STORM WATER MANAGEMENT SEMINAR
PART 11

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CONTENTS

DEFINITIONS

NOTE: Refer to definitions listed in Part 1 of this series.

bee-hive grates- grates in the form of a truncated cone, truncated pyramid, or semi-sphere.

critical flow- discharge at minimum energy.

discharge hydrography- discharge from a watershed at time increments throughout the run-off period.

energy dissipator- any device used to reduce high velocity flow to an acceptably low velocity to prevent downstream damage.

freeboard- the vertical distance between design water surface and top of dam (as used in this publication).

gabon- rock-filled wire basket used for hydraulic or structural purposes.

groyne- a man-made impediment to flow placed near one bank of an open channel in such fashion as to deflect flow from that point, thereby inducing accretion.

high water mark- field determination of flood peaks at specific locations.

impervious surfaces- asphalt, concrete or any other surface which does not admit measurable infiltration.

pervious surfaces- earth or other porous materials which admit measurable infiltration.

reach- a length of open channel or pipe system.

relief- change in elevation.

routing- the computation of inflow, change in storage, and outflow through a storm water retention facility.

run-off factor- that percentage of precipitation which reaches the drainage system of interest.

swellhead- the vertical difference between headwater and tailwater through a flowage obstruction.

thalweg- the low point in any stream cross-section.

unitgraph- a discharge hydrography which accrues from one inch of run-off in a specified time frame.

CHAPTER 1

INTRODUCTION

This booklet attempts to provide technical data of use to those performing storm water management design in urban areas and to furnish generalized data for officials and land developers who share an interest in the subject. Hydrology and hydraulics can be a complex topic involving far more sophistication than that described herein, but experience has shown the need for an elementary reference for engineers and laymen who must pursue other aspects of their professions on a daily basis and of necessity must forego intensive study. This is difficult to accomplish because of the diverse backgrounds of all those who have an engineering, economic, or social interest in the ramifications of storm water management. Some readers will have had no engineering background in hydraulics while others may be accustomed to little more than applications of the "Rational" formula. Still others will be well-versed in both theoretical and applied hydraulics. In order to reach a middle ground of understanding, certain approximations will be reasonable to apply and will not introduce serious errors in the majority of urban problems. Usually the larger the land mass of interest becomes, the greater the complexity of problem solution. While the basic data described herein continues to apply, the reader is encouraged to consult more detailed publications.

The hydrology and hydraulics of urban areas is a rapidly evolving field of engineering which is distinct in itself and there are a number of people currently conducting detailed investigations which will constitute important contributions to the profession. The author takes note of several of these efforts and recognizes that there are undoubtedly others unknown to this writer which may have considerable merit.

In addition to theoretical study, the reader is urged to complement this data by diligent study of field characteristics of storm water behavior, both in overland flow movement and hydraulic behavior in open channels. The designer of excellence possesses the dexterity of judgement deriving from visual experiences just as much as from theoretical knowledge. The designer of worth must also have a practical knowledge of construction and land development methods in the vicinity of any particular project design.

CHAPTER 2

GENERAL ELEMENTS OF URBAN-AREA HYDROLOGY AND HYDRAULICS

(A) RAIN-FALL CHARACTERISTICS

Hydrology includes all aspects of precipitation prior to entry into a defined drainage system. This includes the study of rain-fall, infiltration, evaporation, transpiration, and the overland movement of water prior to reaching a defined system. Hydrology also concerns the study of snow-melt. In most urban areas, evaporation, transpiration and snow-melt characteristics have very little impact on the majority of flooding events. Accordingly, this chapter will dwell only upon the elements of rain-fall, infiltration and overland movement of run-off.

Hydrologists study natural rain-fall phenomena and are able to conclude certain characteristics based on weather records. As a general rule, the accuracy of their observations are directly related to the length of time detailed records have been maintained. Although many universities, businesses and local governments have installed rain gages and maintain records of varying quality, the United States Weather Bureau is by far the leading authority in the collection and analysis of rain-fall data. In some climatological regions the Weather Bureau has compiled over one hundred years of record, but in other regions their records are substantially less. An analysis of records for each region has enabled compilation of the Weather Bureau's "Rain-fall Intensity-Duration-Frequency Curves" for public use. This data is commonly termed frequency curves. An example of these curves for the three regions of Louisville, Ky., Lexington, Ky., and Nashville, Tenn. are portrayed on Plate A-1, Appendix A in Part 3 of this series. The following is an example of one use for these valuable curves in interpreting local rain-fall events.

The 100-Year frequency curve for Nashville indicates that 60 minutes after the start of rain-fall 2.95 inches of rain will accumulate. In formal terms, this means that based on the period of record, a rain-fall accumulation of 2.95 inches 60 minutes after the start of the storm may be expected to be equaled or exceeded at least once every one hundred years. By way of further explanation, let us say that only 2.46 inches of rain had accumulated during the same storm, but at time 50 minutes. This would be equivalent to the same rate of 2.95 inches per hour (50/60 times 2.95 equals 2.46) but at time 50 minutes instead of 60 minutes. Perusal of the Nashville curves indicates that a 2.95 inches per hour rate at 50 minutes falls on the 50-Year curve. Thus, in this example rain-fall event, we observe a 50-Year frequency at 50 minutes and a 100-Year frequency at 60 minutes but with an identical rain-fall rate at both times.

Another rain-fall the following month could produce an accumulation of 2.20 inches at 30 minutes, or a rate of 4.40 inches per hour (30/60 times 4.40 equals 2.20). Once again referring to the Nashville curves, this would be a 100-Year frequency at 30 minutes. Thus, in these two example storms, two 100-Year events took place within one month. It is within the context of these curves for a 100-Year event to take place several times a year, but with the 100-Year intensity taking place at different times with each rain-fall period. That this actually happens can be verified by the installation of multiple rain gages in an urban area and recording data at five minute increments. So-called 100 Year intensities are not as infrequent as the un-informed layman commonly believes, and should not be considered as unreasonable criteria.

Weather cycles in Kentucky have been observed to commonly produce short duration, high intensity storms in the summer months during the winter months. Of course there are exceptions, but the summer-type storms are those which usually produce the serious urban floods along small channels and pipe systems. A storm lasting only ten minutes but with a very high intensity often produces far more damages than a 24-hour storm of lower intensity, even though the longer storm may even have greater accumulations of rain. It is always of paramount importance to note the length of time during which the rain occurs in addition to rain-fall amount. Without a time-quantity relationship, it is not possible to relate any historical or design storm to that storm's severity.

Recent research by notable authorities has indicated a change in weather cycles over metropolitan areas as those areas expand. In particular, the summer-type of high intensity storm tends towards higher intensities. One explanation for this phenomena focuses on increases in impervious areas which, in turn, accelerates rising currents of air during hot periods. Further research in this area of interest is needed for amplification of data regarding any such trend nation wide.

The author suggests that urban storm water management designers utilize either one of two hydrologic bases for any particular project. (1) A theoretical Weather Bureau curve of the local government's selection, or (2) a historical storm of high frequency. Even though theoretical curves may be adjusted in the years to come because of new data, they are well-founded in fact. Historical storms of record also have considerable value in view of community resident tendencies to relate the impact of any new project to historical events. Some researchers, designers and agencies perceive value in re-distributing the rain-fall in a theoretical storm, yet this author has observed that such an approach greatly confuses the non-expert and is viewed by many as a "play" on numbers. On smaller urban projects, there is more to be lost than gained by re-distribution of a theoretical rain-fall.

(B) DETERMINATION OF RUN-OFF

Analytical conversion of rain-fall to run-off can be difficult owing to the many variables in watershed topography. A number of methods have been devised to determine the shape of run-off curves but, in this writer's opinion, no one method is applicable to all watersheds with any degree of reasonable accuracy. Where accuracy is vital, the designer should always select at least two methods which experience has proven applicable to the watershed's characteristics and compare results. Yet one method of run-off derivation is sufficient where a somewhat lesser extent of accuracy is needed, but even then it is crucial that a proper methodology be used.

What is run-off? Designers and public agencies customarily consider it sufficient to determine only the peak amount of flow in a channel or pipe system with a given design rain-fall. Their reasoning is founded on the assumption that, if a culvert or bridge opening is sized to pass the storm's peak rate of discharge, there is not need to determine the shape of the discharge curve before and after the instant of peaking. There is nothing improper with this line of reasoning for those who have no responsibility to protect downstream areas from flood aggravation and whose interests are limited to the particular waterway opening in question. However, as shall be noted in a subsequent chapter "STORM WATER RETENTION", a knowledge of the shape of the entire run-off curve is vital to water management design. Accordingly, this chapter will not dwell on the commonly used "Rational" formula for determining the run-off peak aside from making one observation. The "Rational" method has been used and Miss-used to the point of flagrant abuse in urban areas merely because it is a simple method. More frequently than not, "Rational" solutions err well beyond the bounds of reasonable inaccuracies.

Run-off is actually the entire amount of rain-fall (or snow-melt) which reaches a defined drainage system after subtractions attributable to infiltration, evaporation, localized pondage and other less important factors. Even should rain-fall remain constant, run-off at any stated point on a watercourse would vary with time because of a constant shift in infiltration, evaporation and pondage characteristics during the life of a storm. But the variation in run-off at one point becomes even more pronounced when rain-fall rates themselves vary with time as they usually do behave. In small urban watersheds (up to about 2,000 acres), the amount of run-off is strongly influenced during the first hour of rain-fall by such factors as steepness of topography, the amount of vegetation, the extent and location of impervious areas, the extent of upstream obstructions or depressions in the terrain which impedes flow, and the general efficiency of the watershed's internal drainage conveyance system. Studies in some urban areas have indicated that run-off has tripled in instances where un-developed watersheds have become saturated with developments of varying descriptions. Even quadrupling of run-off is not un-common where the upstream area is totally developed with commercial areas with almost complete impervious surfaces.

The foregoing is not meant as a substantive and thorough commentary on developmental impact on run-off and of the many factors which should be considered in projecting run-off, but rather to indicate that run-off derivation can be a complex matter to even the best of experts in the field of hydraulics. There have been notable researchers in this area of interest.

(B) DETERMINATION OF RUN-OFF (continued)

Some methods, while providing important contributions to the academics of hydraulics, are unfortunately too complex for use by the overwhelming majority of engineers. Other methods are reasonable accurate for certain watershed applications (because they were derived primarily from test data in certain types of watershed) but have little value when applied to other watersheds of a different character. On the other hand, some methods are so grossly simplistic as to have little value in portraying a run-off expectation accurately. By far the most accurate method would be the installation of stream gaging devices whereby run-off at the point of interest is monitored and then theoretically translated to another rainfall or changed watershed characteristic, but this method obviously requires an expenditure for test data and personnel, and requires a considerable amount of time to procure the necessary data. Another method which yields highly accurate results is that of the physical model (as opposed to a computer model), but this is not only time consuming but very expensive.

This author expects the problem of expensive and time-consuming run-off methodology, inaccurate methodology, or non-applicable methodology to be overcome for the most part within the next several years as more and more qualified researchers embank on realistic derivation methodology which can be applied by nonexpert and still yield reasonable results. This, however, does not help the reader for the time being. As an aid to those who do not care to enter into this area of interest exhaustively, the following sub-paragraphs describe a few methods which the author believes encompasses most urban run-off problems. The methods described are not intended to imply that other methods are not also applicable.

DISCHARGE HYDROGRAPH - INSTANTANEOUS METHOD

In the absence of test data, this author has developed an easily applied theoretical method for determining the run-off hydrograph for small urban watersheds. Since this method assumes instantaneous run-off and as a consequence probably produces peaks somewhat greater than naturally occurs, it is considered inadvisable to use this approach for watersheds greater than about 50 acres in size. It should also be noted that this method is best applied to essentially developed watersheds which have primarily impervious areas and/or an internal drainage system which promotes rapid run-off.

By way of explanation, let it be assumed that the following characteristics exist for a small commercial area and it is desired to determine the shape of a 100-Year discharge hydrograph for a one hour period.

Size of watershed area equals project are...20 acres
Computed "C_m"factor...0.90
100-Year rain-fall at 5-minute increments-

TIME (min)	INTENSITY (in/hr)	ACCUMULATED RAIN (inches)	INCREMENTAL RAIN (inches)
5	9.60	0.80	0.80
10	7.56	1.26	0.46
15	6.36	1.59	0.33
20	5.52	1.84	0.25
25	4.92	2.05	0.21
30	4.40	2.20	0.15
35	4.01	2.34	0.14
40	3.70	2.47	0.13
45	3.47	2.60	0.12
50	3.26	2.72	0.12
55	3.10	2.84	0.12
60	2.95	2.95	0.11

Five-minute incremental rain may be converted to a mid-increment instantaneous run-off with the following relation:

Q
instantaneous = C_m x incremental rain-fall accumulation
x drainage area = C_m RA

= C_m x (1/12 x 1/300 x ave. incre. rain) x area

= constant x average incremental rain

For the example problem the constant becomes:
Constant = 0.90 x 1/300
x 1/12 x 20 acres x 43,560 sq. ft/acre = 217.8

A compilation of mid-increment instantaneous discharges yields the following hydrograph for the example problem.

TIME (min)	INCREMENTAL RAIN (inches)	AVE.INCREMENTAL RAIN (inches)	CONSTANT	INSTANTANEOUS DISCHARGE (cfs)
0	-	-	217.8	-
2.5	-	0.4	"	87.1
5.0	0.8	-	"	-
7.5	-	0.63	"	137.3
10.0	0.46	-	"	-
12.5	-	0.395	"	86.0
15.0	0.33	-	"	-
17.5	-	0.29	"	63.2
20.0	0.25	-	"	-
22.5	-	0.23	"	50.1
25.0	0.21	-	"	-
27.5	-	0.18	"	39.2
30.0	0.15	-	"	-
32.5	-	0.145	"	31.6
35.0	0.14	-	"	-
37.5	-	0.135	"	29.4
40.0	0.13	-	"	-
42.5	-	0.125	"	27.3
45.0	0.12	-	"	-
47.5	-	0.12	"	26.1
50.0	0.12	-	"	-
52.5	-	0.12	"	26.1
55.0	0.12	-	"	-
57.5	-	0.115	"	25.0
60.0	0.11	-	"	-

The absence of a straight line relation between time periods and the fact that run-off is never instantaneous are the most obvious approximations in this method. The computed run-off on the front end of the storm is higher than would occur while those near the end of the storm would be lower. Yet when applying the retention principle, these differences can have little impact on total problem solution as long as the drainage area to which the procedure is applied in not large.

This procedure is simple to apply and suffices in most small urban area problems where the watershed is below the 50 acre size. Undoubtedly greater accuracy can be achieved through future field research of the many factors which affect small watershed run-off, but greater accuracy will also increase problem solving complexities to those not adept in this realm of interest.

INSTANTANEOUS RUN-OFF FACTOR, "C_m"

The factor "C_m" in the foregoing INSTANTANEOUS HYDROGRAPH METHOD is intended for use in small urban watersheds which experience high intensity-short duration storms and where evaporation and localized pondage/valley storage have very little influence on run-off. the value of "c " is determined from the following relationship:

$$C_m = \frac{(C_n \text{ x } A_p) + (C_i \text{ x } A_i)}{A} + \frac{(A_p)}{(A)}$$

where; C_m = instantaneous run-off factor as modified by proposed construction

C_n = natural instantaneous run-off factor determined from natural topography. Values of 0.35 for rolling terrain down to 0.20 for flat terrain may be used in the absence of test data.

A_p = pervious areas in project.

C_i = instantaneous run-off factor for impervious areas. A value of 0.95 may be used in the absence of test data.

A_i = impervious areas in project.

A = total area in project.

k = coefficient reflecting the surface drainage efficiency, or re-grade, of pervious areas in the project. In the absence of test data, a value of 0.20 may be used for most re-grades of moderate to flat slopes.

This procedure is a logical progression of the commonly-used value "C_n" and has been observed through practical applications as a reasonable basis for modified run-off determination. Yet test data has not yet been compiled to firmly verified the suggested coefficient values. An example problem for a residential area, "Lake Ayre Estates", is depicted in Appendix B, Part 3. Plate B-1 portrays the subdivision plan and Plate B-2 portrays derivation of C_m.

COLORADO URBAN HYDROGRAPH PROCEDURE

A storm run-off derivation was advanced in 1969 by the firm of Wright-McLaughlin Engineers for the Denver Regional Council of Governments and was financially aided by the U.S. Department of Housing and Urban Development. This procedure is based on a unitgraph derivation which should be readily understandable by the majority of designers. This method, termed CUHP, will no doubt be modified somewhat in different geographic regions as more test data becomes available, but the basic effort constitutes an important contribution as a hydrograph methodology which is reasonable accurate under certain conditions and is fairly easy to apply. For information relative to the entire two volume study, Wright=McLaughlin Engineers should be contacted at 2059 Bryant Street, Denver, Colorado 80211.

An extract from that study describing CUHP is included herewithin Appendix "C", Part 3. This author suggests its' use for watersheds in the range of 50 to about 1,000 acres.

CLARK METHOD

The Corps of Engineers frequently use the Clark method of run-off derivation (after C.O. Clark, ASCE Transaction, 1945, Volume 110) for moderately large watersheds. This method is not complex but should take some time for the reader to develop proper familiarity. It involves a logical analytical approach to unitgraph derivation, but for any particular project the attenuation constant "R" should be determined from a known hydrograph or should be selected on the basis of considerable experience with comparable watersheds. A commentary on this method is found in Appendix "D", Part 3, Plates D-1 through D-9. This method has value for urban watersheds over about 1,000 acres in size. An example application is shown in Appendix "E", Plates E-4 through E-10.

DRAINAGE AREA PROPORTION METHOD

This procedure is applicable to any size watershed and is basically a relationship between a gaged location and an un-gaged location. If a designer is fortunate enough to have rain-fall/run-off records for a watershed of similar topography, size and developmental characteristics in relation to the watershed of interest, then it becomes a relatively simple matter to proportion hydrograph peaks and work backwards into a unitgraph.

DISCHARGE MEASUREMENT METHOD

This method is probably seldom used because of the expense and time required. Of essence to this method is the installation of one or more rain gages in the watershed of interest and field capability to measure stream flow during high intensity storms. With this data for several rain-fall events, a skilled engineer can work backwards into a unitgraph which may then be used to project a design run-off of interest. This method is the most accurate known to the author.

(C) OPEN CHANNELS AND PIPE SYSTEMS

One only needs to closely view drainage systems in most communities to understand that channel and pipe system design has frequently been of poor quality. Often poor system design is the result of ill-founded economies by either the local government or the developer, but many errors in judgement are the result of the designer's inexperience or lack of knowledge regarding all factors which should be considered in a proper design. This section is not intended to undertake this subject in depth, but rather to take note of several major points of interest influencing a total water management design.

PIPE SYSTEMS

Curiously enough, pipe systems are frequently designed so that their capacities may never be realized because of restrictive or insufficient inlets. Designers should always check the throat capacities of inlets to insure that design flows can actually enter the system.

Points of entry into pipe systems, even though of adequate size, frequently do not pass design flows because of the propensity for clogging of drop inlets or at headwalls. One can never insure that clogging will not occur, but the designer can greatly minimize this problem by the installation of bee-hive type grates where feasible and by the installation of properly designed trash racks. This author cautions against the use of trash racks where debris is not a major clogging factor, however, or where clogging may result in hazardous surcharge of the inlet condition and produce undesirable overtopping of facilities above grade. Unless the designer uses good judgement, a trash rack can create more problems than the one the rack is designed to prevent.

Engineers accustomed to sanitary sewer design work frequently make the mistake of opposing entry pipes into a manhole. During high velocity design rain-fall/run-off conditions, opposing flow has been known to negate discharge from both entry pipes. This is not a major factor in sanitary sewer design, but becomes a vital concern in dealing with the higher velocity storm water.

As will be noted in the following paragraphs, an open channel properly designed can be more economical and aesthetical pleasing than a pipe system.

OPEN CHANNELS

Rolling topography and gently meandering streams appear to have substantial sales appeal in residential areas. It is good practice to leave desirable streams in their natural state, or with perhaps slight modification, and afford the developer with an economy. However, a natural channel incorporated into final project design should have the characteristics of sufficient slope to preclude either accretion or erosion. Meanders often should be protected against bank attack. Either one of the factors of accretion, invert erosion, or bank attack can induce substantial maintenance costs to local government in future years. In addition, an easement should be impressed on all contiguous lands at least tot he 100-Year flood level to prevent un-authorized encroachments in the flood plain. The topography within the easement should be such to permit governmental access for future maintenance.

When an open channel is used in rolling terrain, residential record plats should not only reflect the 100-Year easement lines but should also indicate the flooding elevation on each riparian lot. This precludes the possibility that a builder might excavate a natural slope and construct walk-out basements or recreation rooms below the control elevation.

Excavated open channels should not have earthen side slopes any steeper than 2:1. Steeper slopes prevent reasonable attempts at maintenance operations. Channel bottom slopes in the longitudinal direction should not be flatter than 0.5% if at all possible, and even then the bottom should have concrete with finish grades staked at least every 25 feet to avert localized pondage areas. Concrete bottoms should have concrete returns on each side to prevent out-flanking of the bottom section. Earthen bottoms can be acceptable with slopes steeper than 1.0% up to a slope which will computationally generate erosive velocities, and then the bottom should b e of concrete or some other material which will withstand erosive effects. Plate G-2, Appendix "G", Part 3 portrays a design curve based on test data which will indicate stone size necessary to prevent dislodgement by specific stream velocities.

The use of open channels sometimes pivots on a matter of the developer's taste in esthetics versus economy. One factor which should always be considered is a particular area's probability of attracting litter or debris. Open channels tend to become depositories for the type of litter that a pipe system grate often prevents.

The point of emphasis in this section concerns the need for the hydraulic designer to carefully consider maintenance considerations in addition to pure hydraulic design of the channel. A poorly maintained channel is but one element in a total water management design, and if it malfunctions, total project functionality can be impaired.

(D) FLOOD PROFILES

The only precise methods to determine a flood profile for any stated discharge are the following:

(1) Field measurement of the flood discharge and setting high water marks.
(2) Hydraulic modeling.

Since both of the foregoing are generally impractical for the great majority of small urban design problems, the designer must seek practical methods which have a lesser degree of accuracy. The method one utilizes should be a function of the desired accuracy. Hydraulic engineers usually employ the following method for projects of moderate size.

(3) Computational backwater analysis

A backwater study can become extensive in field cross-sectioning, design time and total analysis expenditure, and unless the primary effort for the design rests on a hydraulically oriented project, (for instance a channel improvement) one is not likely to encounter those who are willing to fund extensive investigation of a "secondary" type of design feature. Where the accuracy tolerance is not severe, there is another procedure which is easy to understand and use by non-specialists. This is portrayed on Plates 11 and 12, Appendix "E", Part 3, and is descriptive of a channel rating at steady flow with negligible backwater effects.

(4) Channel rating at steady flow-negligible backwater.

This method is quite simple to use and involves the following:

(4-a) Determine a cross-section at a representative (or typical) cross-sectional location.

(4-b) Determine the thalweg elevation at some up- or downstream location, measuring the distance to the point of cross-section so that a slope is obtained for the channel.

(4-c) Obtain the desired design discharge (Q) from one of the run-off methods and assume that this discharge flows at a depth of your selection at the cross-section.

(4-d) The selected depth will yield a corresponding Hydraulic Radius "R" and Area "A" which may then be substituted in the Mannings's equation shown along with the previously computed Slope "S" to arrive at a corresponding "Q". If the corresponding "Q" differs from the known "Q", the depth selection was obviously in error. A comparison of the two "Q's" will enable a more accurate second trial.

(4-e) Generally after two or three quick trials, the designer obtains an assumed depth which is compatible with the discharge. This procedure may be repeated with additional cross-sections as necessary, but for short reaches in urban areas, it is usually sufficient to strike a profile through the computed point parallel to the thalweg.

In the Appendix "E" example shown, the author performed a slight variation from the foregoing sequence and merely assumed various depths, computed the "R", "S" and "A", and arrived at the corresponding "Q". If this is performed with different depths, a Rating Curve for the cross-section may be drawn. The Rating may then be entered with the "Q" of interest and the corresponding depth determined graphically.

The author cautions that this procedure is approximate and is predicated on the following:

There is no backwater effect.
Steady flow exists.
The cross-section and slope are representative of the reach.

For the reader who may inquire regarding the foregoing use of the channel slope as being equal to the energy gradient slope "S" in Manning"s equation, be advised that the energy slope attempts to attain "critical" value as a limit. Equal values are a reasonable approximation for steady flow conditions which exist at time of peak discharge.

Of course, where a downstream bridge, culvert or fill obviously controls flowage depth, the foregoing will not apply. Backwater methods should then be employed.

(E) DETERMINATION OF SWELLHEAD THROUGH AN OBSTRUCTION

Where the designer desires the rise in discharge profile (or swellhead) through a bridge or similar obstruction, several methods of computation are available. The Bureau of Public Roads and others have advanced noteworthy procedures which vary in complexity. However, for a very simple method within the grasp of most non-specialists an energy balance is usually of sufficient accuracy. The derivation for energy balance is shown on Plate E-13, Appendix "E", Part 3, and an example problem is portrayed on the following Plate E-14.

This method is approximate and does not involve an approach velocity (which invariably exists in channel flow) nor does it involve peculiarities of turbulence unique to every structure. However, it may be noted that approach velocity tends to diminish the swellhead computed by this method while turbulence tends to increase the computed value. It is a simplification to assume that these effects cancel, but once again this is an acceptable approximation for most small urban problems.

CHAPTER 3

STORM WATER RETENTION

(A) THE CASE FOR RETENTION

If all urban drainage systems were designed and constructed to convey the 100-Year floods generated by fully developed watersheds, there would not be much of a flood problem. But most communities have constructed their systems to pass very low frequency storms under developmental conditions that prevailed at the time the systems were built. Some may argue that local governments have been short-sighted, yet it may also be argued that historical governments performed to the best of their financial capabilities each time a piped or open channel element was added to the total system. It is not the intent of this chapter to argue the merits of each point of view, but rather to take note of the fact that many urban drainage systems are not deficient.

Now comes the developer of a school, shopping complex, residential area or some other facility of which the community has need. Impervious areas and project re-grade greatly accelerates storm run-off and, if unchecked, adds to downstream flood stages. Local governments and the developer of any particular project are confronted with three options. (1) The run-off may be allowed to increase and aggravate damages to passive land owners, but this exposes both government and the developer to needless litigation by damaged parties. Irrespective of potential litigation, this course of inaction speaks little of a government on whom its' constituency relies for basic protection. (2) The entire downstream drainage system can be improved to accommodate increased flows. This procedure is encouraged on a long-term basis, but it is hardly practical to improve an element of size each time a building permit is issued. (3) Storm water retention may be employed to temporarily restrain run-off leaking generated by the new project. This alternative is by far the most economically feasible and legitimate of the three options in the majority of problem areas.

While complete storm water management involves drainage system improvement, diversion of watersheds where properly performed, and many other items, storm water retention is a major element which should be considered. The advantages of retention far out-weigh the disadvantages in most instances, provided retention facilities are properly designed. Several major advantages will be described in the following paragraphs. For the reader who has studied this topic elsewhere and may take issue with the term "retention" in lieu of the word "detention", be advised that the author prefers the former to avert confusion in communities where the penal institution is referred to as a detention facility. Since both words have essentially the same meaning in hydraulics, it has proven preferable to use "retention".

Retention of storm water implies that run-off in excess of natural, or even greater amounts, is being temporarily restrained to prevent either flooding or flooding aggravation. From a study of the preceding chapter on run-off, it may be seen that the top portion of a run-off hydrograph generally involves relatively little water volume, and of course it is this top portion of the hydrograph which imposes downstream flood damages. Usually it is far more economical to restrain this relatively small volume than to improve lengthy sections of the downstream drainage system to accommodate the same amount of flow. There will of course be exceptions where the downstream system is short and potential damages nominal, and where this occurs retention may have lesser benefits.

A later section of this chapter will comment on retention criteria which suggests that a new project be held only accountable for restraining its' own run-off increases as opposed to being held responsible for natural run-off as well. Yet there will always be circumstances favorable to specific developers for retaining additional amounts of storm run-off and thus voluntarily reducing natural downstream flooding. Where such favorable circumstances develop, storm water retention has no economic peer and becomes an invaluable community resource.

Another section of this chapter will dwell upon variations in retention design which net both the developer and the community with dual usages. Recreational areas, "green belts" and space buffers are but a few of dual usages of storm water retention areas. Whereas channel improvements are usually devoted to hydraulic purposes exclusively, retention areas which accomplish the same purpose can provide other enhancements.

Off-site siltation of storm piping and open channels, yards and other elements of the public and private community is a continuing problem to most communities, and retention facilities frequently serve as a temporary silt trap during project construction. Construction mud control is not only good for the local government and downstream citizens, but frequently serves to minimize the developer's exposure to litigation or off-site expenditures relating to mud cleaning operations. It has been observed that retention areas often serve an even more important silt control function than that of flood control, and this advantage should not be minimized.

The total case for retention is good provided the designer and the approving authority recognize sound design methods. Versatility and the application of basic techniques are essential.

(B) <u>RETENTION CRITERIA</u>

Each community adopting storm water management must develop its' own criteria which reflects community sensitivity to flooding, the adequacy of the existing drainage system, and the character of topography. The following criteria has been developed by the author on the basis of experience with metropolitan areas which have acute citizen attitudes towards flooding and whose residents do not wish to sustain flooding aggravation from new construction. For the most part this criteria has proven acceptable to the great majority of citizens and has, as of this date, precluded any rational attempts by community residents to obtain financial damages from developers complying with this criteria. To the best of this author's knowledge, this methodology has been perceived by the great majority of the development industry as being equitable. It has been utilized in one metropolitan area for a period of five years and another for about four years and has appeared to stand the test of acceptability by reasonable people and has proven functional. Yet it is recognized that community attitudes differ and community facilities differ. For these reasons the following criteria may be viewed with a flexible attitude.

RETENTION VOLUME-
Downstream areas shall not be subject to any flood aggravation as a result of new construction during a 100-Year frequency rain-fall event. Where improvement of the downstream storm water system is not feasible, retention volumes should be equal to the change in run-off generated by the 100-Year storm for a time period equal to whichever of the two following conditions apply:

(1) Where the drainage outlet for the new construction is, in its' entirety, a surface-gravity system, the change in run-off during the first one hour of the 100-Year storm will apply. (The one hour standard is applicable to most areas because urban storm water movement will usually pass most points of damage within 60 minutes after the start of the storm. A time less than one hour might be applicable, but would involve computational proof of travel time and can introduce confusion to those non-specialists working with urban development.)

(2) Where the drainage outlet for new construction is either a pump and force main or a sink-hole situation, the change in run-off for three hours will apply. (The three hour time frame has as its' basis the authors observation and experience that the first three hours of a 100-Year storm are generally the most critical in non-surface, gravity systems. Thereafter rain-fall rapidly diminishes and most pump-storage and sinkhole situations are able to recover. This is not always the case, but is sufficiently so to enable the three hour time as a general standard).

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RETENTION OUTLET SIZE AND LOCATION

The retention device may restrain on-site storm water from entering a drainage arterial or may be located and designed to allow arterial storm water to drain into the basin, but in any event the retention facility should prevent flood aggravation during 100-Year storm peaking at downstream points of damage. There may be a design exception to the foregoing noted in the following paragraph.

While retention facility volume is predicated on the change in run-off for the 100-Year storm, it may be to the advantage of local government and downstream owners to use the fixed volume for reductions of lesser frequency storms. Where this preference prevails, the outlet may be sized for any low flow release rates desired but with a corresponding increase in spillway capability for a total low flow/spillway release rate equivalent to the 100-Year storm.

The combination low flow and spillway release capability should equal at least the 100-Year storm with a minimum spillway freeboard of one foot. Large structures which fall within the purview of KGS 151.250 (Commonwealth of Kentucky) must satisfy the regulatory procedures of Kentucky's Division of Water Resources pertaining to dams.

RETENTION FACILITY MAINTENANCE

The retention facility must be designed for ease of maintenance and there must be a designated entity for periodic maintenance. There should be a recognized procedure for governmental inspection to insure compliance with maintenance requirements and, if the maintenance entity is non-governmental, there should be a penalty provision for failure to properly maintain the facility.

LEGAL DESIGNATION

The retention facility should be circumscribed by a metes and bounds for inclusion in either a retention easement or a nonbuildable lot. If a separate lot or specific easement is impractical, as would be the case with a retention vault, the facility purpose and maintenance requirements may be described in the deed.

The intent of appropriate legal designation is to insure that successors in title will have reasonable notice of the retention facilities purpose and maintenance provisions.

(C) VARIOUS RETENTION DEVICES

There are a number of storm water retention devices which may be employed in different circumstances, but all available options should meet the following needs.

(1) The measure must function properly to hydraulically prevent off-site flood aggravation.
(2) The measure must be legally identifiable to prevent usurpation of its' intended function and to establish maintenance responsibility.
(3) The measure must be easily maintained.
(4) The measure should be reasonably safe.

The design of any specific retention measure is a function of out-fall characteristics, on-site topography, dual usage potential and compatibility with other on-site features, ease of maintenance, and a host of other considerations which may vary from job to job. It is not practical to attempt a description herein of all the possibilities or combinations of possibilities, but the following will indicate several basic retention facilities.

"NATURAL OPEN AREA-DRY BASIN"

This type utilizes natural terrain for economic or esthetic reasons and consists of a designated storage area with a throttled outlet for effective retention. The hydraulic throttle may be a restricted culvert under an elevated roadway, a man-made dam warped and blended with the terrain for a pleasing appearance, or some other restriction which, when surcharged, will not backflood any on-site feature subject to damage.

"MODIFIED OPEN AREA-DRY BASIN"

This consists of an excavated area which is readily recognized as a retention facility to the casual observer, but otherwise is similar to the foregoing type.

"NATURAL OPEN AREA-WET BASIN"

The "Wet Basin" designation implies the use of a formal permanent pool. this type of basin is usually employed for esthetic reasons and generally drains a sufficient sized watershed to preclude substantial evaporation effects during the summer months. However, this is not always the case when low flow augmentation is used to off-set evaporation. Aside from esthetics. this type is often beneficial for elongated projects and flat slopes wherein a rise in storm piping or channel elevations are critical and the flat permanent pool saves several vital feet in relief.

"MODIFIED OPEN AREA-WET BASIN"

This type consists of a man-made excavation with a permanent pool and is usually employed in an urban project where fountains or other permanent pool appurtenances are desirable.

"LATERAL BASIN"

This type of retention facility is basically an over-sized drainage ditch or channel with appropriate checks to insure temporary pooling of storm water. This measure is particularly appealing in broad, flat areas. and primarily in industrial park sites where run-off is intense and substantial lengths of pooled areas present a minimal of safety hazard.

"RECREATIONAL BASIN"

This is usually similar to the general category of either "Natural Open Area" or "Modified Open Area", but chiefly alludes to the dual usage of tennis courts, ball fields. or some other recreational facility which is not likely to be used during intense rain-fall periods. There should always be at least one percent slopes in these areas to promote rapid drying.

"SUB-GRADE BASINS"

Either a sub-grade vault or over-sized storm piping with throttled outlets would be examples of this category. Where open areas are at a financial premium, the developer may elect to use fairly costly sub-grade facilities. This usually applies to commercial areas.

NON-DESIRABLE TYPES

Some areas employ roof top storage of storm water, but the author finds this method objectionable for several reasons. First. owners generally have a difficult time maintaining a water-tight roof without deliberate storage, so their problems generally escalate where roof top storage is built in to the scupper system. Secondly, it is difficult for governmental inspectors to determine when the roof top retention facility has been modified without authorization. this author also considers roadway pondage undesirable as a deliberate retention measure. It was previously mentioned in this series that deliberate pondage in roadways impede the movement of emergency vehicles. Limited parking area pondage may be acceptable insofar as the depth of inundation during flash flooding would not damage packed vehicles, but extensive pondage exposes unwary automobile owners to needless damages.

(D) STORM ROUTINGS THROUGH RETENTION

Storm routings should be performed through any basin for accuracy of design, but as a matter of everyday practice it appears unnecessary for basins which must store less than about one acre-foot of flood waters. A later section will dwell upon a quick design approach for these smaller basins. But for storage greater than about one acre-foot, the following is one method for storm routings.

INFLOW-STORAGE OUTFLOW

After the retention designer has secured an inflow hydrograph from one of the preceding methods and properly sized the basin, it becomes necessary to route the storm through the basin with at least one, and generally several low flow/spillway outlet combinations to insure that total outflow does not exceed natural outflow. Appendix "F" includes Plates F-1 through F-5 which is an example of a storm routing. The procedure is simply one of balancing inflow, the change in basin storage, and outflow during each increment of time during the storm. If on the first trial selection of low flow/spillway sizes the outflow peak exceeds the natural run-off peak, the outlet combination must be revised accordingly.

It should be noted that there is a graphical solution to a storm routing problem, and there are also programs for large data processing systems which facilitate lengthy designs, but the author suggests that engineers who use the several 'desk top' type of computers currently on the market might consider programming for that purpose. The 'desk top' computer promotes a rapid design while, at the same time, allows the designer a close rapport with the design in progress without loosing accuracy.

(E) OUTLET WORKS DESIGN

A proper storm routing procedure will result in sizing of the low flow/spillway combination. It was previously mentioned however that basins smaller than about one acre-foot in temporary storage size may be designed with an approximate method without routing. The following is descriptive of that method.

SIZING OUTLET-APPROXIMATE METHOD

the entire purpose in storm water retention is to prevent off-site flooding aggravation, or in other words, to insure that the project of interest will not discharge more flood peaking than that which occurred under natural conditions. For small basins of less than one acre-foot of storage, the outlet may be sized for natural run-off from the watershed in question. The reader has noted the previous section on rain-fall characteristics and observed the small, almost negligible difference between the 100-Year storm and small frequency storms in the short time frames near the beginning of rain, say at time five, ten, and fifteen minutes. It is during these early time frames that small projects generally peak and that the total accumulation during those times are nearly the same irrespective of the design storm frequency. For this reason, it is suggested that the outlet be sized for the natural watershed and the storm frequency generally used in the community drainage system. 100-Year inflows are then impounded and surcharge the low flow will accommodate under surcharged conditions. Plate G-1, Appendix "G". Part 3 is included as an aid to those using either this method or the more detailed and accurate storm routing method.

OTHER OUTLET DESIGN CONSIDERATIONS

There are at least two other main considerations in outlet works design. First, the outlet must be durable and capable of withstanding continued erosion or vandalism. Concrete low flow pipes with anti-seep collars should be mandatory when heads over four feet are generated on the inlet, and concrete spillways are desirable when those spillways are subject to frequent use. Second, the outlet velocity under surcharge inlet conditions should be checked for erosive attack on the receiving channel. Where this possibility exists, an energy dissipator should be employed. A following chapter will dwell on this aspect.

Trash racks can be a major consideration, as can open basin fencing, but these elements are subject to specific site circumstances.

(F) RETENTION BASIN MAINTENANCE

It was previously noted that every basin should be legally defined in either a deed or on a record plat, and that the maintenance entity should be specified. It is preferable for local government to assume maintenance operations, but this can be impractical for communities in short supply of funding capability. If a private maintenance entity is specified, the requirements should be set forth in a separate maintenance agreement with a cross reference on the plat or deed.

The maintenance agreement should dictate that vegetative growth should not exceed five inches in height, that all foreign objects and debris are to be kept removed from the site, and that periodic maintenance is to be performed to insure the hydraulic and structural integrity of the project. Structural and landscaping intrusions onto the site are not allowed without the written approval of the regulating agency.

CHAPTER 4

SINK-HOLES AS DRAINAGE OUTLETS AND RETENTION AREAS

A sink-hole is a depression or cavity in the terrain caused by the movement of surface water towards a subterranean drain. A sink may have an exposed outlet or may be a highly pervious earthen depression which transmits surface water to the underground outlet. Sinks are particularly dominant in the Bluegrass and Pennyroyal regions of Kentucky where underlying strata is composed of limestone or other highly erodible material, but they also are not uncommon in other areas of the state. Historical developers and local governments have found it convenient to use sinks as formal drainage outlets, and in many cases encircled sink-hole areas to such an extent with development as to make abandonment of the sinks impractical without considerable expenditure for land acquisition and storm piping.

Sink-holes are very undesirable as formal drainage outlets for a number of reasons. They become plugged with silt or debris and they are prone to collapse in subterranean areas which are not subject to control by local government. Another undesirable aspect focuses on outlet capacity determination.

It is impossible to determine a generalized rule for sink-hole discharge capability. Each sink behaves differently from all other sinks and discharge from each is a function of the unknown subterranean streams. Underground stream-flow is irregular, varying in cross-section, and subject to the vicissitudes of subterranean erosion, channel collapse, backwater effects and varying inflow from many points. This is impossible to determine without specific inflow-outflow tests at each sink in question. Sink-holes should be used as an integral part of a storm water system only where no other outlet is feasible, and even then specific criteria should apply to their use. The following lists critical elements in sink-hole criteria.

DRAINAGE OUTLETS-
There should be as little disruption of the immediate environs of the sink as possible and the placement of mechanized equipment near the subterranean drain should be avoided. All construction work in this area should be by hand, consisting of the following:

(1) Flow exiting from new culverts or focalized points of inflow to the sink area should be controlled by concrete or rip-rap to the drain so as to preclude erosive damage to the outlet.

(2) A steel grate of adequate proportions should encase the drain to prevent stoppage from debris.

(3) The immediate environs of the sink should be fenced to minimize vandalism.

The following paragraph will dwell upon the use of a sink as a retention area, but it should be noted that <u>computational, no outflow should be assumed from any sink unless verified by field tests during rain-fall events.</u> It maybe apparent that a particular sink is functioning the time of project design, but the extent to which it functions must be accurately determined.

RETENTION AREAS

When using a sink-hole area as a drainage outlet and retention area, it has been previously noted that a 100-Year storm over a three hour time span is desirable. There should be sufficient retention volume around the sink to contain the entire run-off from this storm with no outflow, unless field measurements corroborate an acceptable outflow rating for the subterranean drain. This retention area should be defined as an easement or non-buildable lot, and the maintenance entity should be specified.

This author has observed enough sink-hole malfunction, either through stoppage from surface silt or debris or through underground collapse, to suggest that sinks designed as a part of new projects should have an initial emergency plan for discharge relief in the event malfunction occurs. Such a plan may be preliminary in nature, but should verify that either a surface channel, storm piping, r pump station and force main is a feasible alternative, and should specify the entity which would perform this emergency relief construction in the event of sink malfunction.

FIELD MEASUREMENT OF SINK-HOLE DISCHARGE CAPABILITY

Either a staff gage or continuous recorder can be mounted at the low point of the sink. During the run-off event, the variation in ponding level can then be recorded. If the sink environs have been mapped and inflow either recorded or determined computationally through one of the foregoing hydrograph procedures, then a storm routing process will yield the sink outflow rating.

CHAPTER 5

ENERGY DISSIPATORS

Point discharge from a culvert or retention basin often conveys high velocity flow which may tend to degrade the receiving channel or adjoining property. Generally, any velocity over about five feet per second will have an erosive effect on earth. In order to protect the contiguous property, it may be desirable to install some form of revetment on the area in question. If, however, the adjoining tract is being put to some use incompatible with revetment, it them behooves the installation of an energy dissipator on the point discharge facility.

There are a number of energy dissipators which apply to differing situations. The designer may choose to select any one of several effective types, but for economy, ease of design, and a wide range of applications on small, urban projects, the impact basin has met with wide acceptance. Plates G-3 through G-5, Appendix "G", Part 3 portrays an impact basin configuration tested by the Bureau of Reclamation. A chart is shown which enables the designer of a relatively small project to select the proper geometric for impact basin detailing.

There are instances where rip-rap may serve effectively as a dissipator, but this primarily applies where discharge is relatively low. Plate G-2, Appendix "G", Part 3 portrays a curve defining stone size necessary to withstand stream velocities.

CHAPTER 6

100-YEAR FLOODING

(A) DETERMINATION OF 100-YEAR FLOOD LEVELS

Chapter 2 (D) portrayed a simplified method of determining the 100-Year flood level in certain circumstances where formal flood mapping was not available. Every community should have a comprehensive flood plain map which not only includes major rivers and creeks, but all of the lesser tributaries as well. Subdivision drainage easements and roadside ditches are often neglected as sources of flood damages, but in fact these drainage elements are the cause of more extensive and frequent flood damages than hat on riparian properties adjacent to main watercourses.

Sink-hole areas, in particular, are frequently slighted in flood plain mapping determinations. Chapter 4 indicated that flood easements should be impressed around sinks to an elevation which would accrue from the first three hours of a 100-Year inflow, assuming no outflow unless verified from field measurements.

Subsequent to the 100-Year flood level determination, an additional one foot of freeboard should be used for all critical damage points in designing a new project. Without this margin of safety, wave wash and flow impediments from temporary accumulations of debris can quickly nullify the computed 100-Year level.

(B) FLOOD PREVENTATIVE MEASURES

Existing flood prone buildings often have characteristics which lend to flood-proofing. Such measures are rarely desirable in a new structure, but may be the only way to minimize or prevent periodic inundation of a floor level. Typical of flood-proofing devices are beaming the rear yard in conjunction with a low-flow outlet/check valve and sump combination, construction of area-way wingwalls with a removable bulkhead, or similar measure tailored to meet a specific need. These methods, however, can become impractical when flood depths are extensive.

Community financed channel improvements or storm water retention facilities should always be encouraged as a long range solution to flood prevention.

CHAPTER 7

USEFUL CONSTRUCTION PRODUCTS

There are a number of hydraulically oriented construction products which are either new or have not yet circulated into particular urban areas and which may have considerable value to the economy, functionality or durability of specific projects. It is emphasized that no product is ideal for all applications, but the designer should be aware of as many applications as possible to effectively serve both the project and community interest.

Gabions-
A gabion is a galvanized wire or polyethyline-coated wire basket which is field assembled and filled with stones of appropriate size. Gabions are manufactured in various sizes and shapes and are used as retaining walls, channel linings, groynes, ditch checks, and other hydraulic structures. They have been in use for many years in Europe and Canada, and are used extensively in certain areas within the United States. They have both advantages and disadvantages for every application, but several of the chief benefits derive from economy of placement with unskilled labor and esthetic appearance if installed properly.

Fabric-formed mats, pumped concrete-
Where existing channels must be rapidly protected or reconstructed and de-watering or construction access is a problem, at least one manufacturer produces a double-layered fabric with interconnections which can be rolled down a channel slope and filled with pumped concrete.

Mulch-netting combinations-
One manufacturer has developed a bio-degradable netting interwoven with paper mulch strips which serves the dual function of mulch and net. After seeding and fertilizing of slopes, this fabric may be rolled down a slope with reasonable assurance of establishing a vegetative cover without re-working eroded areas. This fabric is also very effective in maintaining moisture on the seeds, even in very dry periods. Generally no watering is necessary as in the case with sod or some other types of mulch.

Sloped headwalls-
While not a product per se', sloped headwalls may frequently be used in lieu of vertical headwalls as an economy and as a hydraulic performance enhancement.

All of the foregoing are but several of the many products or methods being used with which the designer should be familiar.