner should follow in developing such a plan are as follows: (1) Estimate future land needs, listing the quantities and qualities desired for each of the various uses. (2) Make a survey of all potential sites—quantity and quality for each use. (3) Estimate the advantages and disadvantages of each potential site. For the flood-plain sites, this should include the cost of suffering flood losses or building flood protection. (4) Array the uses over the available sites in a way that will produce the greatest economic return. (5) Modify the array where judgment indicates that social values justify the additional cost.

The costs of developing a flood plain include, besides the normal site development costs, the cost of flood losses, or the cost of reducing flood damages by flood proofing or flood prevention works construction.

To estimate the cost of flood losses, detailed information about the flood hazard is required. Information may be obtained through one of the Federal programs previously discussed. This flood hazard information must be applied when estimating the flood damages for various developments considered for the flood-plain site.

Potential flood damages may be reduced by flood proofing. It includes closing openings, either permanently or temporarily, by bulkheads over windows and doors; putting check valves in sewers; and raising floor levels and roadways.

Although Congress has established a Federal interest in flood protection and provides funds for flood prevention works, their cost should not be overlooked when estimating the costs of flood-plain development.

The least expensive alternative or combination of alternatives for developing in the flood plain can be compared with the cost of developing in the nonflood-plain site, for each use. When costs of the alternatives have been determined, the best combination from an economic viewpoint will be obvious.

IMPLEMENTING THE PLAN FOR FLOOD PLAIN USE

A community plan for flood-plain use is not likely to be followed unless legal controls are adopted and enforced. Such controls will receive better acceptance if the plan is well based and its advantages can be shown by facts and figures.

The controls may be in the form of (1) Zoning ordinances that specify the kind of use that can be made of each area; e.g., residential, commercial, and parks. The flood plain may be divided into zones reflecting the different degrees of flood damage risk based on depths of flooding, flow velocities, and frequency of inundation. One of the zones may be designated as a floodway, and controls may be specified that would prevent restrictive actions regarding the free flow of flood waters. Its lateral limits would be identified as encroachment lines and no structure or fill would be permitted between them. A floodway, either by construction or by development regulation, is needed to keep flood heights from being increased in the other portions of the flood plain. The minimum size of openings under bridges, consistent with the specifications for the selected floodway, should be established. (2) Subdivision regulations may accomplish the same purpose as zoning ordinances by applying restrictions regarding use and elevation requirements regarding roadways, structures, and the design of structures. (3) Building codes likewise may include standards for construction that will reduce or eliminate flood damages. Any of these controls may include requirements for flood proofing measures in new developments or during improvement of existing developments.

CONCLUSION

Flood plains are an important part of the land resource. The greatest gain from them can be achieved by cooperative planning that takes into account their advantages and disadvantages for various purposes. The advantages include locations near centers of activity and water. The disadvantages include risk of flood damages or the cost of providing flood protection.

The programs of the U. S. Geological Survey, the Tennessee Valley Authority, and the Corps of Engineers for providing information that can be used to identify and evaluate the flood hazards will make it possible to accomplish such planning.

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Cooperative Planning in Use of Flood Plains

Corps of Engineers Report on Rouge River at Farmington, Michigan

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•THIS PAPER describes cooperative planning for utilization of the Rouge River flood plain at Farmington. Items covered include the purpose and need for the study, the procedures used and analyses made, and the selection and presentation of data.

The objectives of flood plain information studies are as follows: (1) To compile specific information on floods, potential flood hazards, and areas subject to inundation. (2) To encourage optimum and prudent use of flood plains. (3) To disseminate and publicize available information for the guidance of all. (4) To reduce future Federal expenditures to alleviate flood problems arising from improper flood-plain use.

These objectives are applicable to all such studies, but the reasons for initiating studies are not always the same. At Farmington, the local officials had been concerned for some time about their lack of power to control filling and other improper use of the flood plain. In this and adjacent areas, filling of flood plains and other areas is advancing at an accelerated rate due to the disposal of enormous quantities of soil from extensive expressway construction programs and the normal need of an expanding population for refuse disposal areas. In the northwest sector of the Detroit metropolitan area, two expressway projects alone are contributing about 5.5 million cu yd of excavated materials to the disposal problem.

The Farmington City Council became concerned when it found itself without adequate power to prevent conflicting uses of the Rouge River flood plain within the Farmington City Limits. This consisted primarily of filling operations and housing developments. The Council members realized that without proper controls, the best use of the land could not be guaranteed and eventually someone would be injured.

Their concern appears valid in view of the valley's flooding history and the flashy nature of the river. Although there has been a U. S. Geological Survey Gaging Station on the river at Farmington only since March 1958, it was fortunate that four notable floods within the past 30 yr could be defined through newspaper and U. S. Weather Bureau records. These floods occurred as the result of storms in 1933, 1947, 1956, and 1962. The first three of these were the result of storms producing 2.3, 3.0, and 3.65 in. of rain. However, the 1962 flood was caused by a rainfall of only 0.7 in. and an ice-choked channel.

All floods in this part of the Rouge River generally follow the same pattern; the peak discharge occurs 4 to 12 hr after the beginning of rainfall; the duration of valley flooding is usually less than 24 hr.

This pattern is constantly undergoing change because of the urbanization taking place in the valley above Farmington and by changes taking place in the valley at Farmington. The net effect is a shortening of the runoff period and a restriction of the flood plain.

The river at Farmington is a major tributary of the Rouge River and is known as the Upper Rouge River. The Rouge River flows into the Detroit River at Detroit from a basin of 464 square miles.

Farmington, by 1940, had grown to 1,510. By 1950, the population was 2,325; and by 1960, it had increased to 6,881. Although the city development was primarily along the plateau at one side of the valley of the Rouge River, the city now occupies both

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plateaus and the valley as well. At present, the land use in the flood plain is equally divided between residential areas, open idle lands, and park land.

The basin above Farmington, with an area of 17.5 square miles, is a moderately wooded rural area, but numerous isolated residential subdivisions have been developed in recent years. Upstream of the city, the stream flows in a well-defined fairly narrow valley and has a slope of about 30 ft per mile. Below the city, the slope flattens to about 12 ft per mile. The channel, through the city, is about 40 ft wide and is entrenched only a few feet below the valley floor. The flood plain averages about 500 ft in width and is well defined with banks ranging from 20 to 50 ft in height.

The study area extends along the river only from city limit to city limit, a distance of about 2½ miles. Hydrologic studies, however, were not limited to that area.

Preparation of a flood-plain study is basically a data collection process. The essential elements are those that make it possible to illustrate the extent to which river flows of specific magnitudes and frequencies occupy the flood plain. These elements usually consist of but are not necessarily limited to the following four elements: (1) Good maps of the area, preferably good contour maps, showing as much of the area culture as possible. Aerial maps provide the best base for illustrating the hazards of occupying the flood plain for the reason that individual buildings and other natural features can be seen and identified by the layman. (2) Flood marks from one or more recent major floods are needed to provide a check on hydraulic computations and to lend confidence to computed flood profiles. In the Detroit metropolitan area, local units of government have had difficulty in formulating flood plain regulations that will stand up in court. In the light of these experiences, it is evident that if the reports are to be useful, the basic data for the computations must be authentic and well documented. To provide good solid data on prior flooding, as many people living adjacent to the river as possible are interviewed. Photos of past floods and record descriptions of high water marks are collected, and other physical factors affecting past floods are studied. (3) Information concerning the rainfall and runoff of specific floods is extracted from published records and is supplemented by data extracted from local newspapers. (4) It is also important when studying past floods to determine whether or not changes have taken place that would affect the runoff or the stage-discharge relationship of the stream at a specific point. Included in these determinations are the past and future area development factors at the study site and removed therefrom.

When hydraulic computations are necessary in order to define the flood plain, field surveys may be required to provide the necessary basic data. Usually it is necessary to obtain cross-sections of the stream at more or less regular intervals and occasionally of the entire width of the valley. This is an expensive operation; but at Farmington, the use of aerial photos acquired from a local source reduced the cost. The locations of the cross-sections were spotted on the photos thereby eliminating the need for horizontal control. Vertical control was established by running from existing U. S. Geological Survey bench marks to six newly established ones.

To further document high water profiles, a device was installed at five locations along the stream within the study area. This homemade device is a crest-stage gage designed to record the crest stage of a flood. Credit for the device goes to the U. S. Geological Survey and the Michigan Water Resources Commission. These recorders are fabricated from 2-in. pipes cut to the length required by the site. A ¾-in. square stick, the length of the pipe gage, is inserted in the pipe and held with standard pipe caps. A bolt in the lower cap is set so that the head is even with the lip of the pipe cap—the zero point of the gage. Several holes are drilled in the lower end of the pipe to allow the water to flow in. The gage is charged from the upper end of the pipe with one teaspoon of powdered cork and ¼ teaspoon of dry detergent. The peak flood stage is recorded in the pipe by a ring of cork particles that cling to the stick in the gage. The flood stage elevation is found by adding the distance from the end of the stick to the cork ring and the elevation of the gage zero. Some care is required in setting these gages to see that the bottom will not be inundated by every minor stream rise.

It is Corps of Engineers' practice to encourage local governmental units to furnish and install the crest-stage gages and the adjacent bench marks, and to maintain them. This has been successful in most cases. It was also found that because it is usually necessary to mount the gages in relatively exposed locations, damage including vandalism is a factor and frequent inspections are necessary.

Certain computations are generally required in order to portray flood-plain limits. These cannot be made without the types of data previously described. These computations are usually in two stages; first, analysis of the pertinent hydrologic factors concerning the floods to be studied; second, development of the hydraulic computations that are determinations of the stream's capacity to carry the flood flow.

The hydrologic studies usually involve a detailed analysis of the rain, snow, and runoff conditions to determine the characteristics of the watershed and all factors contributing to runoff at a given location. These data make it possible to develop a unit-hydrograph, the flow-versus-time curve for a given point on the stream for a given amount of rainfall. The unit-hydrograph provides the tool for determining such flood characteristics as time of concentration, the nature of the rise of the flood, duration, and flood magnitude. It is also the tool that makes it possible to predict the magnitude of floods caused by any selected runoff including the flood produced by the most severe storm considered to be meteorologically possible in the area. The flood produced by this extreme storm is required in flood plain reports to serve as a warning regarding what could happen.

The next step involves obtaining the hydraulic relationships of the river channel. The basic data are the cross-sections, bridge openings, and other features previously discussed. All these data are integrated in a step-by-step solution of the basic hydraulic equations developed by Bernoulli and Manning. Since this is a trial and error computation, the electronic computer becomes a very useful tool. The collected high water marks are used at this time to provide a check on the computations. The assumptions made regarding roughness and bridge opening coefficients are adjusted until the computed profile matches the historical profile as defined by the flood marks. It is necessary to build-in the physical changes that have taken place since the date of the reconstituted flood. At this point, the work has resulted in an up-to-date mathematical model of the stream permitting computation or profiles for various hypothetical floods with considerable confidence.

One other step is required before the efforts can result in meaningful data for the city planner. To give the city planner a basis for reasoned judgment regarding prudent use of the flood plain or of various levels of the flood plain, the city planner should know how often the various levels of inundation can be expected. This requires that an analysis be made to produce the relationship of flood discharges to time. This relationship expresses the average intervals that can be expected between floods of similar magnitudes. This is neither a prediction nor a prognostication. It is simply a statistical analysis of available data by the best methods known today.

Another feature studied, on request, is the effect of specific fills or obstructions proposed for the flood plain. In the case of Farmington, a determination of the effect on the several flood profiles of a definite proposed fill was requested. This was done and the results were presented in the report.

All of the data developed in this study were presented to the City of Farmington for use in developing and supporting flood-plain use regulations. The data were presented, when possible, in such a manner as to be useful to the engineer and understandable to the layman.

Flood outlines were presented on an aerial mosaic of the area and on detailed contour maps. The topographic maps show cross-sections, gages, bench marks, streets and buildings, and other features of interest. A profile also was furnished. The profile of record was shown as observed and as it would be under present-day conditions.

The report prepared as a means of making the collected and developed data available to the people concerned was really two reports in one.

The main report was intended to be a concise, readable narrative bringing together data on the character of the flood-plain area; descriptions of developments having an effect on flood flows; words of caution regarding possible damage to structures already in the flood plain; discussion of ordinances in effect that pertain to flood plain use; and a description of the extent of the flood problems and the hazards. The report also presented a discussion of development factors that affect the flood flows, means to reduce damages by flood fighting and flood warning, and a general discussion of flood flows and probabilities. It also furnished maps showing the extent to which flows of various magnitudes occupy the flood plain.

Experience gained since the beginning of this program indicates the advisability of emphasizing in the reports the need for flood-plain planning regarding use. To provide this type of guidance, a general information section is included covering such flood-plain regulation and management items as channel encroachment lines, zoning ordinances, building codes, flood proofing, urban redevelopment, open spaces and recreation areas, and warning signs.

The report data make it possible to stake out on the ground the outlines of the several floods developed during the course of the study. These data and the computations were documented for use by the engineer and technician in a technical appendix. This appendix is intended to supplement and expand the information contained in the main report. It contains a section on the vertical control used and established for the study area. Another section lists the crest-stage gages, a description of each, and a discussion of their maintenance and operation. The appendix also tabulates and describes the high water marks, cross-section, and bridge data. Of course, considerable detail is presented regarding the climatological and hydrologic data. It is also important to tabulate numerical results from backwater computations and to present examples regarding their possible use in locating flood outlines on the ground. The appendix, however, only summarizes because the statistics and computations may be consulted by responsible persons in the Office of the District Engineer.

The maps presented with the report are intended to illustrate the areas inundated by floods of selected magnitudes. If possible, an aerial mosaic is used in the main report because it usually provides a more impressive means of showing the extent to which the flood plain is inundated. More conventional maps are made a part of the appendix.

When all field surveys had been made, all studies and computations completed, the results assembled, and the narrative written, the resulting report was reviewed within the Corps of Engineers and by the Michigan Water Resources Commission. When the review was completed, the report was produced in quantity and was presented to the city council by the Detroit District and the Water Resources Commission jointly. The results of the work were discussed, existence of backup data was emphasized, and the hazards of uncontrolled flood-plain development were pointed out. Less than two months after receiving the report, the City of Farmington used the data as the basis for flood-plain use regulations.

Cooperative Planning in Use of Flood Plains

State's Role in Development and Utilization of Corps of Engineers Studies

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•MICHIGAN'S PARTICIPATION in flood-plain information activities is authorized by the statute creating the Water Resources Commission. This statute states in part that:

> The Commission is hereby designated the state agency to cooperate and negotiate with other governments, governmental units and agencies thereof in matters concerning the water resources of the state, including but not limited to flood control and beach erosion control.

By an order issued by the Governor on June 21, 1961, the commission was designated as the coordinating agency of the State on flood-plain studies undertaken and completed by the Corps of Engineers under authority of Section 206 of the Flood Control Act of 1960.

Flood-plain development and encroachment, while occurring to some extent throughout the lower half of Michigan, has been greatest in the southeastern metropolitan region. Since WW II, rapid population growth and accompanying commercial and industrial expansion have placed a premium on valley bottom lands that were formerly ignored as being unsuitable for most types of development. This situation is undoubtedly typical of most industrially oriented areas of the eastern United States. It is exemplified by the Rouge and Clinton River valleys of Michigan, both of which traverse the metropolitan complex centered about the City of Detroit. A complete range of valley developments can be found in this area, starting with rural in the headwaters, through residential and commercial along the reaches passing through the communities surrounding the central city into the industrial complexes in the lower reaches.

The Rouge River valley, in particular, has experienced an additional kind of pressure demanding utilization of bottom lands. Interstate, State, and major local highway additions are being made which interlace the basin. The construction of these traffic arteries created a disposal need for vast quantities of spoil, especially from depressed highway projects. It did not take long for road builders, faced with the disposal of thousands of cubic yards of spoil, to complete negotiations with property owners for permission to fill in the river lowlands and abandoned channel pockets, created by natural changes in the river's course. Landowners, quick to recognize the development and sale possiblilities of these tracts of land, agreed to their use for spoil disposal. Fears arose concerning the effects of these filling operations, and were expressed in letters of complaint addressed to drain commissioners, State water agencies, and other public bodies. Protest meetings were called by local valley protective associations, and petitions were circulated and filed with city councils demanding that further fillings be prevented. Due to the absence of channel restriction information on which to justify flood-plain zoning, local governments were not prepared to control these operations so the complainants resorted to the courts, with inconclusive results insofar as establishing precedents clearly setting forth legal regulation procedures were concerned.

The Water Resources Commission, seeking to resolve the developing conflicts through a unified approach to the problem, called a meeting of Rouge Valley interests in April 1961. The basin then contained 26 separate local government units, all of

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which were involved in some degree with flood-plain encroachments. At this meeting, representatives of the U. S. Geological Survey and the Corps of Engineers described their respective interests and functions in flood-plain problems, and the assistance they were prepared to render in the mapping of the flood plains. This first venture by the commission in this activity resulted in an application to the Corps of Engineers for studies on 99 mi of the Rouge River Valley. This mileage excludes approximately two miles of the valley covered by an application filed with the District Engineer by the City of Farmington prior to the initiation of the commission's measures to coordinate study interests.

In discharging the commission's duties and responsibilities as coordinator at the State level, assistance is provided not only to the local governmental units but also to the Corps of Engineers as well. The State agency has functioned primarily as a service organization to all parties involved in a study, and has adjusted or modified its activities to meet the needs as they develop.

In early contacts with interested officials of local governmental units, it was found that they welcomed the consultation and guidance offered by the commission in appraising the local problems and evaluating the need for studies.

Immediately on learning of the area interests' desire to undertake a study of their problem, the commission's staff informs the local officials of the services available to them. Meetings with local officials to review at first hand the problem area are then scheduled. Through these early meetings, an opportunity is afforded to explain the mechanics of a study program and to discuss the details of required local interests' cooperation. From field reconnaissance, recommendations are made to the local officials concerning the desirable scope of the study. Information is provided that they can draw on in drafting the description of the valley area to be studied. These contacts also allow the staff to assist local officials in preparing an application for the study. To provide the information required for Federal and State action in the study requests, the staff has prepared a six-page application form. It includes a sample resolution proposed for adoption by the local governing body in making its application. The form and sample resolution were drafted to meet certain requirements of Section 206 of Public Law 86-845, particularly with reference to disclosures regarding the statutory authority of the local unit to cooperate with the Federal Government, the willingness of the applicant to supply engineering data where available, and the dissemination of information from the completed flood-plain studies.

The completed application, with the supporting resolution after being reviewed in detail by the commission's staff, is then submitted to the commission for approval. Following the commission's approval, the applications are transmitted to the District Engineer's office in Detroit for further processing. The information supplied on these forms, with the assistance of the commission staff, greatly facilitates the processing of the application both at the State and Federal level.

Coordination with the Corps of Engineers follows a well-established pattern. Shortly after receipt of the application at the district office, arrangements are made for district and commission staffs to conduct a careful field reconnaissance of the study area. Information is obtained on the topography, condition and development of the flood problem area, location of existing gaging stations operated by the U. S. Geological Survey, channel conditions, cost for the detailed study, and on other factors that will influence the work load. This preliminary examination also permits district staff engineers to become acquainted with the local area officials. During this reconnaissance trip or on subsequent visits, joint staff determinations are made concerning the need for and location of crest-stage gages. The crest-stage gages, required for the study, are installed by the local government with the assistance of the commission staff.

The commission staff also works with district personnel in the survey, assisting in the collection of essential field data on channel and flood-plain dimensions, and in the gathering of information on previous floods and high water marks. It was also found desirable to maintain close bilateral liaison with both the District Engineer's staff and local officials as the study progressed. The issuance of status reports at intervals keeps all interests (local, State and Federal) working together so that the approved final report is received with enthusiasm by all.

An added service is provided by the commission staff after completion of the study and approval of the report by the Corps. On notification from the District Engineer of the expected publication date, a meeting is arranged with local officials, their technicians, and representatives from the District Engineer's office. At this time, the report is presented to the local officials, the contents are reviewed, and all questions are clarified.

One meeting of this nature has been held on a completed report. The outcome, in terms of promoting mutual understanding among all parties and in generating support of the recommendations, supports the view that this approach can be used to advantage in future study projects. In this case, the city council adopted flood-plain ordinances soon after the meeting was held.

The commission also handles the distribution of study copies on request, generally to interests outside the study area.

Four applications for flood-plain information studies have been processed at this time through the agency for a total of 319 miles of river systems in the State. The streams involved in these requests and the sponsoring entities are as follows: (1) The Clinton River in Macomb County, covering 56 miles of section along the main stem and two branches. Sponsors are the Macomb County Drain Commission and Macomb County Planning Commission. (2) The Grand River in Ingham, Clinton and Eaton Counties, covering 139 miles of section along the main stem and its tributaries, the Lookingglass, Cedar and Sycamore. Sponsor is the Tri-County Regional Planning Commission. (3) The Rouge River in Wayne and Oakland Counties, covering 99 miles of section on the main stem and three branches. Sponsor is the Detroit Metropolitan Area Regional Planning Commission. As previously noted, a study of the Farmington area was requested in an application filed directly with the District Engineer. Stream mileage reported here excludes that covered in the Farmington area application. (4) Clinton River in Oakland County, covering 25 miles of section on the main stem and its tributary, Paint Creek. Sponsor is the Oakland County Planning Commission.

It has been difficult to accurately estimate the cost for the studies due to limited experience. In 25 separate units, cost estimates ranged from $5,000 to $750 per mile. Many factors influence these costs—most important of which are availability of accurate topographic maps, giving relatively close contour intervals, and previously completed valley flood problem engineering studies. Experiences thus far seem to indicate that $1,500 per mile is a good rule of thumb for preliminary estimates.

With 319 miles of stream valley to map, involving 21 separate reaches, and with extremely limited Congressional funding ($700,000 per year for the entire United States), it was necessary to establish a priority system to assist the Corps in assigning study funds. A "first come, first served" approach does not permit study of those areas that have the most urgent need for this technical assistance. The priority system endeavors to provide for studies in the areas of greatest need and for the maximum valley coverage per study cost dollar.

Once each year, new applications and all other unfunded applications are evaluated and assigned priority points under the following allotment system:

1. Date of application—One to four points are assigned on the basis of the date of the application with respect to other applications on hand.
2. Need—One to four points are assigned on the basis of need for the study based on local conditions. Consideration is given to problems of zoning, lawsuits, local government interest, citizen interest, and public meetings concerning valley flood problems.
3. Study cost—One to four points are assigned on the basis of the anticipated cost of the study. Availability of information in the form of records of high water marks, location of established stream gaging stations, existence of up-to-date topographic maps, aerial photographs, and engineering flood reports are all considered.
4. Area development potential—One to four points are assigned on the basis of the development (both present and anticipated for the future). Patterns of land use and trends in respect to the location and axis of the valley system are considered. New highway routings and industrial development (both creating urban growth pressures) are extremely important.

5. Exposure to flooding—One to four points are assigned on the basis of exposure to floods and flood damage. Frequency and magnitude of flooding, width of flood plains, and other related hydrologic factors are weighed.

Under this system, it is possible to assign a maximum of 20 points to any project. Study applications are certified to the Detroit District Engineer on the basis of point totals assigned, and their respective position with other projects. Thus far, this priority system has served well in establishing the flood-plain areas most deserving of study. At the end of 1963, a total of 76 miles of stream were under study. Should funds allocated for 1964 become available, they will permit completion of three projects covering 56 miles and a modest effort on the remaining 20 miles.

In summary, the role of the commission as the State coordinator in flood-plain information studies has been found to be fruitful and satisfying. It has consisted of consulting with local officials in preparing and filing applications; of cooperating with the District Engineer's office in field reconnaissance activities; and of arranging for exchange of information between all parties through local contacts and public meetings. The objectives sought in this role have been to assist in developing solutions to flood-plain encroachment problems that will receive public acceptance, and to enhance the prospects of constructive action toward placing in effect the remedial measures found necessary.

Acceptance by the District Engineer of the commission's role as coordinator and his encouragement of a partner relationship between his staff and the commission's, has combined to produce an overall effective effort. Experience in Michigan supports the view that the State, acting in a coordinating capacity, can perform a variety of services in formulating and conducting flood-plain information studies that will reflect to the mutual benefit of all interests concerned.

Part III

DEPRESSED CURB-OPENING INLETS

Hydraulic Design of Depressed Curb-Opening Inlets

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New hydraulic design curves for depressed curb-opening inlets have been developed from new experimental data. A general description of the research and of the development of these curves and their application is presented. These curves cover a considerable range of practical conditions and also allow direct comparison of the effect of size of depression to the efficiency of the inlet. The sump condition is included in this paper. The condition of the submerged inlet is not covered, nor is the determination of design discharge. The term "sump condition" in this paper refers to the condition that the inlet is located at the low point of a sag vertical curve.

Nomenclature

The following symbols used throughout this paper are defined where they first appear, but for easy reference are gathered here.

- a = Vertical distance of depression in plane of curb face measured from intersection of normal street surface and curb face (in.);
- d = Water depth of uniform gutter flow at curb face (ft);
- d_{max} = Maximum gutter water depth (ft);
- d_W = Water depth (ft) at distance W from the curb face = $S_x(T-W)$;
- F_W = Froude number based on depth and velocity of uniform gutter flow at distance W from the curb face;
- h_m = Minimum curb opening height for free fall flow (ft);
- H = Total head over crest of curb opening at center of inlet;
- K = Empirical coefficient of transverse acceleration;
- L_i = Curb-opening inlet length (ft);
- n = Roughness coefficient in the modified Manning's formula for triangular gutter flow (6) (Eq. 9);
- q = Modified unit discharge (cu ft per sec per ft);
- Q = Gutter flow (cfs);
- Q_i = The portion of gutter flow intercepted by curb-opening inlet (cfs);

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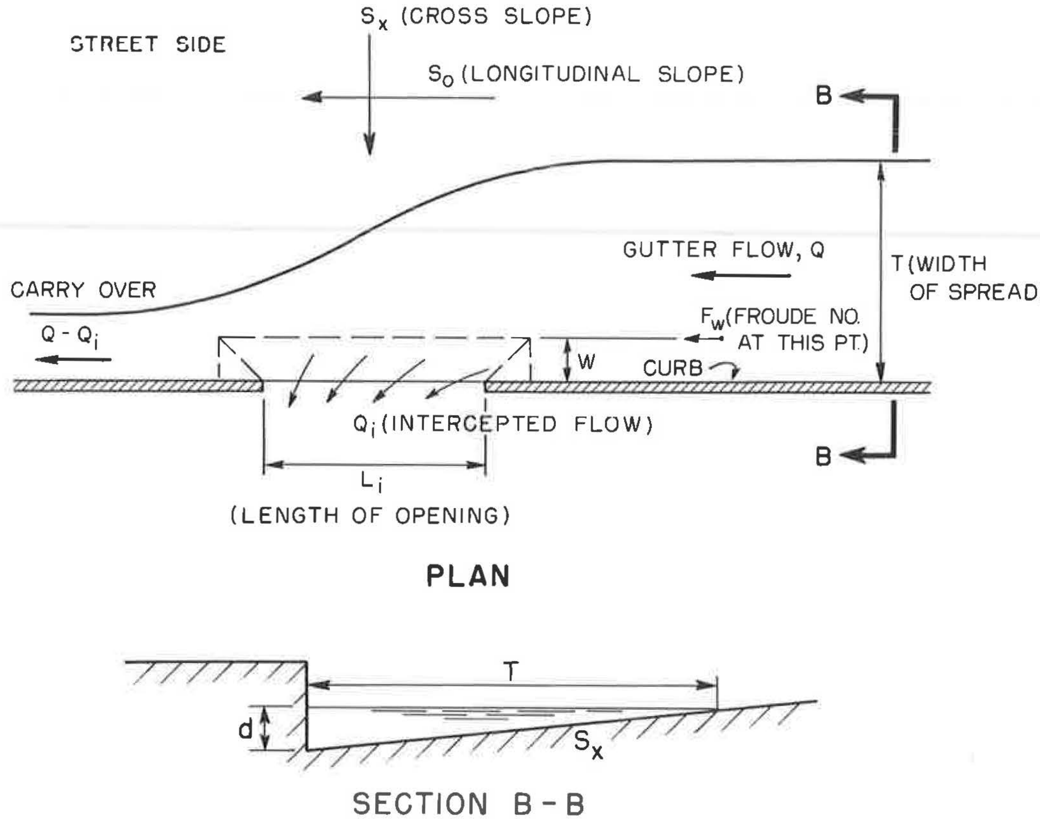


Graphical definition of symbols.

Q_i/Q = Interception rate of curb-opening inlet;
S_o = Longitudinal slope of street;
S_x = Cross slope of street;
T = Width of spread of uniform gutter flow (ft);
T_c = Width of spread of water at centerline of inlet in sump condition; and
W = Width of depression for curb-opening inlet (ft).

The curb-opening inlet is one of the major types of inlets used in highway and city drainage systems. It has the advantage of being clogged with debris, and has particularly good performance at locations where the longitudinal grade is relatively flat.

A curb-opening inlet without depression has poor efficiency for intercepting the gutter flow and is not considered an economical design. The increased capacity of a depressed curb-opening inlet depends on the size and shape of the depression. On the other hand, this depression if too wide could create interference to the passing traffic. Thus, a successful inlet design of this type requires a thorough consideration of all the factors involved.

The hydraulic characteristics of the nondepressed curb-opening inlet have been studied with reasonable success by Izzard (1), Johns Hopkins University (2), and recently Wasley (3). Reliable results for the depressed curb-opening inlet, however, are scarce. The more often used information includes (1) and (2) above and Los Angeles Design Charts (4). Except for Izzard's work (1), all apply to limited special conditions. The Los Angeles Charts deal only with very large flows, their particular depression geometry, and gutter section, with one cross slope of street. Information from the investigation reported here is needed to evaluate many condition combinations not previously measured.

Pavement and gutter runoff during rain storms is a rather complicated problem. A steady uniform gutter flow is assumed, for this study. Design gutter discharge determination is not within the scope of this study.

RESEARCH

Selection of Standard Depression Geometry.—The selection of the standard depression geometry is the result of preliminary tests regarding the effect of depression geometry changes on the efficiency of the inlet. The results of these tests are given in Table 1. The final selection of the proposed standard depression is based not only on this result, but also on consideration of its effect on passing traffic. A depression of W = 2 ft and a = 2 in. that is hydraulically effective yet small enough to avoid interference with passing traffic is used as the basic depression geometry. Figure 1 shows the details of the standard depression used in this study.

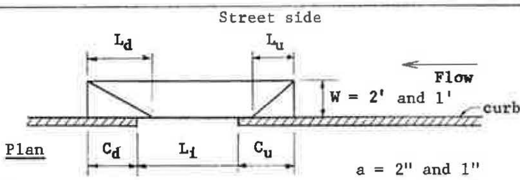
Experimental Work.—Using the proposed standard depression of W = 2 ft and a = 2 in., experimental work was carried out in two parts: (a) the full-scale model experiments for longitudinal slopes from 0.002 to 0.04, and (2) the reduced scale (1:4) model experiments for sump condition.

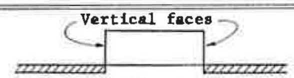
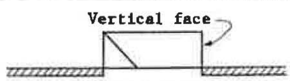
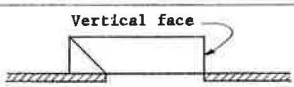
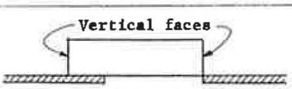
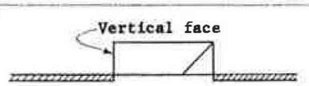
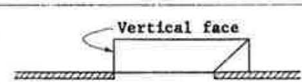
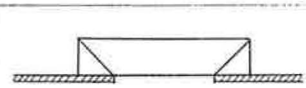
The full scale model experiments were done at Colorado State University, Fort Collins. The flume used for this work had a total width of 12 ft and a total length of 84

TABLE 1

SUMMARY OF DEPRESSION GEOMETRY TEST

Definition of Transition Geometry



L_d (Ft.)	C_d (Ft.)	L_u (Ft.)	C_u (Ft.)	Sketch	Remarks
0	0	0	0	 Vertical faces	Poor downstream transition
2	0	0	0	 Vertical face	Worst downstream transition
2	2	0	0	 Vertical face	Good downstream transition
0	2	0	0	 Vertical faces	Best downstream transition
0	0	2	0	 Vertical face	Worst upstream transition
0	0	2	2	 Vertical face	Best upstream transition
2	2	2	2		Standard Adopted L_d=C_d=L_u=C_u=W a/W = 1/12

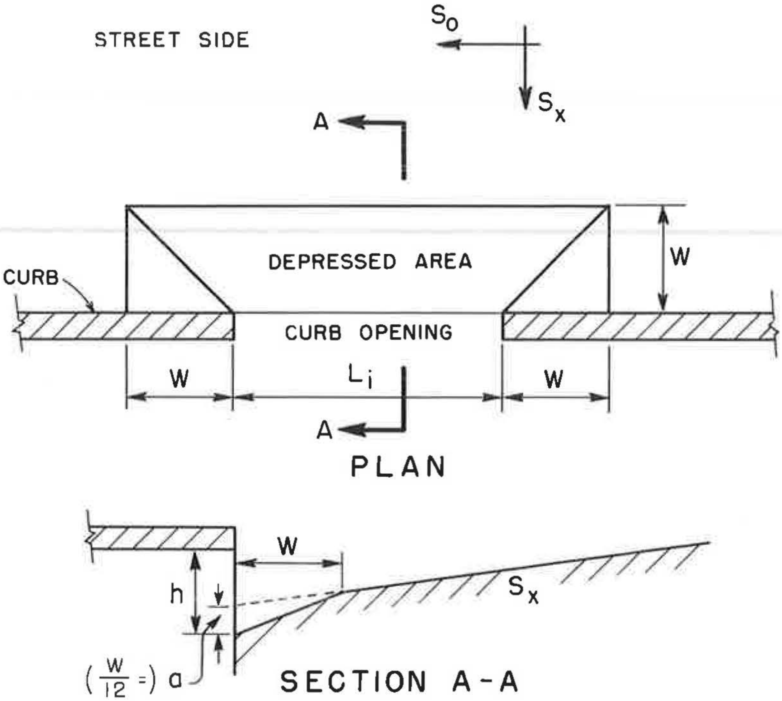


Figure 1. Standard depression used in this study.

ft, of which the upstream 40 ft was used to establish uniform flow. Two kinds of surface were used: the painted plywood with a roughness coefficient of Manning's n equal approximately 0.01; and the fiber glass screen (containing 18 strands to the inch with each fiber approximately 0.015 inch in diameter) stretched tightly over the painted plywood with n close to 0.016.

In order to establish uniform approach flow in the minimum distance possible, the head box was constructed in four compartments across the flume width, and flow into each compartment was separately regulated. By this arrangement, the peculiar variation of the specific head with distance from the curb face, characteristic of gutter flows, was approximated at the point of efflux from the head box. Guide vanes were extended downstream from the head box through the accelerating flow zone. Orifice meters and weirs were used to measure discharges, and an electrical point gage and a stagnation tube were used to measure water depths and velocity distributions. Figure 2 shows the general picture of this laboratory arrangement.

Experiments were run on longitudinal slopes, S_o, of 0.01 and 0.04; on cross slopes, S_x, of 0.015 and 0.06; for width of gutter flow spread, T, of 5 ft and 10 ft (or W/T = 0.2 and 0.4); and for length of curb-opening inlet, L_i, varying from 5 ft to 35 ft in increments of 5 ft. One set of special runs was made for a curb-opening inlet with no depression on S_x of 0.06, S_o of 0.04, for T of 5 ft and for L_i varying from 5 ft to 35 ft. Additional runs were made later on S_o of 0.002 and 0.00585, S_x of 0.04 and 0.06, for L_i of 5 ft, 10 ft and 15 ft, and for T ranging from 5.5 ft to 10.2 ft.

The reduced scale (1:4) model was tested in the Bauer Engineering Hydraulic Laboratory. The flume had a total width of 4 ft and a total length of 17 ft, with a discharge up to 2 cfs. The model was made of transite: 3 ft wide and 16 ft long. The curb opening was located at a point 13 ft downstream from the head box, sufficient distance to form uniform gutter flow. An elbow meter and a point gage were used to measure discharges and water depths. The general arrangement of the model in the flume was similar to work, shown in Figure 2, but without the guide vanes. In this test, experiments were run on cross slopes, S_x, of 0.016 and 0.058, longitudinal slopes, S_o, of 0

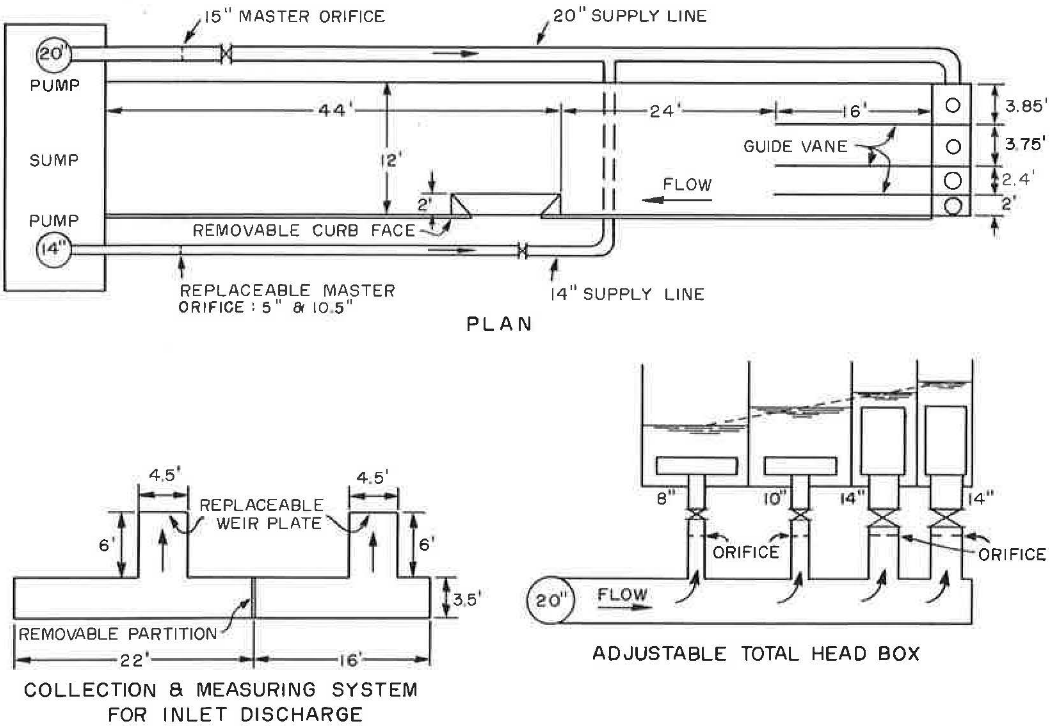


Figure 2. Schematic of laboratory flume.

and 0.002, gutter flow, Q, of 2.56 to 19.2 cfs (prototype values), and with half length of curb-opening inlet of 2.5 ft, 5 ft and 7.5 ft (or L_i of 5 ft, 10 ft and 15 ft)—prototype values.

Analysis and Results.—Because of the triangular shape of the street gutter, the gutter flow was classified into three categories: (1) the supercritical flow, (2) the mixed flow of supercritical and subcritical flow, and (3) the subcritical flow. Each category has its own special hydraulic characteristics. Therefore, the analyses of the experimental data were also different. From the highway designer's point of view, however, the design charts may be used without concern regarding gutter flow category involved.

With longitudinal slopes equal or greater than 0.01, the gutter flow is almost entirely in the supercritical region, except a very small portion at the outer edge of the width of spread. It was observed in this and the earlier research that a disturbance line proceeds across the flow from the upstream end of the transition to the depressed zone if one were present. The angle between this line and the curb face being approximately the wave angle (or the angle whose sine was the reciprocal of the Froude number). Because of this, flow at the curb-opening inlet on steep slopes greatly resembled that at the sudden channel expansion as reported by Rouse, Bhoota and Hsu (5). Much the same dimensionless parameters were found to be useful, involving division of length terms by the Froude number of the approach flow.

The presence of the cross slope and the complications introduced by the depression, however, require special treatment beyond that of the analogous sudden channel expansion. From the experiments, it was discovered that downstream from the line of disturbance the flow outside the depressed zone moved along trajectories that could be approximated by simple parabolas calculated on the assumption that the velocity in the longitudinal direction remained constant, and that the acceleration perpendicular to the curb face corresponds to a piezometric gradient parallel to the cross slope of the pavement. The flow across the depressed surface (downstream from this line of disturbance) could also be considered to move in parabolic trajectories corresponding to a piezometric gradient proportional to the slope of the depressed surface in this direction. Based on this simple mathematical approach and the experimental results, it was found that, for each curve of W/T, the relationship between the interception rate, Q_i/Q, and the dimensionless parameter, $L_i/F_W T$ (F_W is Froude number based on the depth and velocity of uniform gutter flow at a distance W from the curb face), followed a straight line from its origin to a certain point. The location of this point can be expressed in terms of depression geometry dimensions and the percentage of gutter flow in the width of depression W. The equations used are as follows:

$$\frac{Q_i}{Q} = 1 - \left(1 - \frac{W}{T}\right)^{8/3} \tag{1}$$

and

$$\frac{L_i}{F_W T} = K \frac{W}{T} \sqrt{\frac{d_W}{a}} \tag{2}$$

in which K is an empirical coefficient of transverse acceleration (on the order of 1.8 to 2.0). The results of this part of research are condensed in Figure 3. The curves of W/T = 0 were drawn empirically from the experimental data plus the data of Johns Hopkins (2) and Wasley (3).

Figure 3 applies to the street surface with roughness coefficient of Manning's n = 0.01 to 0.016 (note: this is n in the modified Manning's formula for triangular gutter flow shown in Eq. 9). The effect of this roughness factor is embodied in the dimensionless term $L_i/F_W T$.

With longitudinal slopes 0.005 and 0.002, the subcritical portion of the gutter flow comprised all or nearly all of the flow, so that the flow as a whole lost its supercritical characteristics. The results are condensed in Figure 4.

Figure 4 applies only to the street surface with roughness coefficient of Manning's n = 0.016 because the experimental work for these slopes was done only on the rough surface. From experience with the results for S_o equal or greater than 0.01, however,

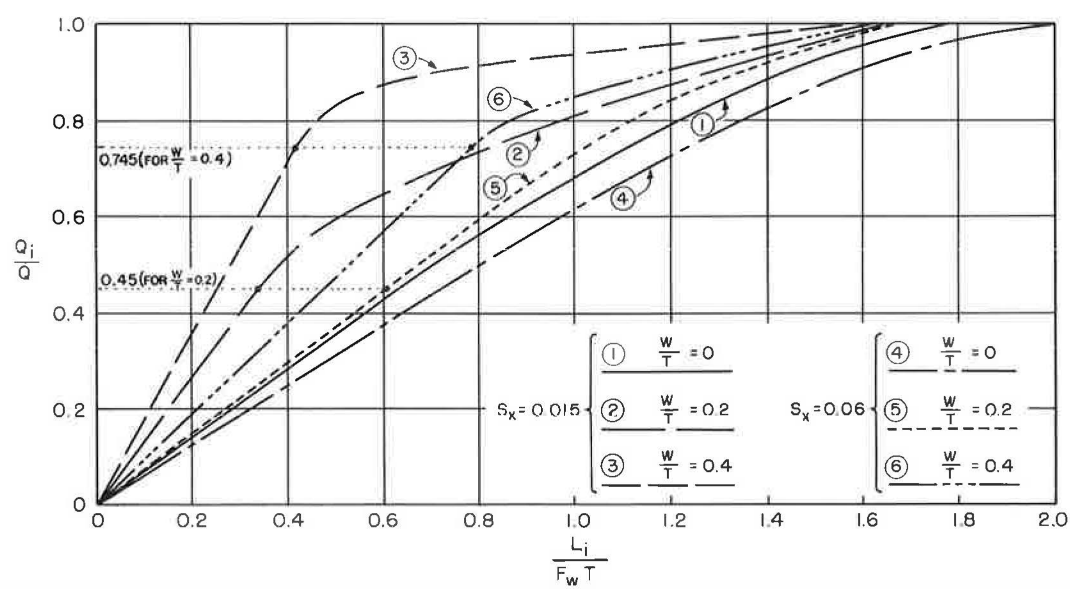


Figure 3. Research results for longitudinal slopes, S_o, ≥ 0.01 (W = 2 ft, a = 2 in., and n = 0.016).

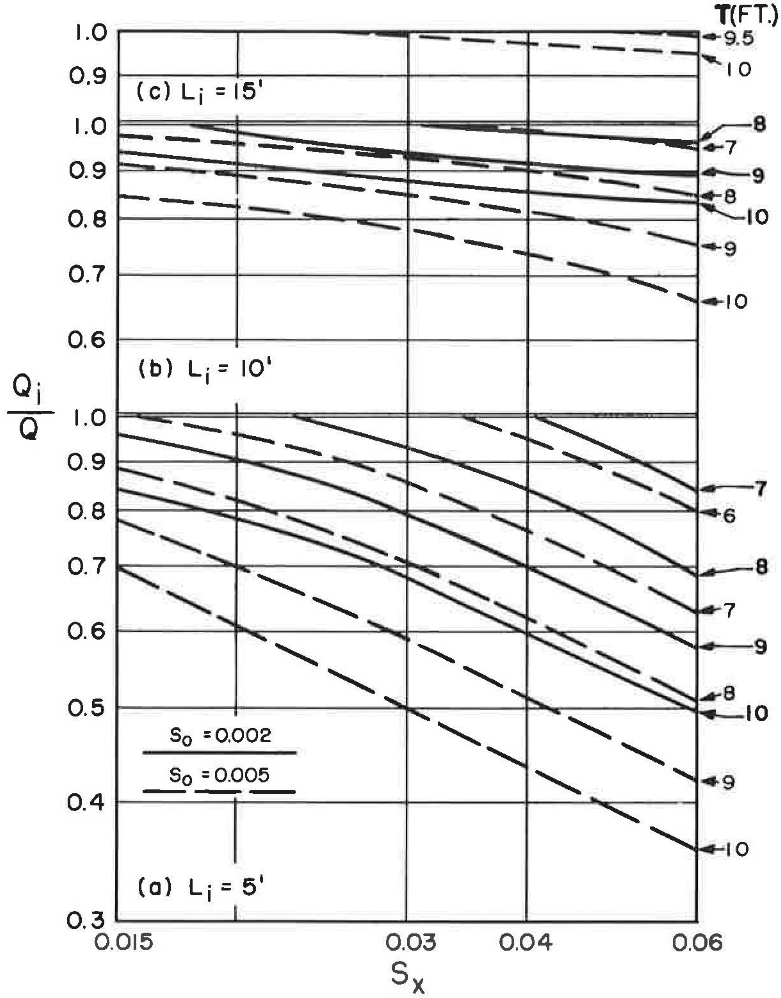


Figure 4. Research results for S_o = 0.005 and 0.002 (W = 2 ft, a = 2in., and n = 0.016).

it is safe to reason that for a smooth surface of equal width of spread, T, the interception rate will be lower than those shown in Figure 4; and for a rough surface, it will be higher.

In the sump condition, the approach velocity of the flow is very low, therefore, the flow into the inlet can be treated as over a weir. A minor modification in the length of the curb-opening was required to take care of the effect of the depression. For the conditions tested, W = 2 ft and a = 2 in., the results can be represented by a single curve, as shown in Figure 5

$$q = 1.7H^{1.85} \tag{3}$$

in which q, the modified unit discharge, is computed by the following expression:

$$q = \frac{Q}{\frac{L_i}{2} + 0.9\ W} \tag{4}$$

and H, the total head over the crest of the curb-opening at the center of the inlet, by

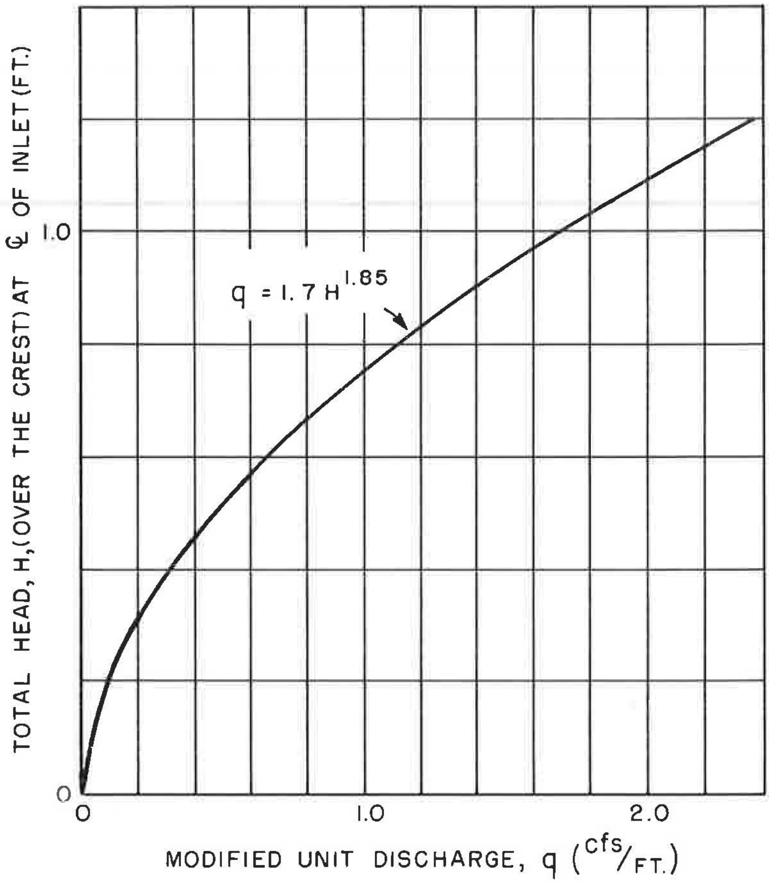


Figure 5. Research results for sump condition (W = 2 ft, a = 2 in., and n = 0.016).

$$H = T_c S_x + a = d_{max} + \frac{W}{12} \quad (5)$$

Combining Eqs. 3, 4, and 5 and doubling the gutter flow, Q, to account for flows from both sides of the inlet, the total flow intercepted is

$$Q_i = 2Q = 1.7\ (L_i + 1.8W) \left(d_{max} + \frac{W}{12}\right)^{1.85} \quad (6)$$

Eq. 6 should not be used to compute discharge for d_{max} larger than 1 ft, because this is the limit of the experimental data.

Surface roughness is not an influencing factor here, therefore Figure 5 can be applied to any surface roughness.

THE DEVELOPMENT OF DESIGN CURVES

Design curves including form determination and basic and extended curve development were developed from the previous research studies.

Determination of Form of Design Curves.—In view of the fact that excessive water spread on the highway pavement during a storm will greatly hamper traffic and create a hazard, a limiting spread of gutter flow is normally the governing criterion in highway surface drainage design. Therefore, this gutter flow spread, T, the cross slope, S_x, the longitudinal slope, S_o, and the length of the curb-opening, L_i, form the basic design curve parameters. The effect of roughness was tested and found to be relatively insignificant for the proper design of curb-opening inlets, as long as the same roughness is assumed in determining the width of spread and the inlet performance.

Basic Design Curves.—From the original research results, design curves for the basic depression geometry of W = 2 ft and a = 2 in. were derived. The range of the spread of gutter flow, T = 2W to 5W, was selected from practical consideration, as were the ranges of other conditions. These curves were condensed into five Figures: (1) Figure 10 for L_i = 5 ft, W = 2 ft, a = 2 in.; (2) Figure 11 for L_i = 10 ft, W = 2 ft, a = 2 in.; (3) Figure 12 for L_i = 15 ft, W = 2 ft, a = 2 in.; (4) Figure 16, showing the minimum height of curb opening required to clear the water surface of flow into the inlet under sump conditions, was derived from the water surface profiles measured at the plane of the curb opening during the sump tests and (5) Figure 18 for W = 2 ft, a = 2 ft under sump conditions. For Figures 10 to 12, and requirement for the minimum curb-opening height for free fall flow is specified ($h_m = TS_x$). Although no actual water surface profile measurements were taken during these tests, these criteria were derived from a few detailed measurements of the flow characteristics at the inlet area and from general knowledge of the previous studies on this subject.

Extended Design Curves.—Using Froude's law of similitude relationships, two more sets of design curves were derived for depressions of W = 3 ft and a = 3 in., and of W = 1 ft and a = 1 in., respectively.

Before this method of basic information extension was applied, the state of flow under the new conditions was checked thoroughly to verify that the Reynolds number was sufficiently large so that differences in viscous effects could be ignored. All flows were found to be in the turbulent region except a very small part of the W = 1 ft and a = 1 in. curves. All curves are, however, believed to give conservative design values.

It should be pointed out that because Eq. 3 is not dimensionally homogeneous, it cannot be applied directly to the depressions of W = 1 ft and W = 3 in. under sump conditions. By using Froude's law of similitude and the experimental results, it was found that for W = 1 ft and a = 1 in.:

$$Q_i = 2Q = 2\ (L_i + 2.4\ W) \left(d_{max} + \frac{W}{12}\right)^{1.78} \qquad (7)$$

and for W = 3 ft and a = 3 in.:

$$Q_i = 2Q = 1.475\ (L_i + 1.8\ W) \left(d_{max} + \frac{W}{12}\right)^{1.85} \qquad (8)$$

Eqs. 7 and 8 should not be used to compute d_{max} discharges larger than 1 ft.

Design Curves.—The new hydraulic design curves for curb-opening inlets with the standard depression (Fig. 1) are presented in Figures 6 to 18. Figures 6 to 14 are for the general condition, here defined as meaning an inlet on a continuous grade. Figures 15 to 18 are for the sump condition, here defined as meaning an inlet at the low point of a sag vertical curve. Because these curves apply only to the free fall flow at the curb opening, the specified requirement for the minimum height of curb opening on Figures 6 to 14 ($h_m = TS_x$) for the general condition and in Figure 15 for the sump condition must be met.

The curves for the general condition are expressed in terms of the width of uniform gutter flow spread, T. But for the sump curves, this term loses its meaning. Due to the small longitudinal slopes of the street, S_o, involved in the sump condition, the maximum water depth in the gutter, d_{max}, is of primary concern. Because the provided inlet must take care of all the flow at these locations, the sump curves are plotted as total flow to maximum water depth in gutter.

The limiting ranges of these design curves are summarized in Table 2. The minimum roadway width from curb to crown, for general curves, is obviously the upper

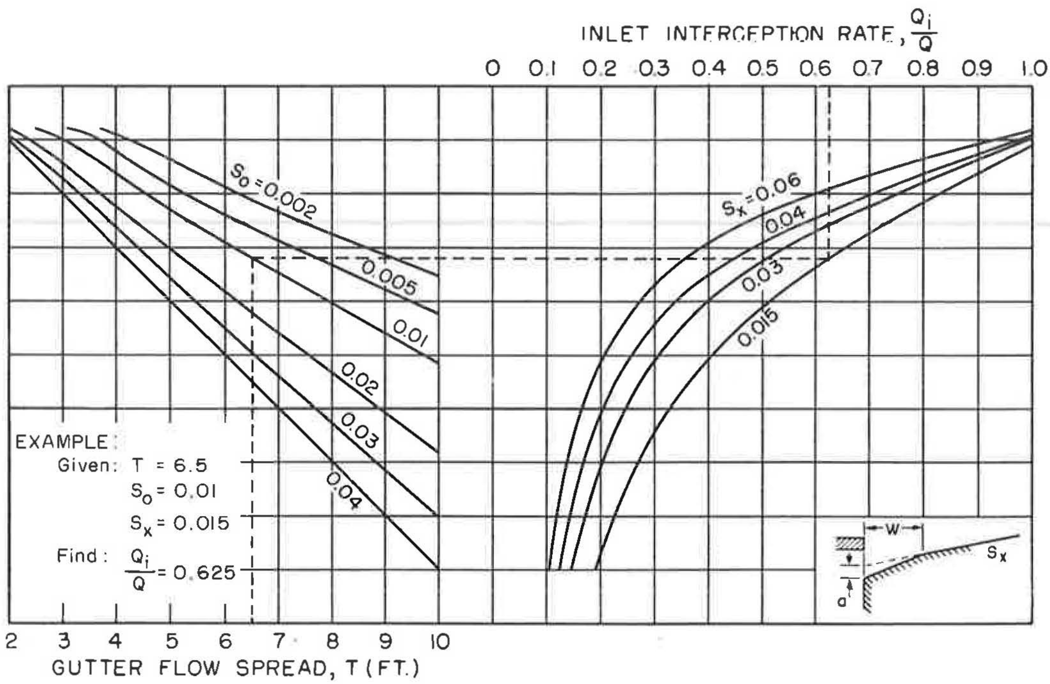


Figure 6. General condition: W = 1 ft, a ≥ 1 in., n = 0.016, length of opening, L_i = 5 ft, and minimum height of curb opening, $h_m = TS_x$.

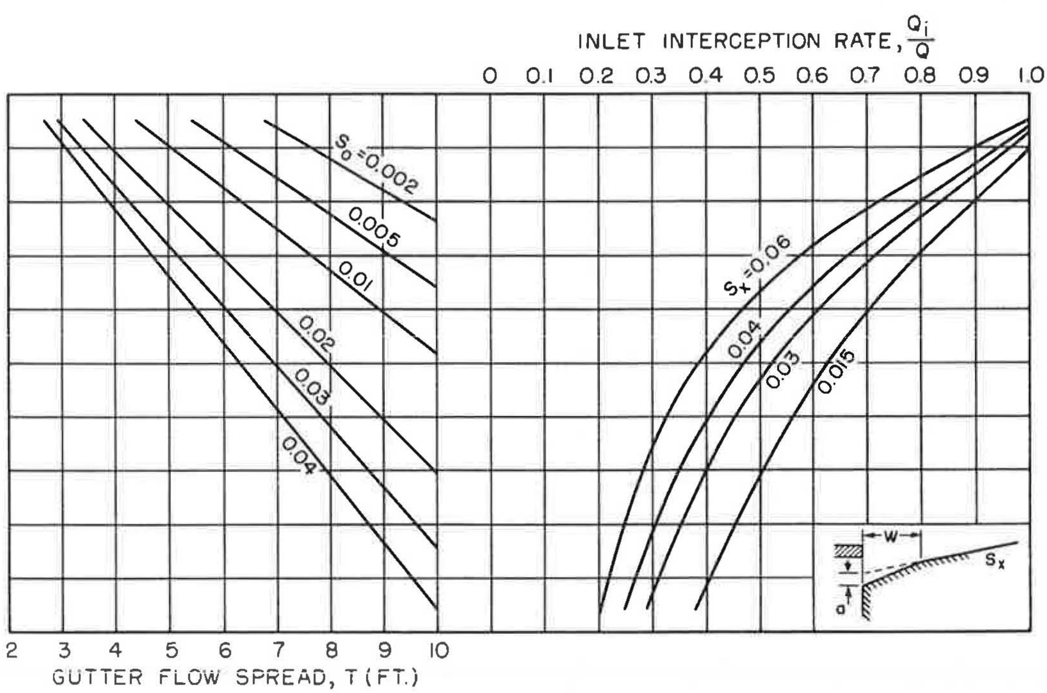


Figure 7. General condition: W = 1 ft, a ≥ 1 in., n = 0.016, length of opening, L_i = 10 ft, and minimum height of curb opening, $h_m = TS_x$.

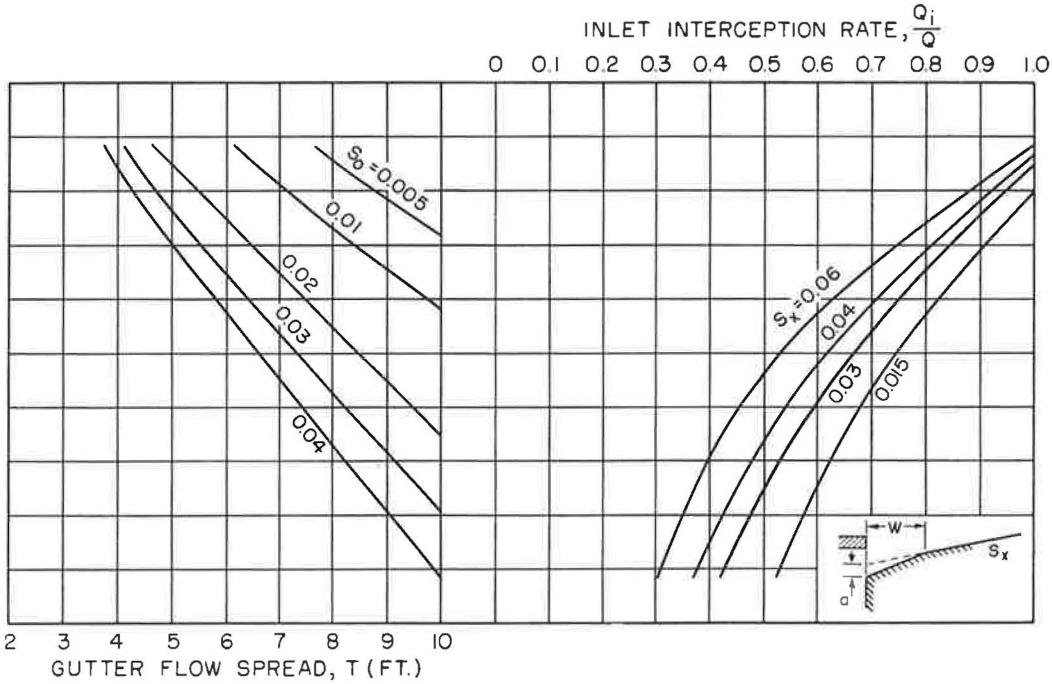


Figure 8. General condition: W = 1 ft, a ≥ 1 in., n = 0.016, length of opening, L_i = 15 ft, and minimum height of curb opening, $h_m = TS_x$.

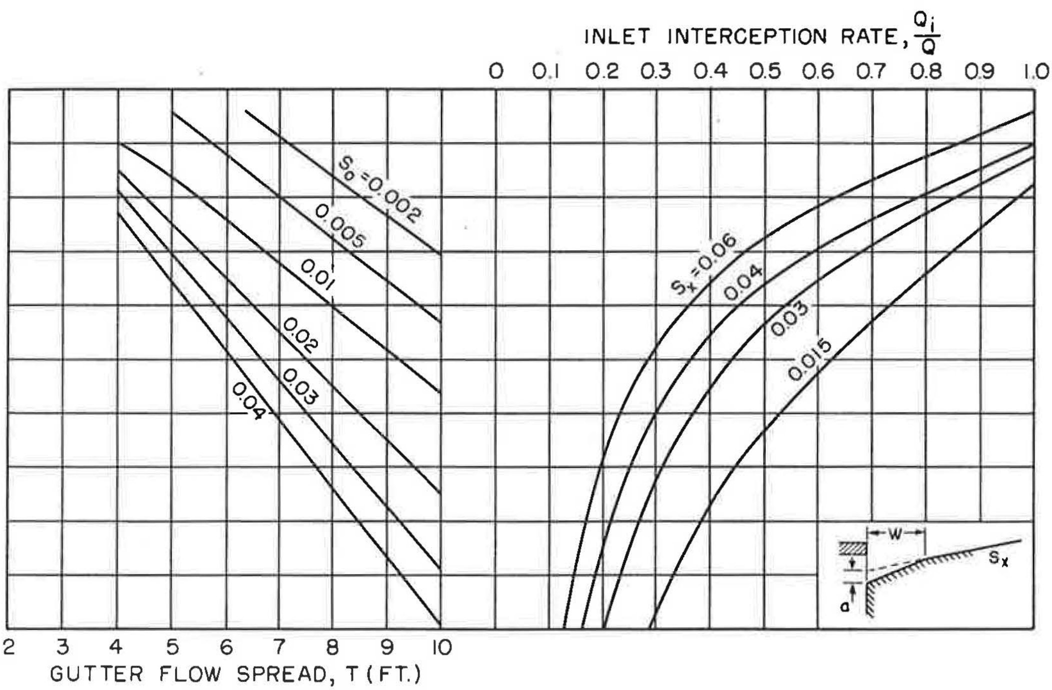


Figure 9. General condition: W = 2 ft, a ≥ 2 in., n = 0.016, length of opening, L_i = 5 ft, and minimum height of curb opening, $h_m = TS_x$.

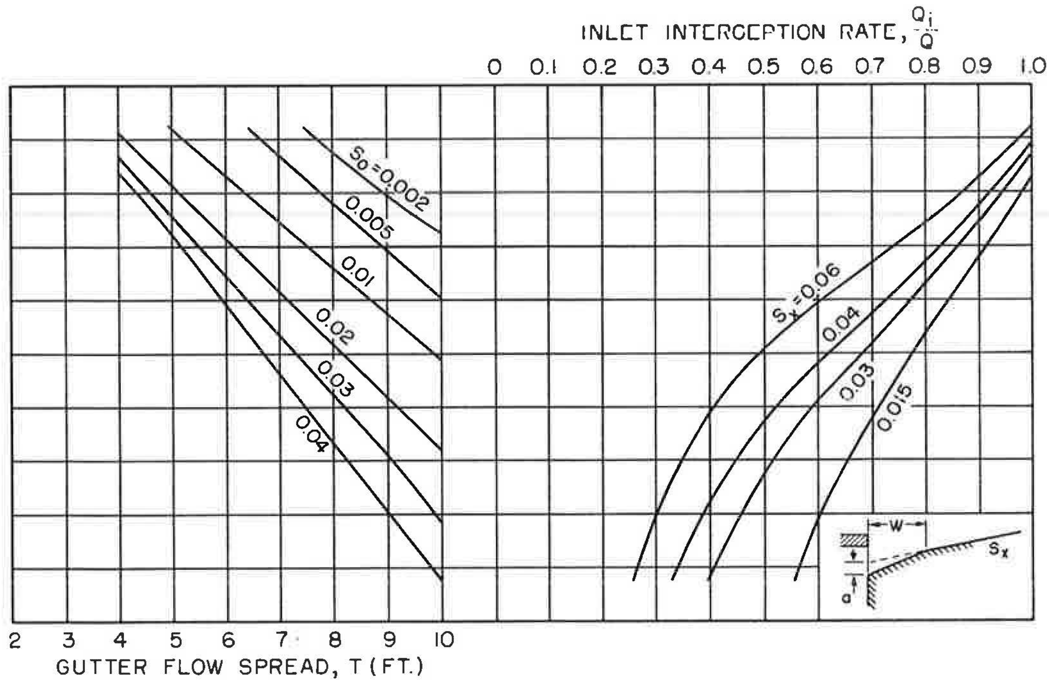


Figure 10. General condition: W = 2 ft, a ≥ 2 in., n = 0.016, length of opening, L_i = 10 ft, and minimum height of curb opening, $h_m = TS_x$.

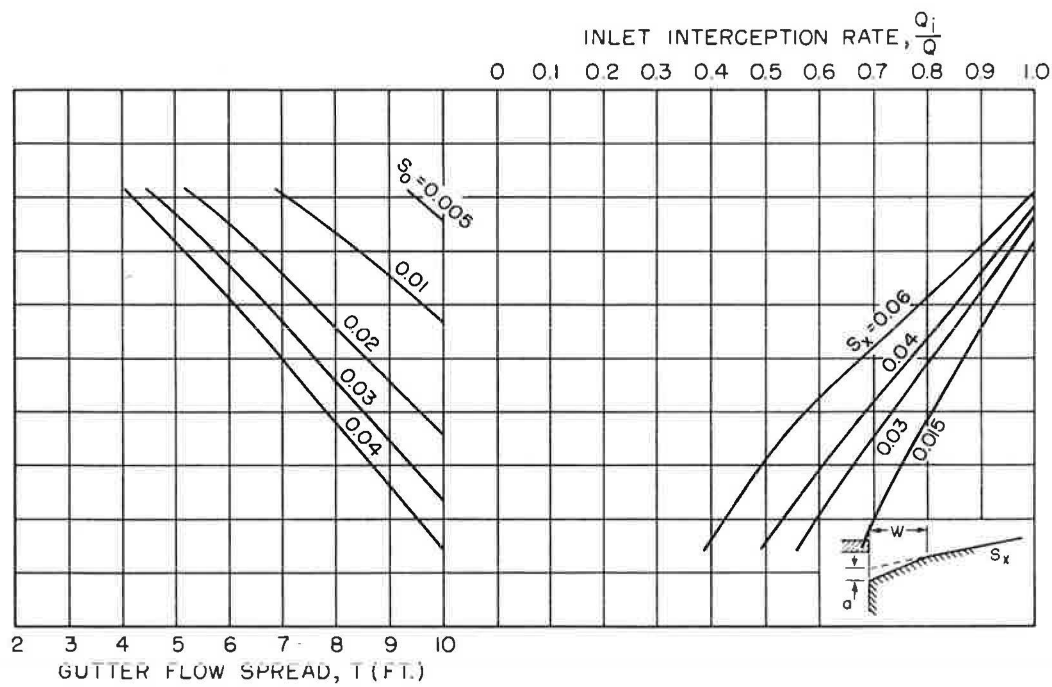


Figure 11. General condition: W = 2 ft, a ≥ 2 in., n = 0.016, length of opening, L_i = 15 ft, and minimum height of curb opening, $h_m = TS_x$.

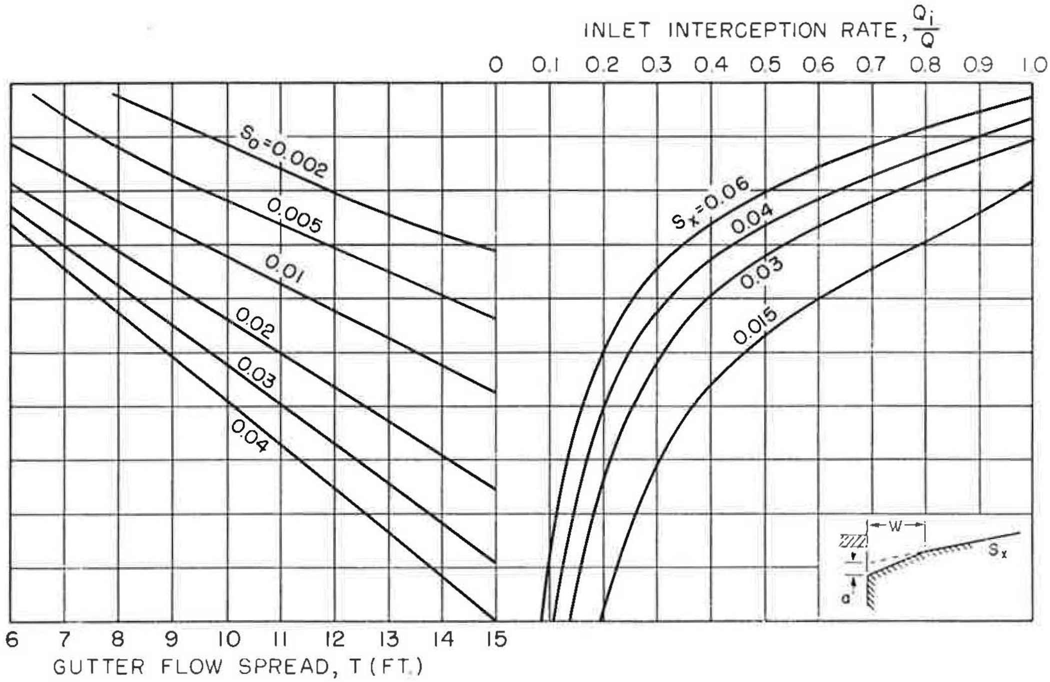


Figure 12. General condition: W = 3 ft, a ≥ 3 in., n = 0.016, length of opening, L_i = 5 ft, and minimum height of curb opening, $h_m = TS_x$.

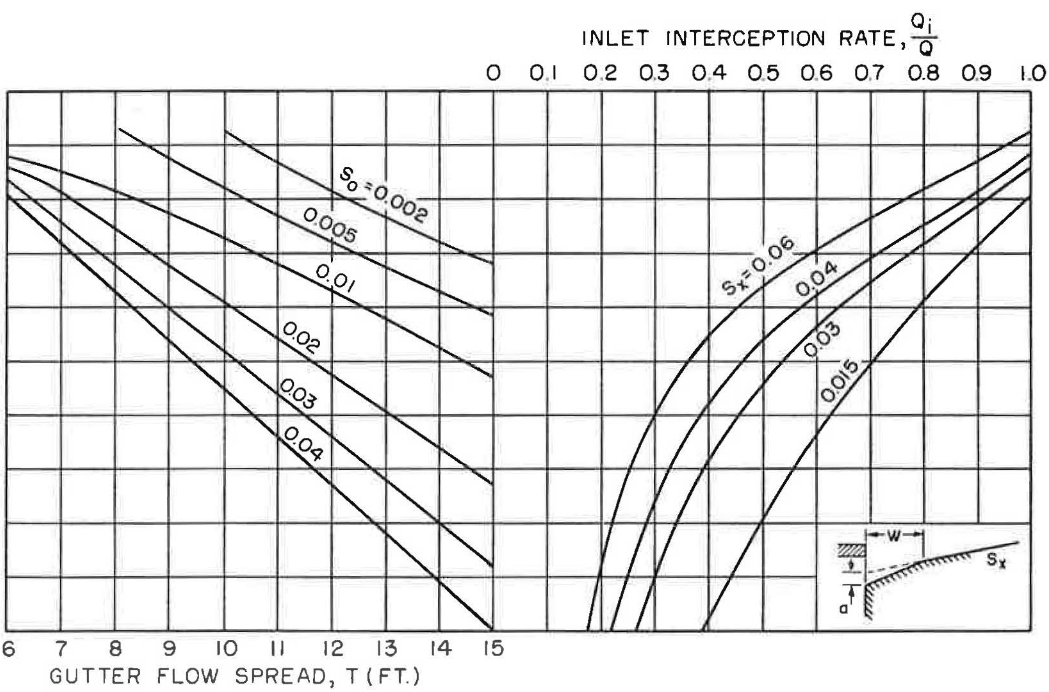


Figure 13. General condition: W = 3 ft, a ≥ 3 in., n = 0.016, length of opening, L_i = 10 ft, and minimum height of curb opening, $h_m = TS_x$.

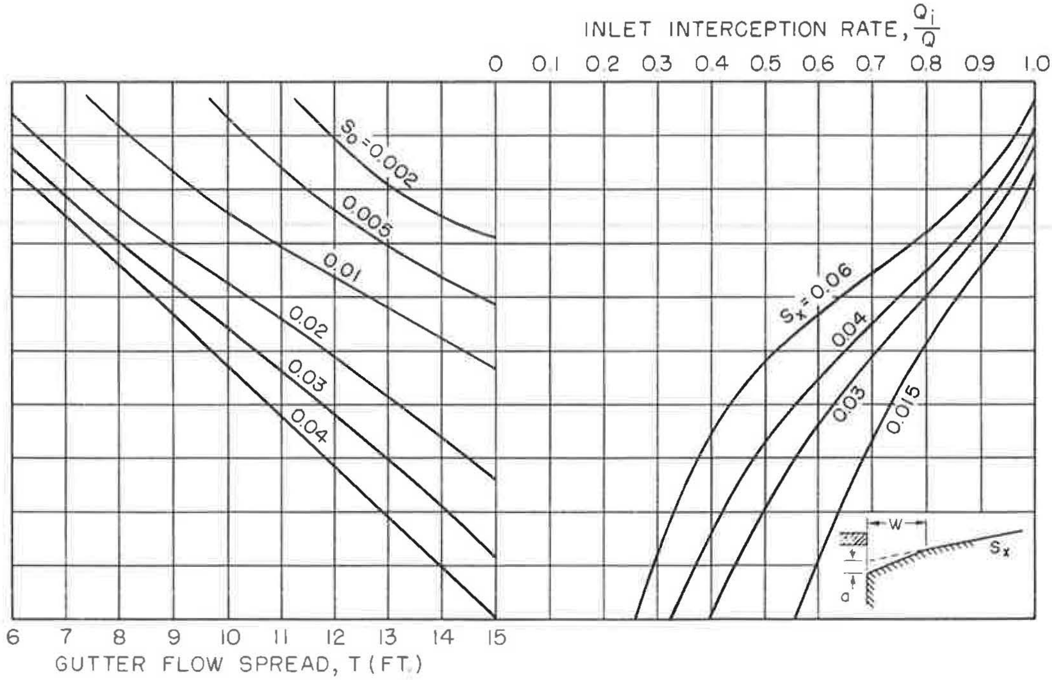


Figure 14. General condition: W = 3 ft, a ≥ 3 in., n = 0.016, length of opening, L_i = 15 ft, and minimum height of curb opening, $h_m = TS_x$.

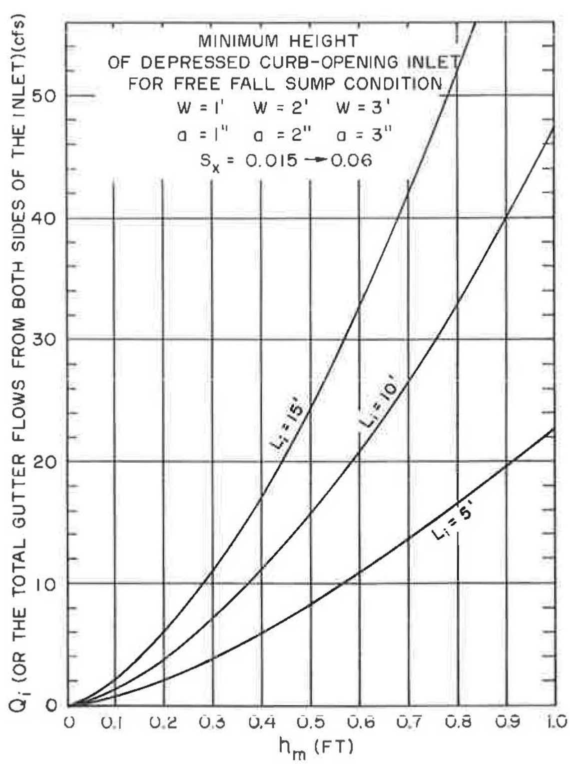


Figure 15.

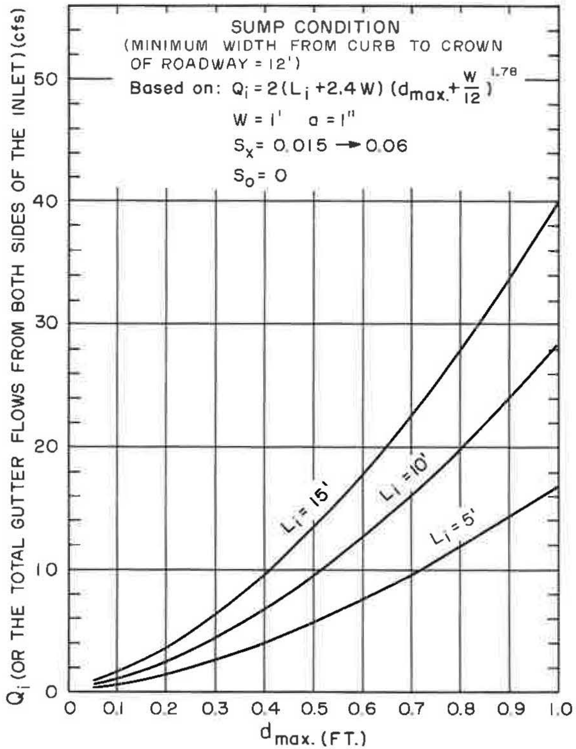


Figure 16.

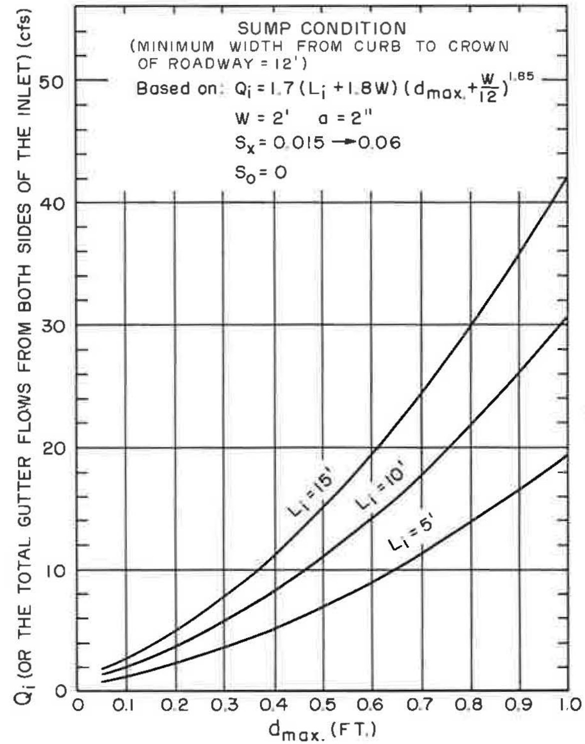


Figure 17.

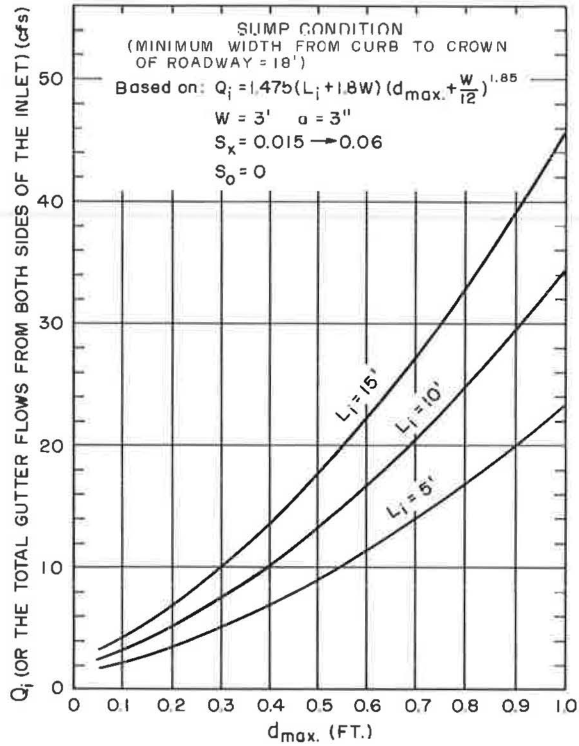


Figure 18.

TABLE 2

LIMITING CONDITIONS OF DESIGN CURVES

Curves	W (ft)	a (in.)	S_o	S_x	L_i (ft)	T (ft)	Minimum Width Roadway Curb to Crown (ft)	d_{max} (ft)	n	h_m
General	1	2	0.002	0.015	5	2-10	10			
	2	2	↓	↓	↓	4-10	10		0.016	TS_x
	3	3	0.04	0.06	15	6-15	15			
Sump	1	1		0.015	5		12	1		See
	2	2	0	↓	↓		12	1		Figure
	3	3		0.06	15		18	1		16

limit of the gutter flow spread, T. For the sump condition, this width affects the approach velocity of the ponded water, and thus becomes a factor influencing the relationship between the maximum gutter water depth, d_{max}, and the capacity of the inlet. This is especially true for narrow streets. These sump curves are specified for the minimum roadway width from curb to crown. A lesser width may produce an effect that amounts to about a five percent increase in the maximum water depth, d_{max}, for a reduction of one-third of the specified width.

These design curves cover only the standard depression geometry of three different sizes with the a/W constant a $1/12$. Consequently, they permit the selection of the best depression size for the particular situation. A conclusive evaluation of the effect of change in the a /W ratio is not possible on the basis of the data. However, limited experimental data for $S_x = 0.015$ and $S_o = 0.04$, show that for W = 2 ft, a reduction of the depression depth, a, from 2 in. to 1 in. may cause a maximum reduction of about one-fourth in the interception rate, Q_i/Q, of the inlet, while, for W = 1 ft, an increase of a from 1 in. to 2 in. can increase the Q_i/Q by one-fourth. By holding a as constant: for a = 2 in., a reduction of W from 2 ft to 1 ft may reduce the Q_i/Q by one-fourth; while, for a = 1 in., and increase of W from 1 ft to 2 ft can increase the Q_i/Q by one-fourth.

Application.—Although these new design curves cover a considerable range of practical conditions, there are still several cases yet to be studied: (1) The partially and completely submerged inlet; in the latter case, orifice type flow is developed. (2) Other types of street cross-sections, particularly one in which the cross slope steepens abruptly at the line between gutter section and pavement proper. Use of the crown slope of the pavement for S_x and the calculated T for this condition will give conservative results, however. (3) Other a/W ratios. (4) The effect of devices to deflect flow into the inlet.

The width of uniform gutter flow spread, T, can be computed from Izzard's integrated Manning formula (6) for street of single cross slope, S_x:

$$Q = 0.56 \left(\frac{1}{n\ S_x}\right) S_o^{1/2}\ d^{8/3} \tag{9}$$

and

$$T = \frac{d}{S_x} \tag{10}$$

The nomograph solution of Eq. 9 can be found in Design Charts for Open-Channel Flow (7).

Because of the special characteristics of the experimental study, extrapolation for conditions beyond the limits of Table 2 should be undertaken only with full recognition of the uncertainties involved. Linear interpolation can be applied.

Figures 15 through 18 apply to the sump condition. All of the discharge coming to the sump from both sides is assumed to eventually pass through the inlet. The inlet discharge capacity is shown as a function of maximum gutter water depth at the curb face, and different curves are drawn for the different lengths of inlet. It is assumed that the height of the opening would be large enough to permit free fall (without orifice type flow) into the inlet box. Figure 15 shows the minimum opening heights for this condition. If this minimum is not met and the inlet is completely submerged, it is possible to calculate the discharge based on an orifice type flow assumption. There is, however, no experimental information about the partially submerged inlet.

One important point in using these sump curves should be clarified. In the lower discharge ranges, the flow depth in approach gutters may be greater than depth, d_{max}, read from these curves. It is recommended that the uniform gutter flow water depth of $S_o = 0.002$, that will be at a point generally within 30 ft of the sump inlet, should be checked. For this reason Figure 19 for uniform gutter flow, based on Eq. 9 and n = 0.016, is provided. If the depth read from Figures 16 to 18 is less than this uniform gutter flow depth, flow will tend to draw down as it approaches the inlet. On the other hand, if sump depth is greater, then the pool backs up water along the gutter.

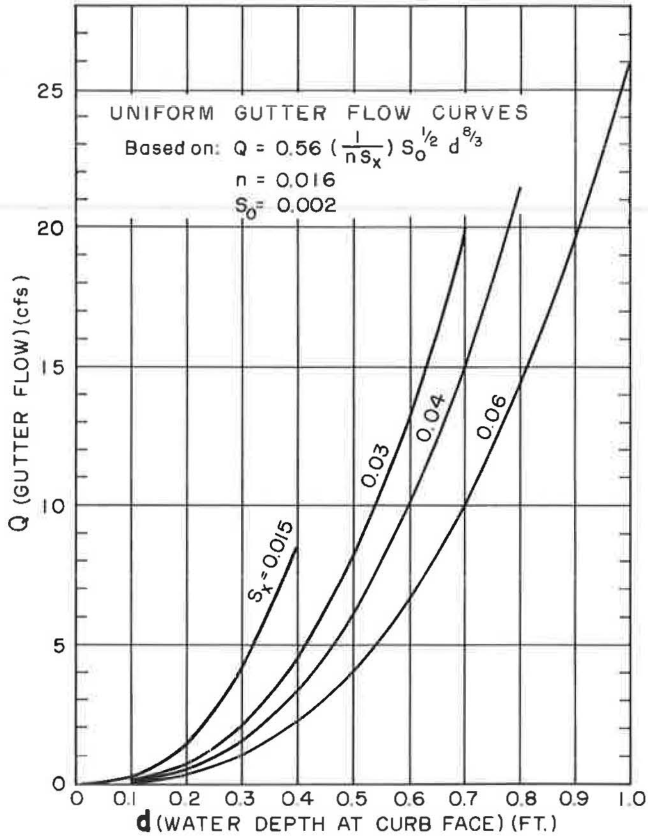


Figure 19.

The use of these sump curves is explained by a detailed example:

Given:

$W = 1$ ft
$a = 1$ in.
$n = 0.016$
$S_x = 0.03$
Height of inlet opening = 7 in. (or 0.58 ft)
Estimated maximum gutter flows from both sides of the inlet:
$Q_1 = 2$ cfs
$Q_2 = 8$ cfs

To find:

L_i and d_{max}

Solution:

The total gutter flow = 2 + 8 = 10 cfs

From Figure 16—It shows that the minimum heights of the curb-opening required for free-fall flow for Q = 10 cfs are 0.28 ft, 0.37 ft and 0.56 ft for L_i = 15 ft, 10 ft and 5 ft, respectively. Since the given height of the inlet is 0.58 ft, free-fall flow will prevail and Figure 17 can be used for the design of this inlet.

From Figure 17—It shows that the following values of L_i and d_{max} are needed at the sump location:

L_i	15 ft	10 ft	5 ft
d_{max}	0.41 ft	0.52 ft	0.72 ft

From Figure 20—It shows that the values of d needed for uniform gutter flows are:

Q	2 cfs	8 cfs
d	0.3 ft	0.5 ft

Therefore:

If L_i = 15 ft is to be selected, then

d_{max} (= 0.41 ft) < d (= 0.5 ft for Q_2 = 8 cfs), the gutter flow Q_2 tends to draw down as it approaches the inlet; and

d_{max} (= 0.41 ft) > d (= 0.3 ft for Q_1 = 2 cfs), the pool at the inlet backs up water along the gutter with Q_1.

If L_i = 10 ft or 5 ft is to be selected, then

d_{max} (= 0.52 ft or 0.72 ft) > d (= 0.5 ft or 0.3 ft), the pool at the inlet backs up water along both gutters.

COMPARISON OF THE NEW DESIGN CURVES TO OTHER AVAILABLE INFORMATION

Izzard's work (1) on the capacity of curb-opening inlets with and without depression has been widely used, but the effect of depression width was not taken into account because of the absence of data. When compared with the new experimental data, the old method tends to substantially underestimate the capacity of inlets with depression widths greater than one foot.

Another often quoted work is Johns Hopkins University's "The Design of Storm-Water Inlets" (2). Although the curves for depressed curb-opening inlets in this publication are for the Baltimore depression only, those for other depression geometry can be computed by using its suggested method. The curves thus derived show higher interception rates than the new design curves presented here. The reason for this discrepancy must be in the differences in the experimental conditions, illustrating that an empirical method derived from experimental data of certain conditions is best applied only within these same limits.

CONCLUSION

The new design curves are more comprehensive then those previously available. They are believed to be easier to use, because they give a direct answer with a minimum amount of calculation.

Future research could be applied to other depression shapes, to the effect of submergence of the opening, to the effect of gutters of different cross-sections, and to the effect of devices to deflect flow into the inlet. Other aspects of natural gutter flow that were ignored in this study as being relatively insignificant in determining inlet efficiencies in the usual case are unsteadiness (variation of discharge with time) and nonuniformity (variation of discharge with position along the gutter). Flow that is decidedly unsteady (for example, slug flow) or decidedly nonuniform (such as a large component of flow entering at an angle to the line of the gutter) could also be studied in future research, as could be the inlet on a curve.

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