American Public Works Association

SPECIAL REPORT

PRACTICES IN DETENTION OF URBAN STORMWATER RUNOFF

AN INVESTIGATION OF CONCEPTS, TECHNIQUES, APPLICATIONS, COSTS, PROBLEMS, LEGISLATION, LEGAL ASPECTS AND OPINIONS

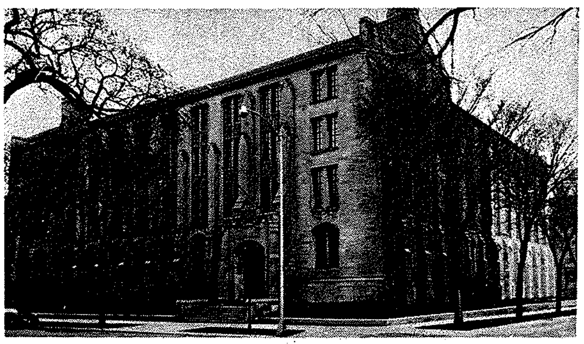
SPECIAL REPORT NO. 43

NCSPA

ABOUT THE APWA

Public works facilities and services are of growing importance to virtually every individual and particularly to those living in urban areas. Many persons are responsible for the development and maintenance of these facilities and services. The purpose of the American Public Works Association is to provide a common meeting ground for administrators, engineers and other responsible officials whose work pertains to this important field of human endeavor, and to promote the advancement of improved practices which best serve the interests of the general public.

The American Public Works Association was organized in 1937 through the merger of the American Society of Municipal Engineers—founded in 1894—and the International Association of Public Works Officials—organized in 1919. It is a non-profit organization which devotes its efforts to the fulfillment of these specific objectives: collect and disseminate information pertaining to public works activities; promote cooperation among all persons and organizations concerned with public works problems; sponsor research projects and committee work so that members may pool their resources and unite their efforts in the study and solution of common problems; stimulate and encourage the advancement of knowledge and the attainment of proficiency in the field of public works engineering and administration; provide opportunities for consultation and the exchange of ideas and experiences; inform members of opportunities for advancement and encourage the adherence by all members to high business and professional standards.



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Headquarters Office of the

AMERICAN PUBLIC WORKS ASSOCIATION

and Other National Organizations of Public Officials

PRACTICES IN DETENTION OF URBAN STORMWATER RUNOFF

An Investigation of Concepts, Techniques, Applications, Costs, Problems, Legislation, Legal Aspects and Opinions

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FOREWORD

Experience has shown that most of the more serious flooding situations are "created." Usually, this occurs from the transportation of more stormwater to a given area than can be carried away. Years ago, engineers determined that it was economical to construct sewers to transport and dispose of stormwater runoff. While this concept is basically sound and the approach logical, this method of handling stormwater runoff is not effective unless the entire watershed adheres to a uniform policy and follows established guidelines. Unfortunately, the only communities that are usually concerned are those in downstream areas where flooding occurs. This lack of concern leads to ever-increasing flooding problems unless well-conceived, cooperative stormwater drainage and flood control programs are undertaken throughout the entire watershed and pursued diligently.

Regardless of what decisions are made in a community concerning how to handle stormwater runoff, there results a selection of space for its temporary storage. It may be decided to store it in ponds, on flat roofs, on parking lots – or perhaps no decision will be made. In the latter instance, the stormwater may find a resting place in highway underpasses, yards or within buildings. The concept of temporarily storing excess stormwater runoff to prevent local flooding, and then releasing it at a regulated rate to prevent flooding downstream, is an important fundamental principle in stormwater management. It is extremely important in areas of gently-sloping terrain.

It is possible to determine the rate at which stormwater can be routed through a watershed without creating problems. Since this safe capacity will normally be far below the anticipated inflow of stormwater from the watershed for the return frequency rainfall chosen for design purposes, it is required that the excess be stored. The ideal design begins with storing of excess stormwater runoff as close as possible to the ridge lines that divide and subdivide a watershed. In other words, it is best to hold the stormwater as close as possible to the point where it falls as rain for as long as necessary and to take precautions so as not to create more problems than have been solved. This concept of stormwater management is most effective when practiced on the higher, more dominant land to prevent the lower, more servient land from flooding.

This report presents the findings of an exhaustive study made of all aspects of on-site detention of excess urban runoff as it relates to reducing local flooding, soil erosion, siltation and pollution. Hopefully, the information presented herein will be useful to all persons who have some responsibility for planning, designing, providing, financing, regulating, operating or maintaining urban drainage systems.

A special acknowledgement is made of the fine assistance received from Stifel W. Jens who prepared background reports of several projects involving on-site stormwater detention. These were used in the preparation of this report. A great deal of help in writing the draft of this report was provided by John Reindl who was, at that time, a graduate student in the Environmental Engineering Program at the University of Wisconsin – Milwaukee. Assistance in editing the final draft and in obtaining information from public agencies and practicing engineers was provided by Richard H. Sullivan, Assistant Executive Director for Technical Services, American Public Works Association. Typing and many other tasks were carried out faithfully by Audrey Poertner. The many persons who participated in this study are listed on the preceding pages.

Herbert G. Poertner
Engineering and Research Consultant

ABSTRACT

On-site detention of runoff was investigated as an alternative to other methods of urban stormwater runoff management. It was found that this method, which involves collecting excess runoff before it enters the main drainage system, can often be applied as an effective and economical means of reducing peak runoff flow rates to lessen or eliminate problems of flooding, pollution, soil erosion and siltation. The captured runoff sometimes can be used to augment water supplies for potable or non-potable uses, and the detention facilities can be designed to serve multiple-purpose uses, especially recreation.

The use of on-site detention facilities has been given emphasis in those urban areas where flooding is a frequent problem. A 1972 survey of selected local jurisdictions in urban areas of the United States and Canada revealed that more than 1,400 facilities were operational in about 100 local jurisdictions reporting applications. Because only about 500 jurisdictions were contacted, the actual number of such facilities in existence is thought to be many times more. Most of the representatives of the 230 public agencies and 40 engineering firms that responded to the survey questionnaire consider on-site detention of runoff in urban areas to be a useful stormwater management method that is worthy of study and implementation.

Many applications of the method were identified in which substantial cost savings over a conventional urban stormwater drainage system had been realized by incorporating on-site detention into the system. The use of on-site detention facilities in managing runoff in urban communities can be expected to increase as the techniques involved become better developed and understood and as the benefits become better documented and publicized.

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CHAPTER 1
OVERVIEW, FINDINGS AND RECOMMENDATIONS

Various methods are used for the control of stormwater runoff. In some areas of the country, systems of separate storm sewers are used. A few large cities with systems of combined sewers have investigated the possible use of underground tunnels to store combined sewage overflows for later treatment. Other cities have considered the use of underground tanks for detaining sewage flows in combined sewers.

Many urban governments have studied the problems of peak sewer flows as they are aggravated by inflows from roof drains. As a result, some cities have required that all roof drains be disconnected from combined or sanitary sewers. A number of urban governments also require connections of building foundation drains to be removed.

Urban governments and other local public agencies having responsibility for stormwater drainage and local flood control have been giving increasing attention to practical and economical means of reducing the losses and inconveniences caused by flooding from surface runoff. In many areas, local jurisdictions have adopted legislation requiring that land developers take steps to assure that peak runoff flow rates after development are not in excess of those that prevailed prior to development.

To meet the requirements of local public agencies for controlling runoff rates, some developers of commercial and industrial properties have installed devices on roof drains of buildings with horizontal roofs to reduce flow rates into the drains, thereby minimizing the effect of roof drainage on peak sewer flows where downspouts are connected to sewers.

Many developers of commercial properties have found it advantageous to construct parking lots with restricted surface drains designed to detain stormwater runoff. Often, this is the only practical means for meeting requirements of the local jurisdiction for limiting the peak runoff flows. This is especially true for developments where little open space is available for constructing detention ponds or basins.

Developers of single-family residential subdivisions and multifamily residential complexes in many parts of the country have constructed ponds and basins in the open spaces of these developments for capturing and detaining stormwater runoff flows. In some areas, these ponds are also intended to reduce soil erosion and the accompanying siltation.

In addition to the above ways of detaining runoff on the site where it originates as rainfall, new concepts for handling and using runoff are being investigated and developed. These include: the use of porous pavements for absorbing rain water and snowmelt, the capturing of stormwater for beneficial uses, and new ways to detain rainfall on rooftops.

Storm Water Management Problems

The problems of urban stormwater management that were investigated can be classified in three major groups: (1) local flooding; (2) pollution resulting from combined sewer overflows, storm sewer discharges and soil erosion; and (3) problems associated with the beneficial use of stormwater.

Local Flooding: Although no data on the evaluation of flood losses is available, estimates of the American Public Works Association in their publication, *Urban Drainage Practices, Procedures and Needs,* 1966, put the cost at over $1 billion per year. This estimate is said to indicate only the general magnitude of the losses and it is expected to mount as urbanization increases. The major losses from flooding include the damage of real and personal property, loss of human and animal life and disruption of natural streams and fish habitats. Flooding also causes inconvenience, nuisances and delays; and storm sewer discharges and unavoidable overflows of combined sewers into receiving waters can produce health hazards.

To document local flood losses sustained in urban areas, an example is given below of extensive flooding that resulted from torrential rainfall in urban and suburban areas of northeastern Illinois in August, 1972. The areas hardest hit were communities located west of the City of Chicago in Cook, DuPage and Will Counties. The storm started Friday, August 25th at about 5 p.m. and lasted until 1 a.m. Saturday morning. Total rainfall was 6.88 inches (unofficially) in one locality and 2.49 inches (officially) several miles away. Over $23 million in damages were reported in preliminary estimates. Electricity was cut off from 40,000 customers and phone service to 45,000 homes was interrupted for days by problems resulting from the flooding. Many homes were flooded with up to 11 feet of water. Some individual well water supplies were polluted, although public water supplies were tested and found to have no contamination.

In a flooding incident such as this, on-site detention facilities would have been of vast help by delaying the entry of stormwater into the sewer systems and rivers. The stormwater could have been released from storage facilities over a long period of time to reduce, if not eliminate, much of the flooding that resulted from sewer surcharging and high stages in rivers, creeks and ditches. It would not have been possible to detain all of the excess runoff from all affected areas, but an area-wide system of detention facilities may have reduced peak runoff discharges to levels that the receiving streams and sewer systems might have been capable of handling.

Pollution: Pollution of stormwater runoff comes largely from four major sources:

1. contact with municipal and industrial wastes in combined sewers;
2. litter, debris and chemicals on parking lots, streets and alleys;
3. silt resulting from soil erosion; and
4. pesticides and fertilizers washed off vegetation.

The pollution from combined sewers is obvious. The high flow rates in such sewers during storm periods carries wastes deposited in the sewers, during low flows, to the outfall. Sanitary waste commingled with stormwater is forced out of sewer inlets and manholes, and is also discharged to receiving waters during unavoidable overflows from intercepting sewers. The problem of pollution from combined sewer overflows has received considerable attention by the Federal Government as evidenced by its extensive funding of research in this field.

The pollution aspects of urban runoff from street debris are becoming more and more obvious. In his paper, *Treatment of Urban Runoff*[1], F.J. Condon describes a hpyothetical situation by comparing the pollution from urban runoff with the pollution from sanitary sewage and secondary treatment plant effluent. He states that the effects of this pollution, especially the heavy metals, is not adequately defined to determine its seriousness, but that it is obvious that stormwater runoff is highly polluted. Mr. Condon notes in his paper that data on the pollution load of stormwater runoff is often contradictory. In some studies, for example, it was found that antecedent rainfall or street cleaning more than 24 hours prior to the rainfall had no effect on water quality. Other investigators found that antecedent events up to 10 days previous to the rainfall had measurable effects on water quality. Nevertheless, the possible need for treatment of runoff to control pollution of receiving streams from drainage of streets and other urban areas is recognized. In the future, discharge of untreated stormwater from separate sewers into lakes or rivers may no longer be acceptable.

Soil erosion is a third area of pollution of stormwater. In developed areas, soil erosion can be very minor; but land under development can contribute large amounts of sediment through erosion. Soil erosion is estimated at over 1 billion tons of soil a year, with land under construction contributing from 50 to 40,000 times the erosion of undeveloped or developed land. Erosion is considered by some to be the largest single source of stream pollution. The application of on-site detention of stormwater runoff to control erosion and accompanying siltation is covered in detail in Chapter 6.

Another significant source of stormwater pollution can be pesticides and fertilizers washed off vegetation.

Beneficial Use of Stormwater: As many

of the areas of our nation have developed and increased in population, the need to develop adequate water supplies has grown. In some areas, surface and groundwater supplies are sufficient to meet expected growth; but in other areas surfacewater supplies are not adequate and groundwater supplies are being rapidly depleted. Stormwater can be used to augment depleted water supplies. The stormwater may be collected, treated (if necessary) and used for groundwater recharge, or it may be collected for direct use in applications not involving human or animal consumption. In previous years, stormwater runoff was regarded as an evil to be disposed of as quickly as possible. It is now often considered as a valuable resource not to be wasted. Stormwater runoff has been aptly termed "a resource out of place." Use of stormwater will depend on two factors – the ability to collect and store such water, and the ability to economically treat the polluted stormwater runoff.

Alternative Solutions

In addition to on-site detention of runoff, other alternative and/or supplementary means of providing solutions to the problems of urban stormwater management encountered in abating or reducing pollution and local flooding include the following:

1. separation of combined sewers;
2. enlargement of sewer system capacities by constructing relief sewers;
3. temporary storage of stormwater in systems of underground tunnels;
4. construction of stormwater treatment facilities;
5. enlargement of present wastewater treatment facilities to handle peak flow rates;
6. infiltration or injection of stormwater into underground waters;
7. flood-plain zoning to limit, or prevent, the development of land in flood-prone areas;
8. flood-proofing of structures; and
9. soil erosion and siltation control measures.

Not all of these alternatives are mutually exclusive to stormwater detention, or to each other. For example, the recognition that urban stormwater runoff is polluted will lead to requirements for treatment. The use of stormwater detention and treatment of stormwater runoff are complementary solutions because detention is an essential step in treatment.

Some factors to consider when comparing the alternatives, and which were investigated and considered in this study are:

1. system reliability as a function of nature, man, and available technology;
2. degree of effectiveness of the method in preventing and/or reducing flooding and pollution problems for various rainfall intensities and duration;
3. flexibility of the proposed solution for adapting to changing urban conditions and possible future requirements of stormwater treatment and/or reuse;
4. evaluation of corollary advantages and disadvantages of the proposed solution;
5. ease of implementation of the solution, considering the potential inconveniences caused by the solution and the availability of needed resources;
6. initial construction cost; and
7. operation and maintenance costs.

Other factors that should be considered by local public agencies in making decisions concerning the selection of methods for handling runoff are:

1. legal basis;
2. needed local and/or state legislation;
3. financing, construction, operation and maintenance;
4. compatibility with methods adopted and/or planned by other jurisdictions within the same watershed; and
5. public acceptability of the proposed management, planning and implementation.

THE STUDY

The objective of the study was to investigate and report on current practices in providing, operating and maintaining facilities for the temporary storage (detention) of excess urban stormwater runoff on the site where it originates. Concepts, techniques, applications, costs, problems, legislation, legal aspects and opinions were of prime interest. The study focused upon the prevention and mitigation of problems associated with providing and operating satisfactory stormwater drainage systems and controlling local flooding, water pollution, soil erosion, and siltation resulting from local soil erosion.

A secondary purpose of the study was to evaluate on-site detention of runoff as a viable alternative to other stormwater management methods used, or planned, by urban communities for controlling runoff. Another area of interest and investigation was the capture and use of urban stormwater runoff for water supply, recreation and enhancement of urban land areas.

The study included investigations of:

1. temporary ponding on ground surfaces;
2. temporary ponding on paved areas;
3. temporary ponding on roofs of buildings;
4. storage in permanent ponds having provision for variable depth;
5. treatment of ground water surfaces to absorb and/or detain water;
6. routing of runoff to infiltration pits to both recharge groundwater supplies and reduce total flows to drainage systems;
7. collection of stormwater for supplementary water supplies; and
8. reducing stormwater runoff rates to reduce soil erosion and siltation.

Conduct of the Study: Inputs to the study were provided by more than 100 participants serving either as symposium participants, consultants, or members of the study team. The project activities included the following:

1. conducting three symposia to discuss on-site detention of runoff (held in Chicago, Denver and Fairfax County, Virginia);
2. literature search of articles on the subject of stormwater management, focusing upon on-site detention of stormwater runoff;
3. survey of public agencies and engineering firms;
4. study of applications of on-site detention of runoff;
5. study of underground storage of runoff;
6. study of new ideas for on-site detention of stormwater runoff;
7. study of legislation and legal aspects of detention of stormwater;
8. examination of factors associated with maintenance, operation, costs, financing, economics, engineering effectiveness, design criteria, and implementation impediments;
9. study of unconventional methods to detain runoff;
10. study of removal of roof drains from sanitary sewers; and
11. study of the use of impervious membranes to trap and collect runoff for beneficial use.

FINDINGS

The general findings of this study, expanded upon in other sections of this report, include the following:

1. On-site detention of runoff can be an effective, economical method of stormwater management.

2. Besides controlling local flooding and pollution from combined sewer overflows, on-site detention techniques can be used to capture runoff for supplementing water supplies or for multiple-purpose use. It is also a useful technique for erosion and siltation control.

3. Use of on-site detention techniques is relatively widespread and has been in general use for at least 15 years. About 100 respondents to a questionnaire survey of approximately 500 randomly-selected local public agencies in the United States and Canada reported the existence of about 1,400 facilities.

4. The principal disadvantages to the use of on-site detention in runoff control are the problems of maintenance and operation of facilities. The problems are twofold – the actual performance of the maintenance and operation, and the delegation of responsibility for this work either to local public agencies or land owners.

5. Many of the key personnel of local jurisdictions were found to have little, if any,

experience with the concept of on-site detention of stormwater runoff.

6. Most of the respondents to the survey questionnaire stated that the concept of on-site detention was worthy of consideration.

7. The use of on-site detention of runoff was found to be the most desirable method of runoff control in some flood-prone or erosion-prone areas of the country.

8. New methods of stormwater detention (such as the use of porous pavements) and other methods of reducing runoff rates appear to have application where climate, topography and soil conditions are suitable.

9. Attitudes on the use of on-site detention of runoff were generally favorable; however, land developers want to be assured that applicable requirements of local and state public agencies are applied uniformly and with flexibility.

10. Legislation pertaining to on-site detention of stormwater ranges from very detailed requirements to almost none. No building codes were found to forbid detention of rainfall on roofs of buildings. Several local building codes specified criteria and standards. Local requirements for on-site detention of runoff were most often found in subdivision regulations, zoning ordinances, sewer permit ordinances and local building codes.

11. Legal aspects of detention storage were found to be poorly defined. Drainage laws were found to vary considerably throughout the country and the legal aspects of detention storage, as a relatively new concept, were also found to vary. Safety hazards of detention ponds, the authority to require on-site detention, the amount of storage required, the legal responsibility for maintenance and operation, the burden of facility cost, and the relationship of detention storage to water-right laws all are important considerations.

12. Costs of stormwater detention facilities were found to vary with the type of facility as well as its geographic location. Cost figures identified include $5,500 per acre-foot of storage (estimated by the Metropolitan Sanitary District of Greater Chicago) to $30 per residential lot of average size for sediment basins in Maryland.

13. Several methods of financing are available. It was found that land developers were often required to bear the entire cost of the construction of detention facilities in the same fashion that they must pay for sewer construction. In existing land developments. costs were not usually borne directly by property owners in the area served by the facility.

14. The economics of on-site detention were often favorable in both new developments and in existing urbanized areas. Besides controlling problems resulting from excessive stormwater runoff rates, detention storage facilities can be utilized to: serve as aesthetic improvement of an area, provide recreational opportunities, and supplement local water supplies (in some geographic areas).

15. Design of detention storage facilities is complicated by a number of factors including accurate determination of runoff rates (both existing and future), availability of space for construction of facilities, capacity of downstream facilities to handle outflows, and the need to build the facilities to be aesthetically pleasing and compatible with the local environment. The design of detention storage on rooftops is impeded by the reluctance of builders, architects and building owners to store water purposefully on roofs of buildings.

16. Problems of implementation of on-site detention of stormwater are not significantly different from the implementation of other public works facilities, especially in areas where the concept is new. Educational programs documenting the need and usefulness of such techniques can be helpful.

17. The biggest problem of implementing effective stormwater detention programs is in obtaining cooperation from neighboring local jurisdictions. Since major floods in a community are often the result of excess

runoff flows from nearby upstream communities, flood-prone areas must depend upon upstream communities to implement programs of flood control which may provide little direct local benefit to these neighboring communities.

18. The removal of connections of roof drains to sanitary or combined sewers is a method commonly used to reduce the hydraulic loading on sewers and sewage treatment plants. A successful program of removal of roof drain connections can provide an effective and economical means of reducing local flooding and pollution problems if satisfactory means are employed on-site to handle resulting roof drainage.

19. The use of on-site detention of stormwater is not a cure-all solution. Although many studies favor the use of detention to reduce runoff flow rates to levels capable of being handled by existing sewers, other studies have favored the construction of new sewers (relief sewers) sufficient to handle the large urban runoff without causing flooding. The evaluation of the alternatives should be based upon economics and anticipated problems of maintenance and operation. If relief sewers are proposed, careful investigations should be made of the possibility of aggravating downstream flooding.

20. On-site detention of runoff may be effective in reducing stormwater pollution – by preventing overflows of combined sewers and reducing flow rates in sewers to levels at which treatment of urban runoff is feasible.

21. Because on-site detention of runoff is a relatively new concept, further studies of all aspects of this method of managing runoff are needed to improve its effectiveness and to develop new ways to achieve stormwater management goals from both technological and administrative viewpoints.

22. Flood plain zoning was found to be an important and effective counterpart to on-site detention of runoff for the development of comprehensive stormwater management programs.

CONCLUSIONS

The study of the use of on-site stormwater detention techniques and their advantages and disadvantages have led to the following conclusions:

1. On-site detention of urban runoff is a viable part of a solution to runoff problems in stormwater management, offering both economy and the opportunity to put stormwater to use rather than treat it as a waste material to be disposed of promptly.

2. Techniques involving on-site detention of stormwater are not always applicable in solving all problems encountered in controlling urban runoff; but, in many cases, on-site detention may be an important part of the best solution available.

3. Future research concerning on-site detention of stormwater will aid in improving the effectiveness and adaptability of the method. Especially important will be mutually acceptable and reliable methods of providing and delegating needed maintenance and operation duties.

4. Dissemination of information on the methods and benefits of on-site detention will probably result in its increased usage. At present, people in many places are unfamiliar with the concepts and techniques even though attitudes on detention storage are generally favorable.

5. Legal aspects of stormwater detention are not well-defined, and many questions need to be answered to facilitate its use.

6. Financing of stormwater detention facilities can be by several methods, especially in multiple-purpose projects.

7. The short-term effectiveness of on-site detention for controlling flooding, pollution, soil erosion and siltation problems has been documented; long-term effectiveness seems probable, but has yet to be substantiated for different methods of application.

8. Design practices for on-site stormwater detention facilities are complicated by local political conditions and

problems of varying climate, topography and soil characteristics; however, design methods and techniques are available and, when used thoughtfully, can be applied satisfactorily in designing the most common forms of stormwater detention – rooftop, plaza, parking lot, and ponds and basins in open spaces.

9. Implementation of on-site stormwater detention facilities presents no unsurmountable problems in places where local physical conditions are amenable to their use.

10. A watershed approach to stormwater management problems will often be the best, or only way to solve problems of flooding, pollution, soil erosion and siltation resulting from urban runoff.

11. Removal of connections of roof drains to sanitary sewers or combined sewers can be an effective method for reducing the loadings on these sewers to help solve flooding and pollution problems – and such removals accentuate the desirability and effectiveness of on-site stormwater detention.

12. Urban runoff, even when kept separate from municipal and industrial wastewater, may some day require treatment. Control of runoff by on-site detention will be useful in reducing peak runoff flows and will facilitate the implementation of economical and practical treatment methods.

13. The exclusive use of on-site detention of runoff, or any other single means of runoff control, is not usually sufficient for solving the problems of local flooding that exist in many urban areas. Other compatible flood control measures, such as flood-proofing and flood plain zoning are often necessary adjuncts to provide effective flood protection.

RECOMMENDATIONS

1. Public agencies, at all levels of government, having stormwater management responsibilities are encouraged to study and consider the use of on-site detention of urban runoff with a goal of implementing stormwater detention programs on a watershed basis in flood-prone areas.

2. Further research should be performed to facilitate the development of programs for urban stormwater drainage and procedures for management of urban stormwater. This should include a detailed study of concepts and techniques, such as on-site detention, as well as studies of alternative means of solving financial, administrative and technical problems pertaining to implementation, operation and maintenance.

3. In providing facilities, local stormwater management agencies should give careful consideration to developing the best attainable balance between collection, detention and treatment of stormwater. Each of these factors may be likened to the equal importance of each of the three legs of a stool. This consideration is particularly apropos in view of the possibility that all urban runoff, whether collected separately or in combined sewers, may in future years require some measure of treatment before ultimate discharge.

CHAPTER 2
ATTITUDES AND OPINIONS

The introduction of any new method or procedure is greeted by varying degrees of skepticism and acceptance. Stormwater detention, although not practiced intensively in past years, is not a new method of stormwater runoff management. Stormwater detention facilities have been used for 15 years or more in some places in the United States. Although the concept of *on-site* detention of runoff is new in many areas of the country, its use is relatively widespread. Attitudes and opinions on the use of on-site detention were obtained through activities connected with this project including surveys of public agencies and engineering firms, three symposia (conducted in Denver, Chicago, and Fairfax, Virginia) and engineering studies of drainage system alternatives.

Surveys were made by the APWA Research Foundation. Questionnaires were sent to about 500 public agencies and 130 engineering firms in the United States and Canada.

APWA Survey

It was evident from the APWA survey that on-site detention of stormwater runoff for many jurisdictions had not been considered Out of the 230 responses, 86 indicated no awareness of on-site detention. Only 71 responded that the concept was not new to them, while 73 did not answer the question.

When asked their opinions as to the worthiness of on-site detention, 118 responded that the idea was worthy of consideration, while only 24 said that the idea was not worthy of consideration. Seventy-two jurisdictions replied that the concept was being implemented in their respective areas, while 65 responded that the concept was being considered, or had been considered, but had not been implemented. On-site detention was viewed as too difficult to implement and enforce by 42 respondents while 69 respondents did not share this opinion.

The use of on-site detention of stormwater runoff was considered to have corollary benefits as well as disadvantages. The major corollary benefits seen were improvement of area aesthetics and provision of recreational opportunities and facilities. The biggest disadvantages were viewed as the nuisance problems of algae growths, mosquito breeding and the poor aesthetics of empty detention basins located on ground surfaces in populated areas.

The survey of engineering firms did not seek attitudes and opinions as much as did the public agency survey; however, some questions were included concerning possible adverse factors. The engineering firms responded that problems of maintenance and operation would be the major adverse factor, although there also would be problems of safety, nuisance and administrative control.

A Regional Evaluation

The Northeastern Illinois Planning Commission (NIPC) in 1972 conducted a survey and conference to determine approaches to solve the area's stormwater management problems. Appendix B, NIPC Conference, describes the extensive program which was conducted. Out of the study procedure came a strong recommendation that on-site stormwater detention be used widely. It was also recommended that state legislation be enacted to define which public agencies have responsibility for stormwater drainage and flood control. The need for greater funding aid for flood hazard reduction and the importance of accurate information concerning flood plains were also reflected in the high-priority list of recommendations.

Symposia

As a part of this study, three symposia were held during 1972 on the subject of on-site detention of stormwater runoff. The symposia, which were conducted in Chicago, Illinois, Denver, Colorado, and Fairfax County Virginia were convened for the purpose of obtaining information concerning experiences and opinions of persons of various professions. The participants were selected to include representatives of public agencies (at all levels of government), engineering firms, land developers, law firms, and special districts having stormwater management responsibilities.

The attitudes of public officials, land developers, lawyers and engineers were discussed at these symposia. Many of the symposia participants were persons who had experience in some aspect of providing or operating stormwater detention facilities, or who were interested in applying the techniques. Their attitudes and opinions were, therefore, based for the most part on personal experience.

Generally these people were favorable in their attitudes towards on-site detention as a method for managing urban runoff. Only the land developers and their lawyers expressed reservations about the use of the technique. Their major objections were to the inflexibility of local laws and requirements which afforded them little, if any, opportunity to use alternative methods for handling stormwater runoff. They told of cases where other stormwater management methods might prove to be better than the method specified by local legislation or regulations – where the rigidness of the law prevented the use of alternative methods. They also felt that the use of large, jointly-used detention facilities was preferable to the use of a large number of smaller individual detention facilities each of which is intended for use by only a single development.

Questions of long-term effectiveness and beneficial use were discussed at the symposia. Although detention facilities appear to be useful and beneficial at the present time, some participants raised the question of the desirability and effectiveness of the method as a long-term solution to flooding problems. Large commitments of land made today might prove to be unjustified in the future, especially if other methods of stormwater management that do not require large land commitments can be satisfactorily used in lieu of on-site detention techniques.

Engineering Studies

The bibliography included in this report contains many references to engineering studies that have favored the use of detention techniques for management of stormwater runoff. In some instances, the detention technique is favored because it reduces the size, and hence the cost, of sewer pipes needed for stormwater drainage because the runoff is discharged from the detention facilities into the sewers at a low flow rate over a long time period. In other instances, detention of runoff is favored because the detention facilities can enhance the aesthetics and multiple-purpose use of the open space provided in a land development.

There are many cases where on-site detention of runoff is not favored over other methods. Sufficient space is sometimes not available for the needed facilities. In some instances, representatives of local public agencies having jurisdiction over stormwater management fear that the maintenance problems will outweigh the advantages of the detention method. This attitude is understandable because storm sewers usually require little maintenance and are out of sight, whereas stormwater detention facilities usually require an appreciable amount of maintenance effort and are usually visible to the public. Finally, the use of stormwater detention techniques are not favored in some areas where downstream flooding is not regularly a major problem. A city on a large lake, for example, may prefer to discharge the stormwater as quickly as possible into the lake.

Summary: The use of on-site detention of stormwater runoff is not commonplace; however, the technique has been in use for at least 15 years. As urbanization progresses and runoff flow rates from developed land increase, the need for effective flood control and stormwater management becomes more evident. The use of stormwater detention methods to reduce peak runoff flows is gaining in favor. This technique is compatible with the public's desire to make our cities more enjoyable by the inclusion of open space and recreational facilities. This public attitude has been instrumental in promoting the concept of on-site detention. A 1973 conference on flood control in northeastern Illinois attended by 550 local public officials and engineers clearly revealed that on-site detention of stormwater is the locally recommended method of managing runoff. It seems likely that the use of on-site detention will become more popular as knowledge of the concept spreads and as design standards and criteria for stormwater management and studies of environmental impact become an integral part of the planning and engineering of stormwater management facilities.

Legislation and Administrative Needs

"On-site detention" of stormwater runoff is a term that few legislators comprehend any more fully than do most of their constituents. The average citizen finds the subject unexciting in terms of civic or political involvement unless property under his ownership or management is poorly drained or subject to flooding. Consequently, few legislators have, in past years, felt a need to crusade for the passage of legislation that would provide the legal basis for improving drainage and reducing local flooding by on-site detention of runoff.

Although flood control has not always been a governmental responsibility in the United States, it has been a major concern of citizens. In recent years, as engineering and technical data have been developed and legal, financial, and policy determinations made, drainage and flood control needs have caught the attention of many legislators. Public interest and concern has often been aroused in the aftermath of flooding disasters in many parts of the United States. One of the most destructive recent storms was hurricane *Agnes* which inundated large areas of several states, particularly areas in the vicinity of Wilkes Barre, Pennsylvania.

It would be impractical to design and construct stormwater detention facilities to protect property from the flooding that is associated with storms of the magnitude and extent of Agnes. However, most rainstorms that occur in a given area are amenable to practical measures that can be applied to ameliorate potential flooding damages. A first step in this direction is for local stormwater management agencies to study, devise and adopt effective legislation and enforcement programs to regulate peak stormwater runoff flows from new land developments and from existing land developments where enlargements or improvements are planned.

Why Legislation? Common sense has determined that in any drainage basin damages are lessened and resources are preserved if stormwater runoff rates are reduced rather than increased. Under the common-enemy concept, a property owner can rid himself of stormwater by fighting it off as best he can; however, this can cause his neighbor downhill to suffer additional damages. If we apply this simple case to a multitude of property owners in an urban drainage basin, we obtain a perspective of the nature of urban stormwater problems. This example helps explain why local governments have become involved in control of stormwater runoff, although legally they do not have to. Detaining stormwater runoff on a particular piece of ground, or within a particular drainage basin, is now a common way of solving the excess runoff problem, or at least some of the problem. This technique works and detention facilities are more economical in many, if not most, cases than traditional storm sewer facilities in handling the same runoff. Therefore, the adoption of local legislation to control runoff flow rates becomes a matter of adopting a new philosophy to require property owners to handle excess stormwater, in lieu of ignoring the problem.

Legislation, then, is necessary for several reasons: first, to clearly delineate the problem of handling excess runoff in urban areas; second, to define the responsibility any owner has, or should have, to control the flow rate of excess runoff from his property; and third, to provide a general solution or remedy by means of legislative definition rather than a multitude of lawsuits among individual property owners.

From a public policy standpoint, it appears that there are at least three premises for public legislation. These are:

1. to protect the health, welfare and safety of the public;
2. to conserve excess stormwater runoff

and make it available for beneficial use by the public; and

3. to determine and implement the best and most equitable methods of providing stormwater runoff control facilities and programs so that those who benefit will pay in accordance with their potential benefits.

Legislative Experience: Legislation directed to the subject of on-site detention of runoff is not prevalent, as indicated by surveys and searches. Use of such legislation is usually confined to areas which have recognized the value of on-site detention in controlling problems of flooding, erosion, siltation and water pollution. This legislation develops in various forms, depending on the local jurisdiction's approach to the problem of stormwater management. Laws and regulations can be enacted by various levels of government including: (1) a local municipality (county, city, village, etc.), (2) a drainage or flood control district, and (3) the state.

Minnesota incorporates stormwater drainage regulations in a state building code. The State of Maryland requires that land developers control soil erosion and siltation, and the State empowers local jurisdictions to accomplish this in a variety of ways including requirements that land developers provide stormwater detention basins.

The Urban Drainage and Flood Control District which has jurisdiction over five counties in the Denver, Colorado area is an example of a state-chartered regional authority having powers to control excess stormwater runoff. The Metropolitan Sanitary District of Greater Chicago is an example of a countywide authority having broad powers granted under a special charter from the State of Illinois. The authority of local units of government (counties, cities, villages, etc.) in stormwater management and flood control prevails in most urban and suburban areas of the United States where special districts or authorities have not assumed this function.

Types of Legislation: Provisions for stormwater management are often made in the laws of local governments. Some of the types of legislation used by local jurisdictions to control stormwater runoff from new land developments and urban renewal projects include:

1. subdivision regulation ordinances,
2. zoning ordinances,
3. building code ordinances,
4. plumbing and sewer ordinances,
5. water pollution control ordinances,
6. flood control ordinances, and
7. drainage fee assessment ordinances, some of which provide for reducing the assessment if stormwater detention facilities are installed.

Application of Legislation: Although many areas use only one type of regulation, other areas, such as Will County, Illinois are using (or proposing to use) a variety of these methods at the same time. Use of a variety of laws helps to insure that adequate local control is placed on the construction of runoff control facilities. For example, if the provision of stormwater detention facilities was required only by the subdivision regulations of a community, a land development plat that had been approved months or years prior to adoption of the requirement would not be subject thereto. In such a case, the developer could proceed to construct the planned development upon obtaining a building permit and other permits and approvals required by the local jurisdictions involved. On the other hand, if either the local building code or zoning ordinance requires stormwater detention facilities, ordinarily the developer would be required to provide these facilities even though the subdivision plat previously had been approved.

Enforcement of local laws pertaining to land development usually includes inspection, approval of construction, and provision for fines or other penalties. For example, under the subdivision regulations of a community, the initial plat may not be approved unless stormwater detention facilities are provided for in the plans submitted for approval. Under the community's sewer permit regulations, connections to the sewers would not be permitted until adequate detention of runoff is provided. If either law is violated, penalties can usually be assessed. This, of course, is an effective means of obtaining compliance.

Water pollution laws in Maryland

recognize silt as a water pollutant, and detention ponding is used to control sedimentation from the erosion of land developments, particularly during the construction period. State flood control laws, such as in Virginia, have been interpreted broadly to allow for the inclusion of the requirement for detention ponds to control flooding.

Assessment of a drainage fee has been used by several cities in Colorado (e.g., Arvada and Boulder) to pay for the construction of drainage facilities. The legislation is structured so that the assessment is dependent upon the area and stormwater runoff rates. In Arvada, as an incentive for individual land developers to reduce the rate of stormwater runoff from their property, the assessment procedure was made flexible so that land developers could reduce the amount of their assessments by providing stormwater detention facilities.

Zoning laws as they pertain to stormwater drainage and flooding, are primarily structured to specify the minimum amount of drainage protection needed in various areas. For instance, flood protection structures or sufficient storage volume for a 100-year storm might be required for a development near the flood plain of a river, while for a development remote from a flood plain a 2-year frequency rain may be specified for design of the system of collector storm sewers. Also, flood plain zoning regulations may prohibit permanent development within the flood plain that would reduce the capacity of the flood plain for natural storage of flood waters.

Most local building codes do not require detention storage, although some public agencies, e.g., the Denver Urban Renewal Agency, require that rooftop storage be incorporated into the design of buildings. Those jurisdictions that mention rooftop detention storage of rainfall in their building codes specify various standards of construction including maximum water depth on a roof, roofslope, size of roof drainage leaders and the number of leaders for a given roof area. At least one national building code, the Building Officials and Code Administrators, International, has developed standards for detention storage of rainfall on roofs.

In most instances, the power to adopt and enforce laws governing detention of stormwater lies within the established powers of cities and counties. Because drainage regulation on a regional, total-watershed basis may prove to be more effective in solving drainage problems than institutional arrangements that are limited by political boundaries, regional drainage authorities may become more popular in the future. The creation of these authorities and the definition of their powers would require state enabling legislation in each instance. In a study done by the American Public Works Association in 1966, it was found that 53 percent of all communities in the United States larger than 250,000 population had established drainage districts and that more than one-half of the remaining 47 percent had authority to do so.

Survey Results: The types of legislation used to require and regulate on-site stormwater detention storage facilities were revealed in a survey of about 500 public agencies and 130 engineering firms across the United States and Canada. Responses were received from 230 agencies and 40 engineering firms.

Legislative and/or administrative action was reported by about 60 local public agencies. The method of requiring and regulating on-site detention of runoff by those agencies is shown in Table 1, Survey of Studies Made and Action Taken.

TABLE 1
Survey of Studies Made and Action Taken by Local Jurisdictions in Requiring and Regulating On-Site Stormwater Detention Facilities

	Studies Made		Positive Action Taken	
Regulation by means of:	Yes	No	Yes	No
Subdivision Regulations	31	115	30	141
Building Code	11	122	12	138
Zoning Ordinance	12	121	9	133
Other Statutory Requirements	18	117	18	131
Administrative Regulations	36	106	43	132

Source: APWA Study 1972

Studies were made by some jurisdictions and some adopted either legislation or administrative regulations. Some jurisdictions used more than one legislative technique to implement on-site detention storage.

A following question showed that a total of 89 jurisdictions, or less than one-half of all respondents, exercised control over requirements for on-site stormwater detention facilities. Table 2, Existence of Controls, gives a tabulation of the responses.

Table 2
Existence of Controls by Local Jurisdictions for On-Site Stormwater Detention Requirements

Control Exercised by Means of:	No. of Agencies Responding Yes	No
Controls of Any Type	89	109
Permits	62	75
Local Ordinances	53	79
Incentives	14	98
Penalties	8	101

Source: 1972 Survey by APWA

Table 3, Responsibility for Administering Controls, shows the office in which the responsibility for control of detention was placed. Most often the responsibility belonged to the city Engineer.

Table 3
Responsibility for Administering Controls

Office or Department Responsible	No. of Agencies Reporting Yes	No
City Engineer's Office	86	47
Building Inspection Office	51	56
Flood Plain Zoning Office	34	59
Sewer and/or Water Dept.	26	65
Health Department	22	66
Zoning Enforcement Office	18	68
County Public Works Dept. (or Engineer)	39	62
County Highway Engineer	15	69
Sanitary or Sewer District	14	74
Other Department	20	61

Source: 1972 Survey by APWA

Forty-two of the responding public agencies reported that their storm drainage criteria incorporate requirements for stormwater detention.

Model Legislation: The development of model ordinances and/or resolutions for the control of excess runoff could serve as an aid to local public agencies having responsibilities for stormwater management. Although at least one example of such model legislation has been drafted, it is considered by its author as preliminary and subject to revision.

The model ordinance was prepared as a guide to municipalities and counties in the State of Colorado. It is based upon providing protection against the hazards of runoff from the 100-year rainstorm event. The ordinance would pertain to new construction and would restrict peak runoff rates to those existing prior to construction by means of the provision of control structures for collecting, storing and disposing of excess runoff. In lieu of providing on-site facilities for detention of runoff and control of the release of runoff, the developer could pay a fee, as determined by the public stormwater management agency, based upon the amount that anticipated runoff exceeds the historic runoff. This fee would be used to pay for the construction of necessary facilities to accommodate the anticipated excess runoff. The fee would be assessed by and paid to the appropriate county assessor who would spread the total fee over a 30-year time period, or until the fee is satisfied.

Summary: Various forms of legislation were found to be in use in different areas for requiring and controlling facilities for on-site detention of runoff. The most prevalent of these is the use of ordinances governing subdivision regulations. Provisions of local building codes and zoning ordinances are also used. In some areas, requirements for on-site detention are specified by more than one local ordinance.

Legislative controls and administrative regulations may be enacted by special districts or regional authorities, where such exist. In most urban areas, the legislation and control of stormwater drainage facilities and programs is assumed by the local municipality. Where special drainage districts or authorities are in operation, legislation and controls imposed by local municipalities must be no less demanding than the requirements of the higher authority.

Some state governments impose requirements for on-site detention of runoff. Maryland does this by means of state laws pertaining to the control of soil erosion and siltation. Other states, such as Minnesota and New York, have state building codes which can be used to impose regulations concerning detention of rainwater on rooftops.

The adoption of effective legislation is needed for implementing effective and equitable local programs designed to regulate peak runoff flows from new land developments or existing developments where improvements are planned. The development of model legislation is recommended as an aid to local governments and other public agencies having responsibilities for stormwater management.

Chapter 10 of this report contains detailed descriptions of provisions of specific legislation pertaining to stormwater detention.

Legal Aspects *

Perhaps no aspect of detention storage of stormwater runoff leaves as many unanswered questions as the legal aspects. Laws on drainage are, in general, not well defined and vary considerably throughout the nation; but the lack of court cases concerning detention storage of stormwater runoff makes the legal aspects of detention of runoff even less well defined. No effort is made in this section to provide answers to pertinent legal questions; however, an attempt is made to call attention to legal questions that may arise and to present some general observations. Information was gathered from several attorneys and publications on drainage law in the preparation of this section of the report.

Pertinent Legal Questions: This section points out some of the legal questions that may be encountered by representatives of local public agencies who are contemplating requiring that detention facilities be provided or, on the other hand, by land developers who are being required to provide them. Some questions that appear to be pertinent are listed below for the purpose of orienting the reader to the discussions that follow in subsequent sections of this chapter.

Questions of Public Agency Representatives:

1. In the absence of specific mention of powers of local governments and districts can we (the public agency) legally require the developer to use a portion of his privately owned acreage for stormwater detention? Might this not constitute a deprivation of the owner's beneficial use of his land?

2. In requiring owners (developers) of private land to provide detention facilities, is our public agency obligated to pay all or a portion of the costs for construction?

3. How restrictive can we be in our requirements for design of detention facilities (volume of storage required, maximum permitted release rate)? Could we require storage of the 200-year rainfall runoff? Could we limit the maximum release rate drastically – even below that which existed on the land in its natural, undeveloped state? Can we require a zero release – thus requiring all excess precipitation to be used for recharging subterranean water supplies?

4. Can we require the private land developer to store (detain) runoff that has its source from land other than that in question? Must the other land owners involved pay a prorata share of the initial construction costs and maintenance and operation?

5. Does the public agency assume an implied responsibility for maintenance and operation of detention facilities that the agency required a private developer to provide on his private property?

6. In an instance where the use of land development ceases but the stormwater detention facility remains (buildings, parking lot, drives), what recourse does the public agency have to assure continued operation and maintenance of the detention facilities?

Questions of Private Land Developers:

7. Is it legal for the public agency having jurisdiction over land development and construction to refuse to issue permits for commencing land development operations and construction if we refuse to comply with the public agency's requirement that we provide detention of runoff on our land.

* This section is not a legal opinion and local law prevails. Rather, the section is intended as a general summary.

8. Can we ask the local public agency requiring the detention facilities to reimburse us for all or a portion of the construction costs involved and the market value of the land required for the detention facility?

9 After we provide detention facilities in accordance with the requirements and standards of the local public agency, can we legally be required at a future date to upgrade the facility to more restrictive standards that may have been adopted subsequent to the date of our initially approved plans?

10. If damage is sustained on our own property from the required detention facility (basements flooded, etc.), is the public agency legally liable for the damages – since they required the facility?

11. For what length of time (years) must we maintain and operate the facility?

12. If we raze all permanent structures (buildings, parking areas, etc.) at a future date, can we remove the detention facility and cease to operate and maintain it?

Providing answers to all of the above legal questions seemingly would be a major effort for a competent attorney; and no doubt, many of the answers would be different in various places because of the difference in laws across the country. The circumstances surrounding specific applications of stormwater detention would be an important factor in determining the answers to the legal questions. For these reasons, it appears that persons involved in requiring or providing major stormwater detention facilities would be acting wisely if they first sought the advice of their legal counsel.

Legal Considerations: Some legal aspects of detention storage of runoff that deserve consideration prior to constructing and/or operating detention facilities are:

1. legal aspects of drainage law;

2. authority of the public jurisdictions to require detention storage of runoff – and the detailed requirements related to such storage and release;

3. legal responsibility for maintenance of detention storage facilities whether they be roof tops, parking lots, surface ponds or other facilities;

4. legal responsibility for damages resulting from the operation or physical failure of stormwater detention facilities;

5. legal responsibility if a detention reservoir at some date be removed, thereby no longer protecting downstream property owners from floods;

6. legal responsibility for damages caused by excessive flows of stormwater when released from storage facilities located on public or private lands;

7. legal responsibility for providing safety facilities to minimize the hazards of the stormwater detention ponds, especially as an attractive nuisance to children; and the

8. legal right to the use or consumption of stored stormwater, thereby disturbing normal flows of water into areas located downstream from detention facilities.

Drainage Laws: There are three types of drainage laws generally recognized in the United States:

1. Common Enemy Rule
2. Civil Law, and
3. Doctrine of Reasonableness.

Under common enemy rules, stormwater runoff is viewed as an undesirable element and a property owner is allowed to dispose of all runoff in whatever method is available to him without regard to the land receiving the water. Few, if any, courts seem to follow this doctrine strictly.

Civil law, on the other hand, says that nothing can be done to change the flow of runoff in any way that is harmful to other property or in any way that is unnatural to normal flow. This, too, is not usually followed closely in court decisions.

The *reasonableness* doctrine lies between these two extremes and is most often the law actually used. Although one of the two previous types of drainage laws may be on the books in a given jurisdiction, the courts historically have interpreted the law with an attempt to provide equity. Thus, under this doctrine, the legal aspects of detention storage of runoff are tested by its reasonableness. If the operation of the stormwater detention storage facility does not cause damage to downstream property, it will probably be found legal. In view of this and because the purpose of detention storage is to protect downstream property, legal problems that arise in the operation of stormwater detention storage facilities do not appear to hinder their implementation from the legal viewpoint of drainage laws.

Authority for Requiring Stormwater Detention: It is generally held that a municipality is not required by the state to provide urban drainage nor is it liable for any damages that result from the failure to provide drainage. However, most municipalities provide urban drainage facilities and require land developers to provide drainage systems in new developments. Subdivision laws usually contain requirements that a drainage system be provided as a condition for plat approval. Detention storage requirements have been included in different types of local laws including subdivision regulations, zoning ordinances, building codes, water pollution regulations, plumbing and sewer ordinances and as general policy statements. There have been no court cases found that challenged the authority to enact these laws. Legal opinions concerning the legal authority to require detention storage of runoff center on the reasonableness of such requirements and the flexibility of these requirements to meet different situations.

Maintenance of Facilities: The question of who has the legal responsibility for maintenance of facilities for detention storage of stormwater runoff is one of great controversy, especially for large facilities. No court cases have been noted and, apparently, no precedent has been set; however, some municipalities seem to agree with lawyers who feel that the maintenance of such structures should be public responsibility – because the detention facilities are constructed for the public good. But, this is not always the case as some local jurisdictions have required private owners to assume maintenance of stormwater detention facilities. In at least one municipality (Palatine, Illinois), maintenance has been deemed the responsibility of the owner, although the municipality will perform necessary maintenance and bill the owner if the owner is negligent.

The responsibility for maintenance of detention facilities on rooftops and parking lots is less well-documented than for facilities on ground surfaces. As a legal requirement for the public good, it might be argued that the maintenance of such facilities should be a public responsibility. However, in contradiction to this reasoning, consider the requirement for maintaining sidewalks on public rights-of-way where the shovelling of snow is required for the public good. In most places, this is the legal responsibility of the owner or tenant of the abutting property. If the latter reasoning is applied to stormwater detention facilities on rooftops and parking lots, maintenance would become the responsibility of property owners.

Failure of Facility: Although no court case is known contesting this point, it is useful to compare stormwater detention storage facilities to other flood control devices. If failure was caused by faulty design, the facility owner would probably be liable for damages. If, however, the failure was caused by factors other than faulty design, such as a rainstorm event larger than that specified in local design requirements, the disaster would fall into the category of *An Act of God.* In this case, the owner of the stormwater detention facility probably would not be liable if past cases that have been researched are an indication of the reasoning currently employed by the courts.

Continuance of Detention Facility: Once built, a detention facility benefits property owners located at and downstream of the facility. It may become desirable for the owner to discontinue operation of the facility. This would subject properties and people once protected from flooding and its accompanying effects to the ravages of floods once more.

By the reasonable use doctrine, it appears that the owner of such a facility is not legally bound to maintain his detention facility and he would be permitted to remove the detention storage facility if he does not alter the runoff flow to downstream property from what would have been the natural flow without the facility. Of course, if his facility had been required by law, this would not apply and the property owner would be required to retain his facility unless the law were ruled invalid or title could be transferred to a new owner.

Flooding From Stormwater Storage Facility: It may happen that the detention of stormwater runoff may intrude onto the land of others. Liability for damages is then dependent on whether or not the design, construction or operation of the facility was faulty or whether it was caused by another factor such as an extremely intense rainfall. Often, it seems, the courts will examine the amount of flooding attributable to the drainage system. Usually, the amount of the judgment will be based upon the increased damage caused by the drainage system at issue.

Safety Features: One of the big questions to public officials contemplating the construction of detention facilities is the safety hazard that the facility presents, especially to children. A stormwater detention pond may be considered an *attractive nuisance.* In this case, the facility owner might be held liable for any harm to persons. Because of this and the desire to protect children, many public officials require fencing the facility to relieve themselves and others from this liability.

The laws governing legal liability for personal accidents attributable to safety hazards vary depending on the jurisdictions involved and the particular circumstances surrounding each case. In Cook County, Illinois, for example, the opinion of the legal counsel of the sanitary district is that the use of fencing does not reduce the liability of the detention facility owner. It appears that stormwater detention storage facilities would not be held to be *attractive nuisances,* per se, according to the drainage laws of most places in the United States, and that the attractive nuisance doctrine is not applicable.

Water Impoundment: Laws governing water rights can be of importance with respect to detention storage in arid and semi-arid regions, or in places that practice irrigation. If a downstream user impounds water for use in irrigation, and an operator of an upstream detention facility reduces the flow over a great enough time span to alter the total released outflow due to evaporation or infiltration or a diversion of his own, the downstream user may sue to regain his former water rights. It may be that the downstream user was allowed to impound water only during periods of flow when the flow rate was greater than a specified minimum. Detention of the stormwater upstream might reduce the peak flows to the extent that impoundment downstream would be possible only for a shorter time-period. This would lessen the total volume of water that could be impounded.

A study involving detention storage and water rights is described in a report made of drainage alternatives for Albuquerque, New Mexico. The City wanted to capture stormwater runoff and provide facilities for infiltration of the water into the ground; but this would reduce the flow to the Rio Grande River and violate the terms of the Rio Grande Water Compact. This agreement, signed in 1938, apportions the water of the Rio Grande between three states based on streamflow records and has international ramifications between the United States and Mexico. Any surface runoff that would be caused to infiltrate into the ground would have to be replaced with water from another source under the terms of the agreement.

Summary: Although legal information was obtained in this study from four practicing attorneys having experience in urban drainage and flooding problems, this section of the report was not authored by a lawyer. Further, it was not intended to be a detailed legal discussion of detention storage. General legal questions relating to detention storage of runoff were merely discussed without attempting to cite legal opinions or cases. Court cases involving many of the issues discussed have not been located; however, it is known that local laws differ in their application to many of the questions raised.

Instead of providing answers to legal questions, an attempt was made to point out some of the legal issues that may be encountered in implementing facilities for detention storage of runoff. Many more questions could be raised. It was concluded that the legal aspects are too involved to be generalized, too underdeveloped to cite opinions and judgments, but too important to neglect.

Because of the many uncertainties involved, land developers contemplating the implementation of major stormwater detention facilities should seek the advice and assistance of a competent attorney qualified in urban drainage law prior to construction of such facilities. Officials of public agencies having responsibility for local drainage should review their authority for requiring detention of stormwater runoff and consider the adoption of needed legislation pertaining to detention storage of runoff.

Operation and Maintenance

The operation and maintenance of stormwater detention facilities is an important factor in determining the effectiveness of the facility and its acceptability to the public. Poor operation and maintenance not only reduces the usefulness of detention storage, but can cause the facility to become an eyesore, nuisance or health hazard. When stormwater detention is weighed against other methods of runoff control, maintenance and operation is usually viewed as the most difficult problem and the factor most often mentioned against the use of this method. This was revealed by the surveys made in this study the results of which are discussed below.

Survey Results: The results of surveys made of both public agencies and engineering firms clearly underline the importance of operation and maintenance difficulties. In each of these surveys, a question was asked to solicit the respondent's evaluation of each of various possible factors that might be considered to constitute a problem or an adverse condition that would be viewed as a disadvantage of stormwater detention. Table 4, Apparent Adverse Factors, includes tabulations of the responses of representatives of the public agencies and engineering firms which responded to this question.

TABLE 4
Apparent Adverse Factors of On-Site Detention
(a) As Seen by Public Agencies

Factor	No. of Agencies Reporting	
	Yes	No
Aesthetics of empty ponds is poor	101	61
Mosquito breeding would increase	107	56
Algal growth would occur in shallow ponds	108	48
Operation difficulties exist	81	69
Ponds are a safety hazard to children	92	54
Other adverse effects are foreseen	18	5

(b) As seen by Engineering Firms

Factor	No. of Firms Responding	
	Yes	No
General maintenance and operation	31	2
Sedimentation	26	7
Safety of children	23	8
Safety and/or property loss from dam failure	21	10
Mosquito breeding	16	15
Aquatic vegetation	14	16
Other	9	3

Source: 1972 Survey by APWA

From Table 4a it is noted that 54 percent of the public agency respondents feel that operation difficulties exist in connection with on-site detention of runoff. About two-thirds of these respondents consider that significant problems would be encountered with aesthetics, mosquito breeding, algal growth, and safety hazards. Table 4b shows that most design engineers feel that significant problems would be encountered with general maintenance and operation, particularly in the areas of safety of children, property loss from failure of dams, and sedimentation. About one-half of the engineers are concerned about mosquito breeding and growth of aquatic vegetation.

These tables show the concern of public officials and design engineers for problems of maintenance and operation, but they give no indication of the seriousness of the problems. Although the responses concerning the adverse effects of detention might indicate that these disadvantages could make stormwater detention an unworkable method, the successful use of detention storage shows that these problems are not sufficient in themselves to eliminate the method as a practical solution to problems of urban stormwater runoff management.

Categories of Maintenance and Operation: There are several categories into which maintenance and operation of stormwater detention facilities can be classified. These include:

1. algae and aquatic vegetation control,
2. mosquito control,
3. pollution problems,
4. debris removal
5. sediment removal,
6. safety features,
7. maintenance of hydraulic facilities and equipment such as pipes, channels control gates and pumps, and
8. general maintenance.

Algae and Aquatic Vegetation Control: Problems of algae and other aquatic vegetation can plague all types of detention facilities, whether they be rooftops or permanent wet ponds. If the detention facility is designed to be dry during most of the time, the best method of vegetative control is to design the facility to dry out quickly and completely. A small puddle standing for weeks on a parking lot will allow algae growth to become a problem and such depressions should be regraded to eliminate standing water. In a large pond with a grass bottom, natural drainage might allow pockets of water to remain for long periods of time, and the use of drain tile can assist in drying out the pond to prevent such problems.

In ponds which have a permanent body of water, algae problems will be more difficult to control. The stormwater may be rich in nutrients, acting as fertilizer for the algae. Minimizing the pollution content of the runoff by controlling erosion and practicing good street cleaning habits will reduce the algae problem. Although there are chemicals available to kill the algae, the subsequent decay of the algae produces odors and returns the nutrients to the water, providing fertilizer for further algae growth. In continually wet ponds there are also problems of cattails and other vegetation growing in the pond. Water depths exceeding four feet will effectively prevent these growths.

The major purposes of preventing growths of aquatic vegetation are for aesthetics, to minimize organic decomposition of plant material, to facilitate recreation, and to minimize clogging of the outlet drains. Even with proper management of detention ponds, there will be some aquatic plant growth, but such growth can be minimized.

Mosquito Control: Control of mosquito breeding is similar to the control of algae growths. Dry storage facilities should be managed to prevent any water from standing for a long enough time, usually four days, to allow mosquitoes to breed. In permanent ponds of water, mosquito breeding problems can be controlled by stocking fish which will eat the larvae. Other methods include using chemicals to kill the larvae and the maintenance of sufficient water flow to avoid the stagnant conditions that are necessary for mosquito breeding. With the latter method, it is particularly difficult to insure satisfactory results, as the water near the shoreline will provide a suitable area for breeding.

Pollution Problems: Pollution problems of stormwater detention facilities will be limited to those ponds that contain a permanent body of water. The pollution will result from runoff which picks up street debris, oils from automobiles, other street contaminants, fertilizers and pesticides, and wastes contributed by users of the ponds. A large pond of about 20 acres might allow the use of boats with motors. In this instance, oil and gasoline will be found to pollute the water. Because of the nature of the water source, it cannot be expected that the water in a detention pond will be of high quality; but recognition of the sources and types of pollution is important nonetheless. Detention storage of runoff would be expected to have favorable consequences for downstream water quality because of dilution provided along with some in-storage treatment by natural processes.

Debris Removal: Debris removal is a maintenance requirement for all types of detention facilities to prevent blockage of the drains. Litter, grass clippings, leaves, tree branches, and miscellaneous debris can find its way into any type of facility although some facilities will be affected more than others.

Surface drains in a parking lot detention facility at a shopping center will be especially susceptible to blockage by litter. Although the drains for the parking lot should be designed in anticipation of litter, clogging of the drains will still be possible. The lot should be kept as litter-free as possible and drains should be cleaned of debris periodically.

Large ponds in open spaces will also collect much debris, not only from the runoff but from debris generated in adjacent areas. Even grass clippings can be a problem by clogging the grating protecting the outlet structure. Permanent ponds also attract children who may throw debris into the water. A debris-retention device on the drain should be installed to prevent plugging of outlet structures.

Sediment Control: The reduction of the velocities of stormwater inflows to a detention pond causes much of the sediment carried by the runoff to be deposited in the pond. Stormwater detention facilities serve as very efficient sediment traps, and sedimentation is perhaps one of the most serious maintenance problems. A typical installation in northeastern Illinois, in an area where 80 percent of the land is developed, will accumulate about 3 1/2 acre-feet of sediment a year per 1,000 acres of drainage area, based on computation methods and data of the United States Soil Conservation Service. A detailed description of the sediment collection efficiency of a detention pond and methods of cleaning the sediment from the pond are discussed in Chapter 6.

In addition to the solids that enter detention facilities with runoff flows, another source of sediment is from erosion of the banks of the facility. If such areas can be planted in grass, and the grass *not* cut, erosion may be minimized.

Safety Features: Safety features of detention facilities include fencing, outlet guards and other measures and devices to protect the public from the hazards of the detained water. Although provision of such safety features does not remove the liability of the owner for accidents (in some areas of the country), such devices do minimize safety hazards and they should be checked regularly to make sure that they are in good operating condition.

Maintenance of Equipment: Typical maintenance of operating equipment installed in stormwater detention facilities includes the cleaning of inlet and outlet channels, repairing all breaks and leaks in pipes, and preventive maintenance of pumping equipment for those ponds and basins that require pumped drainage. The use of pumps for draining detention facilities can be the most costly item of operation and maintenance. It is also one of the most important maintenance items for ponds and basins that use pumping because it is necessary to remove stored stormwater when the rainfall subsides to provide storage for the next rainfall event.

General Maintenance: General maintenance includes all those items which are necessary for the efficient operation of the storage facility and for preserving the aesthetics of the facility and the surrounding area. This includes cutting the grass above the high water level, trimming shrubbery and painting where needed.

Summary: Proper maintenance and operation of stormwater detention facilities will help insure safe, efficient and satisfactory operation of such facilities. Eight categories of maintenance and operation that require attention were outlined and discussed briefly. The two most important maintenance items are the proper maintence of the hydraulic equipment and devices and the control of sedimentation. Hydraulic maintenance and operation will be similar to the maintenance and operation of other stormwater drainage systems. The control of sedimentation is discussed in detail in Chapter 6. In addition to dealing with these two areas of maintenance, it is also necessary to maintain the detention facility as an aesthetically pleasing part of the community.

Costs and Financing of Facilities

The construction of stormwater detention facilities requires a means of financing. Although the estimation of costs and methods of financing on-site detention facilities are not particularly unique, when built by public agencies a discussion of these two factors is, nevertheless, important. Requirements imposed by local jurisdictions for the construction of on-site detention facilities by land developers, where the benefits of such storage occur to the general public is an involved problem and the financing of such facilities is an area of great controversy. Land owners developing property on high ground may be understandably reluctant to pay for facilities to protect neighboring property located in low-lying areas downstream.

Public Agency Survey: A survey made in this study of 230 public agencies included the question of who customarily pays for the cost of detention facilities when required by the local jurisdiction. Table 5, Cost Allocation, is a tabulation of responses received. It is seen that land developers usually pay (59 yes) but that the local public agency sometimes pays (14 yes). Payment is also made jointly, in some cases, by the land developer and the public agency (26 yes).

TABLE 5
Cost Allocation of On-Site Detention Facilities When Required by Local Jurisdictions

Cost Borne by:	No. of Public Agencies Responding	
	Yes	No
Land Developers	59	6
Public Agency	14	30
Jointly by Developer and Public Agency	26	24
Other	3	10

Source: 1972 Survey of 230 Agencies by APWA

Costs: An accurate estimation of the true costs of constructing, operating and maintaining stormwater detention facilities is difficult. The type of facility to be used, storage requirements, geographical and geological conditions, cost of labor, material, and engineering all make the cost of detention facilities variable depending upon local conditions, probable future wages and the need to include both initial and future costs. For example, modification of roofs for rainfall detention may be cheaper than the construction of a pond in an area of high land costs, to provide the same total storage volume. But maintenance costs over many years may prove to be excessively high for roof storage, making pond storage cheaper over the lifetime of the project. Also, land availability and costs will play an important role in determining the cost of storage in open-space ponds.

Thus, instead of itemizing costs, it is more useful to list those types of costs that should be considered when designing a detention facility. These include the following items:

1. land costs for storage basins or ponds,
2. excavation and grading costs for ponds and basins on ground surfaces,
3. erosion protection measures for detention ponds and channels,
4. fencing and/or other security and safety measures for ponds,
5. pumping facilities and associated energy costs (often the major cost of operation for pumped-storage ponds),
6. installation of inlets, outlets and sewers to and from detention areas,
7. cost of added facilities to enhance the multiple-purpose use of detention areas,
8. cost of modifications of existing urban features to accommodate detention facilities (such as regrading and paving streets, installation of bridges, etc.),
9. cost of hydraulic control facilities to limit outflow,
10. cost of spillway structures to handle rare rainstorms,
11. landscaping of ponds in open spaces,
12. engineering and landscape architecture,
13. operation and maintenance,
14. costs of modifying rooftops, parking lots or plazas,
15. administrative costs, and
16. financing costs.

Some of these costs will not be applicable to certain situations, and other cost items may possibly be reduced by incorporating stormwater detention storage in the original land development plans. The cost of providing rooftop storage will be minimized if the storage can be designed into the building prior to construction, rather than added after construction. Estimation of the amount of various cost items would be carried out by methods used in estimating costs for other types of construction.

Land costs are by far the largest expenditures for open-space detention ponds and basins. In the case of a detention basin being considered for northeastern Illinois, for example, the land is expected to cost about $1.8 million which represents about 72 percent, or more, of the total project cost of $2.1 to $2.5 million.

The Metropolitan Sanitary District of Greater Chicago has estimated the overall initial costs of large stormwater detention basins, constructed by them on land purchased by the District, at about $5,500 per acre-foot of storage. This is a rough estimate and the cost will vary with the circumstances, the project location, and unit cost factors.

In a large single-family residential development in Hoffman Estates, Illinois the cost of providing detention ponds and basins in open-space areas was estimated by the developer to cost between $100 to $300 per lot, with lot sizes varying up to 1/2 acre. It is believed that the overall costs of the drainage system serving this development was much less than the cost of a conventional storm sewer system without provision for detention. This probably resulted in lowering the sales prices of the houses below that which would have otherwise been charged. As an added feature in offsetting costs, the detention ponds serve recreational uses and enhance the aesthetics of the area.

Sedimentation control ponds used during the construction of homes in Maryland have cost about $50-$70 per lot. Although these ponds are built to reduce and prevent soil erosion and the accompanying siltation, they would also serve to reduce local flooding and pollution if left as a part of the final development.

At times, arrangements are made with land developers to have land (or a constructed facility) donated to a public agency for stormwater detention. In this way, the cost of detention storage to the public agency is sometimes greatly reduced over that cost which would be incurred if the public agency provided the land and constructed the facility. In addition, the owners of properties served are relieved of the burden and cost of operation and maintenance of such facilities. However, in instances where the land developer pays the original capital costs associated with on-site detention, the actual costs are necessarily transferred to the ultimate owner of each tract or lot. If the on-site detention basin has to withhold significant flows from upstream areas, this imposes inequitable costs on the ultimate owners of the properties undergoing development.

increased costs there are reduced costs associated with on-site detention of stormwater. The use of rooftop storage of rainfall will reduce the size of roof drainage pipes needed; all types of stormwater detention will reduce the size of sewers needed, etc. These factors are discussed more thoroughly in this chapter, and in Chapter 4.

Financing: The financing of stormwater detention facilities is a difficult and important matter that deserves careful consideration. Financing may be provided by many different methods each having variations in the manner of cost allocation. Some possible methods of financing are listed below:

1. Federal aid:
    a. Department of Housing and Urban Development funds
        (1) Open-space programs
        (2) Water and Sewer Facilities programs
    b. Soil Conservation Service watershed project funds
    c. Corps of Engineers flood control projects
    d. National Park Service Land and Water Conservation funds
    e. Department of Interior – Bureau of Outdoor Recreation programs;
2. state flood control funds, and park funds;
3. drainage district funds;
4. sanitary district funds;
5. county forest preserve district funds;
6. general obligation bonds;
7. general improvement bonds;
8. special improvement bonds;
9. drainage assessments based on one, or a combination, of the following:
    a. property value
    b. property size
    c. amount of runoff contributed
    d. linear frontage
    e. benefits received
    f. distance from outfall or treatment plant;

10. local government funds for:
    a. flood control
    b. sewer construction
    c. parks and multiple-purpose projects
    d. general improvements;
11. user charges for use of multiple-purpose projects;
12. sale of excavated material;
13. cost borne totally by land developers;
14. sewer user charges;
15. gasoline taxes; and
16. sales taxes.

The methods of financing listed offer many alternatives, not all of which will apply to a specific facility or a specific area where detention facilities are being built. Allocation of initial and annual costs for assessment of property owners in new land developments is difficult. For example, suppose a new development is planned for an area which is under development or already largely developed. The question arises as to the cost that the new development should bear for the increased size required of the stormwater drainage facility. Six alternatives for cost allocation are discussed below, although other alternatives exist.

1. Method of oversizing: In this method, the new developer pays only the additional cost that his drainage, based on drainage area alone, will add to the planned drainage system to make the basic system adequate for everyone. This method is inadequate as it does not allow for different runoff rates from land having different uses and characteristics.

2. Flow-contributed method: This method is similar to the above method, but it allows for the different values of the runoff coefficient C for various land uses in the new development. The assessed fee is based on the ratio of flow from the lot in question to the total drainage basin flow. This is the method used in Boulder, Colorado.

3. Method of peak flows: A modification of the previous method – the owner of the new development would pay according to the ratio of the peak runoff from his property to the peak runoff from the remainder of the drainage area.

4. Peak flow-time method: This procedure further modifies the previous method by allocating the cost according to the runoff flows at a certain time – namely, the time of peak sewer flow. Thus, if the peak flow from a portion of a new development lags the peak flow from other property in the development, the cost allocated to this property would be less. The owner would pay according to the ratio of his contribution to the runoff flow in the facility at the time of peak flow. Thus, if a new development produced a peak flow of 15 cfs but contributed only 5 cfs at the time of the overall peak flow in the facility, at a time when this total peak flow is 100 cfs, he would be allocated only 5 percent of the costs of the drainage facility, not 15 percent.

5. *Ratio-of-savings-method:* By this method, cost allocations are made based on the cost that would be incurred if each area built its own stormwater drainage system. Preliminary designs and approximate cost estimates are prepared for the separate projects and the cost of the joint project is apportioned to each party in the ratio that the separate costs bear to each other. Thus, if two separate systems would cost \$1 million and \$3 million, respectively, and a combined system would cost \$2.4 million, the cost would be allocated in the ratios of 1:3, or \$0.6 million and \$1.8 million, respectively.

6. Distance from outlet: In this method, the charge for drainage is based on the length of sewer pipe serving the lot owner. A lot one mile from the outlet would pay one-half the amount of a lot 2 miles from the outlet. Modification of this method by one of the previous five methods is also possible.

The methods described above have been used around the country in varying degrees. Boulder, Colorado, for example, makes an assessment of the amount of runoff contributed by a specific lot compared to a standard lot. A standard lot having 9,600 square feet and a runoff coefficient of 0.30 might be assessed \$1.00 a month. A lot twice this size with the same runoff factor would be assessed twice this amount, because (theoretically) it would have twice the runoff of the standard lot. Arvada, Colorado charges a one-time fee depending on lot size and the particular drainage basin. In Fairfax County, Virginia the cost of detention facilities is borne by the developer and is allocated to the price of the developed lots as he sees fit.

Maintenance and operation costs of on-site detention facilities are usually borne by the property owner when detention facilities are built on a rooftop, parking lot, or as part of a subdivision's recreational facilities for private use of residents of the subdivision. Sometimes, on-site detention facilities are deeded to the local government, or the public drainage district, which then assumes the responsibility and cost of providing maintenance and operation.

Summary: The costs of providing, operating and maintaining on-site stormwater detention facilities can be high. Although no definitive costs can be placed on the various categories of detention facilities, a listing of the various kinds of costs that should be considered has been presented. This list can be used as a guide in making cost estimates of providing, operating and maintaining detention facilities.

The financing of detention facilities is possible by a number of means. The major controversy in financing focuses on resolving the question of who should pay for on-site detention facilities required by law that are not primarily constructed for the benefit of the owner, but for downstream residents. There is also the problem of allocating the cost of public detention facilities. Several methods of allocation are described without comment as to their equity. Various local jurisdictions will, no doubt, find that certain methods may be more practical and appropriate than others from the standpoint of actual application.

Economics and Engineering Effectiveness

Experience with on-site detention of stormwater in urban areas as a means of managing runoff has shown that this method often can be the most economical means of handling stormwater drainage. Preliminary data concerning applications in existence for a decade shows the method to be effective. If the initial designed detention volume of a given facility is detained with suitable maintenance and conscientious operation, it appears reasonable to assume that the long-term effectiveness of the facility will be assured. Further, the assumption of satisfactory maintenance and operation must be implicit in most planning for on-site detention storage. Otherwise, such facilities would not be constructed, or they would be built only as temporary expedients.

Economics of Detention Storage: The economics of on-site detention of runoff should be compared to other methods of managing runoff and should include both the initial costs and the annual costs of maintenance and operation. These costs ought to be evaluated on the basis of the effectiveness of the systems. It would not be valid, for instance, to compare the costs of a detention facility designed for the runoff from a 10-year rainfall event against a system designed for a 100-year rainfall event. Exact cost data for comparison of two drainage systems is impossible to obtain since the two systems could never operate under exactly the same conditions. In fact, comparison of maintenance and operation costs for on-site detention systems with other types of runoff control systems is almost impossible because few on-site detention systems have been in operation long enough to develop accurate data. Construction costs can be compared, but the economics of maintenance and operation will need to be discussed from a theoretical standpoint.

In several instances, described in more detail in Chapter 4, the use of detention ponds and basins on ground surfaces or paved areas was the method selected because the initial cost was considerably lower. For example, Consolidated Freightways, Inc., built a trucking terminal in St. Louis, Missouri and found that the use of detention ponding on the parking lot would reduce the size of required storm sewers to the extent that a \$150,000 projected cost for a conventional system was reduced by \$35,000. Ponding occurs in areas of the parking lot not used frequently, and maintenance costs are limited to cleaning collected debris from the drains and from the depressed storage areas. But even normal operation of the parking area would have included routine cleaning of the storm drains. Very little added expense has been incurred by the use of the paved area for stormwater detention.

Another example of the economics of on-site detention systems compared to conventional stormwater drainage systems is Earth City, Missouri which is a planned community now under construction in the Missouri River bottoms near St. Louis. It was found that a system of finger-lakes, serving as stormwater detention reservoirs, changed the estimated cost of the originally planned conventional stormwater drainage system from an estimated $5 million to about $2 million plus the value of 51 acres of land needed for the lakes. The use of the lakes will save funds that would otherwise have been used for the drainage system, and the lakes will add to the value of the property and structures along the shores. Maintenance of the lakes to cope with problems of erosion, siltation, weed growth, algae, etc., will be more costly than would be the cost of maintaining a conventional storm sewer system, but a part of this cost can be allocated to normal lake maintenance.

Other cases of cost savings include Indian Lakes Estates, a single-family residential development in Bloomingdale, Illinois where on-site detention allowed the use of an existing drain pipe instead of installing 7,000 feet of new 72-inch storm sewer. This resulted in saving $370,000 of an estimated cost of $600,000 for the conventional system involving a new sewer line. Another case is Fort Campbell, Kentucky where the use of on-site detention reduced the estimated $5,500,000 construction cost of a conventional stormwater drainage system by more than one million dollars.

The economics of rooftop storage is more difficult to evaluate. Certainly, the additional cost of designing a roof to detain stormwater must be considered. Standardized roof drains for controlling the drainage rate of stored rainfall into downspouts are available from manufacturers, and detailed design charts are available from several manufacturers for use in the design of the spacing and sizes of drainpipes. The ponding of water on roofs reduces the sizes of roof leaders, and hence the cost; but this requires that better workmanship be practiced to guarantee a waterproof roof and extra structural strength be provided to satisfy the weight of the detained water. Because roofs must be designed in most places in the country for a live load equivalent to about 6 inches of water, structural designs meeting present building codes should be satisfactory except in the south and the far west portions of the United States. Regular maintenance must be provided on rooftops having rainfall detention devices to clear away clogged materials.

It appears that rainfall detention on roofs is an extremely economical method of reducing peak flows in storm sewers. Although the storage of rainfall on rooftops should be limited to a maximum of 24 hours, as prescribed by most building codes and manufacturers' data, unforeseen events could lead to longer periods of storage and possible leakage or structural failure. Although the method of rooftop storage has not been observed long enough to evaluate all the long-term effects, it must be noted that the economics appear favorable, especially with proper design and workmanship.

The real economics of rooftop storage is appreciated when the alternatives are compared. In a totally developed urban area, rooftop storage may be the only feasible method. Land for open-space detention ponds and basins may not be available and the use of deep tunnels or underground tanks may be impractical either because of initial cost, cost of operation, geological conditions or rules and regulations of the public agencies involved.

It seems that the economics of on-site stormwater detention can be quite appealing. If the detention facility can serve multiple-purpose uses, such as recreation, the economic potentials become even more attractive because a portion of the cost of the facility is allocated to other uses.

The economics of on-site stormwater detention is not always favorable, and the problems of maintenance and operation, or the lack of sufficient area for on-site detention facilities, may make other methods of urban runoff management more economically justifiable. For example, the concept of on-site stormwater detention is promoted in metropolitan Chicago by public agencies – primarily in suburban areas. The urbanized core of Chicago does not contain available vacant area for detention ponds on ground surfaces, and there are not enough satisfactory flat rooftops to make rooftop storage feasible. Also, implementation of a detention storage program for rooftops or parking lots in Chicago would not be feasible from an administrative standpoint. Therefore, the Metropolitan Sanitary District of Greater Chicago is promoting detention storage in suburban areas, where feasible, and underground storage for the central city area.

Engineering Effectiveness: The effectiveness of any engineering design can only be determined through experience. Actual experience with on-site detention facilities is limited because the method is a relatively new concept, although several examples exist which show it to be effective. For example, at Fort Campbell, Kentucky stormwater detention has been used successfully for about 10 years. As mentioned earlier, the construction of the system was considerably less costly than for a conventional system that was considered. To date, no major problems have been encountered. Detention ponds in a residential development in Hoffman Estates, Illinois have been operating successfully for 15 years. They serve as an aesthetic adjunct, as well as an effective means for reducing peak flow rates in the storm sewer system serving the community.

In portions of the states of Maryland and Virginia, high runoff rates from intense storms have led to the use of detention ponds primarily as protection against erosion and siltation. These detention ponds have operated effectively, even during the intense storm of 1972 known as Hurricane Agnes.

An example of a large detention reservoir which has proven to be effective is the 11 1/2-acre Melvina Ditch Detention Reservoir constructed by the Metropolitan Sanitary District of Greater Chicago at a cost of $892,000 exclusive of land which was furnished by the local government. Pumps are used to drain the filled reservoir in a period of 24 hours when the downstream drainage ditch capacity permits. The detention facility is designed for multiple-purpose use. Since completion of the project, no flooding has occurred in the upstream or downstream areas near the facility. Estimates made of an alternative conventional system of large storm sewers in the downstream areas, in lieu of the detention facility, would have cost about $1,000,000 more than the system that was built which included the detention facility.

The basic philosophy of on-site stormwater detention – to reduce peak runoff flows caused by urbanization to levels approaching predevelopment levels – is an attempt to allow the natural hydrologic cycle of nature to be interfered with by man in the least amount possible. In localities where the high runoff flow rates cause problems, the reduction of runoff rates by detention of the runoff has been shown to be an effective means of returning runoff rates to predevelopment conditions for the protection of life, property and natural resources.

There are, however, areas where there is little urgent need to slow down the flow rate of runoff. A city located adjoining a lake, built on land with sufficient slope to provide for adequate drainage toward the lake, might find it advantageous to transport the runoff through storm sewers as quickly as possible to the lake.

It is now recognized that urban runoff is often badly polluted and that some type of treatment of urban stormwater runoff may be required in future years. In localities served by combined sewers, treatment of combined stormwater and sanitary sewage without some type of detention would require the construction of sewage treatment plants with sufficient capacity to handle high peak flows. This will usually be impractical from an economics standpoint. Treatment of stormwater runoff separately from sanitary sewage is stated by some to be more desirable than the treatment of combined wastes. The reasoning is that the pollutants in stormwater are of a different type than the pollutants in sanitary sewage, and a different type of treatment will be required. If detention storage facilities are incorporated into the construction of urban stormwater drainage systems, the size of needed treatment facilities that may be built in the future can be kept to a minimum. This will have a major effect in reducing construction costs and increasing the effectiveness of the stormwater treatment processes.

Summary: On-site detention of runoff, like any other engineering technique, cannot be expected to be the best solution in all situations to all urban drainage problems. But, in some localities in the United States, it has been demonstrated to be economically more desirable than conventional drainage systems and an effective engineering solution for urban stormwater drainage problems. Newer methods of detaining water, combined with more stringent laws governing water pollution and the desire to augment water supplies with stormwater runoff, should increase the use and improve the economics and effectiveness of on-site detention techniques in urban areas.

Problems of Implementation

Progressing from the planning and design stages to the construction and operation of detention facilities usually requires the solution of a variety of implementation problems, some of which may be unforeseen Discussion of some of these problems may help those who choose to use detention storage by pointing out the obstacles that may be encountered and how some of the problems can be solved.

Problems that may be encountered in implementing on-site detention facilities include:

1. legal problems – that is, the legal basis of the jurisdiction to require property owners and land developers to provide and operate stormwater detention facilities;
2. political problems – the problem of modifying existing laws, building codes, zoning ordinances, subdivision regulations, etc., to include requirements for on-site detention storage that are practical and effective for solving drainage and flooding problems, and acceptable to politicians and officials of various public agencies concerned;
3. administrative matters – related to the enforcement of the laws and regulations as established;
4. public acceptance – problems related to securing public acceptance of on-site detention as the best, or most practical, method for handling runoff in their community;
5. construction difficulties – problems related to the physical construction of the project;
6. financial problems – problems related to allocating the costs of the facility and obtaining financial aid for defraying both initial costs and annual cost; and
7. intergovernmental problems – problems encountered in working with other governmental units to solve a problem which may not be common to them, but which require intergovernmental action.

Legal Problems: The question of legal authority to require on-site stormwater detention was discussed earlier in this chapter. Basically, it seems to be well established that local authorities can legally require detention storage but questions on this matter remain. The restrictiveness of requirements, the type of legislation used to require stormwater detention and questions concerning whether to require detention on a local or regional basis must be answered. The legal aspects of stormwater detention will be different in different states, and land developers contemplating the construction of stormwater detention facilities should acquaint themselves with legal problems that may be encountered in a particular state and in the area of the land development.

Political Problems: Developing or establishing the authority to require on-site stormwater detention is only the first step required for initiating an effective program for handling runoff. The second step is the development and establishment of legislation that will help to solve the physical drainage problems and yet be politically feasible to assure adoption. Oftentimes, compromises and amendments made by legislative bodies may alter the intent of legislation to the point where the initial purpose is no longer fostered by the legislation adopted. This can be an especially difficult problem in areas where on-site detention requirements are considered by land developers to be too restrictive, particularly when proposed developments are welcomed by local politicians and the public. An educational program sponsored by the promoters of on-site detention may be an effective way to convince local politicians and land developers that the benefits will outweigh any disadvantages, promote the best interests of the public, and be compatible with future development plans.

Administration: The passage of legislation requiring on-site stormwater detention is no guarantee that the officials of the responsible local public agency will fulfill the legislative intent. Legislation must be flexible enough to allow for administrative judgment in the application of the law, but at the same time, it must not be so pliable as to weaken the needed administrative controls.

A survey was made of public agencies as a part of this study. It was conducted in cooperation with the American Public Works Association. The following paragraphs include information obtained on types of legislation used in controlling on-site detention and the placement of responsibility for administration and enforcement of the legislation.

Table 1 presented a tabulation of the various means used by local jurisdictions in requiring and controlling on-site stormwater detention. The table reveals that most local public agencies have not adopted legislation or taken administrative action to require and regulate on-site detention. Of those agencies that have taken action, most have used subdivision regulations and administrative regulations. Local building codes and zoning ordinances were used to a lesser degree.

Table 3 is a tabulation of the various offices and departments of local public agencies that have responsibility for administering controls over on-site stormwater detention. The city engineer's office most frequently has administrative responsibility – followed, in order, by the building inspection office, flood plain zoning office, sewer and/or water department, health department and zoning enforcement office. In county governments, the county public works department (or county engineer) usually has administrative responsibility, followed by the county highway engineer. In places where a sewer district or urban drainage district exists, such organizations often have administrative authority. These organizations usually operate in cooperation with the local government.

Provisions should be made for filing appeals with the local jurisdiction concerning administrative decisions made in enforcing local requirements. Efforts should be made periodically to determine whether or not legislative improvements can be made and if the administrative official is carrying out the intent of the law.

Public Acceptance: The acceptance of laws by the public is difficult to evaluate, especially in matters of public works construction. Every citizen wants flood control programs and structures, it seems, until the flood control structure is proposed for his neighborhood or until it requires that he make a change in his lifestyle, or causes him inconvenience. This is human nature. It may be difficult to convince the public that stormwater detention reservoirs built in their neighborhood will benefit them, or that converting parking lots and roofs of commercial buildings to store rainwater will not cause merchants to lose customers. It may be advisable for local officials to conduct public relations programs to explain to the public the alternatives available and the reasons for choosing on-site detention as the most economical or most practical means of solving local flooding or pollution problems.

Construction and Design Difficulties: Problems associated with the construction and design of detention facilities include all the physical problems of building and the engineering problems associated with planning and designing storage facilities. Such problems are discussed in detail in Chapter 3.

For rooftop detention, the roofs must be structurally capable of detaining sufficient water to provide signifcant benefits. Preferably, rooftops should be nearly horizontal. Large rooftops will be more advantageous to use for detention than small rooftops because of the greater storage space available.

Parking lots and commercial plazas present problems of design to allow their use for both stormwater detention and for their primary purpose. These difficulties involving the convenience of the users of such lots and plazas can be partially solved by good design.

Surface detention ponds and basins pose

the biggest problems. There are problems of (1) land availability, (2) land cost, (3) topography, and (4) geology (especially rock formations and other problems involving soil permeability, underground springs, etc.). As an example, a large detention pond may require 50 acres of land which may not be available at a suitable location. Or, cost could be a major factor, as the cost of land may be $25,000, or more, per acre; and, for 50 acres, this would amount to $1.25 million. Or, the topography might be such that large amounts of excavation are necessary to provide sufficient storage, again adding to the total cost of the facility. Favorable topography will allow the use of gravity drainage, while unfavorable topography may require the use of pumps for drainage and will result in increased annual operating costs. Finally, the geology might make construction difficult. Excavation in rock will raise construction costs, while sandy soil might be too permeable and require sealing the bottom of the pond if it is desired to maintain a permanent body of water. If a natural spring is encountered, its flow must be diverted to prevent the pond from filling up with the spring water, as this would defeat the purpose of the detention facility.

Financial Impediments: Most of the items mentioned under *construction problems* were related to increased costs of construction or operation. Raising the money for initial construction or future operation and maintenance may prove difficult from both fiscal and political standpoints. Politically, it may be difficult to raise funds if the benefits of detention storage are not obvious to those who are requested to pay for the facility or those public officials who may be requested to provide public funds. Fiscally, many private and public agency budgets are already stretched to the limit of bursting and additional funds may be difficult to obtain.

Intergovernmental Problems: This may be the most important problem area influencing the implementation of facilities, and the most difficult to solve. It is recognized that regional cooperation and involvement is necessary to solve many of our modern day problems, and stormwater drainage is certainly no exception. Individual units of government usually cannot deal satisfactorily with all of the problems of implementation. A regional, or watershed, approach is needed.

For example, it is unusual for the local flood plains in a community to be flooded because of the runoff from land within that community. The cause of the flooding is invariably the high runoff rates and volumes from areas upstream in the watershed. Hence, it is these upstream areas that can be most helpful in providing solutions to the flooding problems of the area downstream. But without intergovernmental flood control programs, it is almost certain that the upstream communities will not build detention facilities for the good of the downstream communities. In a situation like this, intergovernmental flood control programs are needed. These programs may be effected by agreements between communities or by the establishment of a regional authority, such as an areawide drainage district or sanitary district.

Summary: Obstacles and problems are often encountered in implementing local programs requiring on-site detention of stormwater runoff. These problems include legal questions, political problems, administrative matters, public acceptance, construction difficulties, financing problems and intergovernmental relationships. Recognition of these impediments and efforts made to solve the problems in advance of implementation will make it easier for proponents of on-site stormwater detention to overcome these impediments with a minimum of effort and delay.

CHAPTER 3
DESIGN CRITERIA, PROCEDURES AND TECHNIQUES

The purpose of this chapter is to deal with design procedures and methods of application of on-site detention facilities. Included are: rooftop storage, parking lot storage, local recreational area storage, and small detention basins and ponds constructed within the limits of development areas.

On-site detention of storm waters generally refers to storage of excess runoff on the site of a development prior to its entry into a sewer system and gradual release of the stored runoff after the peak of the runoff has passed. In some applications, the runoff may first be conducted short distances by collector sewers located on or adjacent to the site of the detention facility. On-site detention is usually differentiated from downstream detention by its proximity to the upper limits of the basin, or sub-basin, and the use of small detention facilities as opposed to larger dams normally associated with downstream detention. However, the difference between on-site detention and downstream detention is often a gray area.

Use of the terms *detention* and *retention* is often confusing. Detention generally refers to holding runoff for a short period of time and then releasing it to the natural water course where it returns to the hydrologic cycle. Retention facilities normally refer to schemes whereby water is held for a considerable length of time for aesthetic, agricultural, consumptive, or other uses. The water may never be discharged to a natural water course, but it may be consumed by plants, evaporation, or infiltration into the ground.

The objective of an on-site detention facility is simply to regulate the runoff from a given rainfall event and to control discharges to downstream areas to reduce the impact on downstream drainage systems, natural or man-made. Generally, detention facilities will not reduce the total volume of runoff, but simply redistribute the rate of runoff over a time period. There are exceptions, however, such as the reduced runoff volume from land areas that have been contour-plowed. Numerous fringe benefits may be recognized as a by-product of on-site detention; however, the main objective is that of reducing peak runoff flow rates.

The major benefit derived from properly operated detention facilities is the reduction of downstream flooding and the size of downstream drainage facilities required to handle runoff from a specific rainfall occurrence. One of the auxiliary benefits attributable to this peak flow reduction is the reduction in pollution of receiving streams due to siltation which accompanies erosion. Also, detention ponds and basins can often form the core of blue-green areas in parks or other open space developments. The reduced runoff rates have a tendency to reduce erosion in downstream receiving channels. In some areas, where combined sewers are utilized to convey stormwater runoff, the use of detention ponds greatly relieves the peak loading on the combined sewer and can reduce flooding and pollution of basements, streets and water bodies.

The use of on-site detention facilities may be dictated by governmental ordinances or may be chosen by a developer, at his own discretion, as a method for reducing costs for drainage facilities. In either event, the result is the same – reduction of peak runoff flow rates from a given parcel of land for specific rainfall events.

It is important that planners and designers of on-site detention facilities give careful consideration to the probable impacts of the completed facility. Such impacts can be positive or negative and can be classified broadly as social, economic, political and physical (environmental and ecological). Planners and designers can often influence the positive or negative aspects of these impacts by their evaluations of available alternatives and decisions involved in the design process. It seems prudent that they give special attention to consideration of the following:

a. safety of people and wildlife;
b. protection of real property and wildlife habitats;
c. lowest annual cost of the facility that is attainable within project

constraints and community goals;

d. multiple-purpose use of facilities;

e. aesthetic enhancement of the local area; and

f. cooperation with adjacent communities and governments to promote a watershed approach to providing stormwater drainage and local flood control.

The engineering design of urban stormwater detention facilities is complicated by a number of technical and physical problems. Among these are the following:

1. difficulty of predicting runoff hydrographs accurately because of –
   a. incomplete knowledge of soil conditions, present and future;
   b. incomplete information on rainfall intensity-duration patterns; and
   c. limitations of the adaptability of formulas, models and techniques for calculating runoff rates and volumes;
2. limitations of space for accommodating detention facilities;
3. restrictions imposed by the limited hydraulic capacity of receiving streams and/or downstream sewers for accepting the discharge from the detention facilities; and
4. legislative and/or administrative regulations governing upstream runoff that may become more, or less, restrictive in future years, thereby affecting runoff volumes and flow rates that must be accommodated on a proposed land development.

Although the beneficial effect of on-site detention of storm waters appears to be recognized, standard engineering design methods have not been developed which are accepted universally by the designers of facilities or the agencies that review and approve designs. Further, the technical complications described above and the variations of local policy and regulations that may be encountered delay and frustrate the development of acceptable standard design methods. However, there are some general techniques and procedures that may provide useful guidelines to engineers who have not had experience in the design of stormwater detention facilities.

Results of a Survey of Engineering Design Practices

The responses of representatives of engineering firms to the questionnaire revealed the different design techniques that are applied for different types of detention facilities. The influence of local regulations and personal preferences was also evident. The survey showed that 34 of the 40 engineering firms across the United States and Canada that answered the questionnaire had designed a total of 601 on-site stormwater detention facilities, as shown in Table 6, Number of Detention Facilities Designed by Engineering Firms.

TABLE 6
NUMBER OF DETENTION FACILITIES DESIGNED BY ENGINEERING FIRMS

Type	Number
Rooftop	95
Parking Lot	184
Ponds in parks and playfields	120
Residential and Other Detention Basins	146
Ponds on School grounds	18
Underground tanks	20
Other	18
Total	601

Planning: Often the provision of on-site facilities was incorporated into the planning of storm drainage systems. The firms indicated their incorporation of on-site detention with storm drainage plans as shown in Table 7, Incorporation of Detention Into Drainage System Planning.

TABLE 7
INCORPORATION OF DETENTION INTO DRAINAGE SYSTEM PLANNING

	Number of Firms Responding	
Type of System	Yes	No
Storm Drain Systems	26	5
Combined Sewer Systems	11	14
Comprehensive Urban Drainage Plans	23	7
Rural Drainage Plans	12	11
Other	4	8

Source: 1972 Survey by APWA

Planning and providing on-site detention facilities was often the result of encouragement by local jurisdictions. It seems reasonable to assume that such encouragement included some design limitations and requirements. For example, the design rainfall frequency most often used was reported to be that having 10-year recurrence interval. The second most common design rainfall used was given as the 15-year rainstorm. A few responses indicated the use of design rainfalls of less than the 10-year rainstorm while others indicated use of the 100-year storm or greater for design. Many firms stated that their choice of design rainfall frequency for a specific project is determined solely by the requirements of the local public agency having jurisdiction.

Runoff predictions were based primarily on unit hydrographs and the Rational Formula. Responses of the engineering firms concerning the methods used are given in Table 8, Method of Predicting Runoff.

TABLE 8
METHOD OF PREDICTING RUNOFF – FOR DESIGN OF ON-SITE DETENTION FACILITIES

	No. of Engineering Firms Responding	
Method	**Yes**	**No**
Rational Method	22	4
Unit Hydrographs –		
with record data	14	3
synthetic	17	2
Rainfall-runoff		
Simulation Model	7	8
Other	2	4

Source: 1972 Survey by APWA

Storage Volume Requirements are an important consideration in the design of stormwater detention facilities. Volumes are determined in several ways. The most common method reported by engineering firms is to provide sufficient storage to limit the rate of runoff from the developed land area to the rate that prevailed before development. Often, however, land availability and topography are limiting factors, along with economic considerations. In all cases, the hydraulic capacity of the receiving drainage system below the detention facility is a factor that must be considered in determining the amount of storage necessary.

Some engineers have found that the practical storage volume is dictated by the multi-purpose uses planned for the detention facility. A parking lot, for example, could be used for storage to a water-depth of only about 8 inches before it becomes incompatible with its primary use. Similarly, the variations of water-depth in park ponds must often be limited to improve aesthetics, provide for recreation uses, and provide a suitable habitat for fish.

Representatives of some engineering firms reported that they design detention facilities to store a specific percentage of peak runoff flow. Many firms reported that volume requirements are determined from provisions of local legislation or administrative directives. For example, the Metropolitan Sanitary District of Greater Chicago requires that the 100-year rainfall be used in design and has established a formula for the volume of storage required.

The responses point out that a wide variety of methods are used to determine the storage volume depending upon local circumstances. The basic consideration was to provide enough storage to prevent runoff rates from causing downstream flooding, with a goal of keeping future runoff flow rates below historic peak rates. But, compromises must frequently be made for reasons of economy or land availability.

Mechanisms to Control Release Rates: Table 9, Control Methods for Gravity Release, indicates the various devices used to release detained water including: weirs, spillways. orifices, hydraulically limited outlets and control gates, in order of popularity. Control gates were the least popular, it was found, due to the need to adjust them for proper control for each rainfall period.

The basic design factor used in determining the maximum release rate of stored runoff is the ability of the downstream sewers or stream channel to handle the flow satisfactorily. Often this rate is based upon

TABLE 9
CONTROL METHODS FOR GRAVITY RELEASE

Method	No. of Firms Responding Yes	No
Weirs or Spillways	30	0
Orifices	23	4
Hydraulically Limited Outlets	19	6
Control Gates	15	12
Other	1	4

Source: 1972 Survey by APWA

consideration of the expected future runoff from the watershed after planned land development takes place. Or, the maximum release rate may be limited so as not to exceed the natural flow rate of the receiving sewers or stream that prevailed before land in tributary watershed areas was developed. In many cases, the limit on release rates is specified by a local ordinance which was based upon the flood hazard characteristics and economic characteristics of the watershed. In all cases, the selection of the maximum release rate should be based upon controlling flooding below the detention facility without causing a serious and prolonged problem at the facility itself. For example, a detention basin in a busy parking lot should be drained faster than a detention pond in a park.

Problems: The use of stormwater detention facilities for local flood control is not without problems. The most significant problem was given as maintenance and operation as shown by Table 10, Adverse Effects of On-Site Detention Facilities as Seen by Engineers. Sedimentation was also viewed as an important problem, whereas mosquito breeding and aquatic vegetation were rated significant by only about 50 percent of those who responded.

The significance of these problems varied according to the type of detention storage used. For example, parking lots, when used to detain stormwater, would not have problems of aquatic vegetation, mosquito breeding or sedimentation, but they do require maintenance and operational control. Only one engineering firm, which had built 13 on-site detention ponds, 12 of them in parks, could see no significant problems. Most firms recognized that there were problems associated with detention facilities used for flood control, but they considered these problems to be amenable to control.

TABLE 10
ADVERSE EFFECTS OF ON-SITE DETENTION FACILITIES AS SEEN BY ENGINEERS

Type of Effect	No. of Firms Responding Yes	No
Maintenance and Operation	31	2
Sedimentation	26	7
Administrative Responsibility (by Public Agency)	23	8
Safety of Children	23	8
Safety and/or Property Loss from Dam Failure	21	10
Mosquito Breeding	16	15
Aquatic Vegetation	14	16
Other	3	3

Source: 1972 Survey by APWA

Detention Methods

For undeveloped land areas, the use of contour plowing is one of the best means available for stormwater management and runoff control. Excess stormwater is stored on the side of a hill between the plowed ridges and furrows and this allows time for percolation. The method does not remove any land from agricultural use, or use as a passive recreational area. Contour plowing is an inexpensive technique, and runoff volumes from areas that have been countour-plowed are minimized and sometimes nonexistent.

In developed and developing urban and surburban areas, the use of other means for controlling stormwater runoff must be resorted to. This usually involves storing runoff on permeable or impermeable surfaces on, above or below the ground surface.

Stormwater detention methods, considerations and requirements for detention facilities are discussed for each of the following types of storage facilities — rooftops, plazas, parking lots, and basins or ponds on ground surfaces.

Rooftop Storage: Horizontal rooftops are used in some places for stormwater detention. Rooftops can provide storage which will not inconvenience pedestrians or motorists. A rooftop detention facility is not unsightly because it is not visible, and it is not a safety hazard to children. However, rooftop storage is not a problem-free method as there are problems of leakage, possible structural overloading, maintenance for removal of debris and ice and the possibility that heavy rainfalls will overflow the top of the roof if drains become blocked. This could result in serious damage to the building and its contents.

These problems can be minimized by proper design, especially if detention is designed into the original building plans and not provided later as an afterthought. For example, leakage problems can be reduced by adding extra layers of roofing membrane and by taking special care in installing roof flashings to make a watertight seal. Structural design should not be a problem in northern climates, since roof design currently demands structural strength for snow loadings, usually 30 to 40 pounds per square foot. With the weight of water being 62.4 pounds per cubic foot, a properly designed roof will have the structural strength to handle almost 6 inches of water depths, an amount that is more than sufficient for fulfilling the requirements of on-site detention of rainfall.

Maintenance is a bit more difficult and will require periodic attention, especially in the autumn during and after the leaf-falling season. However, all horizontal roofs in urban areas would need such maintenance and the added effort to maintain a roof designed to detain rain water should not be unreasonable. In many cases, the roofs will be sufficiently high or the buildings will be located in areas where maintenance would not be a problem, because debris would not accumulate enough to cause a blockage of the roof scuppers, gutters or rain leaders.

The possibility of overflows is present with any roof structure, although it is more likely when stormwater is stored on the roof. One alternative usually required by building codes is the use of overflow drains and scuppers in the parapet wall, usually about four inches above the roof drain. Proper maintenance and periodic inspection will reduce the possibility and the hazards of overflows.

A survey of about 25 major cities and all national building code organizations in the United States uncovered no codes prohibiting the use of rooftops for storing rainfall. Detention was specifically covered in the building codes of New York City, Detroit and the Denver Urban Renewal Authority, but it usually is not mentioned in the codes. Responses to inquiry most often indicated merely the added design requirements needed for structural strength, but some responses were more detailed.

The Building Officials and Code Administrators International, Inc., for example, specifies that the water from a 25-year rainstorm shall be drained within 17 hours and maximum water depth shall not exceed 3 inches. Roof scuppers are to be provided in the parapet wall, 3 1/2 inches above the roof level. The roof is to be dead level and a minimum live load of 30 pounds per square foot should be provided. Straining devices are to be provided at outlets and each roof must have a mimimum of two drains if less than or equal to 10,000 square feet in area, and four drains if greater than 10,000 square feet in area.

Factory Mutual Research (an organization for engineering research on factory and industrial buildings) was contacted about the use of rooftops for detention of rain water. This organization recommends a 35 pound per square foot live load for design and a roof pitch of .25 inch per foot to assure drainage within 24 hours after the end of the rainfall.

Insurance Services Office in New York City finds no objection to the use of storing rain water on roofs as long as the building is properly designed for the stored water. They stated that building insurance premiums would not be affected by the use of rooftop detention.

The State of Minnesota, which sets the minimum building code requirements for the entire state, specifies that a 4-inch per hour rainfall intensity be used as a design standard with a dead-level roof for determining roof drain sizes. Roof design is based on a minimum of 40 pounds per square foot. Relief scuppers must be provided, and positioned several inches above the roof elevation to allow a safety factor of at least 2 for the structural design live load. These requirements must be considered in designing roofs to detain rainfall in Minnesota.

The City of Detroit, Michigan, also specifies special design criteria including a dead-level roof provision for control of algae, mosquitos and other insects, the minimum standards for the number of downspouts per roof area, and the roof drainage rate.

Several types of roof drain detention rings have been designed and used in various places. These are shown in Figure 1, Rainfall Detention Ponding Ring.* The detention ring designed by Wright-McLaughlin Engineers (Denver, Colorado) has been analyzed for its effectiveness and compliance with the Building Code of the City and County of Denver and the National Plumbing Code. Both codes relate the size of the vertical and horizontal drains to the maximum projected roof area being drained, in square feet. In the National Plumbing Code, the drain sizes required are larger as the normal rate of rainfall increases. Presumably, the required drain pipe sizes were determined by relating pipe capacity to the amount of water produced by a given rainfall. In any event, the carrying capacity as fixed by the two codes is a function of the roof area and is not directly related to the rainfall frequency, intensity, duration or volume. Similarly, the drain size and capacity are not related to rooftop detention, but the roof drains are designed to remove water immediately, as it falls. This is not in accordance with the drainage criteria specified by the Denver Urban Renewal Authority for the Skyline Urban Renewal Project as given in Table 11, Rate of Runoff and Carrying Capacity, Table 12, Hydraulic Characteristics of Roof Drain Detention Rings, and the explanations that follow the tables.

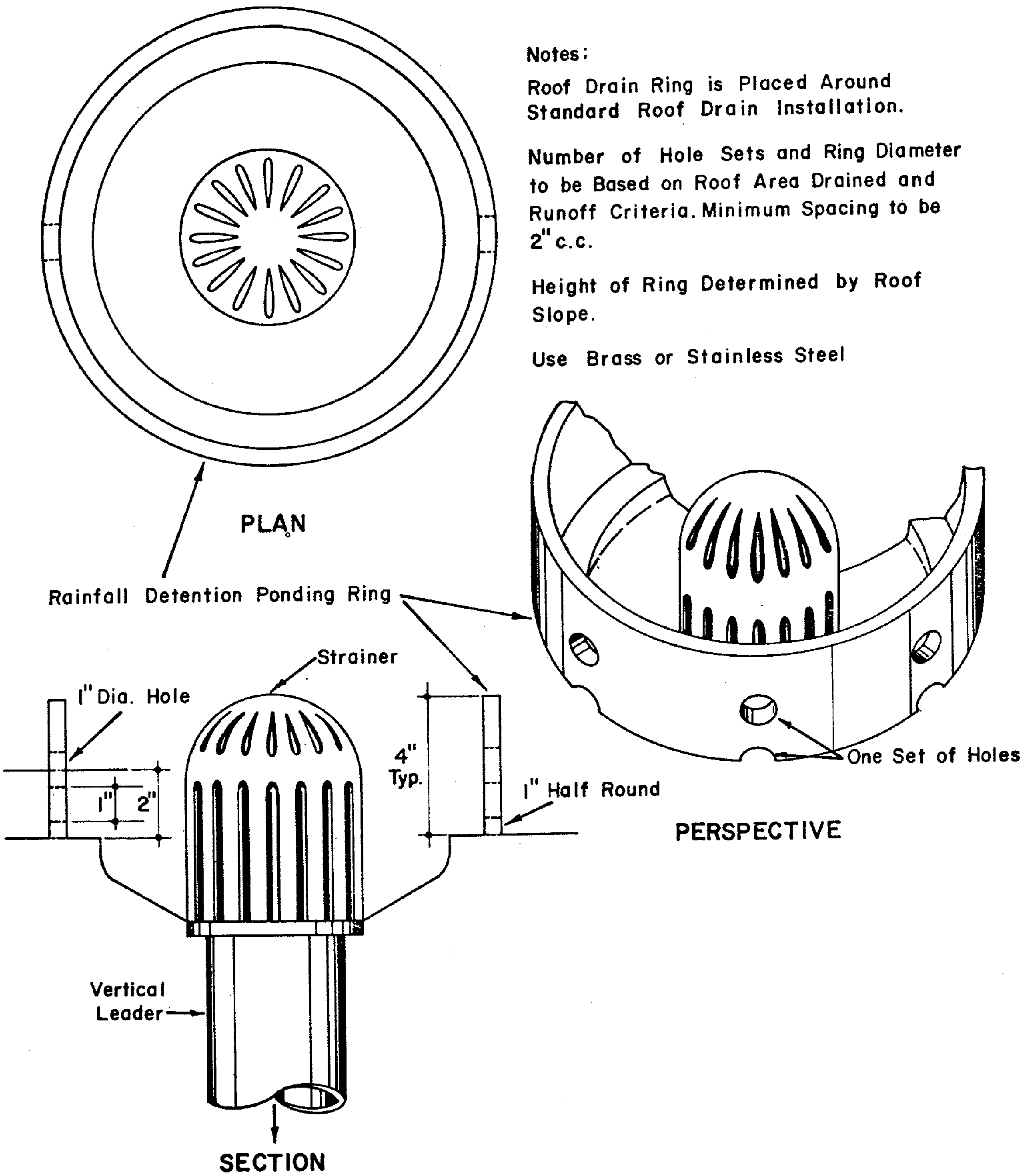
The carrying capacity values in Table 11

*The proprietary products illustrated are included only as examples. Endorsement of these products to the exclusion of similar products made by other manufacturers is not intended.

TABLE 11

RATE OF RUNOFF AND CARRYING CAPACITY

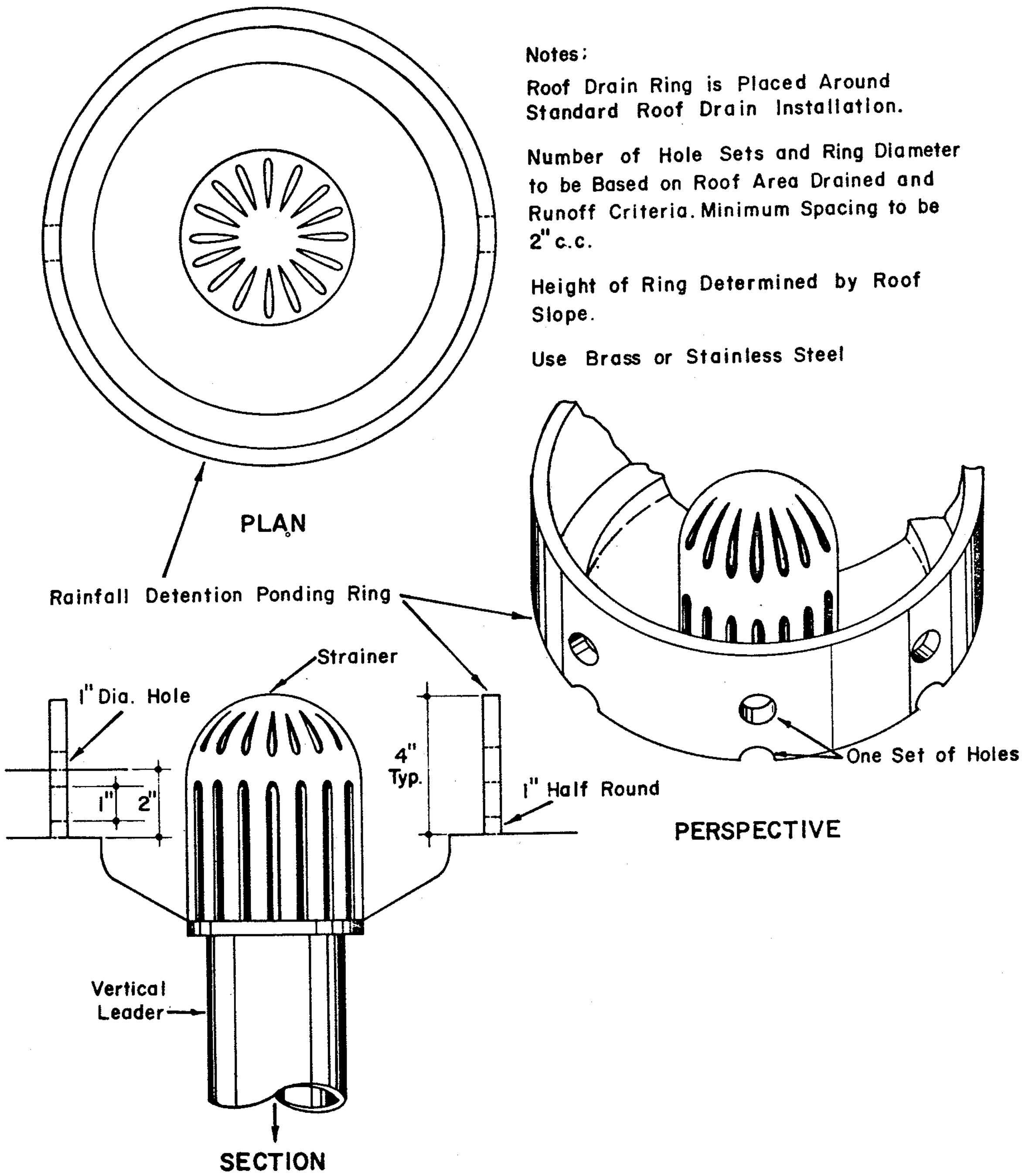
Roof Area (Sq ft)	Downspout Dia., Inches	Maximum Runoff Rate, Skyline Project Criteria: 1 in./hr (gpm)	Maximum Runoff Rate, Skyline Project Criteria: 1/2 in./hr (gpm)	Carrying Capacity Provided: 1 in. Head (gpm)	Carrying Capacity Provided: 4 in. Head (gpm)
DENVER BUILDING CODE					
720	2	8	4	10	27
1,300	2 1/2	14	7	13	43
2,200	3	23	12	15	61
4,600	4	48	24	20	108
8,650	5	90	45	25	200
13,500	6	140	70	30	270
29,000	8	300	150	40	370
NATIONAL BUILDING CODE: 2-INCH RAINFALL					
1,400	2	15	8	10	27
2,600	2 1/4	27	14	13	43
4,400	3	46	23	15	61
9,200	4	96	48	20	108



a. rooftop detention devices

Source: Wright-McLaughlin Engineers.
Denver, Colorado

FIGURE 1 RAINFALL DETENTION PONDING RING FOR FLAT ROOFS



a. rooftop detention devices

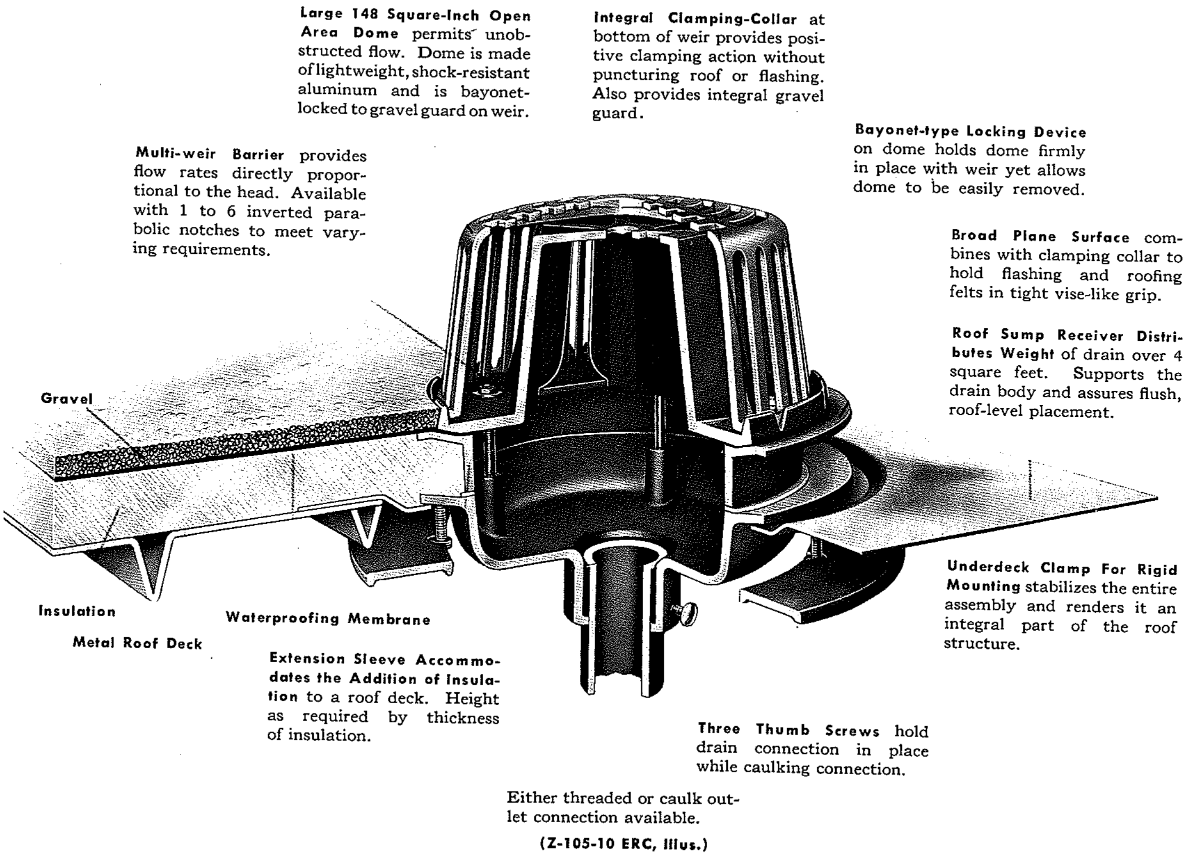
Source: Wright-McLaughlin Engineers, Denver, Colorado

FIGURE 1 RAINFALL DETENTION PONDING RING FOR FLAT ROOFS

were computed by treating the drain as a circular weir, with control at the crest and consideration given to the effects of convergence and low heads on the weir coefficient. When submergence occurred, the drain was considered as an orifice. The effects of trash screens were not considered. The head in inches refers to the depth of water over the crest of the drain inlet.

From Table 11 it can be seen that, with 4 inches of depth over the drain, the carrying capacity exceeds the permitted rates of runoff. With only one inch of head, the situation is reversed, except for the smaller roof areas. It should be noted that the head is the depth of water at the inlet, not the average depth over the area being drained. Because of roof slope and the inserting of drain inlets in sumps, the depth of water at the inlet is usually several inches greater than the average depth. Thus, it is clear that the carrying capacity provided by either the Denver Building Code or the National Plumbing Code is significantly greater than the rate of runoff specified by the criteria established for the Skyline Urban Renewal Project.

To effectively regulate runoff it is

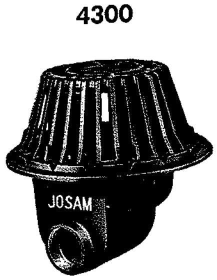


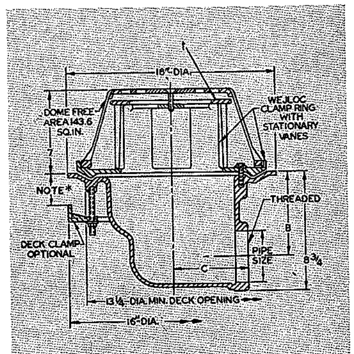
b. "control-flo" roof drain

Source: Zurn Industries, Inc.
Erie, Pennsylvania

FIGURE 1 RAINFALL DETENTION PONDING RING FOR FLAT ROOFS

4300





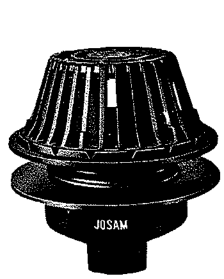
SIDE OUTLET

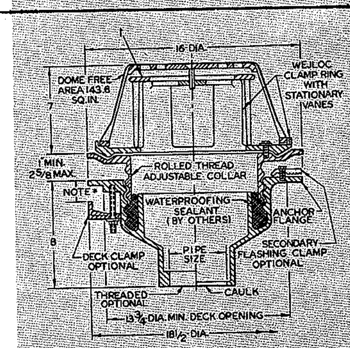
SPECIFICATION: Cast iron roof drain with large sump and flange, side outlet, large dome, adjusted calibrated vane collar, WEJLOC non-puncturing clamp ring wtih stationary vanes and integral gravel stop.

	DIMENSIONS IN INCHES			
Type No.	Pipe Size	B	C	Wgt. Lbs.
4303	3	6½	5½	66
4304	4	6	5½	66
4305	5	5½	5⅝	68
4306	6	5	5⅝	70

♦ (GG) — All Galvanized (D) — Deck Clamp
(E) — Extension Collar (N) — Drain Receiver

4500





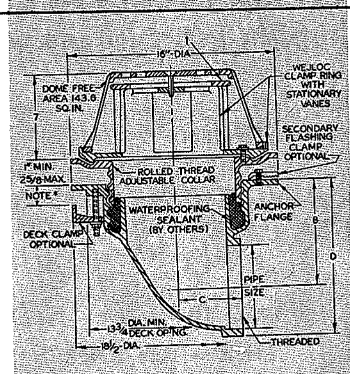
LEVELEZE

SPECIFICATION: Cast iron LEVELEZE roof drain with large sump and anchor flange, roof flange and top adjustable for insulation, bottom outlet, large dome, adjusted calibrated vane collar, WEJLOC non-puncturing clamp ring with stationary vanes and integral gravel stop.

Type No.	Pipe Size In.	Wgt. Lbs.
4503	3	108
4504	4	110
4505	5	112
4506	6	114

♦ (GG) — All Galvanized (C) — Secondary Flashing Clamp
(D) — Deck Clamp (E) — Extension Collar (N) — Drain Receiver

4510



LEVELEZE SIDE OUTLET

SPECIFICATION: Cast iron LEVELEZE roof drain with large sump and anchor flange, roof flange and top adjustable for insulation, side outlet, large dome, adjusted calibrated vane collar, WEJLOC non-puncturing clamp ring with stationary vanes and integral gravel stop.

	DIMENSIONS IN INCHES				
Type No.	Pipe Size	B	C	D	Wgt. Lbs.
4513	3	6⅝	4¾	8¾	112
4514	4	7¼	4¾	9⅞	113
4515	5	7¾	4⅞	11	115
4516	6	8¼	4⅞	12⅛	117

♦ (C) — Secondary Flashing Clamp (D) — Deck Clamp
(E) — Extension Collar (N) — Drain Receiver
(GG) — All galvanized

† Calibrated vane collar provides flows ranging from 15 G.P.M. to 420 G.P.M. at a 6" head. Specify desired flow rate and head. Drain will be furnished pre-set to these specifications.

*NOTE: ⅜ min. 4½ max. with 6" studs std. Longer studs for deeper deck available at extra cost. (On Series 4300, min. is ½", max. is 4¾")

(♦ Add suffix to Type No. for optional at extra cost)

c. "flo-set" roof drains

Source: Josam Manufacturing Co.
Michigan City, Indiana

FIGURE 1 RAINFALL DETENTION PONDING RING FOR FLAT ROOFS

TABLE 12
HYDRAULIC CHARACTERISTICS OF ROOF DRAIN DETENTION RINGS

Discharge Capacity of Various Diameter Detention Rings (gpm)

Water Depth at Inlet (Inches)	Through One Set of Holes	6-In 9 Sets	9-In 14 Sets	12-In 18 Sets	15-In 23 Sets
1.5	1	9	14	18	23
2.0	2	18	28	36	46
2.5	5	45	70	90	115
3.0	6	54	84	108	138
3.5	7	63	98	126	161
4.0	8	72	112	144	184

Overflow Capacity of Various Size Detention Rings (gpm)

Water Over Top of Ring (Inches)	6-In	9-In	12-In	15-In
1	35	55	70	90
2	95	175	250	320
3	130	300	445	610
4	170	350	630	885

NOTES:
1. Number of sets of holes is maximum number of sets for indicated ring diameter, based on a spacing of 2 inches, center to center.
2. Discharge through holes based on free discharge.
3. A *set* of holes refers to a one-half round and a full round over it.
4. This table refers only to the detention ring designed by Wright-McLaughlin engineers (see Figure 1). This detention ring is referred to in the criteria for on-site detention of stormwater published by the Denver Urban Renewal Authority, August 10, 1970.

necessary only to control the rate of flow reaching the inlet. The actual inlets, vertical leaders, and horizontal lines must be designed in accordance with the Denver Building Code. The reason for this is so the system installed will have adequate capacity and be free from clogging and freezing. A simple circular ring with holes in it can be placed around the inlet to limit the rate of flow to the inlet. With such a device, the maximum depth of ponding can be established by setting the top of the ring at the desired height. Figure 1a illustrates the essential elements, and Table 12 sets forth the basic hydraulic criteria for various size rings.

The criteria established by the Denver Urban Renewal Authority, some of which was described, was discussed prior to adoption with municipal officials and representatives of construction companies in Denver. The criteria were considered to be reasonable and were not thought to place significant constraints on architects, construction firms or building owners.

The detention ring designed by Wright-McLaughlin Engineers is useful for converting existing roof drains into detention drains. Roof drain manufacturers have developed roof drains for detention of stormwater. Various styles of fixed and variable capacity roof drains are commercially available. These companies provide technical information on design. This includes the suggested number of drains per roof area, sizes of leader and horizontal pipes, and rainfall data.

The Josam Manufacturing Company, in its publication *Storm Water Roof Drainage Systems,* by Louis Blendermann, outlines the design of controlled rooftop drainage systems and gives a case example for Springfield, Illinois. Rainfall data obtained from *Technical Paper No. 2* of the National Weather Service* for Springfield shows a maximum rainfall rate of 3.2 inches per hour for a 100-year storm of a one hour duration. Converting this information from a table to restrict the maximum ponding depth to 3 inches for a dead level roof, the peak flow per square foot of roof surface is found to be 0.0040 gallons per minute. With one drain per 10,000 square feet of roof area, the roof drain will be required to handle a 40-gallon per minute peak flow and this flow rate can be used to size the drains, leaders and horizontal drain pipes. The design is based upon draining the roof in 24 hours, or less.

In addition to giving information for horizontal roofs, controlled drainage for sloped roofs is described in the same publication. However, building code regulations governing storage of stormwater on roofs usually require horizontal surfaces. The Josam roof drains are designed to reduce maintenance problems. A gravel stop is used to prevent gravel from entering the drain and a large dome with tapered slots is used to intercept floating debris.

Zurn Industries of Erie, Pennsylvania, also makes roof drains to control runoff flow rates. The company publishes technical literature which presents detailed information on roof drain design. Climatic data for several hundred U. S. cities is given in one of these publications for design of roof drains on horizontal roofs and sloped roofs. The advantages of small diameter downspouts and the benefits of detaining rain water on rooftops in reducing flow rates in storm sewer systems is explained.

Other methods for detaining rain water on rooftops are possible without requiring detention rings for the control device. In a study for the U. S. Department of the Army, Sacramento District, Corps of Engineers, Professor Gert Aron of the Pennsylvania State University studied non-conventional forms of detention to determine their effectiveness and feasibility. His analysis is described in detail in Chapter 9. Basically, Professor Aron's proposed technique consists of constructing gravel dams on roofs. These dams would cause the water to collect behind them, but would allow the water to flow through the gravel structure at a reduced rate, to dewater the roof. An experimental study was made of these barriers to determine their hydraulic characteristics. A hypothetical case study was then made of an urban area assumed to have 200 acres of watershed, including 200,000 square feet of horizontally-roofed buildings. It was estimated that it would be possible to reduce peak stormwater runoff flows from the 200 acre watershed by about 11 percent (from 185 cfs to 165 cfs).

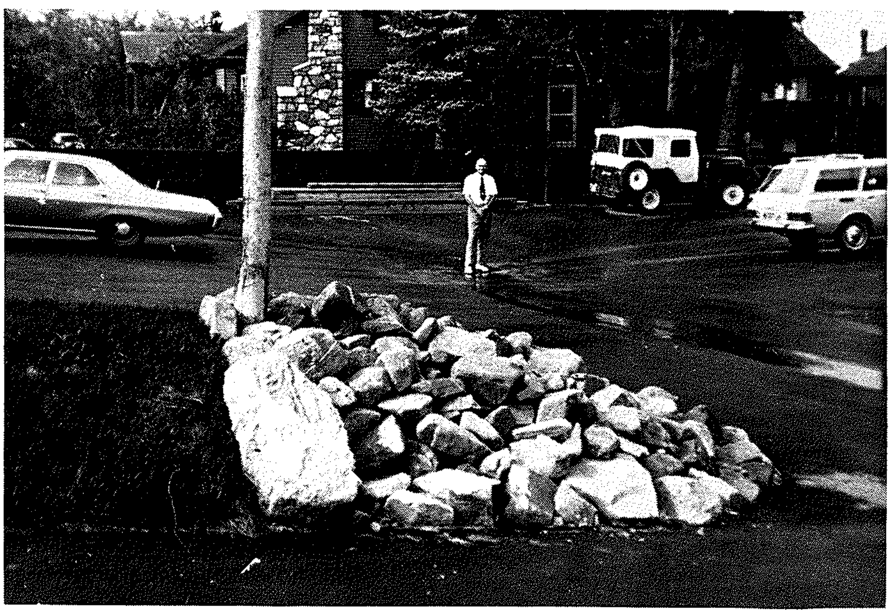
Storage on Plaza Areas: The use of paved plazas in and around commercial buildings and office buildings to detain stormwater is similar to the use of parking lots which is discussed next. However, there are differences between these two types of detention facilities in respect to tributary drainage area, grading requirements, and the maximum depth of water that can be ponded before causing an inconvenience to the public.

Parking Lot Storage: Temporary storage of stormwater on parking lots is another means employed to reduce runoff rates and sewer loading. An example is given in Chapter 4 of this report describing how Consolidated Freightways, Inc., used stormwater detention techniques in conjunction with a parking area and sewers at its terminal in St. Louis, Missouri. The $115,000 cost of the drainage system constructed was $35,000 below the estimated $150,000 cost of a system without provisions for on-site detention of rainfall.

The large area which is characteristic of many parking lots serving shopping centers, office buildings, apartment complexes and

*Formerly the U.S. Weather Bureau.

a. parking lot serving office building constructed to detain stormwater in low areas at grated-inlets – Boulder, Colorado



b. parking lot at apartment complex designed for stormwater detention by means of throttled stormwater inlets – Boulder, Colorado

FIGURE 2 PARKING LOT DETENTION

industrial plants is a factor that makes such parking lots extremely attractive for stormwater detention. Figure 2, Parking Lot Detention, shows attractive parking areas in an apartment complex and at an office complex in Boulder, Colorado. The apartment parking area was designed to detain stormwater and the grass areas between buildings were also dished to store runoff for slow release through throttled drains provided with orifice plates. Large volumes of rainfall and snowmelt can be stored on selected portions of these paved areas.

Unlike ponding on rooftops, there is no limit, from a structural standpoint, to the depth of water that can be stored. Another advantage is that the surface does not need to be dead-level as is true in the case of rooftop ponding. Because of the ease of inspection and access, the maintenance and operation of parking lot detention facilities is a low cost item and easy to perform with mechanical street cleaning equipment. The likelihood of extensive future use of porous pavements in some geographic areas, as detailed in Chapter 9, may mean that detained water can seep into the ground instead of being discharged into the sewer system. This can be an important corollary advantage in water-short areas.

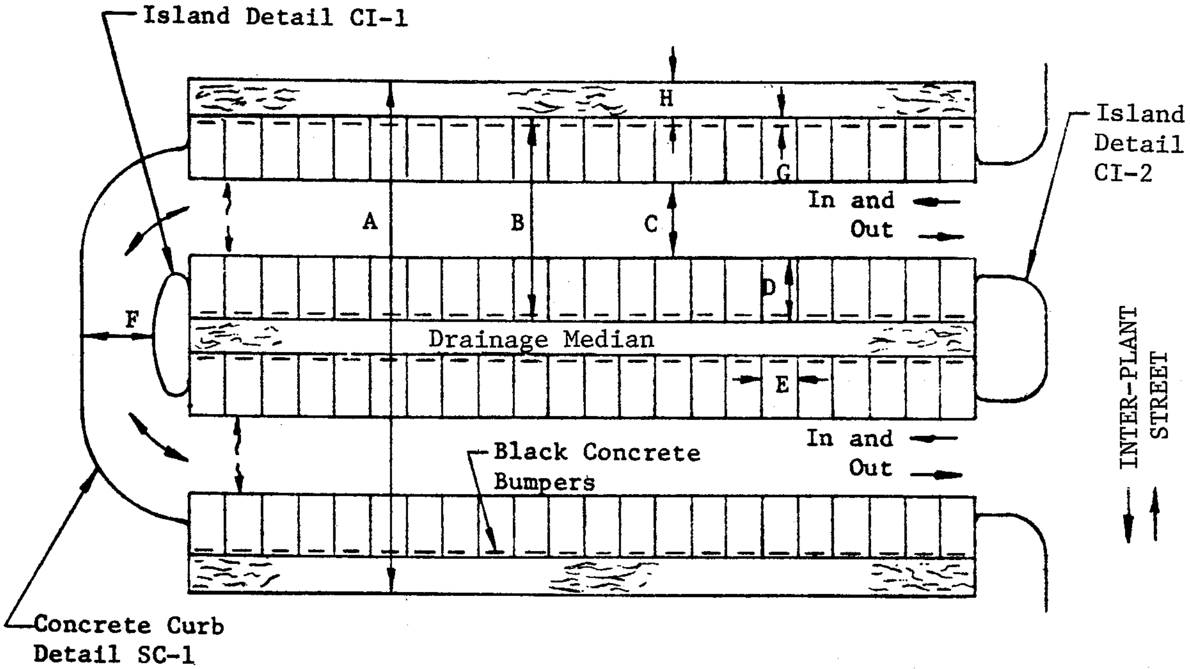
Problems with the use of parking lots for stormwater detention can be reduced to acceptable inconveniences by proper planning and design. Detention of stormwater on parking lots would not be favored by parking lot users because of the inconvenience that ponding imposes and its interference with vehicle access and movements. For example, as shown in Figure 2, the office building parking lot has steep slopes which were required to provide sufficient storage in the small area. Because of the steep slopes, storage of an appreciable amount of water on such a lot would result in water depths that might cause problems for people, at times, when walking to their vehicles. The steepness of the lot might be displeasing to some people, and such a lot might cause difficulty in walking for elderly persons and physically handicapped people. The steep slopes could also cause problems of vehicle entry or exit because of reduced traction at times when ice forms on the paved area.

There are two general forms of stormwater detention on parking lot surfaces. One form involves the storage of runoff in depressions constructed at drain locations. The stored water is drained into the sewer system slowly, using restrictions, such as orifice plates, in the drain. This type of storage is represented by the paved area of the Consolidated Freightways terminal and the parking lots in Boulder, Colorado, described above. Proper design of such paved areas would restrict ponding to areas which will cause the least amount of inconvenience to the users of the parking areas. For example, the parking lot of a shopping center would have the ponding areas located in the least-used portions of the lot, allowing customers to walk to their vehicles in areas of no ponding except when the entire lot is filled with vehicles. Drainage of ponded water would be fairly rapid as compared to rooftop ponding, to prevent customer inconvenience. In most cases, the water would pond to a depth not to exceed 12 inches and the ponding area would most likely be drained within 30 minutes, or less, after the rainfall. Computation of the amount of storage needed would be similar to the analysis used in designing detention basins on ground surfaces. The Modified Rational Method Analysis (described later) will often be applicable, although large parking lots will require other types of analysis for accurate prediction of storage volume requirements. In most instances, the use of the Rational Formula should be satisfactory because of the almost constant imperviousness of parking lot surfaces.

Another type of stormwater detention on parking lots consists of using the paved areas of the lot to channel the runoff to grassed areas or gravel-filled seepage pits. The flow then infiltrates into the ground. Soil conditions and the effects of siltation in reducing infiltration must be considered. An analysis illustrating this method, developed by Professor Gert Aron, is presented in Chapter 9. A theoretical investigation of parking lots indicated that the peak flows of runoff from

PERPENDICULAR PARKING

HEAD IN ONLY



KEY	DESCRIPTION	MINIMUM	NORMAL	OPTIMUM
A	Overall lot width	136'	146'	158'
B	Parking bay width	56'	58'	64'
C	Drive width	20'	22'	26'
D	Parking space length	18'	18'	19'
E	Parking space width	9'	10'	10'
F	End drive width	12'	20'	20'
G	Pavement edge to bumper centerline	1'	1'	1'
H	Median width	8'	10'	10'

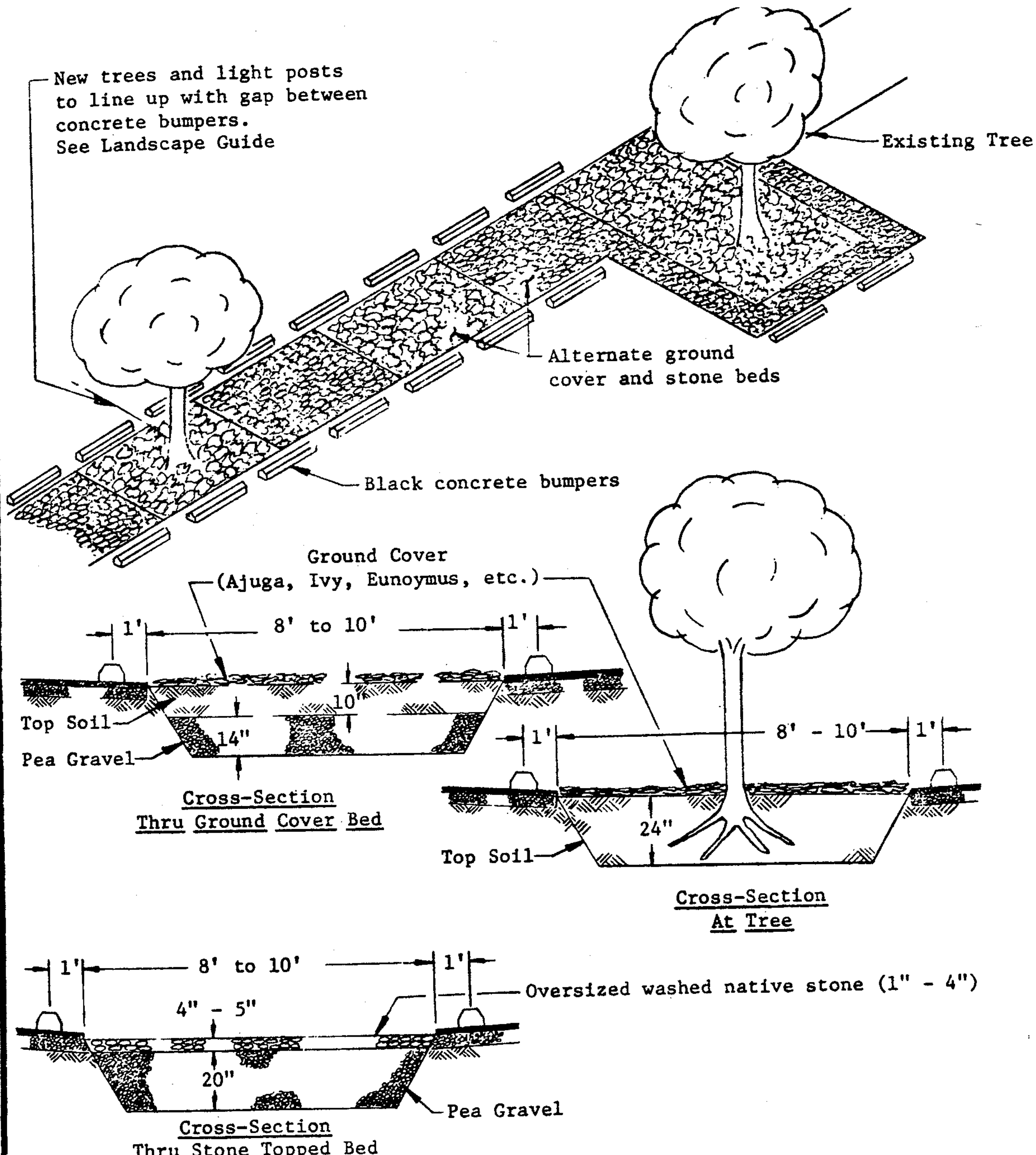
a. layout using pervious median strip

Source: Miles Laboratories, Inc. Building Construction Standards

FIGURE 3 PARKING LOT DETAILS

six acres of paved area could be reduced a maximum of 10 percent for the assumed rainfall under the assumption that the infiltration trenches are only 50 percent effective.

As an example of this method of detention, Miles Laboratories, Inc., has developed parking lots utilizing a pervious median strip to handle storm drainage as shown in Figure 3, Parking Lot Details. Designs of this type reduce construction costs of the drainage system because smaller diameter storm sewers can be used. Such median strips are aesthetically pleasing and



b. details of median strip for parking lot drainage

Source: Miles Laboratories, Inc.
Building Construction Standards

FIGURE 3 PARKING LOT DETAILS

can be used for storage of plowed snow in the winter. The possibility of polluting ground water, if no confining soil strata exists, should be investigated.

Minimum slopes of 1.0 percent are recommended in parking lot detention areas. Maximum slopes should not exceed 4 percent to avoid gasoline spillage from tanks and to minimize vehicle traction problems on icy paving.

Figure 4, Controlled Rate Inlet, shows details often used by a Denver engineering firm in specifications for the design of controlled rate inlet facilities for detention ponding on paved surfaces such as parking lots. The drawing shows three different configurations used for the installation of controlled-rate inlets when incorporated with grated drop-inlets on circular manholes and at curbs.

Surface Basins and Ponds: Usually detention basins and ponds constructed on ground surfaces are relatively large ponds, having the appearance of a small lake or park pond. The design of such facilities will vary depending upon the land costs, space availability, physical and aesthetic characteristics of the area, topography, climate, and other local factors. Whether or not the detention facility is to serve multi-purpose uses, such as recreation, is a factor that may dictate size, shape, depth and landscaping treatment. For example, a detention pond may be designed to serve as a recreational pond for boating and fishing. Such a facility would require different design criteria than a pond which is to serve the single function of stormwater detention. In other instances, the availability of large open areas will permit a design having gentle side slopes and extensive landscaping; while sites where land is limited might dictate deep ponding areas, pumped discharge, and steep side slopes that require fencing and other security measures to minimize safety hazards to children.

The major design considerations are the volume of storage needed and the maximum permitted release rate. Storage volume needed is given by the maximum difference, at any time, between cumulative total inflow volume and cumulative outflow volume measured from the beginning of inflow. The maximum permitted release rate can be calculated by determining the maximum discharge capacities of downstream sewer systems or receiving streams and the administrative restrictions that may be imposed by local authorities to regulate the discharge rate. Calculation of the inflow rates and volumes is sometimes complicated.

Figure 5, Controlled Rate End Section, illustrates a Denver, Colorado, engineering firm's standard design for a controlled rate release structure incorporating a horizontal pipe culvert. Normally, this type of outlet facility would be used where an embankment has been constructed to create the ponding area. An important part of this inlet is the steel grating which covers and protects the inlet from the normal debris which accumulates in drainage facilities of this type.

Engineering Design [2]

Planning: One of the purposes of on-site detention of stormwater is to prevent excess runoff from attaining flow rates that exceed the capacities of downstream drainage systems. Unless every available location for stormwater storage is utilized, the management of stormwater runoff by means of on-site detention will not be completely successful. In cases where steep gradients make on-site detention of significant amounts of stormwater extremely difficult, on-site detention becomes uneconomical. In cases of flat gradients and long distances to acceptable points of stormwater discharge, satisfactory operation of on-site storage facilities is difficult and costly. In the latter case, the alternative method is to store the excess stormwater in the least objectionable locations for the shortest period of time possible. Under some circumstances, it may be prudent to resort to man-made storage structures if reduction of outflow rates is legally unavoidable. The City of San Francisco, for example, is planning to construct a series of underground storage tanks and tunnels.

By using a form of the continuity equation it is possible to determine the rate at which the stormwater can be routed through a watershed without creating flooding

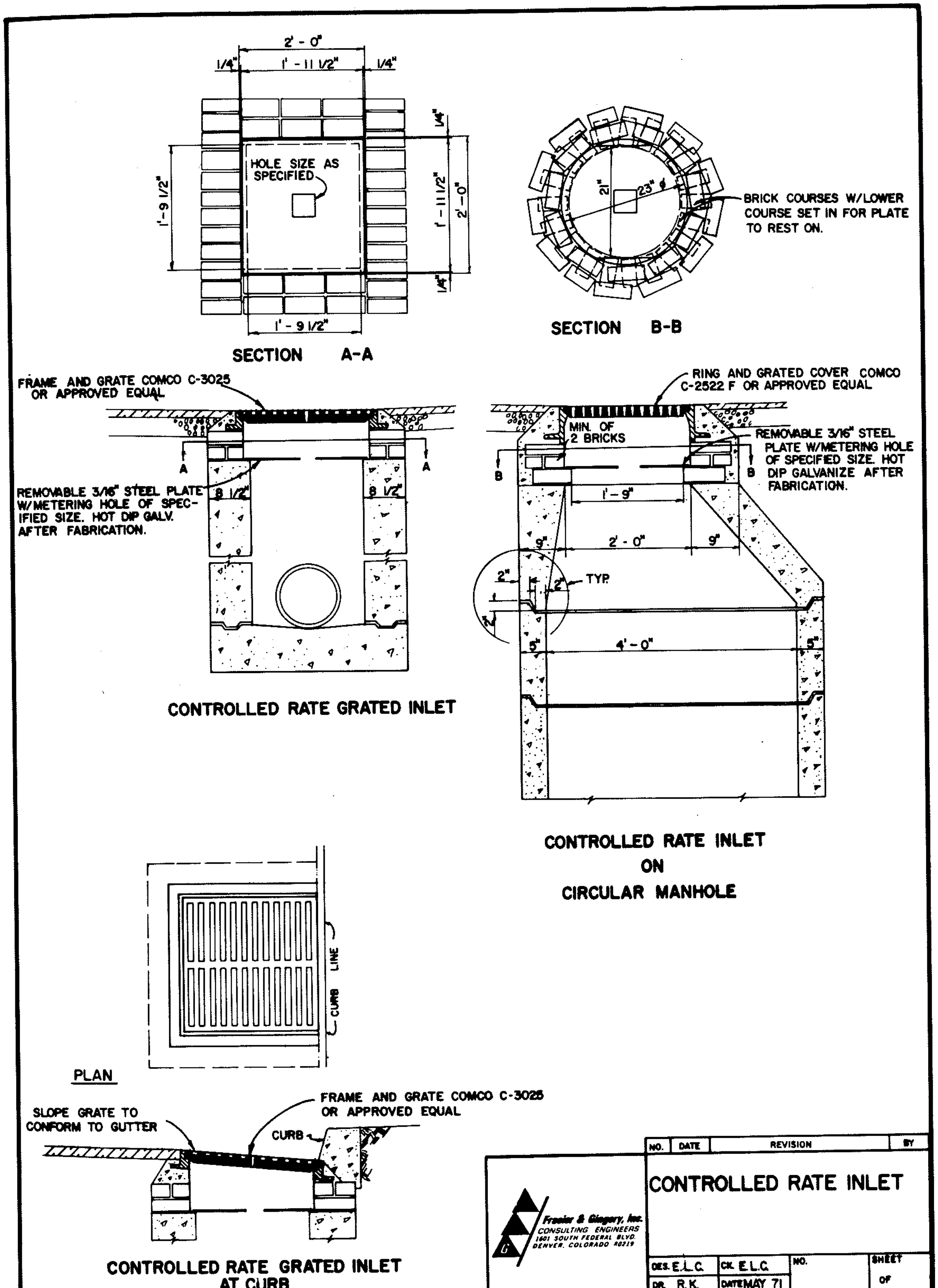


FIGURE 4 CONTROLLED RATE INLET

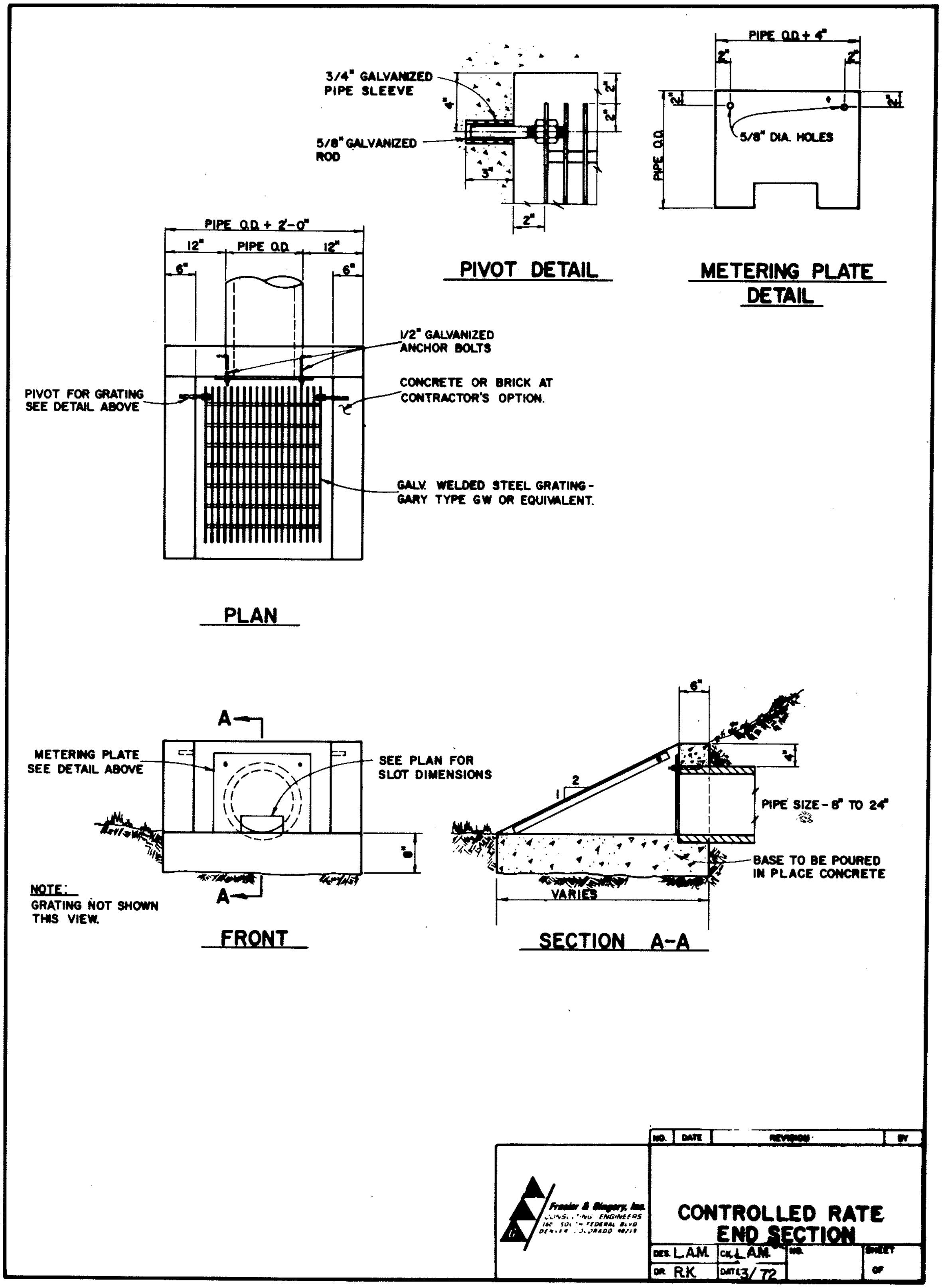


FIGURE 5 CONTROLLED RATE END SECTION

problems. Since this safe capacity will usually be far below the anticipated inflow of stormwater from the watershed for the return frequency rainfall chosen for design purposes, it is required that the excess be stored. The ideal design begins the storing of excess runoff as close as possible to the ridge lines that divide and subdivide a watershed.

When examining a site to determine the feasibility of providing facilities for the temporary storage of excess runoff, it is advisable to note the existing contours of the land and to incorporate these into the drainage plan, if practical. Storage can be achieved by blocking the gravitational flow of water with various land forms, curbs, walls, etc.

Sufficient storage volume should be available to prevent local flooding damage. For example, in Northeastern Illinois some designers provide for storing between 2 1/2 inches to 3 inches of runoff from the tributary watershed, depending upon the type of development proposed and the proportion of impervious to pervious area. Storage depths should be kept shallow and spread out over as wide an area as is practical.

Design Criteria: The more important criteria to consider in designing detention facilities are listed below.

- Stormwater excess should be kept out of proposed habitable areas.
- A positive outlet should be provided for discharge of inflows, in the event the storage capacity is exceeded or the drainage system plugged.
- The surface of the detention area should be constructed with sufficient slopes to drain properly so that all of the runoff is removed following a storm (e.g., slopes of paved surfaces – 1 percent, paved channels – 0.4 percent, grassed areas – 2 percent).
- The deeper portions of the storage areas should be located in the more remote, least-used areas of the site.
- Special care should be taken to note any runoff that is likely to enter the storage site from upstream areas as well as where excess stormwater will discharge into downstream areas.
- The design considerations should be based on the hydraulic gradient, and control structures should provide for uniform regulation of release flow rates, relatively independent of the depth of stormwater being stored.
- Engineers should be *conservative* in the calculation of the storage volume required. This will result in a smaller percentage of the available storage being required by the lesser rainfalls, and this will cause less interference with the primary use of the land.
- The storage area should not be used exclusively for the storage of excess stormwater but multi-purpose use should be provided for. Otherwise, the stormwater storage facility will most likely be offensive to citizens of the community.

Design Factors: It is useful to identify the various technical and physical factors which should be considered in the design of a stormwater detention facility. These include:

- design rainfall frequency, intensity, and duration;
- size and location of the drainage area tributary to the proposed detention facility;
- hydrologic data of the tributary area;
- a graph of the rate of inflow to the detention facility (cfs) vs. time (i.e., the inflow hydrograph);
- the maximum permitted release rate from the detention facility (i.e., the outflow hydrograph);
- the storage volume required for the detention facility;
- spillway, or other means, for release of stored water and for by-passing excess flows of exceedingly rare rainfalls that cannot be accommodated by the storage facility;
- time limitations for draining the stored runoff without causing secondary problems;
- complete and timely drainage of stored runoff by provision of sufficient basin slope, adequate pumping facilities and alternative release mechanisms for times when normal discharge outlets are blocked;
- type of facility for detention (rooftop, parking lot, park pond, etc.);
- safety precautions;
- factors pertinent to efficient maintenance and operation, annual cost, and useful life of the facility; and
- flood routing for runoff greater than the design capacity of the detention facility.

Design Procedures: Prior to initiating engineering designs, the requirements and criteria of local public agencies concerning detention storage should be studied and summarized.

Suggested procedures for designing on-site detention facilities are outlined below in the sequence of application recommended.

- Define the property lines of the specific site involved.
- Determine the areal limits of the watershed tributary to the site and its relationship to the next higher-order watershed.
- Examine the routing of excess stormwater through the site using detailed topographic maps.
- Examine the path of stormwater flow as it is discharged from the site.
- Determine the discharge capacity of the downstream stormwater channel or storm sewers. Use the lowest value of the discharge capacity found to determine the maximum flow-rate at which stormwater may be released from the detention facility.
- Obtain the most reliable rainfall data for the region. The local university or the National Weather Service is usually the best source for this data. The data should include the intensity and duration of various return frequency rainfalls, from the annual event to the 100-year event.
- Produce a hydrograph for the runoff from the area tributary to the proposed detention facility, using parameters that represent existing conditions. Several hydrographs should be prepared to illustrate several return frequencies and show the peak runoff flow-rate and extended duration for each of these storms.
- Evaluate the conditions that are created by the on-site storage of runoff at a rate that exceeds the release rate, determined in a step above. Matters to be considered are: (a) problems, if any, that are created on-site by the storage of stormwater runoff, and (b) problems that are created downstream when the on-site storage capacity is fully utilized and the excess runoff flows overland in downstream areas. An economic evaluation of the potential damage attributable to excess storm flows from the planned detention facility should be made and compared to the expense involved in providing alternative solutions.
- Select the locations of the proposed detention facilities and the method of outlet restriction to be used. In all cases, the maximum release rate should be calculated using the hydraulic gradient created when the storage area is being used to its fullest capacity.
- Make structural designs of the facility based on results of the above steps. Give special attention to providing for an emergency spillway to pass rare excessive flows.

Special Design Considerations for Undeveloped Land: The design procedures outlined above should be modified when undeveloped land is involved to account for potential changes in land use and planned development. These include:

- changes in land use not contemplated at the time of developing original design criteria (many such changes result from rezoning);
- changes in channel configurations brought about by encroachment, precipitated by the lack of adequate right-of-way, etc.;
- failure to *account* adequately for future runoff rates from storms in excess of the drainage design capacity;
- political decisions, based on development pressures, to comply with existing drainage laws and disregard of the problems created on servient land by dominant runoff;
- the great need for providing housing and the lack of control over construction and/or land-filling within a known flood route or flood plain; and
- changes in various portions of the drainage system within a drainage basin without proper review of the consequences that would result from the *improvement*. For example, assume that a community passes a storm sewer bond issue to eliminate street flooding. Large storm sewers are then constructed allowing stormwater to be transported downstream at a rate greater than the existing stream or conduit capacity. The result is that downstream communities are now faced with the need to construct

stormwater facilities to prevent flood damage. Or, litigation can occur in which servient land owners may obtain injunctive court orders or claim provable damages.

Additional Design Steps Required for Developed Land: For previously developed areas, additional factors need to be considered. It is recommended that the design of detention facilities for these areas include the following additional steps:

- Prepare a detailed atlas of the existing drainage system to describe accurately the size and slope of conduits and the rim and invert elevations of existing manholes and inlet structures.
- Prepare a topographic map of the entire watershed tributary to, and including, the site. Use a 1-ft contour interval.
- Make a survey of the site to determine flood-prone areas by contacting reliable sources familiar with the flooding problems. Many times a postcard survey is worthwhile. Sometimes public works agencies keep records of complaints by location.
- Identify and quantify the various sources of the storm runoff that create the flooding conditions.
- Provide detention storage by some type of restriction in the existing drainage system at the source of the runoff which is creating the flooding problems to control the rate of drainage downstream. Check the detailed topography of the proposed storage areas to insure that excessive storage depths are not created and that the possibility of flooding inhabited areas is eliminated.
- By use of a flood routing analysis, check any proposed design that exceeds the design criteria and determine the effect that flow restrictions in storm sewers would have on area drainage and flooding.

Many of the design criteria proposed for undeveloped areas also apply to developed property. The major difference is the degree of difficulty in providing an acceptable location for on-site detention of stormwater runoff. Some of the locations that have been used in the past include:

a. vehicle parking areas,
b. horizontal rooftops of buildings,
c. existing rights-of-way (public or private),
d. parks and playgrounds,
e. vacant land that is easily drained,
f. school yards,
g. golf courses (municipal or semi-private), and
h. swamps or existing ponds.

The use of these properties for stormwater detention may involve legal and political problems. To make on-site storage of excess stormwater runoff acceptable to all local parties affected, including local officials, a detailed survey and analysis of the drainage hydraulics is required. An extensive educational program is also recommended so that some of the local landowners and municipal officials are well-schooled in what is being accomplished by stormwater management.

Examples of Various Design Methods

One problem that is central to the design of any stormwater drainage system is the prediction of the volume of runoff with time and calculation of the peak flow rates. Simplified computation methods, such as the method employing the widely-used Rational Formula, rely heavily upon personal judgment and are often unsatisfactory for producing accurate estimates of runoff flow rates. It is the conviction of many professional engineers that only by utilizing hydrographs can proper computations be made. However, inquiries made of practicing engineers reveal that most of them make use of the Rational Formula, but they restrict its application to the analysis of relatively small watersheds.

This formula is usually stated as

$$Q = CiA$$

where

Q = flow rate (cfs)
C = runoff coefficient (assumed)
i = intensity of rainfall (inches/hour) for the selected design duration and frequency
A = tributary area, in acres

The physical characteristics of the specific watershed under consideration will determine the amount of possible discrepancy between the computed runoff flow rates and the rates that would actually develop in the field for the design rainfall. For a given rainfall intensity and tributary drainage area, the Rational Method has only one manipulative variable, the runoff coefficient. Because of the impossibility of accounting for different and varying watershed characteristics with the Rational Formula, many engineers, educators and authors decry its use. They are hopeful that current research efforts will result in improvements in techniques of design.

More sophisticated techniques for calculating runoff rates and volumes have been developed, most of which are particularly applicable to specific geographical areas. For example, the Colorado Urban Hydrograph Procedure has been developed based on local data and is more accurate for the Colorado region than is the Rational Formula.

In the State of Illinois, a computation method for prediction of runoff flow rates has been developed by Dr. Ven Te Chow of the University of Illinois Engineering Experiment Station. His method is applied to Illinois. Climatic conditions, soil types, antecedent precipitation and local rainfall records have been combined to develop a model that relates rainfall and runoff. Similarly, methods have been developed in other places which are better suited to local conditions than the basic Rational Formula.

Another method of runoff analysis, developed by Dr. Gert Aron of Pennsylvania State University, examines the tributary watershed by the strip routing method to determine which portion of the watershed contributes most to flooding. The watershed is divided into zones as a function of the time-of-concentration at the flooded area as indicated in Figure 6, Time of Concentration Contours. The hydrographs of each of these zones is plotted and can be summed to form the total hydrograph, as shown conceptually in Figure 7, Subbasin Hydrographs, Summed. This allows the designer to identify the hydrographs which produce the peak flow. Then the flood-producing zones can be identified as indicated in Figure 8, Flood Producing and Flood-Prone Zone.

Besides the question of whether stormwater storage is needed in a given situation, the factors that should be considered in planning and designing detention facilities include:

- available space and topography
- maximum depth of storage as limited by
  a. legal requirements
  b. safety concerns,
  c. Inconvenience of storage greater than a specified depth,
  d. time required to drain a specified depth of storage;
- the maximum release rate allowed;
- economics;
- legal requirements for storage such as
  a. storage of peak flow for a specified time, and
  b. storage of the runoff flow that exceeds the historic flow rates.

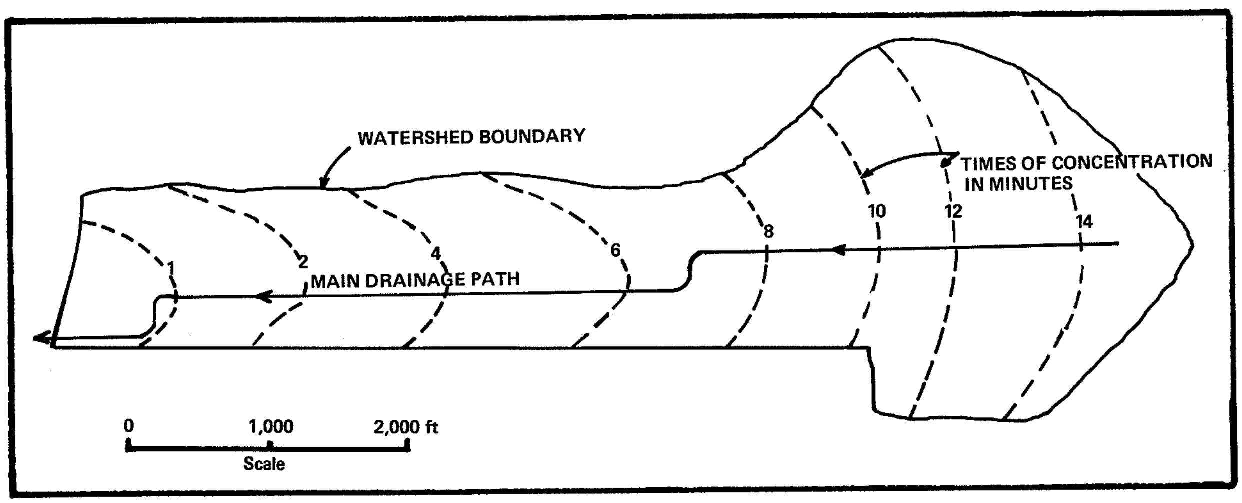


FIGURE 6 TIME OF CONCENTRATION CONTOURS

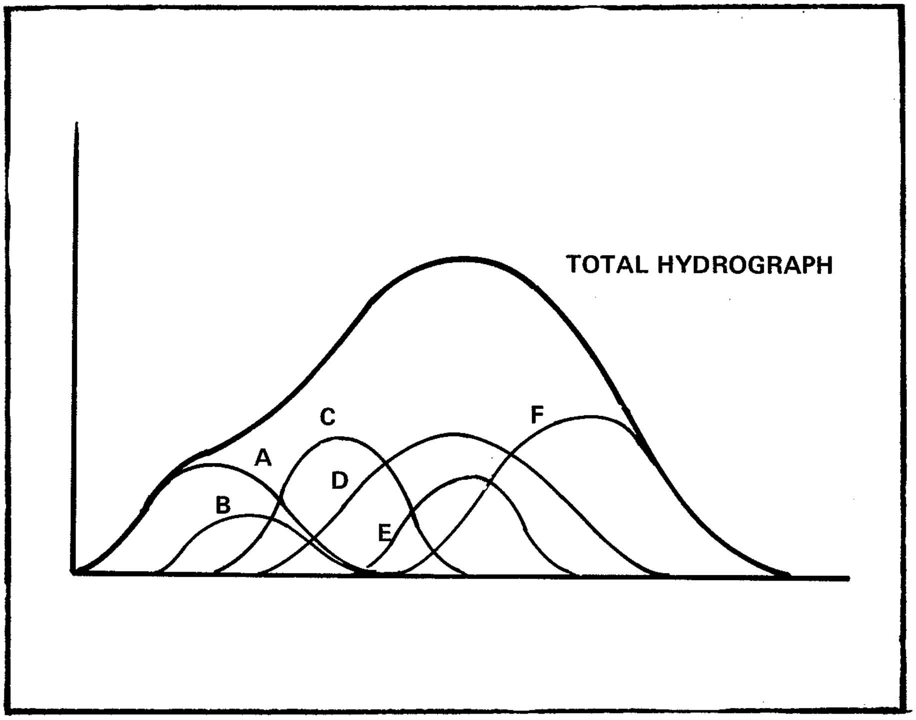


FIGURE 7 SUBBASIN HYDROGRAPHS, SUMMED

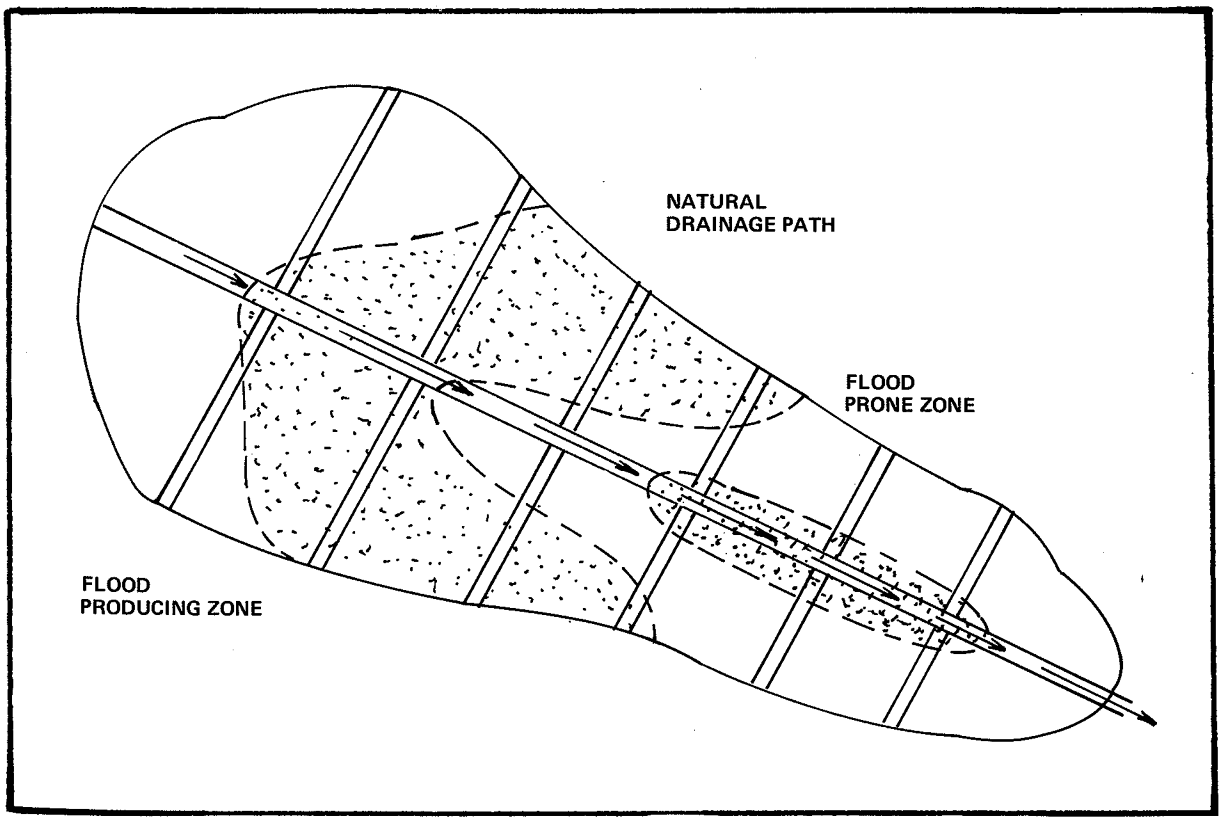


FIGURE 8 FLOOD PRODUCING AND FLOOD-PRONE ZONE
IN A SMALL URBAN WATERSHED

Several examples of the computation of runoff flow rates and runoff volumes as applied to the design of stormwater detention facilities are given in the following pages to illustrate the use of various methods. Although examples are included that embody the use of the basic Rational Formula, it is not intended to suggest, encourage or perpetuate the use of this method. Such examples are included because they are typical of the design practices of personnel of many engineering firms and public agencies across the country.

Examples are given of the Modified Rational Method Analysis (used in Madison, Wisconsin, and in other places); a method developed by Dr. Ven Te Chow for particular application in the State of Illinois; and the Colorado Urban Hydrograph Procedure.

Modified Rational Method Analysis:[3] The term Modified Rational Method Analysis refers to a procedure for manipulating the basic Rational Method techniques to reflect the fact that storms with durations greater than the normal time of concentration for a basin will result in a larger volume of runoff even though the peak discharge is reduced. This greater volume of runoff produced by longer duration storms must be analyzed to determine the correct sizing for detention facilities.

Many limitations and shortcomings in the assumptions behind this method are evident. The approach becomes more valid on progressively smaller basins, eventually reaching a size so small that watershed modeling is approached. The procedure should, therefore, be limited to relatively small areas such as rooftops, parking lots, or other upstream areas with tributary basins less than 20 acres. This would minimize major damage which could result from overtopping or failure of the proposed detention facility.

Figure 9, Modified Rational Method Hydrographs, presents a family of curves for a theoretical basin. These hydrographs are developed by using the basic Rational Method assumptions of constant rainfall intensity (i) time of Concentration (T_c) from the most distant point, timewise, and the coefficient of runoff (C). The typical Rational Formula hydrograph with the peak discharge coinciding with the time of concentration for the basin (T_c), is first calculated using the normal formula Q = CiA. Following this, a family of hydrographs representing storms of greater duration are developed. The peak runoff rate for each hydrograph is equal to CiA where (i) is the rainfall intensity for the storm duration in question. The rising limb and falling limb of the hydrograph are, in each case, equal to (T_c) for the basin. The basic assumption of this method is that the area under the assumed trapazoidal hydrograph equals the volume of runoff from the theoretical rainfall. The area under the hydrograph is also equal to the peak discharge rate for that particular rainfall times the duration of the rainfall.

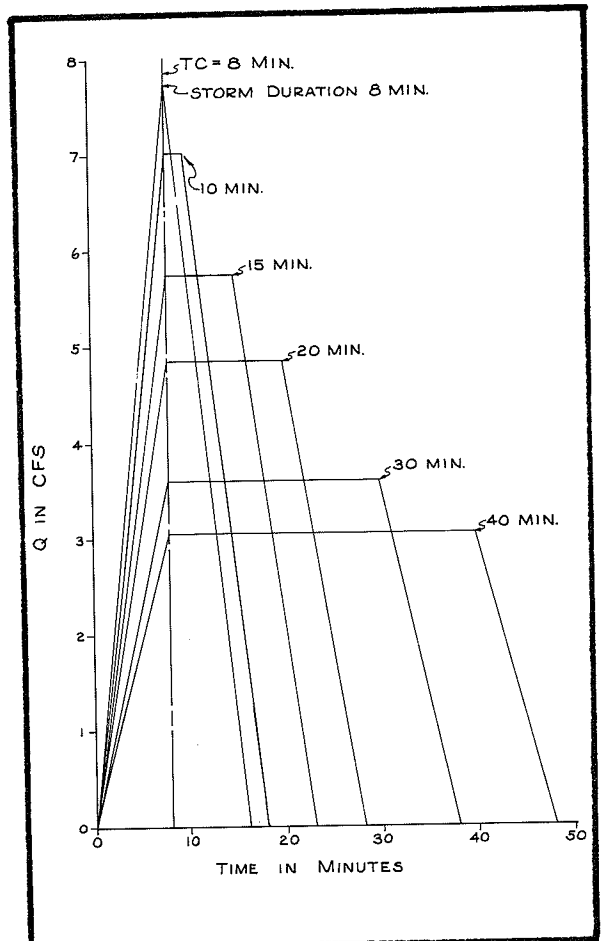


FIGURE 9 MODIFIED RATIONAL METHOD HYDROGRAPHS

The following example presents the calculation method for a typical two-acre basin.

Example No. 1

Given

Area: A = 2.0 acres

Type of development: commercial parking lot, fully paved, C = 0.9

Design rainfall frequency: five-year

Rainfall time–intensity–frequency curves: as indicated in Figure 10, Rainfall Time–Intensity–Frequency Chart

Time of Concentration: T_c = 8 minutes

Required:

Develop family of curves representing Modified Rational Method hydrographs for the 8, 10,15,20,30 and 40 minute rainfall durations.

Rainfall Duration (minutes)	Rainfall Intensity (in./hr.)	Peak Runoff Rate (cfs)
8	4.3	7.74
10	3.9	7.02
15	3.2	5.76
20	2.7	4.86
30	2.0	3.60
40	1.7	3.06

Answer: The resulting storm hydrographs are depicted in Figure 9.

It is recommended that a coefficient be added to the Rational Method to account for antecedent precipitation conditions for major storms with recurrence intervals greater than 25 years. Table 13, Recommended Antecedent Precipitation Factors, presents a set of recommended coefficients. Under these conditions, the Rational Formula becomes $Q = CC_aiA$. Although this approach does not totally reconcile the difficulties in representing volume of runoff by the Rational Method, it does attempt to predict more realistic hydrograph volumes characteristic of the higher frequency storms.

TABLE 13
Recommended Antecedent Precipitation Factors for the Rational Formula

Recurrence Interval (Years)	C_a
2 to 10	1.0
25	1.1
50	1.2
100	1.25

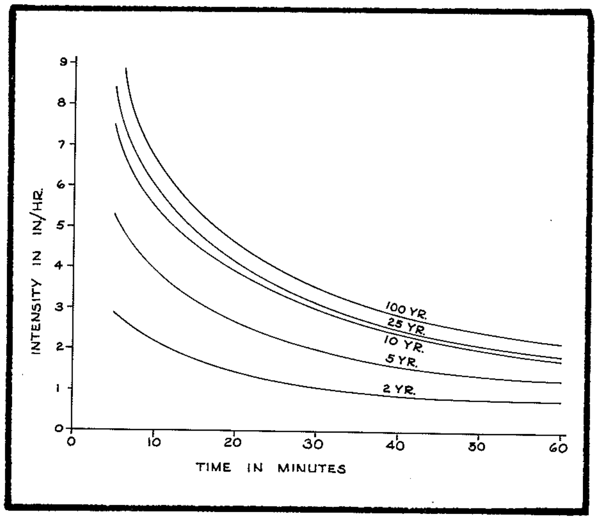


FIGURE 10 RAINFALL TIME-INTENSITY-FREQUENCY CHART

The next step in determining the necessary storage volume for the detention facility is to (1) set a release rate and determine the volume of storage necessary to accomplish this release rate or (2) determine the amount of stormwater storage volume available on the site and then determine the minimum release rate required so as to not exceed the storage volume. The first possibility, that of determining necessary storage volume when a pre-determined release rate is selected, will be dealt with first.

To determine the storage volume required, a reservoir routing procedure should be accomplished on each of the hydrographs, with the critical storm duration and required volume being determined. The importance of the particular project should govern the type of routing utilized. For small areas requiring repetitive calculations, such as in bays of a parking lot, an assumed release curve is normally satisfactory. For larger areas, such as a pond in a small park area with 20 acres of tributary area, a simple reservoir routing procedure would be in order.

Figure 11, Typical Example of On-Site Detention – Rational Method Analysis, represents the method actually utilized by Frasier & Gingery, Inc., for small area

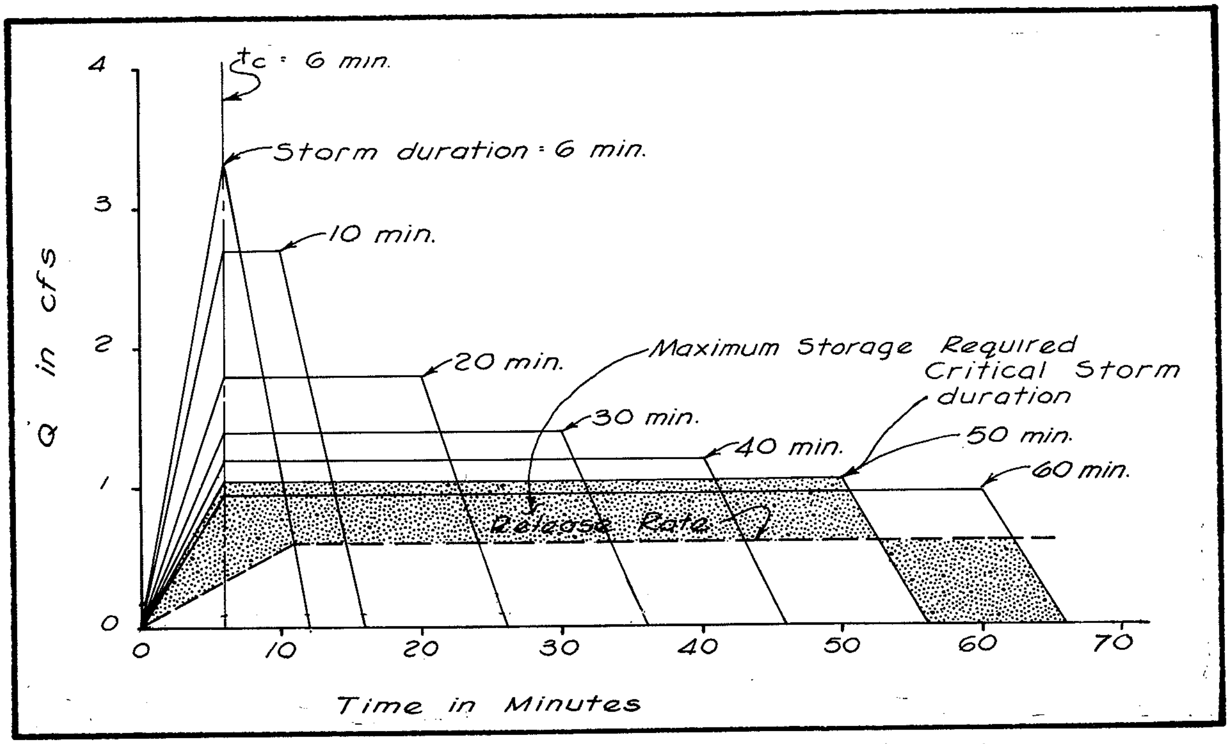


FIGURE 11 TYPICAL EXAMPLE OF ON-SITE DETENTION RATIONAL METHOD ANALYSIS

detention analyses. The assumed release curve approximates a formal reservoir routing in much the same way the Rational Method Hydrograph approximates a true storm hydrograph. The curve allows for the low release rate at the beginning of a storm and an increasing release rate as the storage volume increases. In normal flood routing, the maximum release rate will always occur at the point where the outflow hydrograph crosses the receding limb of the inflow hydrograph. For this reason, the design release rate is forced to coincide with that point on the falling limb of the hydrograph resulting from the storm of duration equal to the time of concentration for the basin. The release rate is held constant past this point. The critical storage volume is then found by determining the area between the inflow and release hydrographs. Example No. 2 continues the calculations initiated in Example No. 1 to determine the required storage volume.

Example No. 2

Given:

Drainage basin and other hydrologic information presented in Example No. 1

Allowable release rate: Q = 2.5 cfs

Required:

Determine the critical storage volume

Storm Duration (Minutes)	Storm Runoff Volume (cu ft)	Release Flow Volume (cu ft)	Required Storage Volume (cu ft)
8	3710	1200	2510
10	4206	1500	2706
15	5184	2250	2934
20	5820	3000	2820
30	6480	4500	1980
40	7344	6000	1344

The critical storage volume is then 2,934 cubic feet occurring for a 15-minute rainfall duration, or time of concentration.

Many cities and counties in the Denver Metropolitan Area require that the release rate be held to the historic level for a particular rainfall frequency. Under these circumstances the release rate is calculated utilizing the Rational Formula with a *C* value characteristic of the undeveloped conditions and an i value for a storm duration equal to the time of concentration for the basin under historic development. Also, the developed basin is oftentimes different from the historic basin requiring the determination of the historic basin area for the calculation of the historic flow rate.

Because this approach is used regularly by Frasier & Gingery, Inc., for the design of on-site detention facilities, where as many as a dozen storage bays may exist within a 10-acre site, it has been programmed on an IBM 1130 computer to assist in the completion of the repetitive calculations necessary in the analysis. A sample computer output sheet for the program which condenses all previous long-hand calculations into a simple computer operation is as follows:

HISTORIC C	= 0.00	COMPOSITE C	= 0.90
HISTORIC TC	= 0. Min	DEVELOPED TC	= 8. Min
ROOF AREA	= 0.00 AC	ROOF REL. RATE	= 0.00 In/Hr
TOTAL AREA	= 2.00 AC	STORM FREQ.	= 100 Year

DURATION (Min)	INTENSITY (In/Hr)	PEAK Q (CFS)	STORM VOL (Cu Ft)	RELEASE VOL (Cu Ft)	STORAGE (Cu Ft)
8.	4.30	7.73	3,715.19	1,200.00	2,515.15
10.	3.90	7.01	4,212.00	1,500.00	2,711.99
15.	3.20	5.76	5,184.00	2,256.00	2,933.99
20.	2.70	4.25	5,831.99	3,000.00	2,831.99

MAX STORAGE	= 2,933.99 Cu Ft
CRITICAL DURATION	= 15. Min
RELEASE RATE	= 2.50 CFS

Many limitations and shortcomings in the assumptions behind this method are evident. The approach becomes more valid on progressively smaller basins eventually reaching a size so small that watershed modeling is approached. The procedure should, therefore, be limited to relatively small areas where no major damage would result from over-topping or failure of the proposed detention facility.

Method Developed by Ven Te Chow: A case study of the design of an existing detention pond located (on ground surface) in northeastern Illinois is presented to illustrate the application of a design method developed by Dr. Ven Te Chow. The method is described in detail in a 1962 publication of the University of Illinois (Urbana) titled *Hydrologic Determination of Waterway Areas for the Design of Drainage Structures in Small Drainage Basins,* Engineering Experiment Station Bulletin No. 462.

The publication describes the development and application of a scientific, simple, practical method to determine the peak discharge rate from small rural drainage basins. The method was developed for application to the design of waterway openings of minor drainage structures such as culverts and small bridges. For practical applications of the method, a design chart for climatic and physiographic conditions characteristic of Illinois is included in Bulletin No. 462.

The method was derived utilizing the concept of unit hydrographs and is based upon unit hydrograph synthesis. Reference to Bulletin No. 462 is suggested for those readers who wish to follow the example in detail.

Dr. Chow's formula for determining the direct peak discharge from a drainage basin is computed as a product of the rainfall excess and the peak discharge of a unit hydrograph. The derived formula for the direct peak discharge, Q, is given as:

$$Q = AXYZ$$

where

- Q = Peak Discharge Rate (cfs)
- A = Area of Drainage Basin (acres)
- X = Runoff Factor, determined by the design rainfall duration and frequency and the soil type, cover and surface condition (values are obtained from curves in Bulletin No. 462)
- Y = Climatic Factor dependent on rainfall, as developed for various regions in Illinois (from a chart in Bulletin No. 462)
- Z = Peak - Reduction Factor – dependent on the ratio of the design rainfall duration to the lag time. The lag time is a function of the length of the drainage basin measured along the watercourse and the average channel slope. The value of Z is obtained from a curve in Bulletin No. 462.

Although the curves, charts and tables presented in Bulletin No. 462 for determining the values of the three factors X, Y and Z are based on the particular climate and physiography that prevails in various places in Illinois, it is feasible to develop curves, charts and tables to permit applying the design method to locations outside Illinois.

It was mentioned previously that this method was developed for small, rural drainage basins. It is also feasible to make the method applicable to non-rural watersheds (e.g., suburban or semi-rural) by determining reasonably accurate values of the Runoff Number (N) used in Chow's method. This number is a function of soil type, ground cover and the surface condition. For impervious areas, such as concrete-paved surfaces, the runoff number has the value *100* assigned to it by Dr. Chow. For roofs and roadways, the runoff number is not given but 95 seems reasonable; and for yards and parkways, 70; and 65 is a reasonable value for use in park areas and open spaces. As is specified in Bulletin No. 462, a weighted runoff number is computed for the various component areas within the drainage basin. This can be expressed by the formula

N_c = $\Sigma N_i A_i \div A$, where:

A_i = area of a particular type of land use

A = total area of basin

N_i = Runoff Number for the component area A_i.

The example that follows illustrates the application of the method in a rapidly urbanizing semi-rural area in the northwestern part of Cook County, Illinois. The tributary drainage area is about 40 percent open space (parks and farmland), 30 percent yards and parkways, 20 percent rooftops and roadway, and 10 percent commercial developments (impervious). This information is used to compute the Runoff Factor as shown in Figure 12, Computation of Runoff Rates.

In the example, the watershed area (A) was 1,700 acres and the climatic factor (Y) was 1.09. The channel length was 17,000 feet; the average slope was 0.41 percent and the lag time (t_p) was found to be 1.7 hours. Based on these values, the values of the reduction factor, *Z*, for various rainfall durations are selected from Bulletin No. 462 and tabulated in Figure 12. Estimates are made of the percentage of land used for: (1) parks and open space, (2) yards and parkways, (3) roofs and roadways, and (4) commercial purposes. These percentages are used to obtain a *weighted* runoff number, *N* which was calculated to be 76 in this example. Using this value of *N* the values of the runoff factor (X) are then taken from curves in Bulletin No. 462 for each rainfall frequency to be considered and for various rainfall durations. The values of *X* are tabulated and values of *Q* are then computed and tabulated for each rainfall duration and rainfall frequency – from the relationship $Q = AXYZ$.

A set of hydrographs of maximum discharges is next prepared to express the runoff flow (cfs) for each of the various design rainfall frequencies studied as a function of the rainfall duration. The hydrographs are shown at the bottom of Figure 12.

The storage volume required for each rainfall event is determined by calculating the total area between the runoff hydrograph and the release rate curve, here assumed at a constant 0.04-inch per hour, or 70 cfs.

Another method of computing the storage is by constructing Table 14, Calculation of Required Storage Volume. Column 1 of this table is a listing of ranges of total rainfall quantity from various rainstorms, starting with a small rainfall not exceeding 0.1-inch to a rainfall of 5.0-inches. Column 2 lists the average runoff (inches) for each total rainfall. These values, which are dependent on local conditions, must be based on generally accepted engineering practice in the particular locality. Column 3 is a list of the average number of rainfall events of different magnitude that occur in the geographical area under study. Column 4 is the annual distribution of storms for each rainfall magnitude, expressed as a percentage. Column 5 is the annual distribution, expressed as a percentage, of all storms that produce a rainfall quantity of the specified amount or a lesser amount. Column 6 is the estimated average duration of rainfall for each rainfall quantity shown in the first column.

Column 7, the average runoff released for the duration of the storage, is found by

$$Q = A \times X \times Y \times Z$$

Time (Hrs.)	t/tp	X for Frequency 5	10	25	50	100	Z	Q (cfs) for Frequency 5	10	25	50	100
0.2	.12	0.06	0.12	0.34	0.56	0.76	0.08	9	18	50	83	112
0.5	.29	0.24	0.47	0.65	0.92	1.16	0.22	98	192	265	375	473
1.0	.59	0.27	0.38	0.55	0.72	0.86	0.45	225	317	458	600	717
1.5	.88	0.25	0.33	0.44	0.57	0.69	0.60	320	367	490	634	767
2.0	1.18	0.22	0.27	0.37	0.47	0.58	0.70	285	350	480	610	752
2.5	1.47	0.19	0.24	0.32	0.41	0.49	0.80	281	356	475	608	726
3.0	1.76	0.18	0.23	0.29	0.36	0.43	0.90	300	384	484	600	717
4.0	2.35	0.15	0.20	0.23	0.30	0.36	1.0	278	370	426	556	667
5.0	2.35	0.13	0.16	0.21	0.26	0.29	1.0	240	296	389	482	537
6.0	2.35	0.12	0.15	0.19	0.22	0.26	1.0	222	278	352	408	432
7.0	2.35	0.11	0.13	0.16	0.19	0.23	1.0	204	241	297	352	426
8.0	2.35	0.10	0.12	0.15	0.18	0.21	1.0	185	222	278	334	389

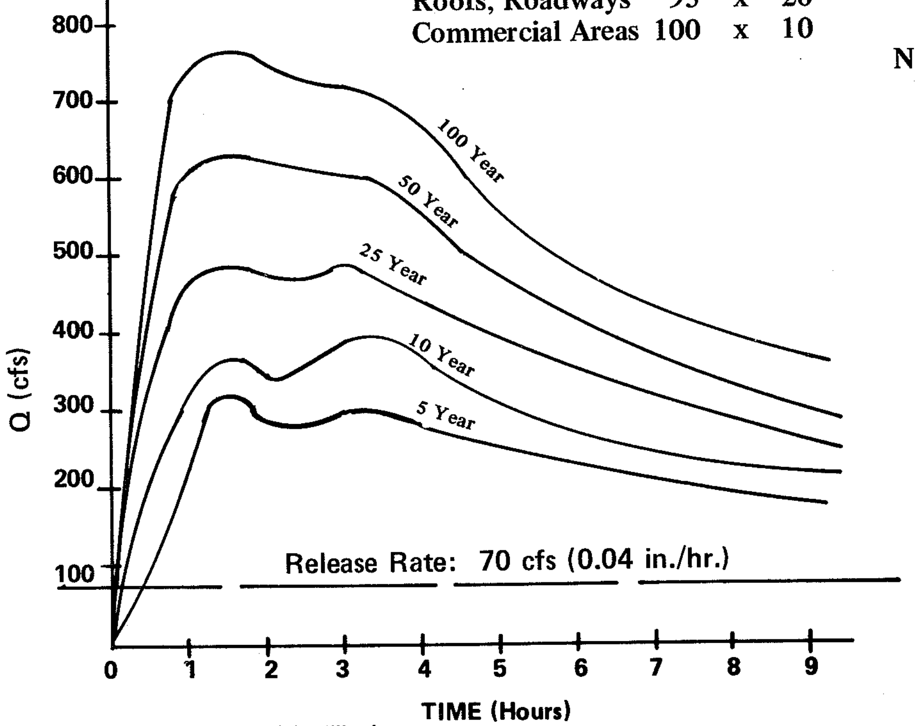
HYDROLOGIC STUDIES

TYPE: Detention Pond
DATE: 1973
LOCATION: Cook County, Illinois

Basin Area "A": 1,700 Acres
Soil Type "C" (from Bull. No. 462)

Climate Factor "Y": 1.09 (Bull. No. 462)
Channel: Length 17,000 ft; Slope 0.41
Lag Time "t_p": 1.7 hrs (from Bull. No. 462)

Land Use	N		% Use			Product
Parks, Open Space	65	x	40	÷ 100	=	26
Yards, Parkways	70	x	30		=	21
Roofs, Roadways	95	x	20		=	19
Commercial Areas	100	x	10		=	10
				N	=	76



Source: Lindley & Sons, Inc., Hinsdale, Illinois

FIGURE 12 COMPUTATION OF RUNOFF RATES

TABLE 14
CALCULATION OF REQUIRED STORAGE VOLUME

1	2	3	4	5	6	7	8	9
			Annual Distribution of Rainstorms, %					
Total Rainfall (In.)	Avg. Runoff (In.)	Annual No. of Events	Amount Shown	Amount Shown or Less	Est. Avg. Dur. (Hrs.)	Avg. Runoff (in.) Released @ 0.04 in./hr	Avg. Storage Vol. Required Inches	Ac. ft.
0.0–0.1	0.04	57.30	47.00	47.0	0.5	0.02	0.02	3
0.1–0.2	0.07	20.40	17.00	64.0	1.0	0.04	0.03	4
0.2–0.4	0.15	19.70	16.00	80.0	1.5	0.06	0.09	13
0.4–0.6	0.25	9.60	8.00	88.0	2.0	0.08	0.17	24
0.6–0.8	0.35	5.10	4.00	92.0	2.5	0.10	0.25	35
0.8–1.0	0.45	3.20	2.50	94.5	3.0	0.12	0.33	47
1.0–1.5	0.63	4.26	3.50	98.0	3.5	0.14	0.49	70
1.5–2.0	0.88	1.50	1.30	(Annual)	4.0	0.16	0.72	102
2.0–3.0	1.25	0.80	0.61	(5-10 yr)	6.5	0.26	0.99	140
3.0–4.0	1.71	0.07	0.05	(25 yr)	9.0	0.36	1.35	191
4.0–5.0	2.32	0.05	0.03	(50 yr)	11.5	0.46	1.86	263
Over 5.0	2.82	0.02	0.01	(100 yr)	14.0	0.56	2.26	320

Avg. Annual Runoff = 10.94 in.   Total Events = 122.00/yr

multiplying the estimated rainfall duration (Column 6) by the permitted release rate (in this example 0.04-in/hour). Column 8, the average storage required, is the difference of the average runoff (Column 2) and the average runoff released (Column 7). Column 9 converts the average storage volume required from *inches of depth* over the entire 1,700-acre watershed to *acre-feet.*

Finally, by knowing the practical limitations on the area or depth to be used for the detention pond, or basin, the dimensions and shape of the storage area can now be determined and the time period required for complete drainage of excess stormwater can be calculated.

Colorado Urban Hydrograph Procedure:[3] The Colorado Urban Hydrograph Procedure (CUHP) as a design approach to detention storage lends itself to more proper application in the downstream areas of a drainage basin. It is in the dowstream areas where the magnitude of the flood damage is always the greatest and, thus, the more dependable and straightforward approach of the hydrograph procedure seems most applicable. Also, application of a realistic hydrograph to the practical problem provides more flexibility in the use of reasonable engineering judgment by the engineer.

The CUHP is presented in a very thorough manner in the Runoff Section of the *Urban Storm Drainage Criteria Manual.*[4] The procedure is based on the synthetic unit hydrograph theory developed by Sherman in 1932, with later revisions by Snyder and Eagleson. The CUHP title is used because the coefficients used in the procedure are based primarily on data collected and studies completed in the Denver, Colorado area, specifically to improve this approach to urban drainage. A detailed review of the method of determining a rainfall hydrograph from the unit hydrograph is covered in the manual.

The analysis of a detention reservoir by the hydrograph method follows the simple reservoir routing procedure. In this procedure, the reservoir discharge is a function of the water surface elevation in the reservoir. Such a reservoir would have a well-maintained, controlled outlet structure and spillway.

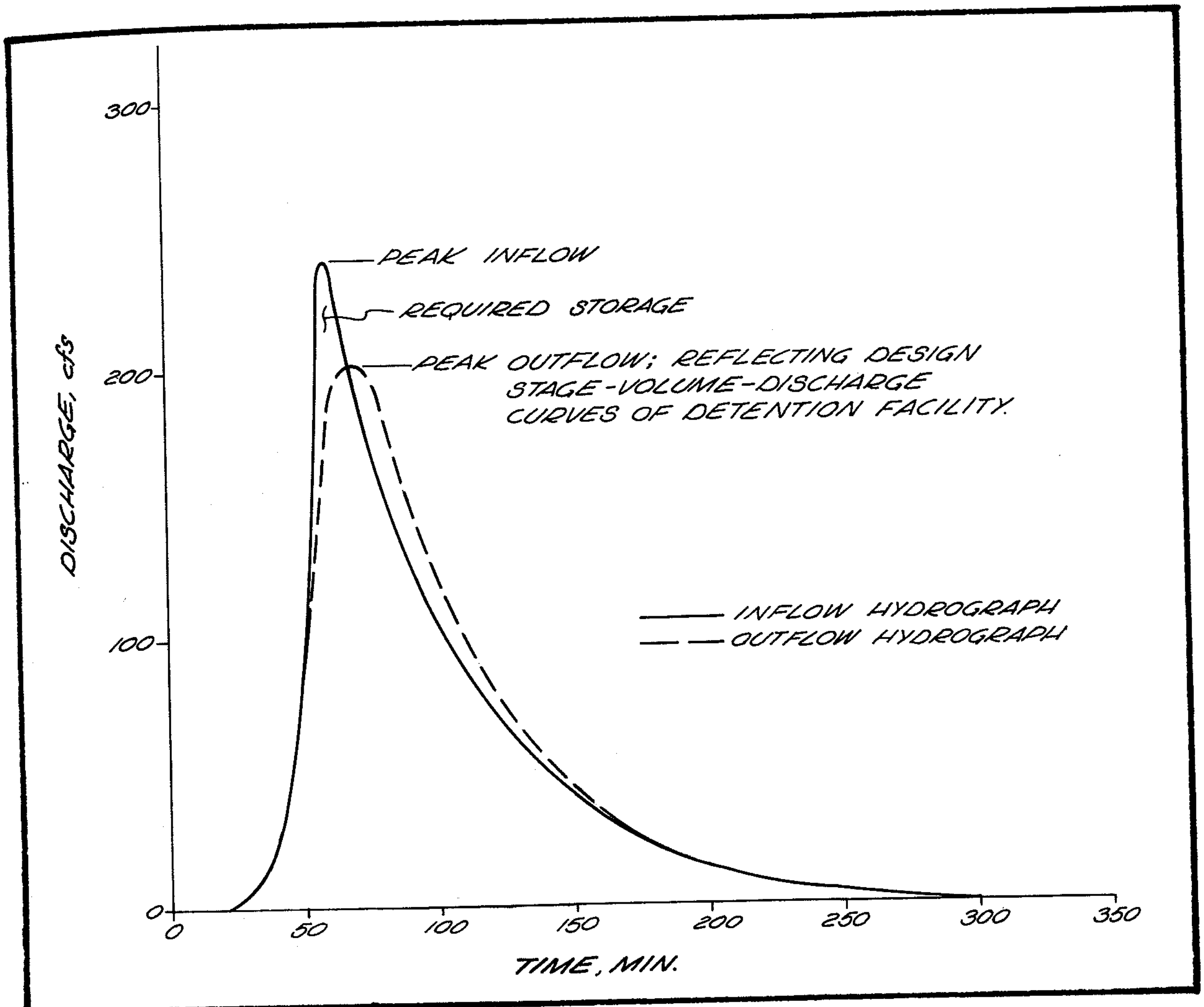


FIGURE 13 DOWNSTREAM DETENTION ANALYSIS BY HYDROGRAPH METHOD

Known data on the reservoir would include the stage-storage and stage-discharge curves. A detailed explanation of this analysis method will not be given here as it is properly and thoroughly covered in most hydrology textbooks.

A graphical presentation of the analysis of downsteam detention storage by the hydrograph approach is given in Figure 13, Downstream Detention Analysis by Hydrograph Method. Here the inflow hydrograph to the detention pond, calculated by the CUHP is shown by the solid line. The outflow hydrograph from the reservoir, characteristic of the outlet structure or structures, is shown by the dashed line. The shape of the overflow hydrograph reflects the carrying capacity of the outlet facility with various headwater elevations. It is imperative that outlet facilities, exclusive of overflow spillways, be analyzed for inlet or outlet control on the structure rather than assuming the structure to be flowing full under constant uniform flow as determined by Manning's Equation. As mentioned earlier, the peak outflow from an unregulated reservoir must coincide with some point on the receding limb of the inflow hydrograph. The reasoning on this is that the outflow hydrograph cannot have a time to peak less than the inflow hydrograph and, because the outflow is a function of the water surface level in the reservoir, the outflow cannot increase once the two curves have crossed as the water surface level is receding. The area between the inflow and outflow hydrographs represents the storage volume required within the reservoir.

The design and sizing of detention facilities in downstream areas requires a great deal of judgment by the design engineer. A number of factors are involved in the design with the objective being to optimize the utilization of available storage volume. Specifically, however, the engineer must determine the control design variable. Normally the variable will be either a specified release rate from the detention pond governed by downstream facilities and constrictions or the maximum available storage which can be provided through possible restrictions in ponding areas which might be utilized.

The criteria required in the design of such a detention facility varies with location. In Colorado, a reservoir with a storage capacity over 1,000-acre-feet, or having a dam embankment extending over 10 feet from the channel bottom or having a surface area at the high water line in excess of 20 acres, must be filed with the State Engineer. This requires that the reservoir or detention facility must be designed to pass the runoff of the probable maximum precipitation occurrence. This, of course, is an extreme event much greater in magnitude than the 100-year rainfall occurrence normally used in drainage planning and design. This design provision applies to the reservoir only and does not set requirements on the channel facilities above and below the detention reservoir. If the detention facility does not fall within these categories, criteria are usually set by the local governing agency. Normally, their provisions will call for the capability of safely passing the runoff of the 100-year rainfall occurrence. Regardless of the criteria set, designers of detention facilities should remember that they are, in fact, designing reservoirs. Recent Colorado court cases have held that the designer and owner of a reservoir may be held liable for any failure of that structure, even if failure is cause by an *Act of God* type storm occurrence.

For any design criteria, the detention facility must be capable of properly functioning for both the major and minor rainstorm occurrence. Also, from a logical and legal viewpoint, the use of a downstream storage facility should not create any unnecessary personal or property hazard which might not have existed without the reservoir. A poorly or haphazardly planned and designed facility could create such a situation. The Colorado Urban Hydrograph Procedure coupled with simple reservoir routing computations is the general type of thorough analysis that can be justified on any major project having a tributary drainage area exceeding about 50 acres. The most reliable results are obtained for areas greater than 200 acres.

Summarizing, for downstream detention facilities the CUHP, or some other accepted hydrograph method, should be the basic design concept used in the design of the facility. Outlet facilities should be designed on the basis of inlet or outlet control, whichever is applicable, reflecting the actual stage-discharge relationship. The facility should be capable of safely and properly passing the full range of hydrologic runoff events through the 100-year rainfall occurrence and, for the larger facilities, the probable maximum precipitation event. Finally, any new detention facility must not bring about otherwise unnecessary legal hazards which could be avoided through proper planning and design.

Design Methods Permitted, Suggested or Required by Public Agencies

Some local public agencies having jurisdiction and responsibility for stormwater management have suggested methods for the engineering design of detention facilities. Others have published examples of design methods that would be permitted to meet established local criteria and regulations pertaining to such facilities. A review of the information distributed by four public agencies located in different areas of the United States is presented in this section.

Federal Aviation Agency:[10] A design concept for detention storage design has been utilized by the Federal Aviation Agency in designing airport drainage facilities.[11] The FAA method is a graphical procedure which represents the cumulative amount of storm runoff volume and the cumulative amount of volume released through an outlet facility as functions of time. The greatest volume difference between the two curves represents the required storage volume of the storage basin.

The normal misapplication of this method is in assuming a constant release from the pond from time zero. This comes about through sizing the outlet pipe using Manning's Equation and not recognizing the headwater depth – discharge relationship characteristic of such a facility. This procedure will consistently result in undersizing detention facilities. Recently, when Frasier & Gingery had occasion to review the design of a detention facility designed by this method, the facility was found adequate for only the 10-year rainfall rather than the 100-year rainfall event for which it was intended. The 100-year runoff would actually overtop the entire embankment, possibly resulting in failure of the embankment.

MSD of Greater Chicago: In some localities, detailed information is given by the local jurisdiction on techniques to use in designing stormwater detention facilities. For example, the Metropolitan Sanitary District of Greater Chicago outlines a concept or design procedure that is basically the same as the Modified Rational Formula presented previously. The MSD method considers the required storage for various duration storms utilizing the following relationship:

$$\text{Storage} = t_d\,(C \times i_{100} - 0.15 \times i_3)$$

Where:

Storage = inches of water depth over the drainage area

t_d = duration of 100-year rainfall (must be varied to determine most critical condition)

C = Rational Formula *C* value characteristic of the developed drainage area

i_{100} = rainfall intensity of the 100-year rainstorm for each t_d (inches/hr)

0.15 = Rational Formula *C* value used for the undeveloped area

i_3 = rainfall intensity of the 3-year rainstorm for the time of concentration of the undeveloped area (inches/hour)

The required storage volume is then computed by multiplying the value calculated for *S* by the total drainage area (in acres) and dividing by 12 to convert the units to acre-feet. An information pamphlet on design procedures has been developed by the Sanitary District and is included as Appendix D of this report.

Even though this procedure specifies the coefficients to be used which would be applicable in the Chicago area, provision is made for the use of other coefficients when such a change can be substantiated. However, no specific provision is made for the non-use, or inapplicability, of this method which would be the case for large drainage basins as well as the situation of locating one detention pond directly downstream of another. Normal use of this method should be limited to tributary areas of approximately 20 acres or less. Also, upstream detention would accordingly reduce the inflow rate to the downstream facility. At this stage of development of on-site detention design concepts, these two items should be considered when utilizing this particular design approach.

City of Boulder, Colorado: Boulder, Colorado, has established a procedure for the design of stormwater detention facilities. The different sectors of the city must provide storage for rains of specified return frequencies. Release rates are based either on predevelopment runoff rates or on the proposed use of the land after development. For example, developed land is allowed to have the following release rates:

Land Use	Allowable Release Rate
Parking lots, driveways, sidewalks	1.0 inch/hour
Rooftops	0.5 inch/hour
Plazas	1.0 inch/hour
Grassed area	0.5 inch/hour

The storage volume required is to be computed with the use of multiple triangular hydrographs. The required storage is determined by calculating the area between the selected input hydrograph and the release flow. Standardized values are given for: the coefficient of runoff for various conditions, the overland flow time, and the applicable rainfall intensity-duration curves (See Table 15, Specified Values of Coefficient of Runoff; Figure 14, Overland Time-of-Flow Curves; and Figure 15, Time-Intensity-Frequency Curves).

Using this information, flow rates of runoff entering the ponding area Q_n should be determined for each successive time of concentration (for various reaches) until the runoff flow rate into the pond is approximately equal to the flow rate out of the pond, at which time the pond will not be

TABLE 15
SPECIFIED VALUES OF COEFFICIENT OF RUNOFF
(Boulder, Colorado)

Surface Character	Coeff. of Runoff, C
Asphalt	0.9
Concrete	0.9
Roofs	0.9
Lawns and undeveloped land	
Gravelly Soil (very little clay)	
Flat, 2%	0.1
Average, 2% to 7%	0.15
Steep, 7%+	0.2
Clayey Soil (considerable gravel)	
Flat, 2%	0.2
Average, 2% to 7%	0.25
Steep, 7%+	0.35

Note: A value of 0.2 should be used for most areas in Boulder where gravelly-clayey soils prevail and slopes are less than about 4%.

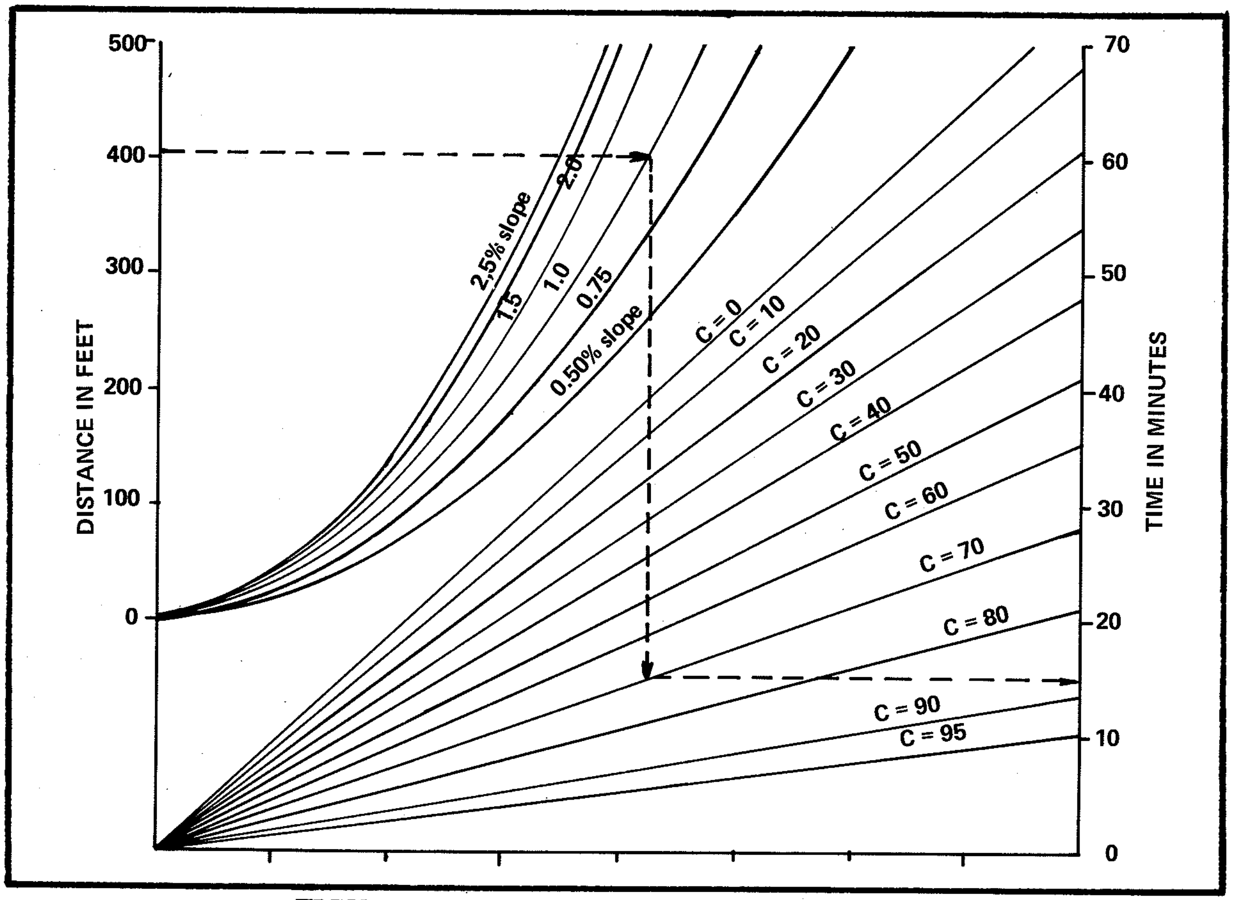


FIGURE 14 OVERLAND TIME-OF-FLOW CURVES FOR STORMWATER RUNOFF

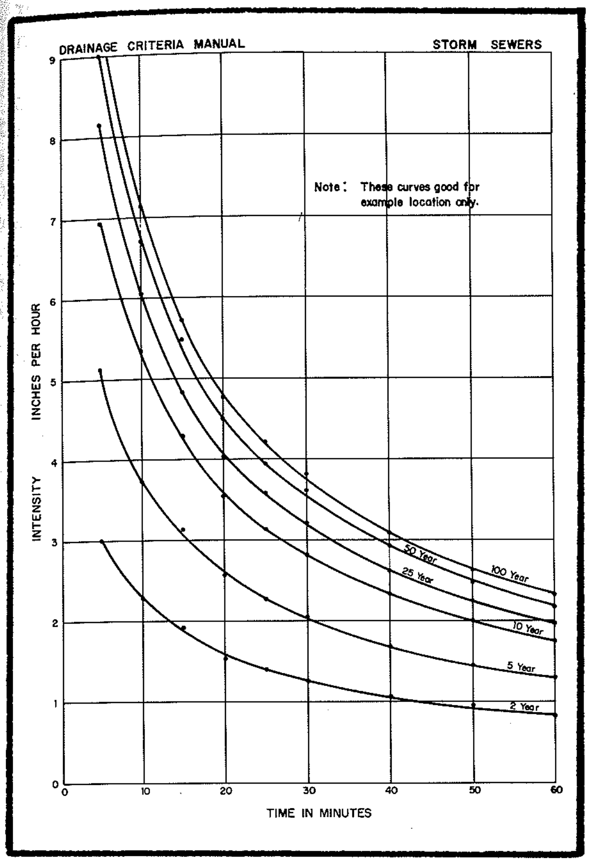


FIGURE 15 TIME-INTENSITY-FREQUENCY CURVES

collecting a net gain of water. The formula to be used is

$$Q_n = CA(ni_n-(n-1)(i_{n-1})) + Q_c$$

where

Q_c is the net inflow rate from areas such as rooftops, parking lots, etc. Q_n is the inflow in cfs at the end of the nth-time of concentration

i_n is the intensity in inches/hour, from Figure 15

A = area of watershed (in acres)

C = coefficient of runoff

n = number of triangular hydrographs used

Then, the total volume to reach the pond in cubic feet (Vn) is given by

$V_n = 60 \cdot C \cdot A \cdot n \cdot T_c \cdot i_n$, where T_c = time of concentration of the first peak of the multiple hydrograph; and

when Q_n, the inflow rate, equals R, the permitted release rate, the maximum storage volume is attained. The total storage volume required (S), in cubic feet, can be calculated as

$S = V_n$–(Released Volume), where the Released Volume is the area below the horizontal line on the multiple triangular hydrograph.

The City of Boulder cautions design engineers to allow for entrance and exit losses and possible debris-plugging of devices (such as weirs, orifices and pipe constrictions) used to restrict release flows. This will help assure the attainment of desired stormwater release rates and reduce maintenance of the overflow structure and other components of the detention facility. A 50 percent increase in the net area of grated-inlets is suggested to allow for possible blocking of the inlet openings by debris accumulations.

Montgomery County, Maryland: Montgomery County, Maryland is another jurisdiction which has set down a specific method for designing stormwater detention facilities. The method is largely graphical. The graphs and instructions for their use are given in Appendix E of this report.

Summary: The use of on-site detention facilities may be dictated by governmental ordinances or may be chosen by a developer, at his own discretion, as a method for reducing costs of drainage facilities. In either event, the result is the same, reduction of peak runoff flows from a given parcel of land for specific rainfall events.

The engineering design of detention facilities is complicated by several factors, including: problems of predicting runoff hydrographs accurately, limitations of space for accommodating detention facilities, limited downstream capacity for accepting the discharge from detention facilities, and uncertainties of future policy and legislative and administrative requirements of public agencies.

The two most important design considerations are the determination of the stormwater storage volume required and the maximum permissible release flow rate. Several local jurisdictions were found to promulgate criteria and design procedures, although many others are not explicit in delineating criteria, design requirements and techniques.

The beneficial effect of on-site detention of stormwaters is well recognized; however, standard design methods have not been developed which are universally accepted by the designers of facilities or the agencies required to review and approve designs. Several approaches to the engineering design of detention facilities are given together with specific examples.

The Rational Formula is widely used in making estimates of peak runoff flows; however, its use is restricted to small watershed areas. A great number of engineers consider the Rational Method to be obsolete and decry its use. Engineers also use a method known as the Modified Rational Method Analysis. At least one firm limits its use to small areas such as rooftops, parking lots or other upstream basins having tributary areas of 20 acres, or less. For larger drainage areas, some form of urban hydrograph method coupled with simple reservoir routing computations is often used. One such method utilizes the Colorado Urban Hydrograph Procedure. Special methods for computing runoff have been developed for application in specific parts of the country. One of these developed by Ven Te Chow, for applications in the State of Illinois, is illustrated with an example. Examples of the use of other methods mentioned above are also given.

Regardless of which design method is utilized, the designer must keep in mind that he is in effect designing a reservoir, and that the construction details must reflect this fact. Final plans must assure that the necessary storage volume is maintained through the construction stages and that the proper outlet control facilities are installed. After installation, the detention facility and outlet structure must be maintained free of debris and other hazards which could greatly impair the regular and continuous operation expected of the facility.

A 1972 survey of engineering firms revealed that detention basins and ponds located on ground surfaces are more prevalent than any other type of stormwater detention facility. Detention of rainfall on parking lots ranked next in popularity, followed by detention of rainfall on rooftops of buildings. Engineering design criteria and procedures vary with each of these types of detention facilities. The nature and extent of previous developments in the tributary watershed, including the site under consideration, are important factors in establishing design considerations and criteria.

A survey of 25 major cities and all national building code organizations in the United States did not uncover codes that prohibit the use of rooftops for storing rainfall. Several different designs of roof drain detention rings are used for rooftop detention of rainfall and standard types are available from several manufacturing companies.

There are two general forms of stormwater detention on parking lot surfaces. One form involves the storage of rainfall in depressions; the other employs the paved area to channel the runoff to grassed areas or gravel-filled seepage pits. Minimum slopes of paved areas should be about 1.0 percent, but no more than about 4 percent to avoid gasoline spillage from vehicle fuel tanks and to minimize vehicle traction problems on icy paving.

The design features of detention basins and ponds constructed directly on ground surfaces will vary, depending upon land cost, space availability, physical and aesthetic characteristics of the area, topography, climate and other local factors. The design is also influenced by any multiple-purpose uses which must be provided for.

CHAPTER 4
PLANNING, AESTHETICS, COSTS AND APPLICATIONS

PLANNING

Pollution control and flood protection from urban drainage are generally studied only after these problems are well advanced. The usual solutions proposed for control of such problems are corrective measures, not integrated with the development of the community. In planned communities, however, there is the opportunity to develop control measures prior to construction.

The planning and development of the Pohick Creek watershed in Fairfax County, Virginia, is a good example of how an informed and concerned local government can attack the problems of urban runoff caused by rapid urbanization.

The Pohick Creek Watershed Project

The Pohick Creek watershed lies in the northern part of Fairfax County, Virginia, about 17 miles from downtown Washington, D.C. It is largely undeveloped – 70 percent of its 22,690 acres are forested and the total population in 1965 was about 4,800 persons living in single-family dwellings. Only six percent of the area is classified as urban and there is no major commercial or industrial development in the area.

However, this situation is expected to change rapidly. Installation of sewers and rising land prices in the Washington area are expected to cause a dramatic change in the area, with population projections for the watershed for the year 2000 ranging from 85,000 to over 160,000 – from a population of 14,300 in 1971. About 85 percent of the forest land is expected to be developed as subdivisions, shopping centers, schools and other urban uses within 25 years.

The almost total lack of past development and the expected rapid future growth made it important to develop a comprehensive plan for the area in late 1966. The concern of Fairfax County officials for stormwater management and erosion and siltation control is reflected in the planning for this area.

As urban development takes place, excavation will expose large areas of subsoil resulting in accelerated sheet, rill and gully erosion. It was estimated that 7.2 million tons of sediment would be delivered to the Pohick channel in the next 100 years, if no corrective measures were taken, with 4.3 million tons being transported to the Potomac River which already is having severe siltation problems.

Also, the urbanization of the watershed will reduce the permeability of the ground cover, resulting in larger flow volumes and rates. This will not only increase the flood characteristics of Pohick Creek, but will change the physical characteristics of the stream channel. Rapid urbanization will change runoff conditions so drastically that stream channelization was thought to be necessary to increase the capacity of the stream to handle the flow. It is these problems which the program of comprehensive planning hopes to prevent or reduce.

Methods of Control: The original plan for stormwater drainage was prepared in January, 1967 and consisted of four major types of control with a total cost of $5,202,764 (1965 prices). These were:

1. Flood plain zoning – The limits of the 100-year flood were to be delineated by the U.S. Geological Survey and construction on such land would be prohibited. This land would be set aside for open space and recreational use.

2. Flood control structures – Eight dams along the watershed were recommended. These dams would control release rates to the level of the 5-year storm and serve as sedimentation traps. As originally contemplated, the sediment would not be removed, but would become a permanent part of the impoundment with the design computed to have the sediment completely fill the storage area in 100 years. Total impoundment of water for the eight dams would cover 220 acres of permanent water acreage, increasing to 537 acres for maximum flood control. One of the impoundments, with a normal surface area of 22 acres, would be open for recreational use, such as fishing, boating and swimming.

3. Channel improvements were suggested for about 6 1/4 miles of channel, including 2 2/3 miles of brush and snag removal and slightly over 3 1/2 miles of channelization. These measures would increase the capacity of the stream for handling the increased flows.

4. Control of erosion and runoff at the source has long been required in Fairfax County.

To comply with the county's erosion and sediment control ordinance, the developer must prepare a conservation plan for approval by the Department of County Development. This plan will usually include both temporary and permanent conservation practices for treatment of the land. Some of the practices are designated to prevent erosion and minimize sedimentation during the critical period of construction. Other practices are more permanent and will have a lasting effect on the conservation values of the area. The following are some of the conservation plans for developing the Pohick watershed.

a. Conservation practices are included as an integral part of the subdivision and site plans. These practices will be applied in a definite sequence as the development proceeds.
b. The site is developed in a manner that requires a minimum of land grading and other site preparation. For example, streets are planned to follow the contours of the existing topography where possible.
c. Flood plains are preserved, to the maximum extent possible, with natural vegetation. Under present county ordinances, development is not permitted on flood plains.
d. Existing vegetation is being preserved, to the maximum extent possible, on steep slopes. Also, desirable trees, shrubs, and other vegetation are being preserved to the extent possible. Scenic easements are being obtained in the major stream valleys both to mask the development and reduce erosion of steep slopes.
e. There are several stages of development planned. This will permit land clearing and grading to be done in small increments. Thus, the land is without plant cover for the shortest time possible and the chance of serious damage by erosion during the construction period is greatly reduced.
f. Top soil is stockpiled and used later in areas that will be stabilized by permanent vegetation.
g. High sediment-producing areas are established in temporary vegetation if such areas will not be built on within a period of 60 days and will not be protected by structural measures. Seeding should be done immediately following rough grading.
h. A number of temporary sediment basins are constructed near the lower reaches of the small drainage ways. The exact location of these is determined as detailed subdivision and site plans are completed. The purpose of these structures is to trap sediment and debris during construction. These basins are desilted as necessary to achieve optimum trap efficiency.
i. Permanent vegetation is established immediately upon completion of final grading on all areas where this is applicable.
j. Mulch, temporary diversions, contour furrows, terraces, interceptor dikes, and other remedial conservation measures are used where appropriate for erosion control.
k. Storm drainage facilities are completed and made operational as soon as possible during construction. Small debris guards and micro-basins are used to protect the storm drain inlets from sedimentation during construction.
l. Streets, parking lots, and other areas are paved as soon as possible.
m. To insure compliance with the appropriate county ordinances, including those that cover subdivision design, storm drainage, and erosion and sediment control, the county requires the developer to post bond for site improvements. Cash in escrow is also required for erosion and sediment control practices. This money can be used by the county for emergency purposes if the developer does not satisfactorily comply with the ordinances.

It was estimated that these measures would prevent 98 percent of the possible flood damage and 68 percent of the siltation damage. Over the 100-year life of the project, the cost is estimated at $65,750 per year compared to benefits of $89,625 annually.

Analysis of Recommendations: Because of the pioneering nature of this project – one of the first-planned conversions of a rural watershed into a total urban watershed* evaluations of the program were desired as the program progressed.

Comments on the project were received and prepared by public agencies, land developers, land owners and concerned citizens. A compilation of these comments is given in the publication, *Environmental Evaluation, Pohick Creek Watershed Project, Fairfax County, Virginia,* by the Northern Virginia Soil and Water Conservation District, March 1, 1972.**

The major objection to these initial recommendations was directed to the proposed stream improvement. It was felt that this improvement would be helpful in reducing flood flows of the 5-year storm but would destroy much of the natural vegetation of the area which served as wildlife protection and habitat.

As a result of the objections to all stream channel improvement work, the initial plan was re-examined and the Northern Virginia Soil and Water Conservation District, a co-sponsor of the project, recommended that the channel improvement work be deleted. Although this would increase flooding, this flooding would occur in areas that would contain no development and damages would be minor. The benefit of the protection of the natural habitat of the stream was considered more important than the flood protection offered.

Other objections to the initial plan were directed against the design and use of the impoundments. The impoundments themselves were viewed as desirable, but it was felt that multiple use should be made of all the reservoirs, instead of just one reservoir, and that some provision for the removal of silt be made. No comment has been made on the multiple use of the other reservoirs, but the removal of silt was viewed to be prohibitively costly by the project proponents. However, the County has adopted a policy of impoundment clean-out to preserve the lakes' capacities, indefinitely.

Use of On-Site Stormwater Detention. In the evaluation of the project by Fairfax County, dated January 31, 1972, the use of on-site detention was discussed. Fairfax County was watching the experiments of Montgomery County, Maryland, with detention storage and saw three possible limitations of on-site detention. These are discussed below.

1. Increased duration of flow – Although it was recognized that stormwater detention reduces peak flows, it does so by increasing the duration of storm flows. This longer storm flow would upset the natural equilibrium of the channel and studies would be necessary to determine if this long duration of large storm flows would be better or worse for the stream than the non-detailed, larger peak flows over a shorter period of time that would occur without on-site detention.

2. Area needed – On-site detention storage would need to supply the same acre-feet of storage as the eight impoundments on the creek. But where the impoundments would be relatively deep, on-site detention storage would be shallow and would require a larger area. For example, at one impoundment, storage is provided by an 8-foot rise of water level, supplying 151 acre-feet of storage in a pond of maximum of 30 acres. If on-site detention storage were to be used with an assumed average depth of one foot, 151 acres of land would be flooded, equal to 35 percent of the area of the watershed.

3. Pollution – The polluted materials in the runoff, such as oil, grease, fertilizer, trash and other undesirable elements would be deposited on the detention storage areas, instead of being carried away to deeper water.

Further evaluation of the benefits of on-site stormwater detention has, apparently, shown that the disadvantages are outweighed by the advantages. In a newspaper article on February 8, 1973, in the Fairfax County edition of *The Journal,* it is stated that:

"On-site stormwater detention has

*Maryland National Capital Park and Planning Commission also claims the honor for Rock Creek basin.

**This evaluation was directed primarily at the proposed channelization section of the plan.

become a basic technique in Fairfax's anti-erosion enforcement and the massive federally-funded flood control project in the Pohick Valley, and is seen as a regular practice in the County's storm drainage strategy."

Summary: The development of the Pohick Creek watershed in Fairfax County, Virginia, is unique in that it is a planned conversion from rural watershed to an almost totally urban watershed. Storm drainage planning was included in the comprehensive planning of the area to provide protection from flooding, erosion and sedimentation. Flood plain zoning, stream impoundments, erosion control techniques, and on-site detention storage are all parts of the methods to be used. By planning for development, instead of trying to solve existing problems, it is estimated that 98 percent of the potential flood damage and 68 percent of the potential siltation damage will be eliminated.

AESTHETICS

Beautification of land areas adjacent to waterways, detention ponds and drainage ditches should be considered an integral part of planning, designing and constructing stormwater drainage facilities and flood control improvements. Planting and preservation of desirable trees and other vegetation should be a part of the improvement plan.

By conserving the resources of the natural environment, new erosion and siltation problems can be averted and wildlife will benefit. Also, the beauty of natural surroundings is a factor which increases real property values and enhances the quality of living in the area.

Landscaping principles can do much to improve the appearance of facilities. Banks of stormwater storage areas and drainage ditches should be graded smoothly into adjacent areas where feasible. Slopes should be as flat as practicable. Steep slopes should be protected against erosion by slope stabilization techniques. This may involve the use of gabions, rip-rap, or other acceptable protection that detracts as little as possible from the natural setting. New plantings should be placed above high water levels so as not to interfere with the flow of water and to provide proper conditions for survival.

Control of sediment and waterlogging are other important considerations. Sediment accumulations and waterlogging of otherwise usable land areas can be avoided by the use of proper design, construction and operation techniques. Information and data concerning techniques for minimizing soil erosion and the resulting siltation of land and water bodies can be obtained from local offices of the United States Soil Conservation Service, in all parts of the country.

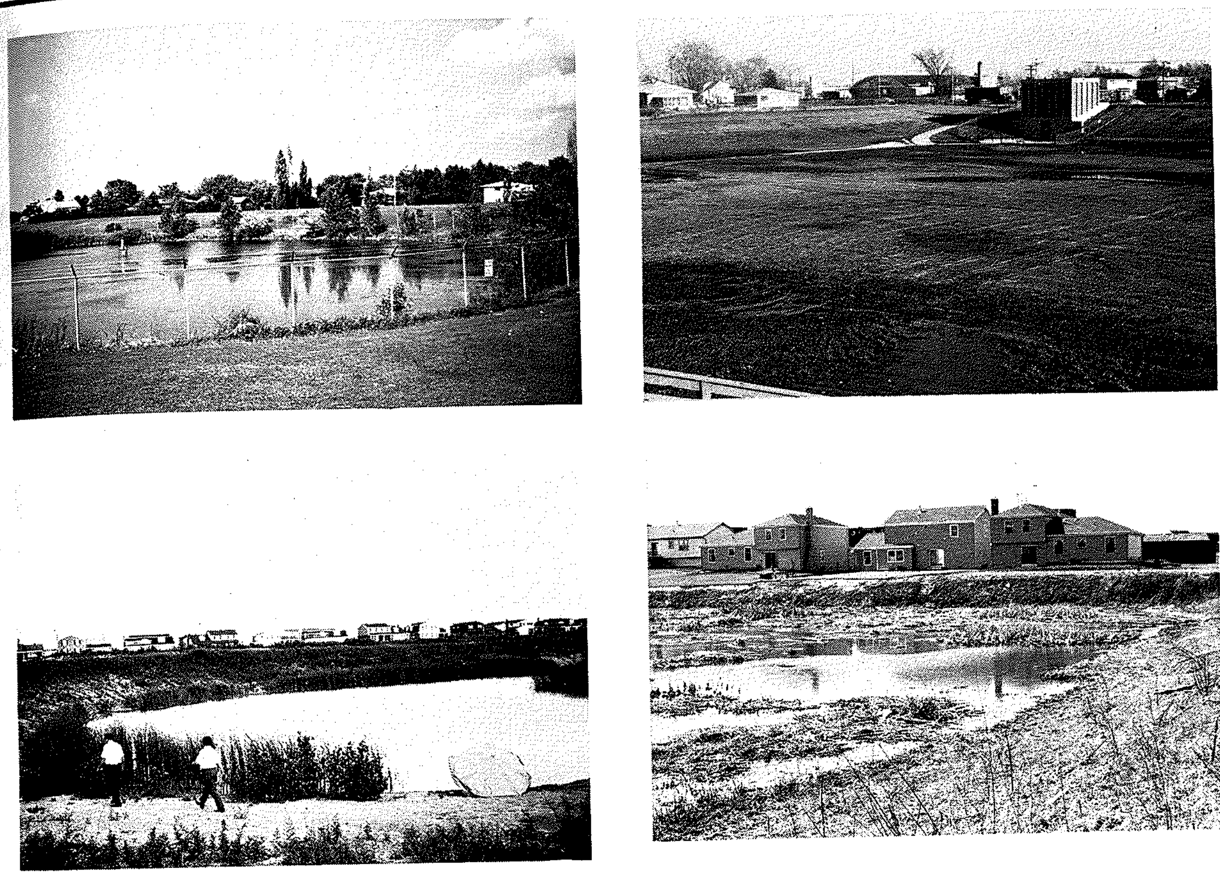
Stormwater storage ponds and basins can be spared from excessive sediment accumulations by the use of forebays for silt collection. Paved areas used for storage of stormwater runoff can be protected from silt by directing runoff through vegetated areas and/or specially-designed stormwater filters.

Waterlogging of land surrounding stormwater storage areas can be minimized by sloping the ground toward storage areas, eliminating water pockets, and minimizing the frequency and time duration of ponding on areas otherwise suitable for multi-purpose use.

Figure 16, Appearance of Detention Ponds and Area, illustrates various aesthetic considerations that are important in the design, construction and maintenance of stormwater detention facilities and other components of surface drainage systems. Two photographs of similar facilities are shown. One depicts an example of a facility that was planned and built with careful consideration of its aesthetic appeal; the other shows a facility that either was not designed and built with aesthetics as a criteria, or that deteriorated from unsatisfactory operation and maintenance.

COSTS

Many stormwater runoff detention facilities have been constructed in connection with new urban land developments. In most instances these facilities have been provided by the land developer because on-site detention was required by the local public agency having jurisdiction over stormwater drainage. However, many developers have found that appreciable cost savings may result



a. detention ponds (*wet* type)
Upper Photo: aesthetically pleasing, wind-actuated aerator, fence
Lower Photo: poor appearance, fence broken down

b. detention basins (*dry* type)
Upper Photo: neatly graded, grass, fence, recreational opportunities
Lower Photo: poorly graded, poor appearance, health hazard

FIGURE 16 APPEARANCE OF DETENTION PONDS AND AREA

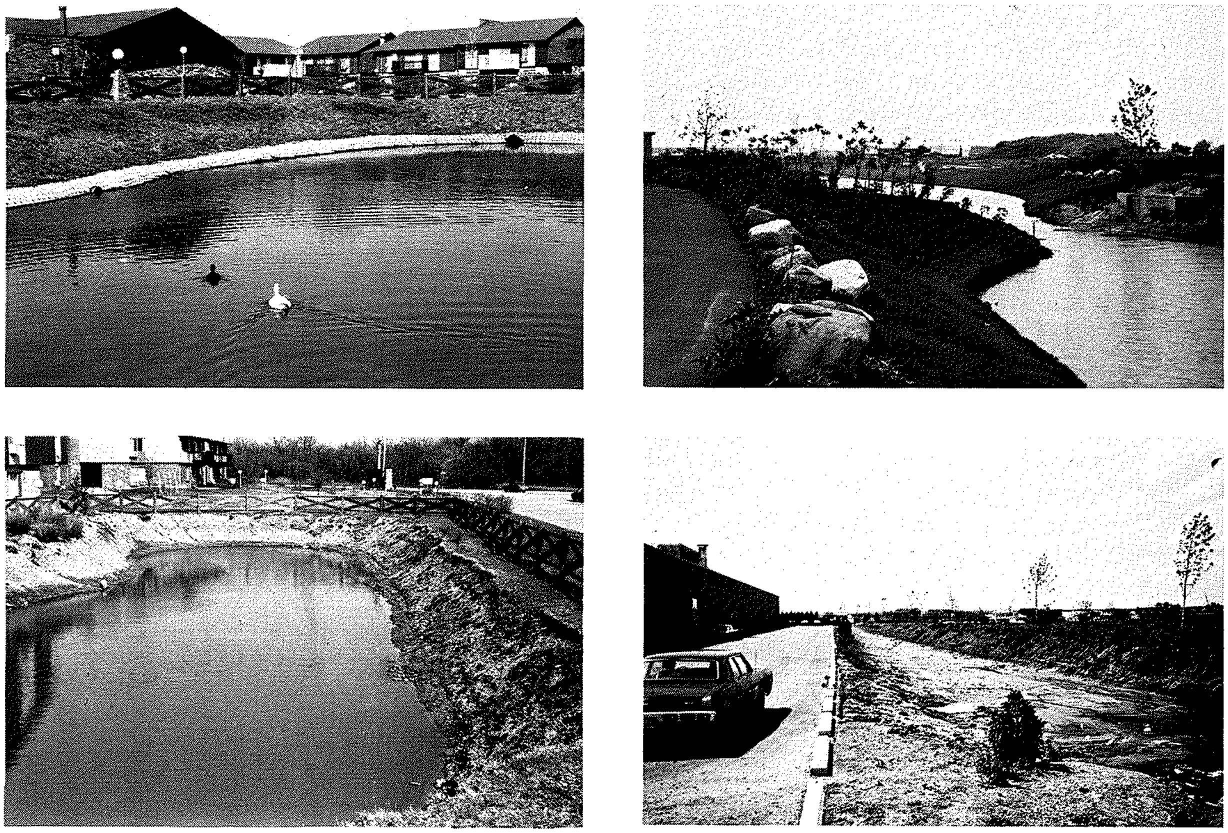
by incorporating on-site stormwater storage facilities in their project planning and construction.

Five examples of various kinds of land developments constructed in three areas of the United States are described in this section of the report. In each of these, appreciable savings in construction cost were realized by providing facilities for stormwater detention.

One is a new city being constructed in the Missouri River bottoms near St. Louis, Missouri. Savings of approximately $3 million in construction costs are attributed to the use of stormwater detention by means of a system of inter-connected lakes.

For a storm drainage project at Fort Campbell, Kentucky, a savings of approximately one million dollars in construction costs was made by providing detention ponds.

Three other examples are given of how construction cost economies were effected by means of providing stormwater detention facilities in the initial planning and construction of urban developments. One of these is a large interstate trucking terminal located in St. Louis, Missouri. The other two examples are large single-family residential developments in the Chicago suburbs.



c. detention ponds (*wet* type)
Upper Photo: landscaped, fenced, bank protection, wildlife
Lower Photo: not landscaped, bank erosion, poor maintenance

d. detention areas along driveway
Upper Photo: neatly landscaped, permanent body of water
Lower Photo: poorly landscaped, erosion, siltation, dry basin

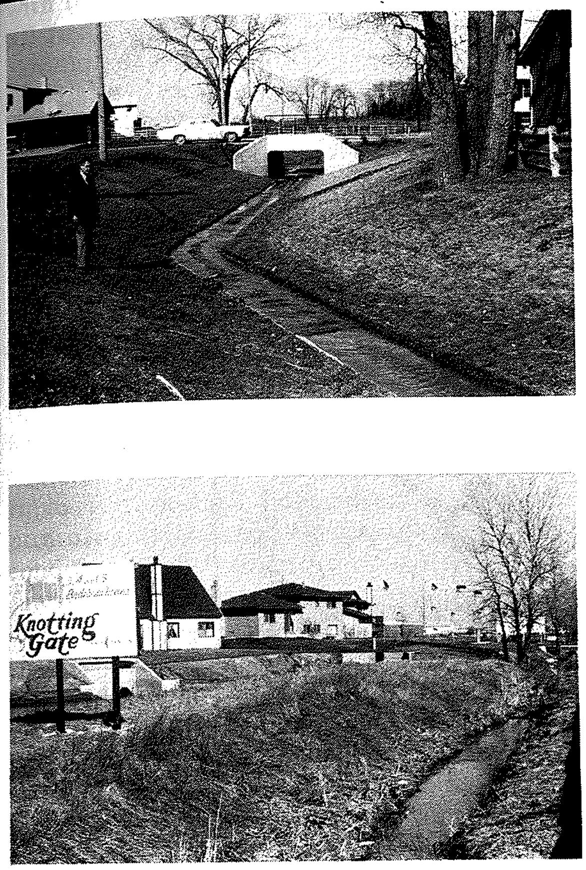
FIGURE 16 APPEARANCE OF DETENTION PONDS AND AREA

Earth City – St. Louis County, Missouri [5]

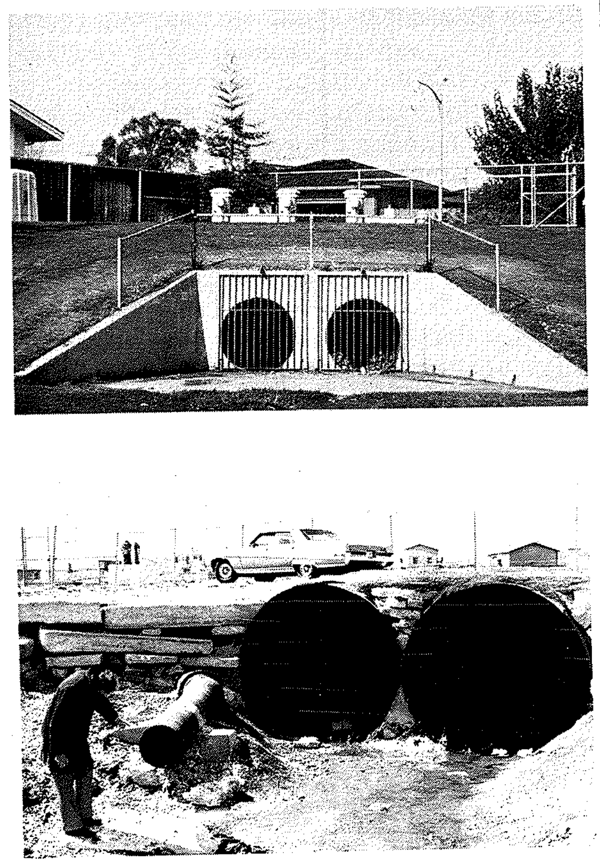
A planned, balanced community is under development in the Missouri River bottoms on the east bank, northwest of the City of St. Louis, opposite the City of St. Charles, Missouri. Of the available 1,500 acres, the architects' master plan foresees the initial 1,313 acres as 470 industrial, 274 office and commercial, 213 residential and 356 acres for two school sites with associated recreational areas.

Because this community (to be known as Earth City) is located on the Missouri River flood plain, two primary considerations are: (1) satisfactory protection of the occupied flood plain, and (2) proper provision for interior drainage of the project.

Fortuitously, the project area is bounded on the south by the embankment of Interstate Highway No. 70 and on the north by the Norfolk and Western Railroad fill, both approaching their respective Missouri River bridges. The character and elevations of these two east-west embankments as shown in Figure 17, Earth City, make it feasible to consider them as flank levees. A front levee between these two has recently been completed along the east bank of the Missouri River, constructed to the highest urban standards of the Kansas City District



e. natural drainage ditches
Upper Photo: neatly graded, grass, paved bottom, gentle slopes, easy maintenance
Lower Photo: weeds, unpaved, difficult to maintain



f. inlets to detention basins
Upper Photo: safety features, neatly graded, debris grate, grass, long life
Lower Photo: hazardous, unsightly, temporary life

FIGURE 16 APPEARANCE OF DETENTION PONDS AND AREA

Engineer's Office, Corps of Engineers, U.S. Army. Incorporated in the levee is a stormwater pumping station as part of the interior drainage facilities.

Several factors led to the inclusion of detention storage in the interior drainage system planning. The site planners wanted a strong planning factor to tie together the various parts of the project. The scheme of oblong finger lakes as shown in Figure 17 permits views between the proposed central urban plaza and the peripheral developments through visual corridors of water and open space. Excavation for the lakes and main channel provides much of the borrow needed for site grading. In addition, it is proposed to develop recreational activities such as boating and fishing. Aesthetic enjoyment of the lakes will be abetted by the provision of walkways around the lakes throughout the residential, commercial and industrial areas.

From an engineering standpoint, hydraulically, the advantages of the finger lakes are two-fold. First, the provision of appreciable volumes of storage above normal lake levels permits the use of considerably smaller discharge facilities – notably the open channels, culverts and pumping station.

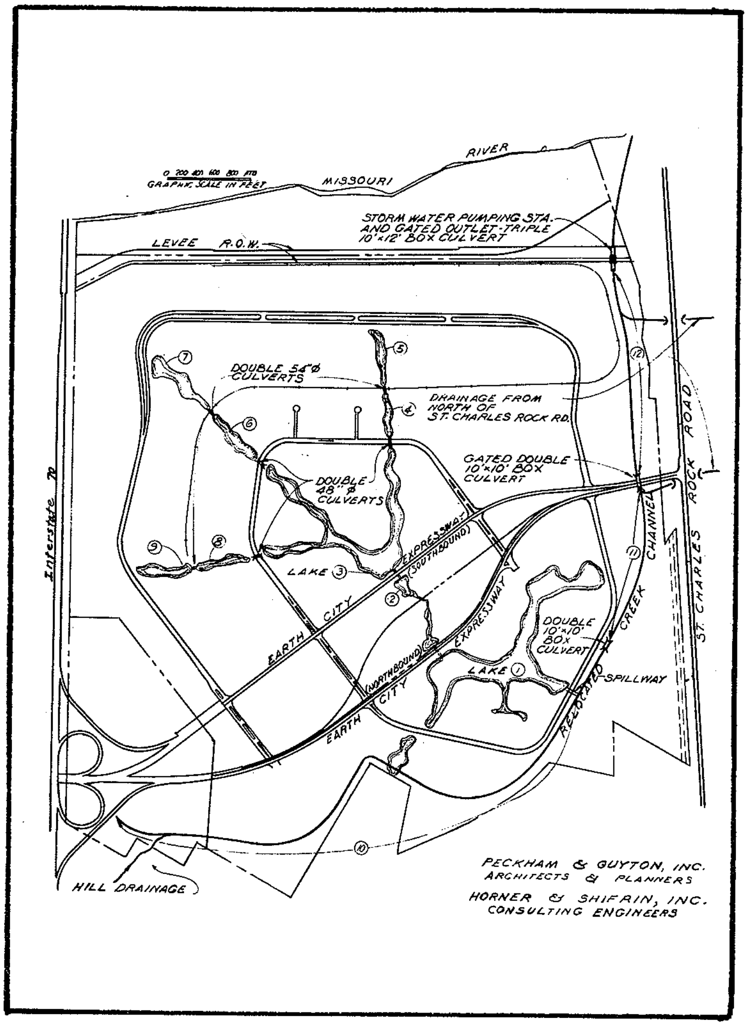


FIGURE 17 STORM RUNOFF DETENTION LAKES AND MAIN DRAINAGE CHANNEL EARTH CITY, ST. LOUIS COUNTY, MISSOURI

Instantaneous peak runoffs would require immense conduits or open channels, and a huge pumping capacity at the levee, due to the very flat gradients inherent in large flood plains. Second, the use of interconnected finger lakes extending throughout the project, attains lower controlled maximum design water levels at the upper ends of the fingers than could have been developed with long drainage channels. This is of importance because a county regulation requires that the first floor elevation of all buildings shall be at least two feet above the maximum design water level in the lake or drainage channel adjacent to the structure. The construction and site development costs would be smallest when floor elevations are made as low as feasible.

The general interior drainage scheme as shown in Figure 17 involves a major drainage channel from the hill drainage channel or outlet near the southwest corner of the project, continuing along the east boundary of the area, then along the south side of St. Charles Rock Road to the levee where a gated triple box under the pumping station permits either gravity discharge or pumped discharge as required by river stages. The lakes, which will be maintained usually at elevation 433 (Mean Gulf Datum), have a water surface area at that level of 51.4 acres and a perimeter of almost 6.1 miles. They are interconnected with the main drainage channel by means of a 50-foot long narrow-crested spillway at elevation 433 at the north edge of the center of Lake No. 1. Flows can interchange between the channel and the lakes in either direction as differential levels dictate.

All of the lakes are interconnected. Either bridges or double pipe culverts are provided at the northbound and southbound expressways. These structures do not produce significant head differentials for flow transfers between the lakes.

Remote-controlled slide gates are used on the upstream end of the double 10-ft x 10-ft box culvert on the main channel at the expressway and at the upstream end of the triple 10-ft x 12-ft box culvert at the levee pumping station. Under gravity outlet conditions and during storm runoff, the levee gates and the expressway culvert gates are kept open, except when the latter are closed to maintain the lakes at elevation 433. With no storm runoff, all gates are kept closed. In the case of the river gates, the purpose is to prevent inflow of silt-laden river waters.

Whenever the river stage at the St. Charles gauge (immediately upstream of the levee pumping station) reaches 19.5 (elev. 433), the gates at the levee and at the expressway will be closed. During runoff, all flows from the hill area and from the areas tributary to the lakes will be stored in the lakes, except during periods when the runoff from the balance of the project area is less than the capacity of the pumping station. At such times, sufficient stored flows upstream of the expressway culvert will be released to utilize the full capacity of the pumps. Under periods of design storm runoff, the lake levels will be allowed to rise to elevations not exceeding 439.

Design of Drainage System: The following rains were selected for design of the interior drainage system:

• *Gravity Drainage:* A 15-year frequency rain of 6-hour duration was used to design channels, swales and culverts. This gives comparable drainage quality to that required by the county for upland areas.

• *Blocked Drainage:* A 30-year rain coincidental in frequency with the selected gate-closing stage of elevation 433 (stage 19.5) governed the design of the lakes and the capacity of the pumping station.

• The operation of the channel and lake system under gravity outlet conditions, and the extent of ponding for a more intense, less frequent rain was studied for a 100-year frequency rainfall of 6-hour duration. Also checked were the probable maximum lake levels resulting from the 30-year coincidental rainfalls of 12-hour and 24-hour durations.

Rainfall values for the 15-year and 100-year frequency events are from Technical Paper No. 40 of the National Weather Service. The rainfall values for the 30-year, 6-hour, 12-hour and 24-hour coincidental rainfall events are from U.S. Army Corps of Engineers' studies.

Synthetic rainfall patterns were developed by 15-minute intervals and infiltration losses were computed giving consideration to the amount of rainfall occurring during each period. These infiltration loss rates, deducted from their associated rainfall rates, gave precipitation excess or the runoff rates from pervious areas. Total runoff rates were computed by using rainfall rates as equivalent runoff rates from impervious areas and combining the two in proportion to the assumed percentages of imperviousness.

Runoff hydrographs for the hill area were developed using a unit hydrograph. For the bottoms, triangular hydrographs were developed for each of the many relatively small (averaging about 20 acres) tributary areas. These were then summed by appropriate time-off setting. time-offsetting.

A routing procedure was set up for calculations by computer. The maximum lake levels were computed to be:

With Gravity Outlet, 15-year Design Rainfall:

	Elevation
Maximum Industrial Lake Level, No. 7	438.7
Maximum Residential Lake Level, No. 1	436.9

With Blocked Drainage, 30-year 6-hour Coincidental Design Rainfall:

Maximum Industrial Lake No. 7	438.9
Maximum Other Lakes	438.9

With Gravity Drainage, 100-year 6-hour Rainfall:

Maximum Industrial Lake No. 7 ....440.7
Maximum Residential Lake No. 1 ....437.8

Determination of the effects of 12-hour and 24-hour, 30-year, coincidental rainstorms routed through the main channel and lakes indicated the following:

	6-Hour		12-Hour		24-Hour	
	Runoff Mass ac-ft	Pool Level msl	Runoff Mass ac-ft	Pool Level msl	Runoff Mass ac-ft	Pool Level msl
Upper Ponding Area	515	438.8	575	439.5	670	440.3
Lower Ponding Area	63	436.5	67	437.0	78	438.3

Although these computer routings of hydrographs based on the 100-year and the two longer duration 30-year coincidental storms indicate the desired maximum lake level of 439 may be exceeded, the computations do not reflect the storage available in the many tributary swales and ditches, nor in the local shallow pondage which would unavoidably be present in the vast areas surrounding the buildings. Also it must be recognized that the pumping station and gates could be manipulated in a manner such that additional storage capacities could be provided to reduce lake levels for the greater (longer duration) storms.

Operation of Drainage System: Operation of the pumping station and the slide gates can be manual or automatic. During periods of surface runoff, the pumping station will be manned continuously with the following information availabel to the operator:

a. River level,

b. Water level in the channel upstream of pumping station,

c. Water level in the channel upstream of expressway, and

d. Positions of the roller slide gates at both the triple box level culvert and the double box expressway culvert.

The operator will have available the following controls:

a. Switches to start or stop each pump,

b. Switches to operate each roller gate and sluice gate up or down, and

c. Optional switch to control inflow from 395 acres on the north side of St. Charles Rock Road.

For automatic control conditions, alarm circuits will be provided for malfunctions; these will sound at a suitable place where 24-hour surveillance will be provided.

Lake Management: Lake Management considerations include: maintenance of lake levels at elevation 433 during low river stages and dry periods; stocking the lakes with game fish; minimizing shoreline erosion; and the provision of a small marina. It is proposed to accomplish the first of these by pumping into the lakes from the existing riverside borrow pits as may be necessary. The alternate of sealing the lake bottoms was considered but is thought to be less desirable than the supplementary pumping option.

Costs: The interior drainage system as designed, including the finger lakes, main channel and the 150 cfs main pumping station is expected to cost about $2 million. The total construction costs of "instant-runoff" facilities with the complementary large capacity pumping station at the levee (and no designed detention storage in the system) was estimated to be about $5 million. Thus, a savings of $3 million can be attributed to the use of detention facilities.

Conclusions: The incorporation of multiple-purpose stormwater detention lakes in the 1,500-acre Earth City development presently under construction in the Missouri River bottoms has improved project aesthetics because of its intelligent use as a basic planning concept. The lakes offer recreational opportunity and enhance freedom of pedestrian circulation. In addition to the intangible values of this "blue-green" concept provided by the lakes and surrounding landscaped vistas, there are significant development economies.

It appears to be a reasonable, informed opinion that land developments in the flat bottomlands of large rivers, with satisfactory and adequate flood protection, can only be economically feasible if the planning and design of their interior surface drainage systems include well-designed stormwater detention facilities.

Trucking Terminal, Consolidated Freightways, Inc., – St. Louis, Missouri [6]

In 1968, Consolidated Freightways, Inc., constructed an interstate truck terminal on a 23.1-acre site in the protected Mississippi River flood plain in the northeastern portion of the City of St. Louis. Before construction of major flood control facilities to protect the St. Louis waterfront, this area was flood prone and was used as a sanitary landfill. No significant, high-value developments were built. As a corollary to this fact, no planned surface drainage facilities were constructed. As the prospect of high quality flood protection became more certain, many valuable improvements, some of them large trucking terminals, were constructed. Developers of each of these had to plan and construct their own storm and sanitary sewers. Existing combined sewers are generally inadequate to handle the design runoff flow rates from a 15-year frequency rainfall which is a design requirement of the Metropolitan St. Louis Sewer District.

Surface water disposition both before and after construction of the flood control project is to a natural creek or ditch entering from the north, located generally parallel to the Mississippi River levee and the railroad immediately west thereof. With the construction of the levee and floodwalls, several levee pumping stations have been constructed to handle interior drainage when high river stages prevent gravity discharges.

The property is developed with an 85,000 square-foot office-warehouse surrounded by large areas of concrete-paved aprons and a 20,000 square-foot shop building with concrete aprons. The remaining area is paved with a heavy crushed stone base. The east end of the property serves as an employee parking area.

Fortunately, no stormwater runoff originates outside the Consolidated property itself, other than the runoff from the adjacent street. This fact, when coupled with the very flat character of the site, added to the circumstance that most of the site would be used for operation and parking of large tractor-trailer trucks, dictated the logic of detention storage in large, shaped pockets.

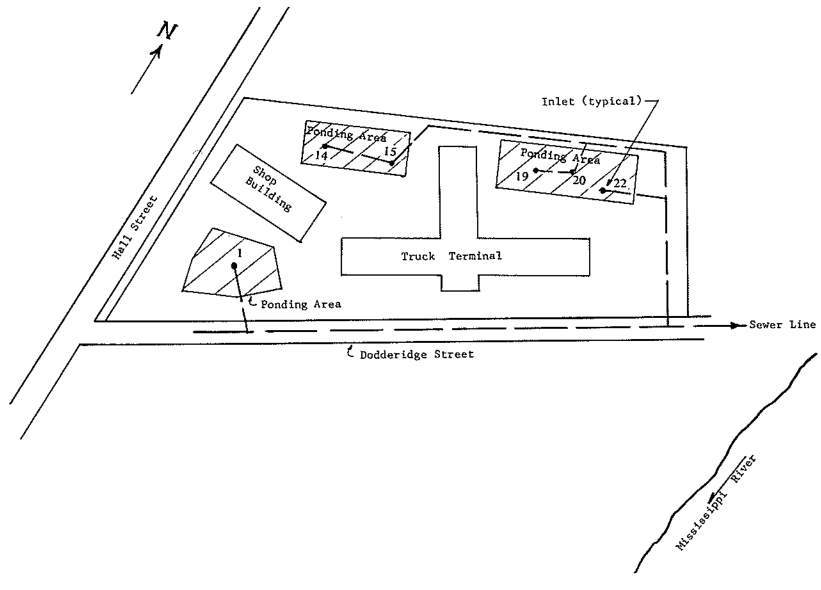
The consulting engineers, Reitz and Jens, Inc., designed three ponding areas, having a total area of 3.5 acres. These drain 13.28 acres and detain 11.3 acre-inches of runoff with a maximum ponding depth of 10.5 inches. The approximate extent of pond areas that drain through the six inlets numbered 1, 14, 15, 19, 20 and 22 is shown on Figure 18, Parking Lot Detention, Consolidated Freightways. Significant facts concerning each ponding area are shown below.

Inlet No.	Tributary Area (Acres)	Storage Vol. (Acre-Inches)	Surface Area (Acres)	Max. Depth (Inches)
1	3.34	2.839	0.929	9.17
14	3.39	2.882	0.773	10.50
15	2.10	1.785	0.499	9.66
19	1.99	1.692	0.642	9.44
20	1.22	1.038	0.369	7.70
22	1.24	1.055	0.289	9.42
Totals	13.28	11.291	3.501	

Metropolitan St. Louis Sewer District requirements for storm drainage utilize the "rational method" and assume a minimum time of concentration of 20 minutes with a 20-year average recurrence interval rainfall rate of 4.84 inches/hr. For 100 percent impervious areas, such as this truck terminal, a maximum runoff rate of 3.7 cfs per acre is required.

Each of the ponding areas has a one percent slope from the perimeter of the ponding area to the top of the lowest surface inlet. Inlets are untrapped, slotted gratings resting on angle iron frames set in concrete drop structures. Pipe sizes were selected to give suitable hydraulic gradients for design conditions.

Operation: The duration of ponding will rarely exceed 30 minutes, and design runoff pondages are expected to occur about once every two years. The passenger car parking lot is located along a property line, and concrete walkways are provided to encourage pedestrian traffic through areas that do not have ponding.



Source: Reitz & Jens, Inc., St. Louis, Mo.

FIGURE 18 PARKING LOT DETENTION, CONSOLIDATED FREIGHTWAYS

Costs: A preliminary design was also made for a conventional drainage system designed to remove stormwater as fast as runoff developed. The design was based on a 100 percent impervious area and a 20-minute, 20-year rainfall.

Cost estimates prepared for this conventional drainage system, composed of inlets and closed conduits, indicated a $150,000 total construction cost. The system constructed, utilizing ponding, cost $35,000 less than this.

Conclusions: Experience of several years has justified the practicality of the shallow stormwater ponding areas at this trucking terminal. No operating difficulties have developed. The economy of detention of stormwater in the internal surface drainage facility for this major truck terminal has been demonstrated.

Fort Campbell, Kentucky [7]

The use of on-site detention storage in the storm drainage system at Fort Campbell, Kentucky reduced the initial construction cost by over a million dollars and has proved to be satisfactory and environmentally attractive since it was placed in operation in 1963.

Fort Campbell is located on the Kentucky-Tennessee state line about 50 miles northwest of Nashville, Tennessee. The total area of the cantonment is about 6,000 acres and the region has gently rolling terrain with thick clay overlying cavernous limestone formations.

Planned expansion of Fort Campbell onto 2,000 acres initially led to preliminary drainage designs embodying an all-gravity system having an estimated cost of $3,370,000. This system was to replace a previous series of sinks using 6-in. to 8-in. diameter metal-cased shafts constructed through the clay soil into voids in the underlying limestone. These were unreliable in disposing of runoff, creating hazards in builtup areas, including family housing.

Alternative studies for providing stormwater drainage included the use of detention storage. This system, combined with the use of some open channels instead of closed conduits, was adopted and built at a cost of $2,000,000. Final design was by the Mobile District of the Corps of Engineers.

Significant reductions in pipe sizes were made possible by the use of temporary detention storage, as shown in Figure 19, Profile of Main Trunk Sewer. For example, the inflow pipe to one pond is 84 in. in diameter, while the outflow pipe from the pond has a diameter of only 30 in.

Without the use of ponding, a 90-in. diameter outflow pipe would have been required, together with corresponding increases in pipe sizes all the way downstream from the pond. The outflow pipe from the

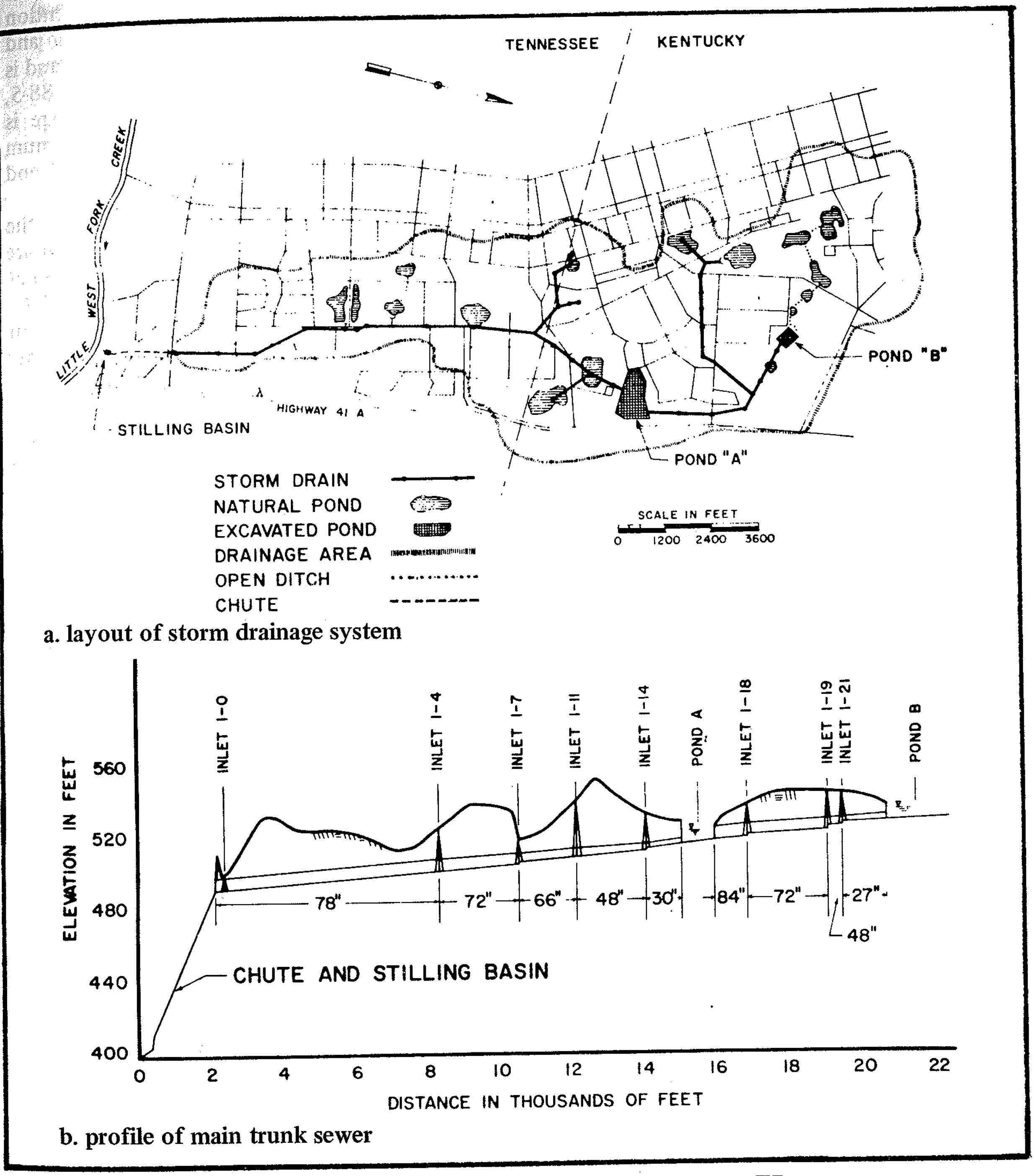


FIGURE 19 PROFILE OF MAIN TRUNK SEWER

pond is 13,000 ft in length and the total cost of the pipeline, and that upstream at a second pond, was reduced by over $1,000,000.

The total storage volume of each pond is about 130 acre-feet. Pond A is approximately 1,200 feet long and from 400 to 800 feet wide. Pond B is smaller in area – about 600 ft x 400 ft – but the average depth is greater.

Figure 20, Inflow-Outflow Hydrograph for Pond A, was developed. Similar hydrographs were developed for other ponds in the system.

To restrict the rate of runoff entering the system, most inlets were constructed with a short control pipe. Critical flow with inlet control was assumed when the control pipe is flowing partially full; flowing full, the discharge was computed by the conventional orifice formula. The capacity of the long pipes draining Ponds A and B assumed friction control plus an entrance loss of 0.1 of the velocity head.

Routing: The adopted drainage system was checked for its stormwater routing characteristics using a 50-year frequency rainfall. No flooding of any facilities was predicted. The depth and duration of more frequent ponding was determined by routing a 1-year event through the system. Table 16, Comparison of Hydrographic Data for Storms of Various Frequencies, gives ponding data for storms of 1, 10, and 50-year frequency.

The United States Army has published a technical manual on the use of detention ponds in the drainage of airfields and heliports. It is identified as TM 5-820-1, and is also used by the U.S. Air Force as AFM 88-5, Chapter 1. The use of detention storage is encouraged in the manual – for maximum application "consistent with operational and earth-grading requirements."

Details of the hydraulic design of the surface drainage system at Fort Campbell are given in a paper, *Hydraulic Design of the Fort Campbell Storm Drainage System,* by L.G. Leach and B.L. Kittle of the Corps of Engineers South Atlantic Division. This paper appeared in Highway Research Record No. 116 published in 1966 by the Highway Research Board. This entire section of the report is taken principally from the Leach &

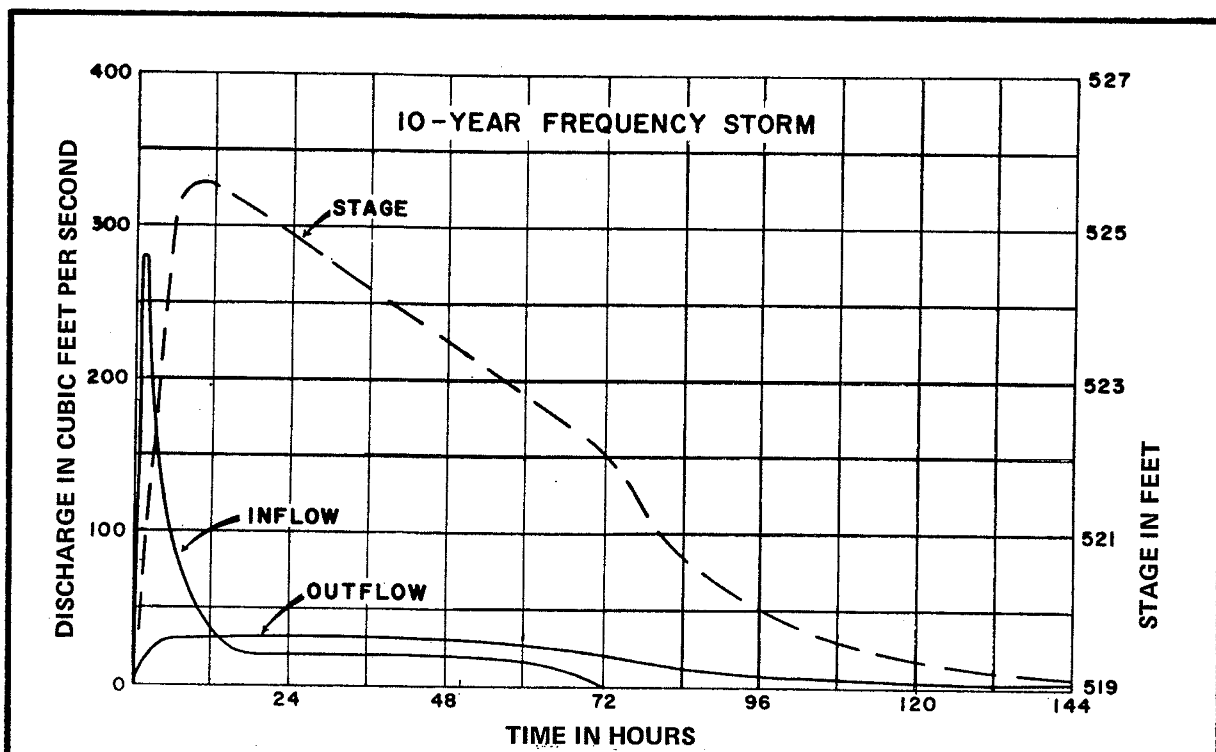


FIGURE 20 INFLOW-OUTFLOW HYDROGRAPH FOR POND A

TABLE 16
COMPARISON OF HYDROGRAPH DATA FOR STORMS OF VARIOUS FREQUENCIES

		1 – Year				10 – Year				50 – Year			
Area No.	Drainage Area (acres)	Max. Inflow (cfs)	Max. Outflow (cfs)	Max. Pond Elev.	Pond Time (hr.)	Max. Inflow (cfs)	Max. Outflow (cfs)	Max. Pond Elev.	Pond Time (hr.)	Max. Inflow (cfs)	Max. Outflow (cfs)	Max. Pond Elev.	Pond Time (hr.)
1	198.6	63.5	40.0	539.0	6.5	103.5	63.6	539.9	12.5	137.5	77.0	540.7	13.0
6a	372.0	165.0	18.7	536.4	30.0	270.0	22.3	538.9	72.0	347.0	23.8	540.0	96.0
7	38.4	29.3	16.0	541.8	4.5	31.0	18.4	642.9	8.0	38.9	19.6	543.5	10.5
8	31.9	15.3	6.1	539.2	6.0	25.2	12.1	539.8	10.0	31.6	14.8	540.2	12.0
9	44.3	17.4	7.4	543.2	6.0	28.6	8.2	544.2	12.5	36.4	8.6	544.6	42.0
10	61.5	40.2	26.7	539.2	4.5	64.2	32.9	540.0	9.0	79.8	34.8	540.5	10.0
11	39.9	25.0	7.0	537.9	6.5	40.2	7.8	538.7	12.0	49.8	8.0	539.1	18.5
12	47.9	30.4	12.7	529.8	6.0	49.1	18.3	531.0	10.5	61.3	20.0	532.0	11.5
13b	244.7	180.0	19.6	521.8	137.0	270.0	32.0	525.6	192.0	333.0	36.0	528.2	219.0
14	100.0	40.8	12.5	539.3	10.0	66.3	20.6	540.4	17.5	85.0	23.0	540.8	21.0
15	66.2	26.2	7.9	537.9	6.5	42.6	9.0	538.6	18.5	54.6	9.0	539.4	25.0
16c	19.3	14.2	14.2	–	–	22.9	22.9	–	–	28.6	28.6	–	–
17	87.2	58.4	50.0	531.2	4.5	93.5	62.0	534.7	10.0	116.2	68.0	535.1	10.0
18c	24.9	17.3	17.3	–	–	27.8	27.8	–	–	35.0	35.0	–	–
19	257.0	97.8	26.2	521.0	13.5	132.5	37.0	523.9	21.0	172.9	41.0	525.4	33.0
20	5.4	3.7	1.9	520.8	3.5	5.9	2.6	521.0	5.5	7.2	3.3	521.5	8.5
21b	32.0	14.6	11.7	516.9	5.0	22.7	17.4	517.8	9.0	29.8	18.4	519.0	10.0
22b	32.7	22.2	9.8	511.1	10.0	37.1	19.9	512.2	13.0	49.7	22.5	513.4	16.5
23	208.0	87.6	26.2	512.1	18.5	144.7	39.0	513.6	19.0	185.0	46.2	514.7	25.0
24	54.6	30.4	7.7	522.6	6.0	50.0	8.8	523.9	15.5	62.3	9.2	524.3	21.0
25c	23.3	10.0	10.0	–	–	16.5	16.5	–	–	20.8	20.8	–	–

Notes: a. Includes areas 2 through 6
b. Includes discharge from upstream area
c. No ponding in these areas

Kittle paper. The figure and table are direct copies from the paper.

A reply to an inquiry made in 1971 revealed that the system had performed in a very satisfactory manner during the eight years that it had been in operation.

Chain of Lakes
Village of Hoffman Estates, Illinois

Hoffman Estates, a Cook County community in Metropolitan Chicago, initiated a stormwater detention program about 15 years ago. The decision to use detention storage was primarily an economic one, because detention of runoff would reduce the required sizes of various drainage facilities needed. At the present time, there are 17 ponds which have permanent pools of water ranging in size from 0.5 to 10 acres. These have storage capacities of from 3 to 80 acre-feet. There are numerous smaller storage facilities of various types – dry basins, parking lot detention, and detention in buried culverts.

The earliest portions of the village were all developed by Hoffman Rosner Corporation. The existing drainage from a 700-acre tract flowed under the tollroad through a 30-inch corrugated metal pipe and a 15-inch tile underdrain located nearby. This flow passed through a forest preserve and thence into a tributary of Salt Creek.

The agricultural land in its natural state had several natural retention basins, where stormwater collected and was retained in swamp-like areas until it could flow from the area through the culvert and farm tile. Most of these farm ponds were generally in the locations later selected for the detention ponds. Considerable portions of these swamp-like areas were underlain with thick layers of peat and, therefore, were unsuitable as building sites. This determined their ultimate use as open lands for recreation and enhancement of the local environment.

While Hoffman Rosner did not own all of the 700 acres involved, they decided that this area would ultimately be developed and that they should build a storm runoff system which would be adequate to serve the entire 700 acres when completely developed, regardless of who the developer might be. To drain the entire area with conventional drains would have required a structure under the tollroad of 750 cubic feet per second flow capacity. Such a sizeable box culvert would have been quite costly, traffic flow on the tollroad would have been detoured and it would have been difficult to secure sufficient headroom for this structure. Because the land beyond the tollroad is very flat and swamp-like, handling the peak runoff would have required the dredging of drainage ditches for a mile or more.

The storm drains, due to their length and size, would have been expensive, and providing cover material over lines of such size would have been a problem in the prevailing flat terrain. On the other hand, it was reasoned that if detention sites could be selected in the areas of natural retention where soils were not suitable for building, the amount of excavation needed to provide detention ponds and their ultimate cost should be minimal. If such ponds were dug to depths sufficient to discourage growth of moss and cattails at low water level the resulting water areas could be pleasant additions to the landscape and should have considerable recreational value. Because the peat areas were generally much larger than would be needed for retention ponds, adequate adjacent land would be available for normal park purposes, and the ponds could then become an integral part of the park system.

Based upon these findings, Hoffman-Rosner engineers set out to design a series of ponds with their outlets sized so that the drainage could be handled through the existing 30-in. culvert and 15-in. tile under the tollway. The locations of the detention lakes and the approximate boundaries of each sub-basin in the "Highlands West" watershed portion of the development are shown in the map, Figure 21, Highlands West Subdivision. The area of each sub-basin and the sequence of flow routing is given in Table 17, Watershed Areas. Storage volumes, depths, surface areas, water elevations, outlet sizes and flow capacities, and type of pond (wet or dry) are given in Table 18, Details of Retention Pond Design.

The area was developed in phases with Areas B and C-2 being the first to be developed. Highland Lake and the adjoining park lay over an extensive peat bed and were drained through storm sewers to the low-lying area located where Jones Lake now stands. From this point, the water was allowed to flow through farm tiles and overland through undeveloped land to the outlet under the tollroad.

Next to be developed was the A-1 area. Here a 10-acre lake was excavated with the waste material being used to fill some of the lower areas to the southwest which now lie in the park. This lower area was also used for a waste dump for excess building materials and dirt during the construction of the homes. Perforated underdrains were placed throughout the area for proper drainage following rainstorms. After the construction was completed, topsoil was placed over the entire area and the banks of the lake and the park area were seeded.

Drainage from the Highpoint Lake passed through an 18-in. storm sewer to the eastern edge of the area then being developed, which was approximately 1,200 feet to the east. At that point normal flow entered a farm tile and ultimately reached the outlet under the tollroad while storm runoff passed overland, through the undeveloped area, to the same outlet.

Later, when Area D was developed, the Twin Lakes were established in areas underlain with peat. The storm sewer system

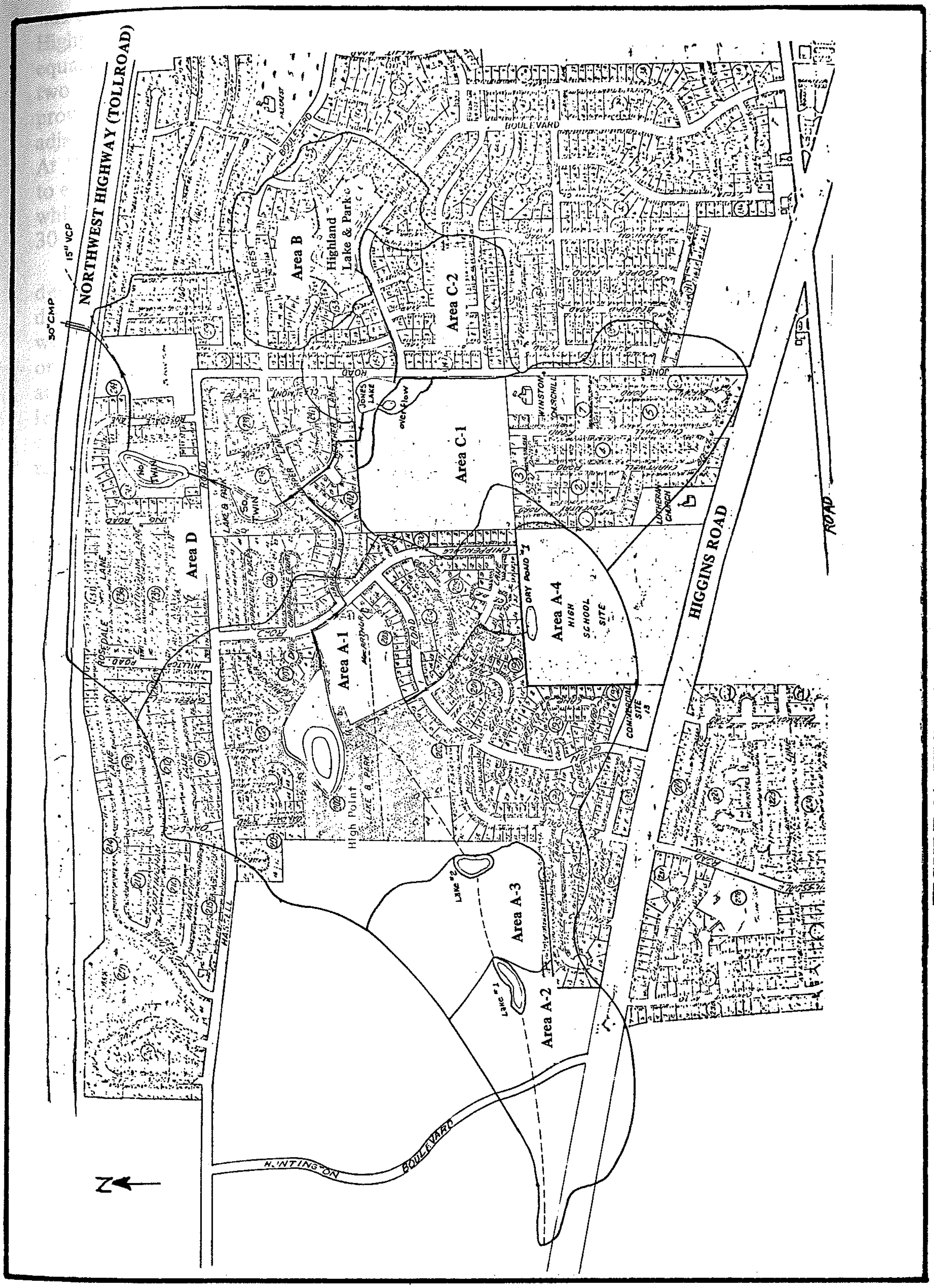


FIGURE 21 HIGHLANDS WEST SUBDIVISION
HOFFMAN ESTATES, ILLINOIS

TABLE 17

WATERSHED AREAS
"HIGHLANDS WEST" RETENTION PONDS
HOFFMAN ESTATES, ILLINOIS

Area (Identification)	Drainage Area (acres)	Runoff Coefficient For Developed Area	Pond of Original Storage for Runoff	Outflow Later Passes Through These Ponds
A – 1	217	.35	Highpoint	Twin Lakes
A – 2	55	.41	Lake No. 1	Lake No. 2 Highpoint and Twin Lakes
A – 3	35	.41	Lake No. 2	Highpoint and Twin Lakes
A – 4	33	.42	Dry Pond No. 1	Highpoint and Twin Lakes
B	50	.35	Highland	Jones Lake (lower level) and Twin Lakes
C – 1	105	.35	Jones Lake (upper level)	Jones Lake (lower level) and Twin Lakes
C – 2	45	.35	Jones Lake (lower level)	Twin Lakes
D	160	.35	Twin Lakes	none

TABLE 18

DETAILS OF RETENTION POND DESIGN – "HIGHLANDS WEST"
HOFFMAN ESTATES, ILLINOIS

Pond Name	Type of Pond	Maximum Depth of Normal Pool (ft)	Size of Area Original Service (acres)	Inflow From Other Area (acres)	Normal Pool		Flood Pool Elevation (ft)	Flood Storage Capacity (acre ft)	Outlet		Design Capacity For 100-yr Flood (acre ft)
					Size (acres)	Elevation (ft)			Size	Capacity CFS	
Highpoint	Wet	7	217	123	10.0	779.0	784.0	50.0[1]	18"CP	3.5	50.5
Lake No. 1	Wet	4	55	–	1.2	784.0	786.5	3.2	16"CP	3.0	8.4
Lake No. 2	Wet	4	35	55	1.0	779.0	783.5	5.1	27"CP	12.0	
Dry Pond No. 1	Dry	0	33	–	0.2	812.0	817.0	1.5	12"VCP	6.5	1.5
Highland	Wet	4	50	–	4.0	780.0	784.0	20.0	15"CP	5.0[2]	5.0
Jones Lake (Upper Level)	Dry[3]	4	105	–	0.4	778.4	785.0	9.5	15"CP	5.0	10.9
Jones Lake (Lower Level)	Wet	3	45	155	1.4	778.0	783.0	8.0	30"CMP	8.0	7.1
Twin Lake – South	Wet	4	70	540	3.5	775.0	780.0	19.5	36"CMP	Equalizer	27.0
Twin Lake – North	Wet	4	90	610	4.0	775.0	780.0	22.0	27"CP	15.0	

Outlets under Tollway – 30" CMP – Cap. 12.0 CFS
– 15" VCP – Cap. 3.0 CFS

[1] An additional 50 acre feet (or more) of overflow storage is available before water reaches within one foot of floor level.
[2] Controlled by valve to 3.0 CFS.
[3] Has small permanent pond, balance of overflow on play field.

was then extended to connect the outlet from Highpoint Lake to the South Twin Lake. An equalizer pipeline was provided between the two Twin Lakes and a 27-in. outlet was provided to carry the water to a point adjacent to the 30-in. pipe under the tollroad. At this point, the normal flow was permitted to enter the 15-in. farm tile under the tollroad while the flood flows were carried to the 30-in. pipe.

In short, the design as ultimately developed followed the pattern prior to development. The series of lakes provided were located in the general vicinity of the original retention areas. The lakes and the accompanying park-like areas were developed into desirable assets for the residential community and are used extensively today as recreational facilities. By utilizing small-size drains to carry the outflow to the ultimate outlet under the tollroad, the cost of the drainage system was greatly reduced from the estimated cost of a conventional drainage system.

To provide an additional safety margin, the ponds were designed to hold a minimum of one foot more water than the runoff from the 100-year rainfall before houses would be flooded. The system has worked as anticipated by the designers and is a satisfactory method of controlling runoff from this 700-acre area. The only serious problem was encountered in Area C-1 where the retention pond that was planned originally was not built. That detention pond is now under construction and, while it is somewhat undersized, it should alleviate the flooding conditions which have occurred there.

The ponds and adjacent park areas are used for recreation. Some have been stocked with fish and others now have ducks inhabiting them. Others are used as parts of golf courses, and some, located near buildings, enhance aesthetic values.

The most serious problem to date is preventing land developers from deviating from the original master drainage plan, as was done in the C-1 area. An overall master plan was developed for the entire sub-watershed, and only by following this plan will adequate drainage be obtained. Control by the Metropolitan Sanitary District of Greater Chicago will help coordinate such plans in the future.

There have been maintenance problems. Children playing at pond outlets have stuffed sticks and debris into the outlet pipes causing blockages and reduced flow. Objects thrown into the pond have had similar effects. Ready access to each outlet should be available to operating personnel and a manhole should be installed downstream of each outlet to aid in cleaning operations. Ice plugs forming in sewer pipes during the winter and spring can also be cleared more easily with such provisions.

Slow drainage of ponds can kill grass and shrubs. It is important to incorporate design features to prevent this from happening.

On small ponds where the slopes are steeper than 3 1/2 horizontal to 1 vertical, maintenance is difficult and the ponds become a safety hazard for small children unless they are fenced. Ponds having gentle side slopes cause no problems of this type and are not fenced.

Siltation during construction of the subdivision was also a problem and it is advised either that the pond be dredged after construction is terminated or that measures be taken to control erosion.

Suggestions by the developer for facility design are: (1) limit the construction of impervious area to the assumed area upon which the original design of the detention facilities was based; (2) provide emergency spillways through streets, etc., to handle abnormal flows; (3) use outfalls larger than required by calculations, and provide for control of flow rates to permit rapid drainage when needed; (4) construct banks of ponds with gentle slopes for safety and ease of maintenance; (5) provide for erosion and siltation control; and (6) install a manhole downstream of each outlet to simplify clearing of debris in outlet pipes.

In conclusion, Hoffman Estates has experienced no serious difficulty with stormwater detention facilities. The ponds are economically advantageous. They are extremely useful for controlling stormwater drainage and reducing flooding, and they provide significant recreational and aesthetic benefits.

That proper engineering pays off was evident in 1972 when the general area had 3.5 inches of rainfall in 45 minutes on August 23rd and six to seven inches in a two-hour period two days later. According to the land development company (Hoffman-Rosner Corporation) only a handful of flooding complaints were registered by the 8,000 homeowners, and none in any of their newest developments.

Indian Lakes Estates
Bloomingdale, Illinois

Indian Lakes Estates is a single-family residential development located in the Village of Bloomingdale, northeastern DuPage County, Illinois. It includes 1/2-acre residential lots, two 18-hole golf courses and a clubhouse. The drainage system, designed by Bauer Engineering, Inc. (Chicago), was put into operation in 1969. It serves 400 acres of gently rolling watershed. Much of the area was formerly swampy and had no well-defined natural drainage channels.

Two basic alternative designs were investigated. One required the construction of a 72-inch diameter sewer to carry the surface runoff from the watershed to Salt Creek. This would have entailed constructing 7,000 feet of precast concrete pipe across farm land owned by a party who objected to having this sewer constructed on his property.

The alternative chosen involved constructing small-diameter sewer lines on the Estates to connect with an old existing farm drain built of 16-inch diameter field tile. Engineering investigations and calculations showed that this drain, much of which was in poor condition, had a capacity for handling about 0.01 in./hr. (0.25 in./day) of runoff. This flow rate is extremely small compared with the capacity of the alternative design involving the 72-inch sewer. The rate is small enough to permit treatment of the stormwater runoff when desired or required at some future date. Also, this slow discharge rate would not contribute to rapid rises in the water levels in Salt Creek.

The estimated costs of constructing the two alternative drainage systems indicated a net saving of $370,000 in favor of a system incorporating the farm drain tile with on-site detention lakes. A tabulation of estimated costs is given in Table 19, Comparison of Estimated Costs.

The hyetograph of the largest recorded rainfall in the history of Chicago was used as the design runoff. The difference in mass diagrams constructed for both the uncontrolled runoff and the controlled runoff situations was used to estimate the detention storage volume required. This was computed to be a volume equivalent to 3.0 inches of water spread over the 400-acre watershed. This amounts to 100 acre-feet of water stored over 17 acres of water surface at an average depth of six feet.

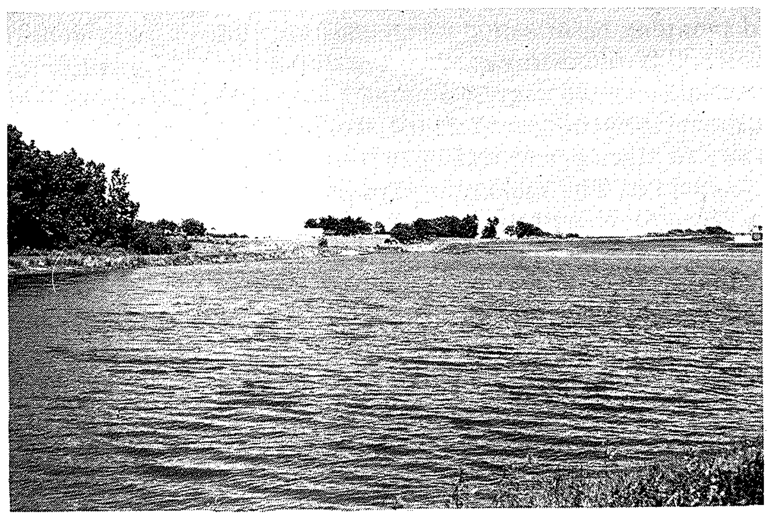
Figure 22, Indian Lakes Estates, contains photographs of (a) an existing permanent, variable-depth lake on the golf course area; (b) a new permanent excavated lake at a lower level, created in a swamp, to collect surface runoff and to provide additional

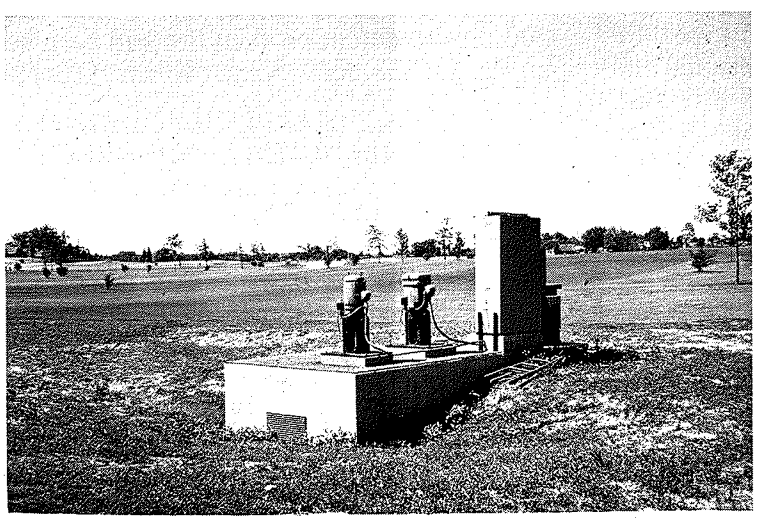
TABLE 19
COMPARISON OF ESTIMATED COSTS – INDIAN LAKES ESTATES

Item	Costs of 72-inch Sewer System	Costs Using Farm Drain with Detention	Savings Using Detention System
Piping (Installed)	$ 500,000	$ 40,000	$ 460,000
Pumping Station	0	50,000	(50,000)
Excavation for Lakes	0	100,000	(100,000)
Contingencies	100,000	40,000	60,000
TOTALS	$ 600,000	$ 230,000	$ 370,000

a. View of the upper detention lake on the golf course area.

b. Lake created from swamp located in lower area where surface runoff collects. Dike constructed from peat excavated from the swamp is shown on the far side of the lake. A portion of a residence can be seen at the upper right of the photo.





c. Pumping station located in shallow basin from which water is pumped to the upper lake on the golf course. Water enters this basin by gravity flow from the lake excavated in the swamp area during periods when the surface runoff into the lower lake causes the lake level to rise above the horizontal grating at the outlet.

FIGURE 22 INDIAN LAKES ESTATES

storage through a 5-ft rise in its water surface; and (c) a pumping station designed to pump excess runoff from the low-lying excavated lake to the upper lake. An 18-in. diameter two-way flow force main was constructed between the upper lake and the pumping station; and a 12-in. diameter existing storm sewer between the low-lying lake and the pumping station. Small-diameter sewers permit gravity discharge of excess stored runoff from both the upper and lower lakes into the existing farm drain.

Two additional interconnected, small lakes located on the golf course drain excess stored runoff into a different storm sewer, separate from the system described above.

A total of 40 acre-feet of runoff can be stored in the upper lake, and the lower lake and pumping basin can store an additional 60 acre-feet. If filled to capacity, the upper and lower lakes would require about 12 days time to drain the 100 acre-feet of stored water down to the permanent five-foot average water depths. The maximum flow capacity of the farm drain system controls the rate of outflow from the upper and lower lakes. This maximum flow rate is, in turn, dependent upon water levels in Salt Creek where the system discharges.

In summary, the man-made collection lake, located in a peat bog, is an example of how a liability was converted into an asset. Not only does this lake constitute an important component of the detention storage system for handling stormwater runoff, but it enhances the aesthetic appeal of this residential area. This has resulted in higher sales prices for the abutting lots. But most important, by detaining the surface runoff at the site, flow rates into Salt Creek were minimized, thereby sparing property owners along the creek, and its tributaries, from flood waters that would otherwise have been cast upon them.

By incorporating on-site detention facilities into the design and construction of the surface drainage system of this subdivision, about $370,000 in construction cost was saved. This amounts to 160 percent of the actual construction expenditures.

APPLICATIONS

Key engineering personnel of municipalities, sanitary districts, urban drainage and flood control districts, and engineering design firms in the United States and Canada were surveyed in 1972. A total of 230 completed questionnaires were received from public agencies and 40 completed questionnaires were received from engineering firms.

Of the 230 questionnaires completed by public agencies, 99 reported that detention facilities exist in their jurisdictions, while 109 reported that they had none in their area. Twenty-two respondents did not answer this question.

Ownership of the facilities and the land was reported by 58 respondents to be by public agencies, while 66 jurisdictions reported private ownership of facilities, and 12 jurisdictions reported ownership by others. Of the 1,410 detention facilities reported, 29 percent were identified as parking lot facilities, 14 percent were in parks, 7 percent were on rooftops of buildings, 2 percent were on schoolgrounds, and 48 percent of the facilities were listed under the "other" category. Apparently, the respondents were using this category for ponds and basins located in open spaces of various developments other than parks or schools. A tabulation of the responses is shown in Table 20, Number of Detention Facilities.

One public agency reported that about 200 on-site detention facilities had been built in its jurisdiction. Areas which promoted

TABLE 20
NUMBER OF DETENTION FACILITIES

Type of Detention Facility	Number
Rooftop	100
Parking Lot	400
Park	200
Schoolground	30
Other	680
Total	1,410

Source: Survey of 230 Public Agencies

detention ponds had many such facilities; and areas like Denver, Chicago and Montgomery County, Maryland, each reported over 100 facilities in their respective jurisdictions. Other areas with many detention ponds include Jefferson County, Kentucky (102), Buffalo, New York (200), and Suffolk County, New York (101). These six areas had a total of about 710 installations. The remaining 700 installations were reported by 93 other jurisdictions.

Engineering firms across the country were also surveyed. Of the 40 replies, it was found that 34 firms had designed a total of 602 stormwater detention facilities. One firm had designed 120, of which 70 were on parking lots. Parking lots were the most commonly used installation accounting for 184 detention facilities. Table 21, Design of Detention Facilities, gives a tabulation of the number of various types of facilities reported.

TABLE 21
DESIGN OF DETENTION FACILITIES

Type of Detention Facility	Number
Rooftop	95
Parking Lot	184
Ponds in Parks and Playfields	120
Ponds on Schoolgrounds	18
Ponds in Residential Areas	146
Underground Tanks	20
Other	18
Total	601

Source: Survey of 40 Engineering Firms

Geographically, most of the detention facilities were located in areas that encourage the use of detention facilities for surface drainage. Five firms located near Denver, Colorado, accounted for the design of 238 facilities, and five engineering firms in the Chicago, Illinois, area accounted for 207 projects. In both instances the use of stormwater detention facilities is either required or strongly recommended by local jurisdictions.

A total of 556 of the 601 on-site stormwater detention facilities were built in areas where such facilities were required, or encouraged, by local public agencies. Only 45 of the facilities were constructed in areas where they were not encouraged.

On-site detention facilities are in widespread use, although their use is more prevalent in areas where the concept is recommended or required. It was found that on-site detention ponding is practiced in many urban areas primarily for the purpose of reducing the frequency and extent of local flooding. Approximately 1,400 such facilities were reported by local public agencies to be in use or in the planning stage. Detention ponding in open spaces is the most prevalent practice. The use of parking lots was reported in 400 instances. Detention of runoff on rooftops and in park areas is implemented less frequently. Although public agencies often own the land and facility, seldom do they bear the total cost of providing the facility.

Relatively few jurisdictions require detention storage or other means of limiting stormwater runoff rates, except by the disconnection of roof drains from sanitary sewers. The greatest advantage besides reducing flooding and pollution problems, was said to be improvement in the aesthetics of urban areas.

The biggest environmental problems foreseen were mosquito breeding, algal growth and displeasing appearances of empty detention ponds. Maintenance and operation was clearly identified as a major problem of concern to public agencies.

CHAPTER 5
PREVENTING AND REDUCING FLOODING

By reducing peak stormwater runoff flows to the level that the sewer systems can handle, on-site detention of stormwater runoff can reduce flooding caused by sewer surcharging and can also reduce the frequency of pollution caused by combined sewer overflows. If practiced widely, it can also protect against major drainage system (river) flooding by detaining the water until capacity exists for the system to handle the runoff. These are the goals of the systems described in this section.

On-site stormwater detention programs are emphasized in at least two areas of the United States where it is either promoted, or required, under the leadership of regional authorities.

In the Denver region, the Urban Drainage and Flood Control District has not adopted any legal requirements for on-site detention, but its guidance has promoted the adoption of on-site detention requirements by communities located within its jurisdiction.

The Metropolitan Sanitary District of Greater Chicago, in 1971, adopted requirements for on-site detention of stormwater. The requirements were established by amending the District's sewer permit ordinance. The requirement for on-site detention by the District required all municipalities within its jurisdiction (Cook County) to adopt the concept, and has influenced neighboring jurisdictions to adopt similar requirements and techniques in their local stormwater management programs.

Skyline Urban Renewal Project
Denver, Colorado

General Requirements and Criteria – In the planning of its 80-acre Skyline Urban Renewal Project in downtown Denver, the Denver Urban Renewal Authority (DURA) took action in 1970 to require private developers to temporarily store (on-site) stormwaters directly falling on their properties. The purpose was to detain the local runoff to reduce the surcharging of the storm drainage system in the downtown area until such time as tributary areas had been drained. A land-use map of the Skyline Urban Renewal Project area is shown in Figure 23, Skyline Urban Renewal Project. To implement this requirement, DURA published and distributed to potential redevelopers a set of criteria outlining requirements for on-site detention of stormwater. The criteria includes requirements and suggested means for detaining rainfall in both new construction and in renovation of buildings. In general, three types of on-site detention facilities are included: rooftop ponding, ponding in plazas, and ponding in open spaces and grassed areas.

Flat roofs obviously provide a storage area that does not conflict with vehicle traffic and pedestrians. The associated costs and inconvenience are minimal because:

a. roofs in the Denver area are presently designed for a snow load equivalent to the weight of, approximately, six inches of water, and
b. horizontal roofs need to be constructed to be water-tight to prevent leaks from ponding that often occurs unintentionally during rainstorms.

A detention ring for installation around a standard roof drain has been designed for rooftop ponding. The hydraulic characteristics of the ring limit the maximum flow rate tributary to the storm sewer system. The detention ring can be designed for such variable factors as roof slope, roof area, and maximum rainfall intensity and duration. It is safe for use in large storms with high intensities of rainfall, such as the 100-year rain, because the water can flow over the ring into the roof drain, thus preventing any unsafe structural load.

Elevated plazas and parking lots can be designed so that the runoff contribution is limited to a pre-determined rate, with storage being provided by placing surface drainage inlets, with orifice regulators or other flow restricting devices, in depressions. Pedestrian inconvenience can be minimized by careful selection of walkway and drain locations. The

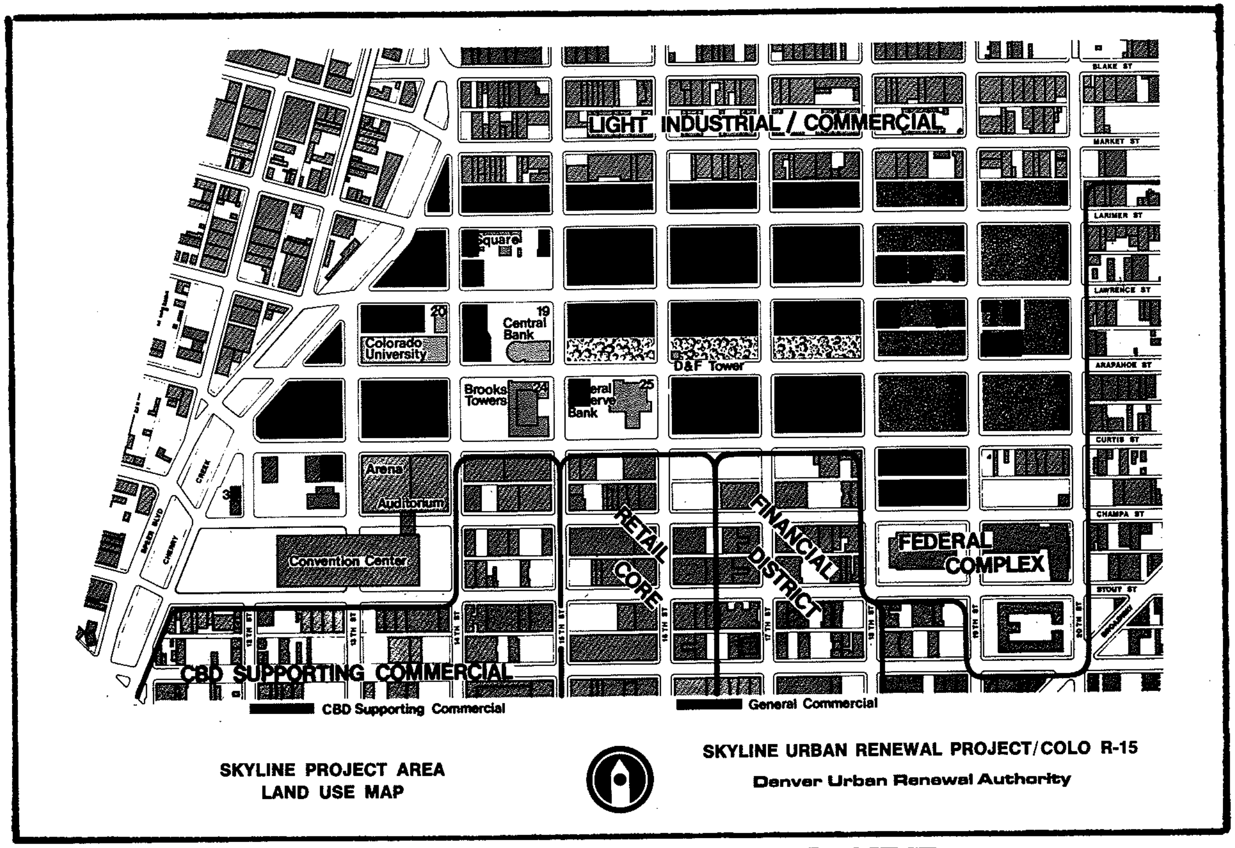


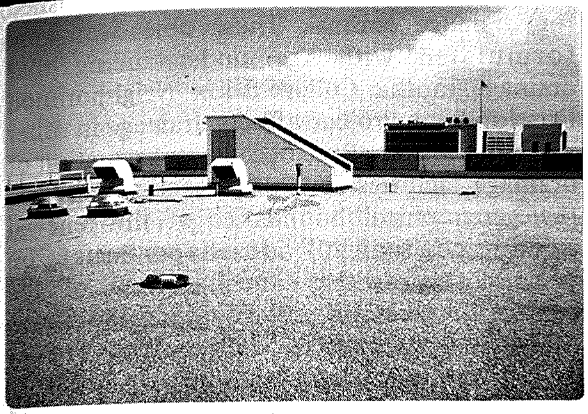
FIGURE 23 SKYLINE URBAN RENEWAL PROJECT

depth of storage required will depend on the total area being drained, the design storm characteristics, and the selected outflow rate.

Drains on roofs of buildings and in plaza areas are designed in accordance with the Denver Building Code; however, the peak drainage rate is limited to comply with the Denver Urban Renewal Authority site drainage criteria. These criteria limit the runoff from roofs of all buildings to 0.5 inch per hour, when the stored rainfall is discharged to the storm sewer. This can be related to gallons per minute or cubic feet per second on a direct basis. The inlet to the drain leaders are to be designed to limit ponding on the roof during a 100-year rain to three inches of depth at the discharge point, with the maximum discharge of 0.5 inch per hour. Actually, the water depth at the inlet to the drain may exceed three inches due to the slope of a relatively flat roof toward the drain. Figure 24, Rooftop Detention, contains photographs of ponding rings installed on the roof of the new Prudential Office Building in Denver.

Elevated plazas may be designed to drain at a rate of one inch per hour for the total plaza area. It is preferred that elevated plazas drain directly to the storm sewer. No drainage from private areas, including roofs, plazas, etc., are permitted to cross over public rights-of-way. If there are special problems related to a particular development in meeting the criteria, reasonable modifications in requirements are approved provided that compensatory storage is provided elsewhere on the site.

The criteria pertain to two distinct types of ponding based on the area and the use. One type is that of elevated plazas, pedestrian malls, arcades and other extended flat areas in which a minor amount of ponding at designed locations would not cause serious inconvenience. For these areas, the design has assumed a rate of runoff of one inch per hour, which should result in a maximum water



a. ponding rings installed around roof drain conductor heads, Denver

b. close-up of rainfall ponding ring and conductor head

FIGURE 24 ROOFTOP DETENTION

depth of 0.75 inch during a 10-year return-frequency rainfall.

The other category includes roofs of buildings, structures, parking lots, and other areas where a greater depth of ponding can be tolerated. For these areas, the design has assumed a rate of runoff of only 0.5 inch per hour. During the ten-year return-frequency rainfall, this would result in a ponding depth of approximately one inch. During a 100-year rainfall event, the ponding depth would not exceed three inches.

The assumed maximum rates of runoff (specified in the criteria), in inches per hour, are given in Table 22, Maximum Release Rates, in units which may be more familiar to architects and others. Also shown is the maximum accumulated depth of ponding that could be expected to occur for each of the two runoff rates specified.

To incorporate the above detention criteria in rooftop drainage systems, it is necessary to limit the flow rate of the rainfall into the downspouts or storm sewer inlets. This can be accomplished on rooftops by installing a weir-type device at the drain conductor head. A sketch of a roof drain detention ring is shown in Figure 1. This device also provides for overflow at the 3 or 4-inch level, depending upon the height of the device. On paved surfaces in plazas, orifice plates can be installed below the grating or perforated plates covering storm sewer inlets. These detention devices delay the storm runoff in the project until the peak has passed; yet, they allow for a more economical and realistic design of the storm sewer system throughout the entire project.

The Denver Urban Renewal Authority requirements for the design of roof drains differ from those set forth in the plumbing section of the building code of the City and County of Denver in that detention of rainfall is not required by the latter code. The requirements for the design of the downspouts are the same in both cases. This

TABLE 22

MAXIMUM RELEASE RATES – RUNOFF AND PONDING DEPTH

Inches/hour	cfs/acre	cfs/1,000 sqft	gpm/100 sqft	Accumulated Depth for 10-Yr Rainfall
1	1	0.023	1.04	3/4 inch
1/2	0.5	0.012	0.52	1 inch

assures that the discharge capacities of rain leaders designed under the DURA criteria will be more than sufficient to discharge the peak flows of the water stored on rooftops as well as any water that may overflow the roof drain detention devices.

Construction in the Skyline region is progressing rapidly. Of the eleven major building developments initiated, all but one was scheduled to be completed in 1973. The rooftops and plaza areas of these buildings are used for detention storage in accordance with the criteria described. In another area of Skyline Project, a park, three blocks long and one-half block wide, was constructed. Its surface was depressed below adjacent street elevations and designed to detain rain water falling directly on the park property.

Summary: The entire Skyline Urban Renewal Project provides for on-site detention of rainfall in new construction and in the renovation of old buildings as well. Being almost a city within a city, the Skyline Project is an excellent example of successful application of the concept and techniques of on-site detention of stormwater to help solve existing problems of stormwater management in the central business district of a large urban area. Furthermore, the obvious success and the relative ease with which detention of rainfall was incorporated into the renewal developments is concrete evidence that it is feasible to secure cooperation from land developers and builders, even in central business district projects, in providing for stormwater drainage.

College View Neighborhood Development Project – Denver

Part of the renewal work needed for the College View rehabilitation area was for improvement of the stormwater drainage system. Located in southwest Denver, this predominately residential area of 579 acres has three drainage ditches. The program for controlling stormwater includes stormwater detention, flood plain zoning, and multiple use of drainage areas. Construction of the stormwater drainage system, recreational facilities and other improvements is now underway.

A set of major objectives was established for drainage control. These objectives were formulated with the understanding that drainage in the College View Neighborhood Development Project affects drainage in other parts of Denver. But, because construction of drainage facilities for this project is limited to the geographical boundaries of the renewal area, control of drainage must be accomplished within the confines of the project area. Major objectives of the storm drainage works in the College View Project include the following:

1. design discharges should not exceed previous (that is, pre-redevelopment) discharge rates for rains of the same frequency;
2. efforts should be made to keep discharge rates at historic levels, that is, pre-urban levels;
3. multi-means and multi-purpose concepts, including park development of drainage ditches, should be used to increase benefits and reduce costs;
4. on-site ponding should be used to both reduce the peak flow requirements of the system and to improve water quality;
5. on-stream ponding should also be used as much as possible;
6. a 100-year rainfall frequency should be used for the drainage system design, if feasible – otherwise provision should be made to protect property against the runoff flows of a 100-year rainfall event by means of flood-proofing;
7. where base flows are adequate, permanent pools should be developed for park and recreational purposes; and
8. all drainage ditches are to be flood plain zoned.

Objective number four indicates the desirability of utilizing on-site storage. A 1971 study for development of one of the drainage ditches in the project area, the West Evans ditch, called the use of ponding relatively new; and it was concluded that this method could significantly improve runoff characteristics for urban basins. The report recognized five types of ponding:

1. rooftop ponding,
2. plaza and parking lot ponding,
3. open space and grassland area ponding,
4. recreational-field ponding, and
5. other types of ponding as described in the Denver Regional Council of Government's publication entitled *Urban Storm Drainage Criteria Manual.*

The various methods of stormwater detention were viewed as being practical if designed properly. Landscaping of lawns and other open spaces to include relatively small depressions in the ground surface to retard the runoff was recommended as was the use of ponds and basins in recreational areas.

Evaluations of planned future land use were made to determine the expected runoff and the amount of ponding necessary for surface drainage control. Four land use categories were described and restrictions were placed on the amount of development of land area in each land-use category. For example, in commercial developments an equal amount of area must be provided outside the buildings as the floor area inside the buildings. This means that as much as 50 percent of the developed land area can be used for ponding.

The design of the West Evans Ditch calls for the use of ponding wherever practical, except for streets and land already developed. Due to limited space, detention storage in the flood plain is kept to a minimum. A "wet" detention reservoir is included at the downstream edge of the project. This permanent pond of varying water depth is designed to reduce discharge rates to, or below, pre-redevelopment discharge rates.

Other ditches in the Project area are being developed with multiple-use features, including recreation, such as bicycle trails, playgrounds, and picnic grounds.

Summary. The College View Project is evidence of the economic feasibility and practicality of improving stormwater drainage systems in connection with renewal of urban neighborhoods. In this renewal project, initial planning called for improving the area aesthetics and recreational use of large portions of the land designated for stormwater control.

The project described above is an excellent example for study by urban planners and designers, particularly those engaged in urban renewal activities.

Denver's East Harvard Gulch Project

The East Harvard Gulch Project for flood and erosion control in southeastern Denver solved the problems of flooding and erosion with methods that are aesthetically pleasing and compatible with area land use. The drainage basin had long been a problem for the neighborhood and the entire city. Urbanization of the basin increased stormwater runoff to such an extent that rainfalls of 1-year frequency caused flooding. Steep grades contributed to high runoff flow rates and channel erosion.

Major encroachment on the channel's flood plain had occurred prior to the enactment of city zoning laws to protect the flood plain. Infringement on the channel was so intensive that the defined channel ended about 4,000 feet from the South Platte River. To reach the River, flood waters have regularly flowed down a major business street.

With help from neighborhood citizen groups, a $2.3 million general obligation bond issue was passed in a city-wide election and financed by a city-wide sales tax.

Channel improvements were proposed to extend from the South Platte River to Colorado Boulevard, a distance of three miles, through a heavily urbanized area. Thorough hydrologic studies and efficient engineering designs were required. Careful concern for aesthetics and compatibility with local land-use were recognized as important considerations for obtaining the greatest benefits.

Directives were given to the project engineer that the benefits of the project should be the maximum possible with the limited funds available. The synthetic unit hydrograph method was used to determine the design flood for the project. Hydrologic studies were undertaken for recurrence intervals of 2.5, 5, 10, 25, 50, and 100 years and the final choice was based on the cost estimates of preliminary designs. The 25-year flood was subsequently chosen as the design basis for the project. However, freeboard clearance has since allowed larger floods to be passed safely.

Five basic criteria for the project were:

1. The last 4,000 feet of the channel, which had been intensely encroached upon, had to be built underground to prevent interference with existing commercial activities and to avoid placing limitations on future city planning.
2. Project cost could not exceed the $2.3 million bond issue.
3. New construction on 20 acres of state-owned property which borders the channel should result in an aesthetically pleasing park area and open space for the citizens.
4. Channel construction must be on city right-of-way whenever possible to avoid the added cost and problems of land and building acquisition.
5. All new construction must be designed not only to reduce the flood hazard and erosion problems but also to improve neighborhood aesthetics as a means of encouraging new well-planned buildings and landscaping.

As a result of these criteria, the final design was prepared with the following features:

1. The 4,000-foot underground conduit was designed as a 12-foot diameter concrete culvert. Alternate designs included an equivalent cast-in-place concrete box culvert and a prestressed concrete box culvert. Bidding on all three alternatives resulted in the choice of the cast-in-place concrete box culvert. The design called for the conduit to have open channel flow at all flow rates. The conduit has a progressively steeper slope as it approaches the river, following the natural terrain and providing velocity acceleration. Air breathers are provided approximately every 330 feet. These increase conduit efficiency by allowing rapid expulsion of air during a period of increasing flows and admission of air during times of decreasing flow. Each air breather can also release water to the street above should the conduit become blocked or surcharged. The main safety control on the culvert capacity limitation was a specially designed inlet.

A model of the hydraulics of the inlet was prepared and studied at Colorado State University. Inflows were to be limited to 2,100 cfs, and maximum velocity in the conduit was to be 21 fps.

2. An inlet to the conduit was designed to accelerate as well as limit the flows into the conduit. Any excess flow would be routed to the river along a paved street.

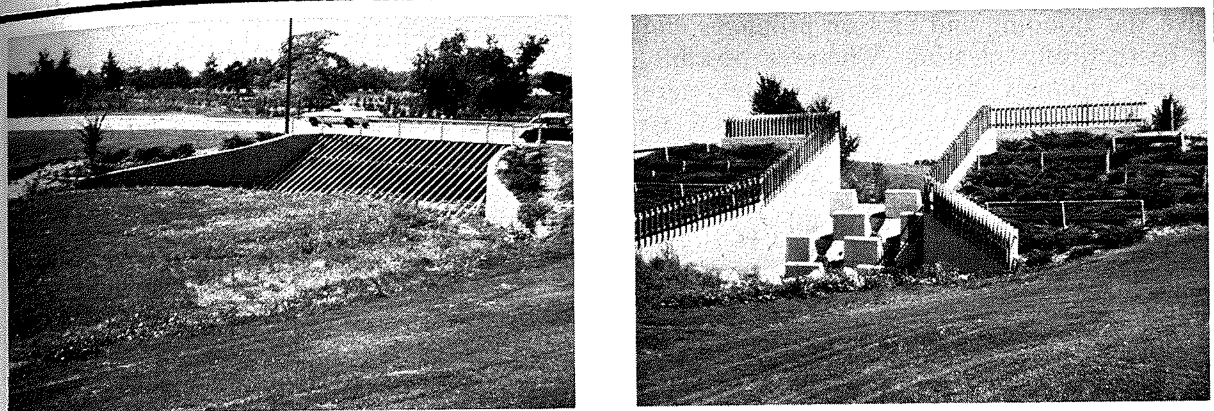
3. A detention basin was installed upstream from this inlet on the state-owned property. The detention basin was designed to handle high water flows that would spill over a low side-channel spillway into the basin – to be released when water levels recede. Figure 25, East Harvard Gulch Project, shows the energy dissipator and inlet to the box culvert.

The detention pond was designed to reduce peak flows from 1,970 cfs to 1,600 cfs by storing about 12 acre-feet of water during flood stages. Besides serving for stormwater detention, a permanent pond was constructed for recreational purposes and to enhance area aesthetics.

4. Upstream from the detention basin, a concrete spillway was built with an energy dissipator. This reduced the energy of the approaching runoff flow and the slope of the downstream channel bed, allowing it to be planted in grass, with maximum flow rates of 7.5 fps. This was done to reduce erosion of this channel and to provide a scenic area. Figure 25 (b) shows the energy dissipator.

5. Upstream from the spillway, a 0.5-mile long high-velocity concrete channel was constructed. A narrow channel was needed because of the limited right-of-way owned by the city.

6. A slow-flow grassed channel was designed for the last portion of the channel improvement, upstream of the high-velocity concrete channel. A grassed channel was chosen because it fit in better with



a. inlet to box culvert

b. energy dissipator

FIGURE 25 EAST HARVARD GULCH PROJECT

neighborhood aesthetics, was less expensive, and the slow flow would increase the time of concentration of runoff flows and decrease downstream peak flow rates. This section would also provide channel storage, further reducing peak flows downstream.

7. All bridges (there are 21 bridges crossing the East Harvard Gulch) were designed to withstand the full dynamic force of high-velocity flows that may result from a blockage or a flood much larger than the design flow. This would cause local flooding instead of passing the flow downstream rapidly – which would cause a major flood in the more densely populated areas downstream. For the bridges constructed over the grass channels, freeboard was kept to a minimum, and on some bridges freeboard was eliminated altogether. In this region, the objective was to create local ponding of water behind the bridges during any storm larger than the design storm without losing the bridges.

Furthermore, all bridges were built with streamlined shapes to reduce the debris collection problem.

8. Collapsible trash racks are used at the entrance of both the enclosed conduit and at the high-flow concrete channel. They were designed to be collapsible to prevent unnecessary local flooding problems that would result from plugged racks.

Construction took place in three stages, progressing from the downstream end to the upstream end. This was done to insure that sufficient water-carrying capacity existed downstream prior to making upstream improvements which would produce increased flow rates. Extensive excavations were required. Cuts of 22 feet deep were made in streets for box culvert construction. Disposal of some of the 120,000 cubic yards of excess earth was accomplished by regrading the state-owned land and filling private lots along the construction route. The remainder was saved for future city projects. Broken concrete from other city projects was recycled to the project for underground emergency barriers to control erosion during unprecedented events. Construction was completed in 1967, in time for Denver's wettest year in history.

Summary: The East Harvard Gulch flood control project in southeastern Denver solved problems of flooding and soil erosion with a variety of experimental techniques. In 1969 the facility handled peak runoff flows of 2,000 cfs and functioned very well. The project was limited in funds provided by a bond issue, and limited by the constraints of intensive encroachment on flood plains. In some areas, land developments totally occupied the normal channel, causing the runoff flows to use the streets as channels.

It was decided that this project had to solve the flooding and erosion problems and be aesthetically pleasing. Wherever possible, grassed channels having small slopes were used. Baffled chutes were constructed to dissipate the high energy of the runoff flows produced by differences in elevation along the channel length. Detention storage of high flows was provided for on state-owned property in a park-like setting. Local ponding of flows above the 25-year design rainfall was encouraged by bridge construction with little or no freeboard above the water surface. Laboratory model studies were conducted to test the functioning of an enclosed conduit inlet in order to produce a design which would optimize the efficiency of the conduit.

Boulder, Colorado

The problems resulting from stormwater runoff in Boulder, Colorado are accentuated by the hilly terrain and the city's location in the foothills of the east slope of the Rocky Mountains. Because of this location and the terrain, stormwater runoff from both the mountains and the urban area can cause great damage due to both the high velocities and the large volumes of runoff flows. Boulder has adopted the use of on-site stormwater detention along with other means for managing runoff.

The City of Boulder recognizes two distinct parts of the drainage system. One is the major drainage system consisting of all natural drainage channels, paths and outfalls; the other is the secondary (collection) system which receives stormwater runoff from the minor storms and conducts as much of it as its capacity permits into the major system.

Design criteria were adopted by the city for the flood-handling characteristics of the two types of drainage systems. All components of the major system are to be designed to handle the 100-year rainfall event. The secondary system components are assigned design rainfall requirements according to land use and property value. In high-intensity use and high property valuation areas, a 10-year return period is used for the design rainfall. In single-family residential subdivisions, the 2-year rainfall is used; and in other areas within the city, a 5-year return period is specified.

The maximum allowable release rate of stormwater from temporary storage in detention facilities is computed by either of two methods. In one method, the pre-development runoff flow-rate is used as the maximum allowable rate. The Rational Formula is used to compute the permitted release rate. Values of C and i are obtained from standardized information provided by the city in the form of graphs and a table. The other method sets the limit on the allowable release rate based upon the percentage of various types of land use areas planned within the proposed development. Information concerning the determination of permitted release rates was given in Chapter 3.

Detailed design instructions are given by the city for computing detention storage volume requirements. Several techniques are available for providing on-site detention facilities. Of these, rooftop storage is considered one of the best alternatives where building design lends itself to this method. Other methods include detention in depressed areas in parking lots or landscaped areas, and collection of runoff in wet wells which are used to recharge the ground water table through release of the stormwater.

Examples of stormwater management facilities in Boulder are shown in Figure 26, Detention Facilities – Boulder, Colorado. Figure 26a shows a series of low check dams installed across a stream to control flow velocities of the mountain stream. Figure 26b illustrates the use of the open space of an apartment building complex for detention of stormwater. Storm sewer inlets with restricted capacities are installed in low spots in grassed areas and in parking lots.

Enforcement of the rules for stormwater detention is accomplished by means of subdivision regulations, building regulations, and a fee system.

In a new development that requires land subdivision, plat approval is contingent upon including facilities for on-site detention of stormwater. In a case where only a building permit is required, the developer must include on-site stormwater detention in the plans

a. check dams across a stream, through an urban area in Rocky Mountain foothills

b. storm sewer inlets in grass areas restrict inflow rates

FIGURE 26 DETENTION FACILITIES – BOULDER, COLORADO before a building permit is issued. In all cases, drainage design must be done by a registered engineer and plans are checked by the city hydraulics engineer.

Opposition to the requirement for detention storage came from architects who complained about the added design restriction – and from builders who would submit plans for detention storage facilities, but would not actually build these facilities. An educational program explaining the advantages of on-site stormwater detention overcame the objections of architects. Inspection of buildings prior to final construction approval resolved the problems with the builders.

An added method of securing compliance for the use of on-site detention is a fee system by which a service charge is levied monthly against every lot to pay for upgrading the public stormwater drainage facilities. The service charge is based on the flow rates of runoff from each lot draining into the system. Two factors used in computing the annual fee for a specific piece of real estate are the square feet of area and the computed coefficient of runoff. Boulder specifies a formula for calculating the fee as explained in Chapter 2. In many cases, it is beneficial to a landowner to reduce runoff to lower his service charge.

Boulder has adopted a flood plain zoning ordinance which forbids development of buildings and most other permanent structures within the limits of the flood plain of a 100-year rainfall event. Permitted in the flood plain areas are recreational facilities, wildlife preserves, agriculture, open pit mining, utility transmission lines of some types, and certain commercial and industrial uses such as material-loading facilities and railroad rights-of-way.

Summary. The initial results of Boulder's program to control stormwater runoff by means of on-site detention have been good. Flooding from rainfalls of the 2-year and 5-year frequency in problem areas of the older parts of the city have been greatly reduced or eliminated. Maintenance of nuisance areas after small rainfalls has also been reduced greatly.

Five basic steps followed in setting up Boulder's program to manage runoff are:

1. development of a set of criteria in the areas of policy, law and design;
2. development of a complete master plan for every drainage basin involved, giving the proper direction for the assignment of priorities;
3. adoption and enforcement of necessary ordinances to provide flood plain zoning, management, and flood insurance until the program is completed;
4. provision of a financing program to allow program implementations; and
5. provision for multi-purpose use of drainage areas for open space, green belts, detention storage of runoff, and recreation – including bike paths, horse riding trails and play areas.

Metropolitan Sanitary District of Greater Chicago

Because of the flat topography of Metropolitan Chicago, the area has poor natural drainage. The rapid pace of urban development has compounded existing flooding problems and caused significant increases in flow rates and volumes of stormwater runoff which must be handled by the natural waterways.

Concern for flood control in the metropolitan Chicago area began in the early 1900's when the flow of the Chicago River and the Calumet River were reversed away from Lake Michigan. Continued concern for flood control resulted in the request by the Metropolitan Sanitary District of Greater Chicago that builders and developers voluntarily provide temporary storage of rainfall on parking lots, roofs and open spaces. This program, begun in about 1967, fell far short of controlling the added runoff resulting from increased urbanization. More stringent requirements were obviously needed and the MSD, which has jurisdiction over sewer systems in all of Cook County, initiated a program aimed at developing effective management of runoff.

Following the adoption of a resolution passed by the Board of Trustees of the MSD, an amendment to the District's Sewer Permit Ordinance was adopted to require provision of stormwater detention facilities as a prerequisite to obtaining a sewer connection permit. This requirement, which applies to new construction in unsewered and separately-sewered areas within the District's jurisdiction, became effective January 1, 1972. The action was based upon the fact that there would be further aggravation of flooding problems and creation of new flooding problems if steps were not taken to provide for additional stormwater detention in new land developments.

Basically, the resolution adopted by the district was a "policy statement for flood control." It contained a request that the Governor of Illinois direct the appropriate State department to: (1) establish a flood control program for the state based upon the principle of detaining stormwater runoff at or near its source; (2) regulate and control stormwater flows that pass from one county to another by establishing maximum flows at county lines; and (3) regulate and control stormwater runoff from all improvements in the drainage basin that are ahorized (including federal, state and local road improvements) through the issuance of permits by the State Department of Public Works and Buildings, by requiring that permittees construct and maintain storm detention facilities capable of storing runoff from the storm of record.

The amendment to the Sewer Permit Ordinance is not an attempt to solve the flood problem in total. Actions under the amendment must be coordinated with other programs – such as better management of floodplain areas, construction of detention reservoirs to replace some of the lost storage potential, and provision of storage for the runoff issuing from existing developments. The District is now constructing reservoirs to help alleviate flooding caused by existing developments.

The District has also undertaken a major planning effort in conjunction with the U.S. Soil Conservation Service. This includes the preparation of detailed plans for implementation of flood control projects throughout the Chicago Metropolitan Area. Neighboring counties and states are being included in this planning work.

Prior to adoption of the amendment to the Sewer Permit Ordinance, a subcommittee of a specially-appointed Blue Ribbon Committee studied the proposed action. In addition to recommending adoption of the amendment, the Subcommittee urged the establishment of a Flood Control Coordinating Committee which would act to set responsibility, budgets and policy for flood control improvements on a region-wide basis. In addition, the Subcommittee recommended the establishment of Basin Steering Committees to develop the planning of flood control facilities within the respective drainage basins.

The essence of the findings of the Subcommittee was that the natural waterways in the Chicago area are very restricted in their capacities to discharge water and that their carrying capacity for the average annual flood is approximately 0.022 cfs/acre of tributary drainage area. Based upon this capacity of the natural waterways, the District staff prepared the details of the amendment.

Computations are based upon the Rational Formula for determining the two critical factors in providing detention storage; namely, (1) the "release rate" that is allowed for off-site discharges, and (2) the "volume of on-site detention storage" to be provided.

The maximum release rate is the equivalent of the runoff from a 3-year return frequency storm occurring on an undeveloped site having a runoff coefficient of 0.15 for use in the Rational Formula. The rainfall frequency rain occurring on an undeveloped National Weather Service Technical Bulletin No. 40. The time of concentration guidelines were prepared by the staff of the District. These, generally, conform to the standards of the U.S. Army Corps of Engineers.

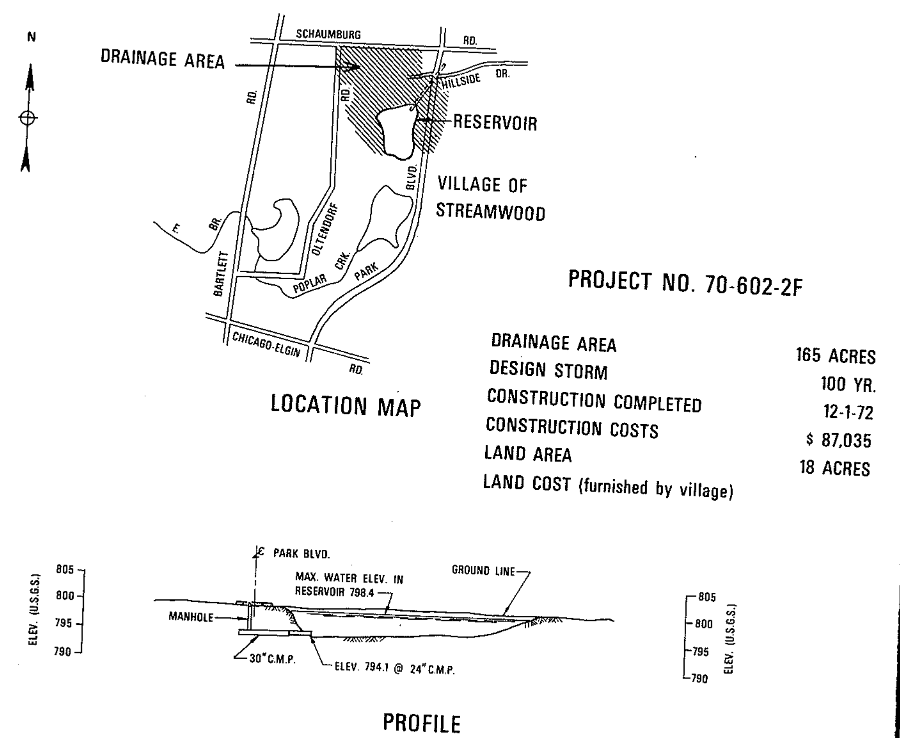
Detention storage volume requirements are calculated based upon the runoff from the 100-year design rainfall on the "fully-developed" site, diminished by the volume of runoff computed using the permitted release rate. A formula for calculating the required "live detention storage" is included in the amendment.

The amendment provides an exclusion when dealing with small parcels of land – under five acres for commercial developments, under 10 acres for residential, and residential development between five and 10 acres where the impervious area is below 60 percent of the total area of the site.

An information pamphlet has been developed for use by architects, engineers, etc., to meet the requirements of the ordinance. This information is reproduced in this report in Appendix D.

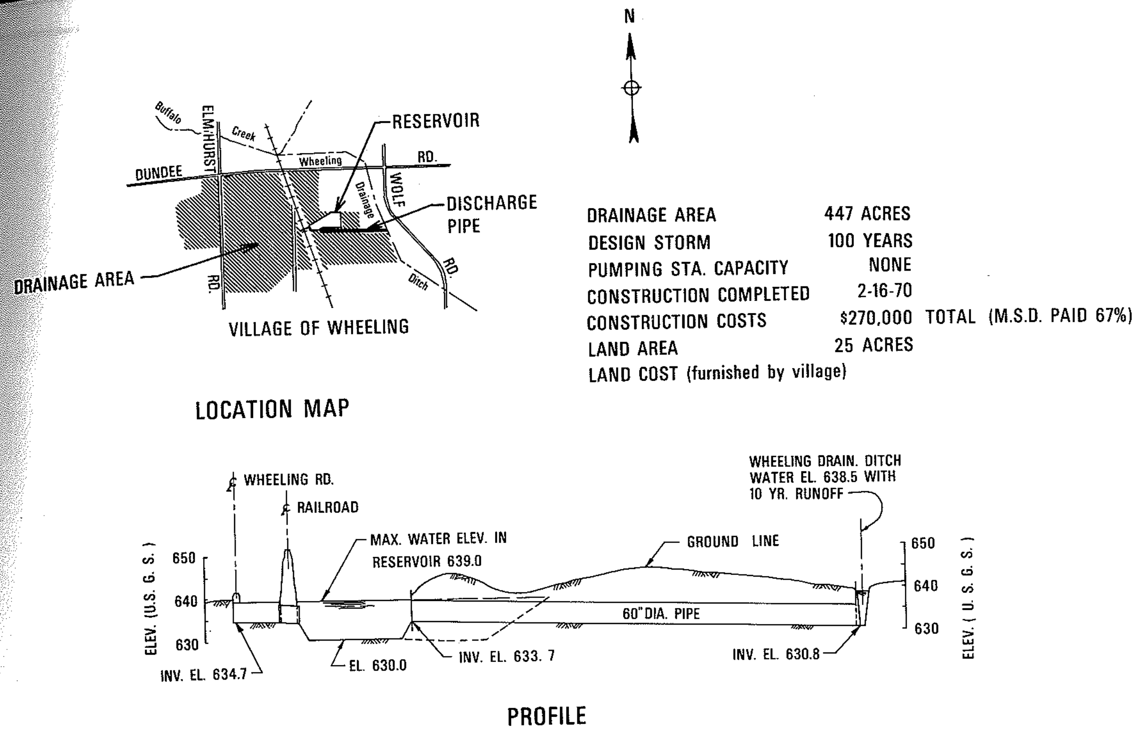
In addition to requiring the construction of on-site detention facilities for new developments, the MSD has also constructed or financed large detention reservoirs to handle the runoff from existing problem areas. Examples of such facilities are shown in Figure 27, Detention Facilities, Metropolitan Sanitary District of Greater Chicago. The standard event used for design is the 100-year rainfall. The MSD usually financed construction costs, although the land was most often furnished by the local government.

Melvina Ditch Detention Reservoir. An example of a large-scale municipal multi-purpose stormwater detention facility is the Melvina Ditch Detention Reservoir (Figure 27f) constructed by the MSD at a cost of $892,000. This project is unique not only in terms of its size and multi-purpose nature but because it has a pumping station rather than gravity outflow from the reservoir. The basin, which is 21 feet deep, covers 11.5 acres and has a capacity of 165 acre-feet of storage. It serves a four-square mile drainage agea, principally residential, and was designed to accommodate a 10-year rainfall event. Actually, it is the 100 cfs capacity of the downstream ditch which limits the flood protection potential of the reservoir. Planned improvements of this ditch and construction

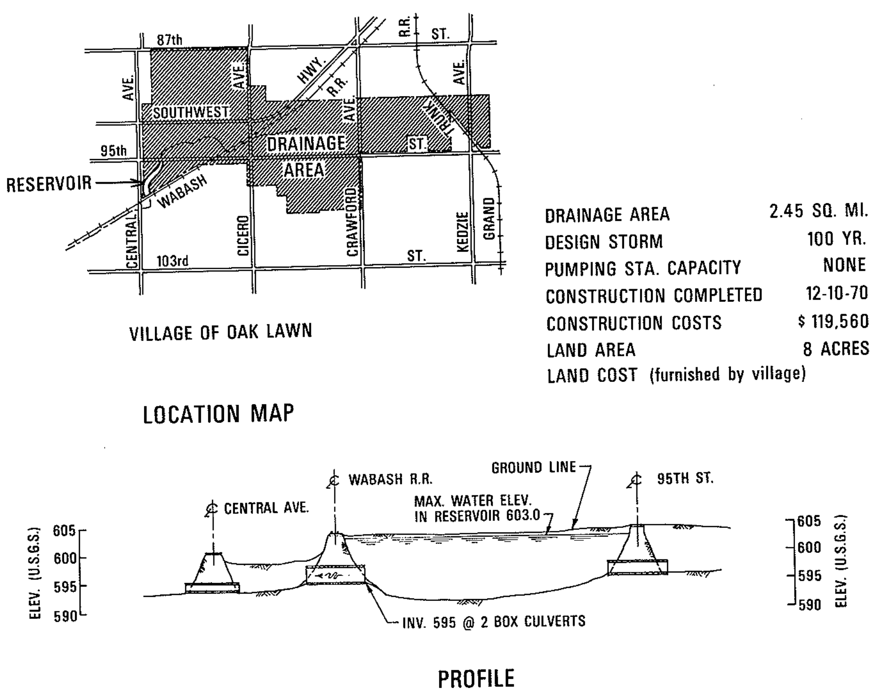


a. Hillside Park retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO



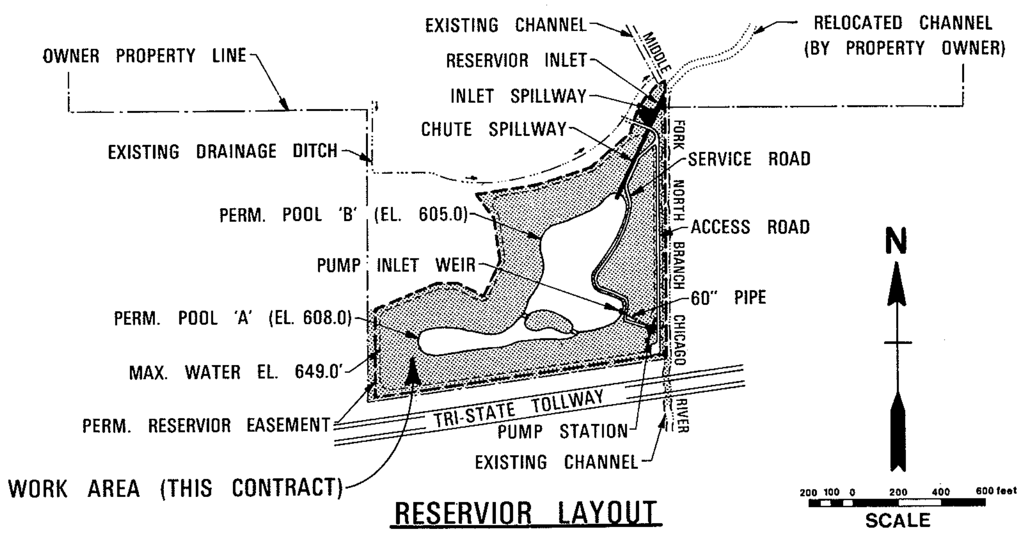
b. Heritage Park West retention reservoir



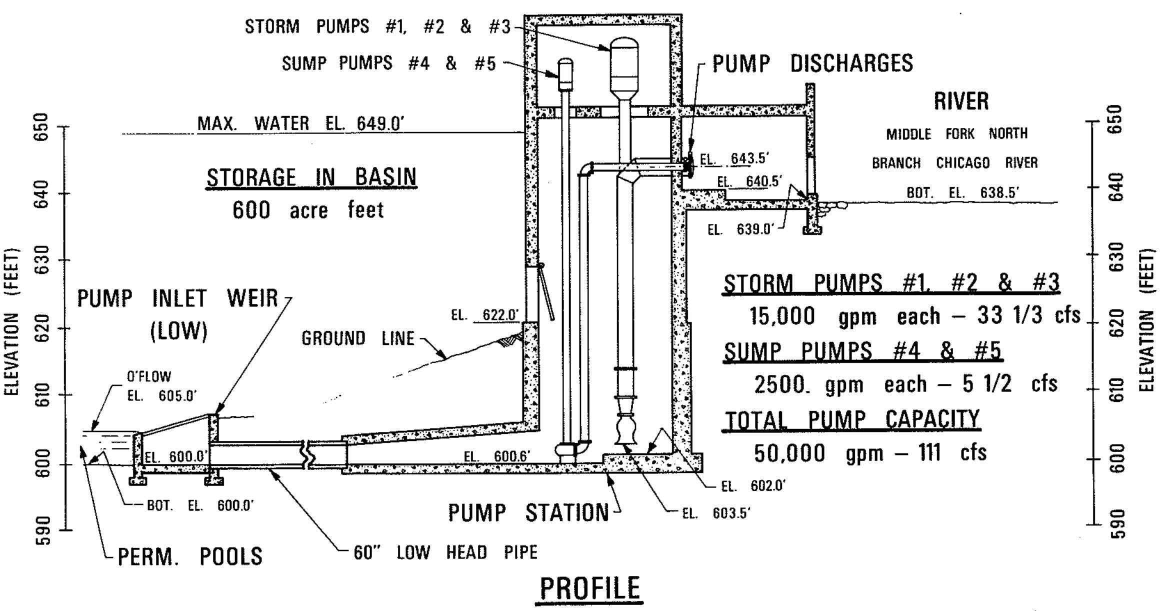
c. Oak Lawn retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

DRAINAGE AREA	20.7 SQ. MILES
DESIGN STORM	100 YEARS
PUMPING STA. CAPACITY	111.0 C.F.S.
CONSTRUCTION COMPLETED	11-1-74
CONSTRUCTION COSTS	$2,900,000
LAND AREA	22 ACRES
LAND COST	(FURNISHED BY OWNER)



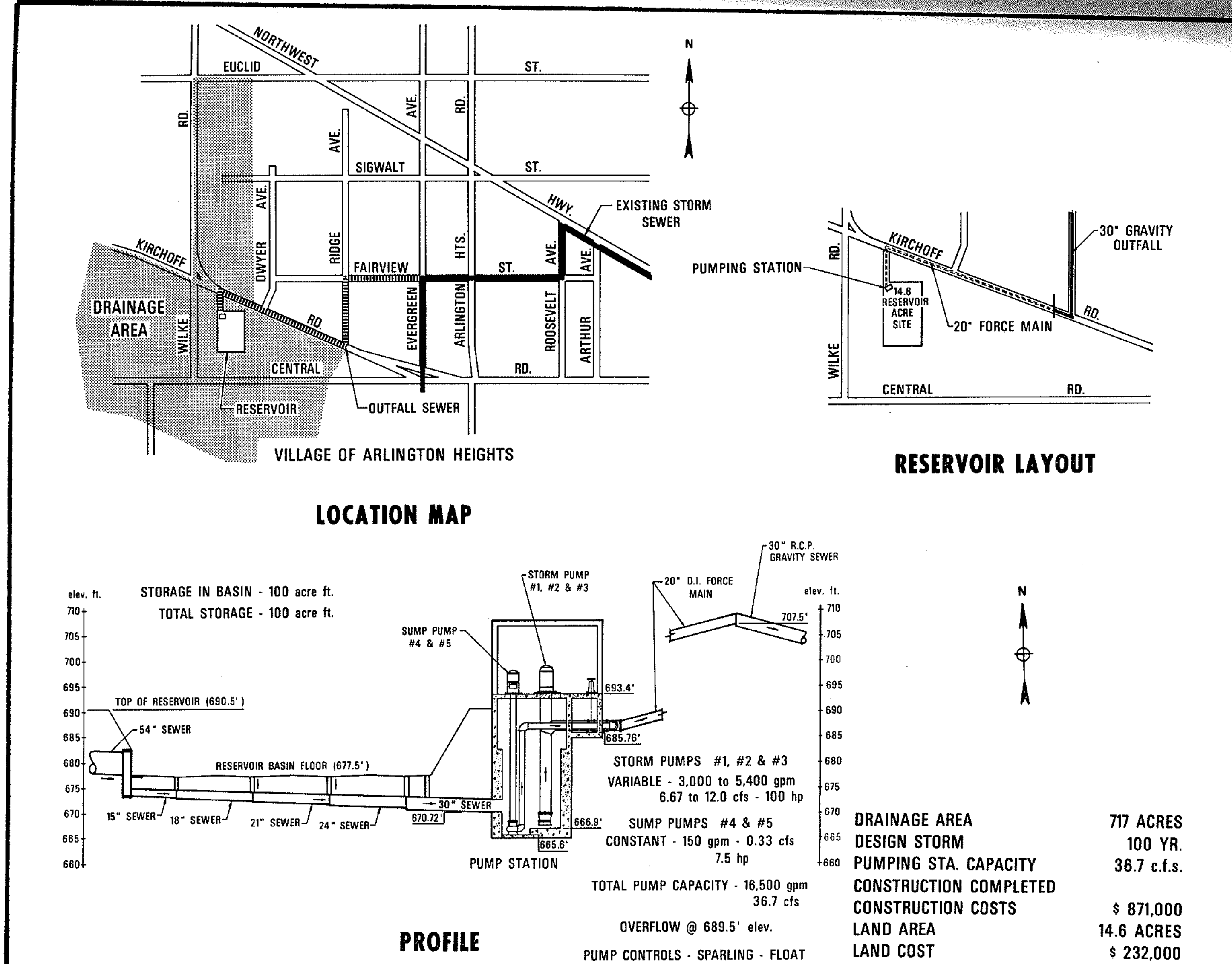
RESERVIOR LAYOUT



PROFILE

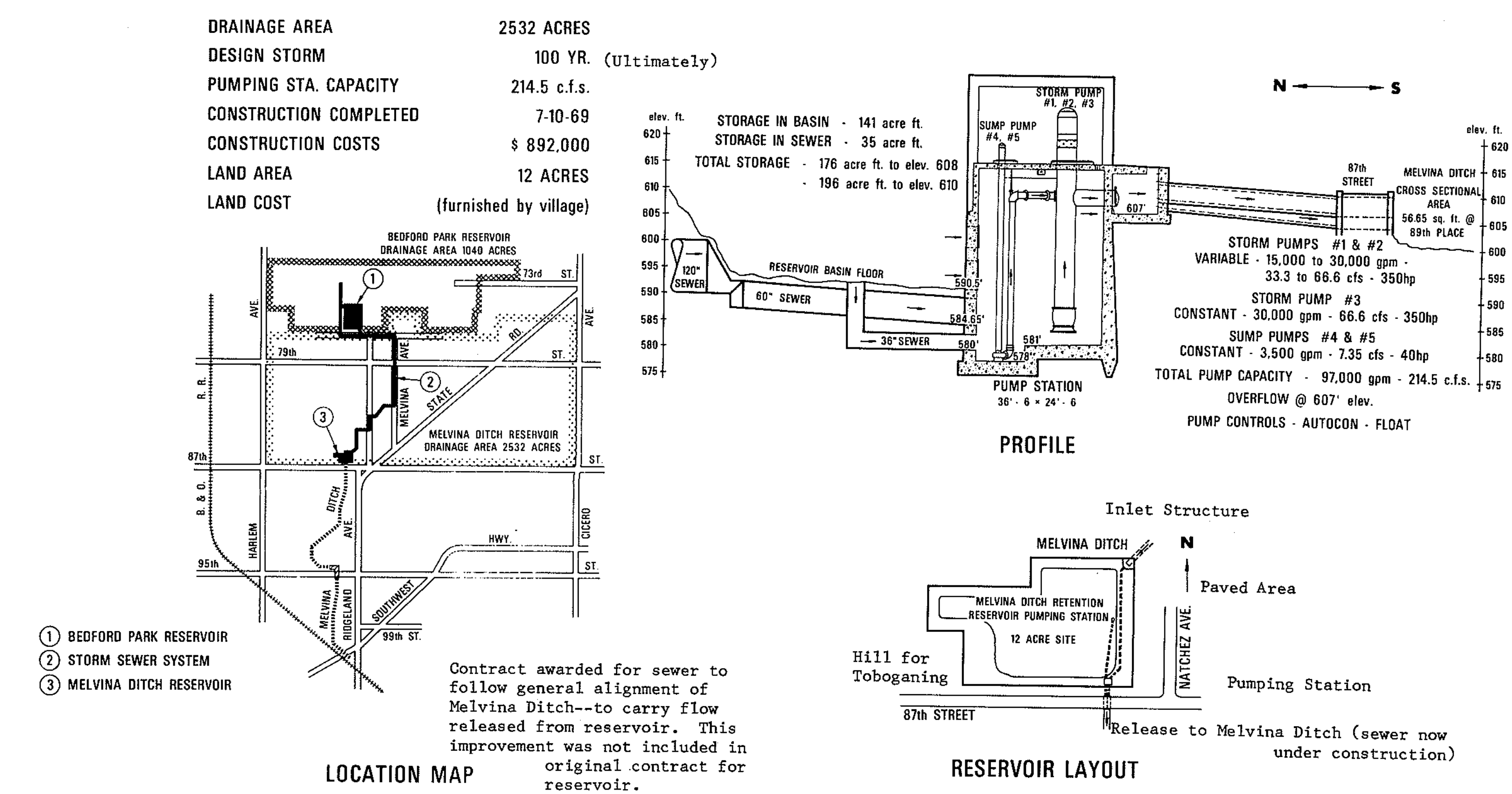
d. Middle Fork North Branch of the Chicago River reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO



e. Wilke-Kirchoff retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO



f. Melvina Ditch retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

of an additional reservoir upstream will enable this system to accommodate the runoff from a 100-year rainfall.

The basin was dug out of a clay soil which provides a tight seal. The bottom is grass, and the grassed sides with 4:1 slopes are enclosed with an 8-foot chain-link fence. The pumping station, located at one corner of the basin, contains three 66 cfs pumps and two 7.5 cfs low-flow pumps. These pumps could empty the full basin in 12 hours; however, because of downstream flow limitations, a period of 24 hours is currently required. After most rains, the basin is pumped dry in four to six hours.

Storm sewers draining the tributary area carry the runoff into the basin through a concrete inlet structure located at a corner of the basin, remote from the pumping station. Upon being discharged from the inlet into a sloping concrete chute, the flow is directed to a 100 x 200-ft concrete-paved area installed to prevent erosion of the basin bottom. At low flow, the runoff drops through a grate in the inlet structure and is guided to the pumping station through a 60-inch diameter underground pipe. This allows low flows to by-pass the basin, leaving it dry during low-flow periods. This enhances the multi-purpose use of the facility.

A reverse-crown concrete roadway, located in the bottom of the basin, extends from the basin inlet structure to the intake of the pumping station. This serves as a roadway for maintenance trucks and as an erosion prevention channel for runoff inflows that exceed the low-flow capacity of the underground pipeline. When the basin begins to fill, the paved areas become completely submerged; and, with further increase in water depth in the basin, the inlet structure is also submerged.

The detention basin was designed to serve as a recreation facility in addition to its primary function of reducing local flooding. Steps were constructed down the basin side slope for access to the basin bottom. Winter activities include tobogganing and skiing on a large earth mound constructed in one corner of the basin, using excavated materials. The concrete-paved area in the basin is flooded during winter months to serve as an ice-skating rink. During summer months, it is used for volleyball, basketball and general play. All recreational activities are supervised by the South Stickney Township Park District under an agreement between the Park District and Sanitary District for use of the property for recreational programs.

The reservoir was built as part of a cooperatively-financed general drainage improvement in the area. When completed, the improvement will consist of: (1) storm sewers upstream of the reservoir provided by the South Stickney Township Road District at a cost of \$4.5 million; (2) the Melvina Detention Reservoir and downstream channel modifications provided by the Sanitary District at a cost of \$1.9 million; and (3) downstream channel modifications provided by the Village of Oak Lawn, at a cost of \$500,000. Without these improvements, programs for street paving with curb and gutter, elimination of roadside ditches, and general upgrading of neighborhood conditions would have been impossible.

Since the completion of the Melvina Detention Reservoir no flood damage has been reported downstream or upstream of the facility. Recently, this basin took runoff from a 10-year rainfall event lasting for six hours, with the pumps inoperable. There was no downstream damage. It is estimated that this detention basin cost about one million dollars less than it would have cost to construct large storm sewers to an adequate outlet located about two miles downstream.

Analysis of Program Effectiveness. An analysis of the effectiveness of the MSD program was made in July, 1972, by the Sanitary District staff. Prior to January 1, 1972, the date that the amendment to the Sewer Permit Ordinance became effective, it was estimated that there existed a total runoff detention deficiency of 35,044 acre-feet. It was estimated that the cost of providing the needed detention capacity would be about \$5,500 per acre-foot or a total cost of \$192,742,000.

In the three-year period, 1969-1971, immediately preceding the requirement for land developers to provide detention facilities, an average of 1,181 acre-feet of detention capacity was added annually. During this period, other land development (where detention facilities were not provided) produced an increase in stormwater detention deficiencies estimated to cost about $6,500,000, annually, for correction.

For the period of January 1, 1972, to June 28, 1972, a total of 570 sewer permits were approved, representing developments that served a population of 40,926. The construction produced 1,305 acres of impervious area. A total of 253 acre-feet of detention was provided, leaving a net detention deficiency of only 74 acre-feet estimated to cost $407,000. If these results are extrapolated for the entire year (1972), the net added detention deficiency would require expenditures of about $815,000 for correction, compared to $6,500,000 estimated average annual costs that would have been required to correct detention deficiencies created annually in the preceding three years. This shows conclusively that the program has been very successful in reducing the rate at which flood hazards are being added annually by urban development. The MSD keeps accurate records of new developments, impervious area, detention capacity required for a 3-inch stormwater runoff, and the amount of detention volume provided. This is done for each of the nine drainage basins that affect the operations of the District.

Summary. The Metropolitan Sanitary District of Greater Chicago assumed an active role in stormwater management in the 1950's, although the District has had interest in controlling flooding since the early 1900's. Modern techniques employed and planned by the MSD include detention of stormwater runoff in large surface reservoirs, underground tunnels and on individual land developments. On-site detention of runoff is required for obtaining sewer connection permits in new developments exceeding specified acreages.

The MSD is building detention basins to reduce flooding in existing developed areas. Preliminary results of a recent amendment to the District's Sewer Permit Ordinance are very encouraging. Most aboveground detention facilities have been designed for multiple-purpose use. This has added to their desirability and acceptance by residents of nearby communities.

Arlington Heights, Illinois

Arlington Heights is a Village of 73,000 population located in Cook County, Illinois, all of which falls within the jurisdiction of the Metropolitan Sanitary District of Greater Chicago. Therefore, the rules of the MSD, including the requirements and provisions of the District's Sewer Permit Ordinance, are applicable to the Village. In addition, the MSD has encouraged municipalities in their jurisdiction to adopt local legislation requiring on-site detention of stormwater in new developments. This encouragement led to the adoption of a stormwater detention ordinance in Arlington Heights. The District is also urging local governments in Cook County to develop master plans for stormwater management for review and approval by the District.

Arlington Heights requires that detention facilities meet the MSD requirements and criteria in order to obtain village approval of any plat submitted for subdivision of land. The requirement for on-site detention of stormwater is coupled with a village flood plain ordinance which has met the approval of the MSD. With the backing of the District, the ordinance has operated satisfactorily and it has the flexibility to allow the details of storage to be planned jointly by land developers and the village engineering department.

About 12 major detention facilities have been built, or are in the planning stage, in Arlington Heights. The largest, costing $1.1 million and providing 100 acre-feet of storage, is the Wilke-Kirchoff Retention Reservoir which is being constructed in cooperation with the MSD of Greater Chicago. The 100-year rainfall was used in designing the facility which will serve a 717-acre drainage area. The reservoir will be emptied by pumping, using three pumps having a capacity of 5,400 gpm, and two 150-gpm sump pumps. Other detention facilities in Arlington Heights include the use of tennis courts and permanent ponds located in residential complexes.

Figure 28, Detention Facilities, Arlington Heights, contains photographs of a permanent pond in an apartment complex. This is a multi-purpose detention facility as is evidenced by the children shown readying a pole for fishing. Also shown is a photograph of a tennis court at an apartment complex. The stormwater inlet and the open flow channel can be seen at the bottom of the ponding area. The grassed slopes along the sides of the tennis courts, which form the sides of the detention pond, are flat enough to permit power mowing.

Residents of Arlington Heights seem to prefer the use of permanent ponds for stormwater detention because of the aesthetic appeal. In agreement with this, village officials feel that permanent ponds require less maintenance than do dry basins.

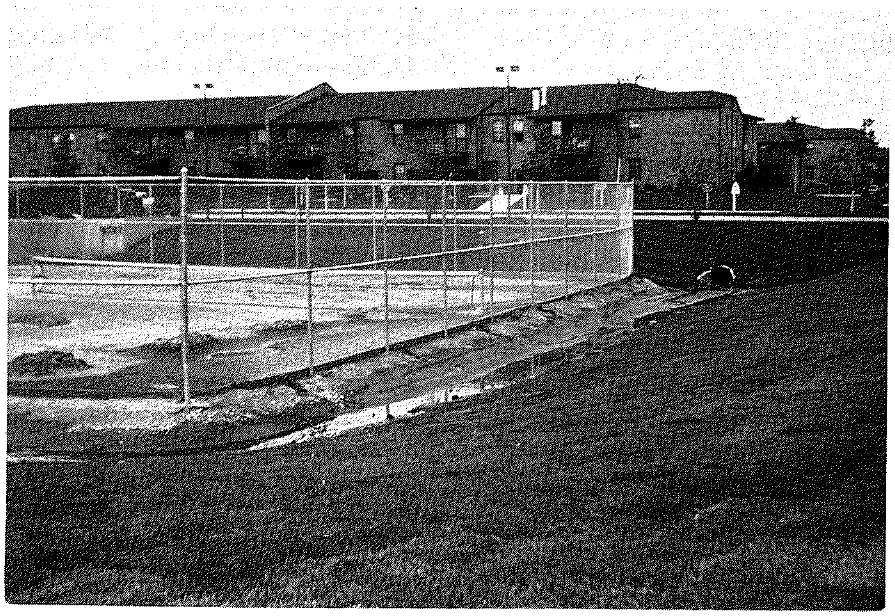
Maintenance responsibilities of the village for publicly-owned detention facilities are limited to maintaining the structures, while the Park District provides the ground maintenance, such as the grass mowing. A unique feature of one permanent-type detention pond is a wind-actuated stirrer which aerates the water, thus reducing the opportunity for algae growth.

Summary. Arlington Heights, a large village in Cook County subject to the regulations of the MSD of Greater Chicago, has passed ordinances concerning flood plain zoning and on-site detention of stormwater to combat problems of flooding from surface runoff in the village. The ordinance on stormwater detention is not detailed and can be administered flexibly. This makes it possible for the village engineering department to work with land developers in planning and providing stormwater detention facilities. Such cooperation has worked well.

The only major difficulty that the village engineer has reported in administering the village's stormwater detention program is with the use of runoff formulas, such as the Rational Formula, that do not allow for the relatively-low infiltration that occurs during intense rainfalls. During these periods, the runoff rate can be much greater than the values computed using the Rational Formula.

a. detention pond in residential area

FIGURE 28 DETENTION FACILITIES – ARLINGTON HEIGHTS, ILLINOIS



b. stormwater runoff is collected on a tennis court

FIGURE 28 DETENTION FACILITIES – ARLINGTON HEIGHTS, ILLINOIS

Mount Prospect, Illinois

The Village of Mount Prospect, Illinois has a population of 50,000 persons and is located in Cook County, within the jurisdiction of the Metropolitan Sanitary District of Greater Chicago. In response to the requirements for stormwater detention adopted by the MSD, the village passed an ordinance in 1971 requiring on-site detention of stormwater.

This ordinance generally follows the criteria set down by the MSD, but is more stringent in that it requires on-site detention for all commercial and industrial developments, regardless of size. Residential developments must exceed five acres to require detention storage; whereas, the district's requirements generally stipulate 10 acres for residential developments. Storage may be of any suitable type, as long as the basic criteria are fulfilled.

Residential developments have turned to the use of permanent ponds in open spaces for temporary storage of stormwater on development sites. These ponds serve multiple purposes such as boating, fishing, swimming, and ice-skating. They also improve the aesthetics of these land areas.

The largest of these permanent ponds is known as Clearwater Park. It has a storage capacity of about 178 acre-feet and controls the runoff from a 780-acre tributary drainage area. The pond was constructed in conjunction with a new housing development by means of the joint efforts of the village, park district and land developer. It is owned by the village and the park district. Figure 29, Detention Facilities, Mount Prospect, shows part of the pond, which maintains a permanent level of water. This beautifully landscaped pond is in direct contrast to the other photograph which shows a detention facility that was constructed by excavating a basin on three adjacent residential lots.

A total of about eight detention ponds in residential areas have been constructed or are in the planning stage in Mount Prospect. For some, ownership will be turned over to the park district, while for others the facility will remain the responsibility of the developer. If proper maintenance is not performed to control weeds, the village will perform the maintenance and charge the owner.

Commercial and industrial developments of all types and sizes, from gasoline stations and hamburger stands to large commercial

a. Clearwater Park detention pond

b. detention basin on three residential lots

FIGURE 29 DETENTION FACILITIES – MOUNT PROSPECT, ILLINOIS

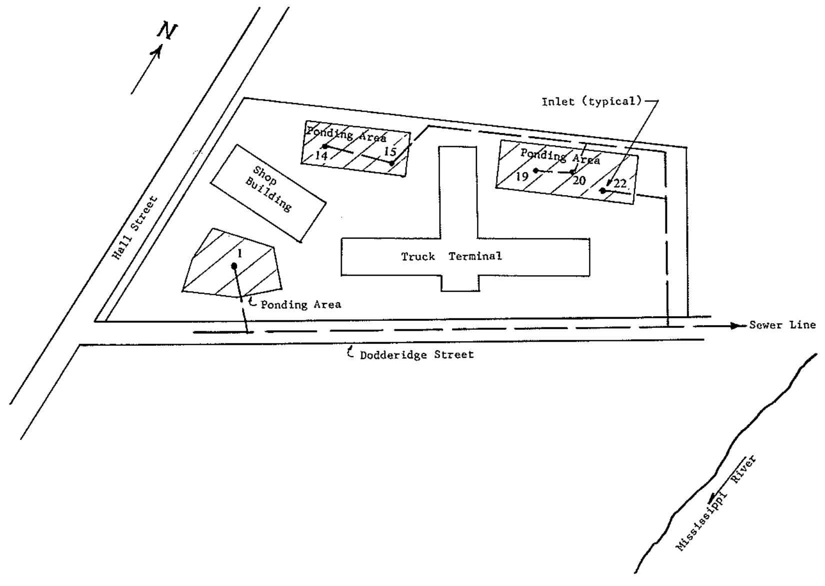
developments, must provide on-site stormwater detention for the 100-year design rainfall. The use of storage in large sewers is discouraged and is expensive, and sheet flow to the streets is not allowed. Architects have been wary of rooftop storage. As a result, commercial developments have turned to the use of parking lots for stormwater detention.

Because of the possible disadvantages of rooftop storage, as seen by local architects, few such facilities have been built. The village, however, views rooftop storage as a desirable detention method and has information describing the safety features of rooftop storage and cost reduction attributable to the use of smaller roof drain leaders. Part of this savings can be used to provide better waterproofing for rooftops. Structural designs do not need to be altered, since the maximum storage of three inches of water is equivalent to a live load of only 15 pounds per square foot. The local building code specifies that roofs shall be designed for a minimum live load of 30 pounds per square foot.

Part of the flooding problem in Mount

Prospect is caused by the surcharging of sewers from high water levels in the local creeks. To alleviate this problem, the Division of Water Resources Management of the State of Illinois has begun to dredge the creeks, removing obstructions and debris and increasing flow capacities up to 100 percent. Deep tunnel storage of combined sewer overflows and the construction of a new treatment plant near O'Hare Airport are also proposed by the MSD of Greater Chicago to solve the flooding and pollution problems.

Summary. In Mount Prospect, completed detention facilities are doing their job in meeting design criteria, although one facility was not built to be aesthetically pleasing. Permanent ponds in open spaces of some residential developments are used for stormwater detention. Parking lots are used for storage of rainfall in commercial and industrial developments. Architects are cautious about using rooftops of buildings for detention of rainfall, although the village is encouraging the use of this method.



Source: Reitz & Jens, Inc., St. Louis, Mo.

FIGURE 18 PARKING LOT DETENTION, CONSOLIDATED FREIGHTWAYS

Costs: A preliminary design was also made for a conventional drainage system designed to remove stormwater as fast as runoff developed. The design was based on a 100 percent impervious area and a 20-minute, 20-year rainfall.

Cost estimates prepared for this conventional drainage system, composed of inlets and closed conduits, indicated a $150,000 total construction cost. The system constructed, utilizing ponding, cost $35,000 less than this.

Conclusions: Experience of several years has justified the practicality of the shallow stormwater ponding areas at this trucking terminal. No operating difficulties have developed. The economy of detention of stormwater in the internal surface drainage facility for this major truck terminal has been demonstrated.

Fort Campbell, Kentucky [7]

The use of on-site detention storage in the storm drainage system at Fort Campbell, Kentucky reduced the initial construction cost by over a million dollars and has proved to be satisfactory and environmentally attractive since it was placed in operation in 1963.

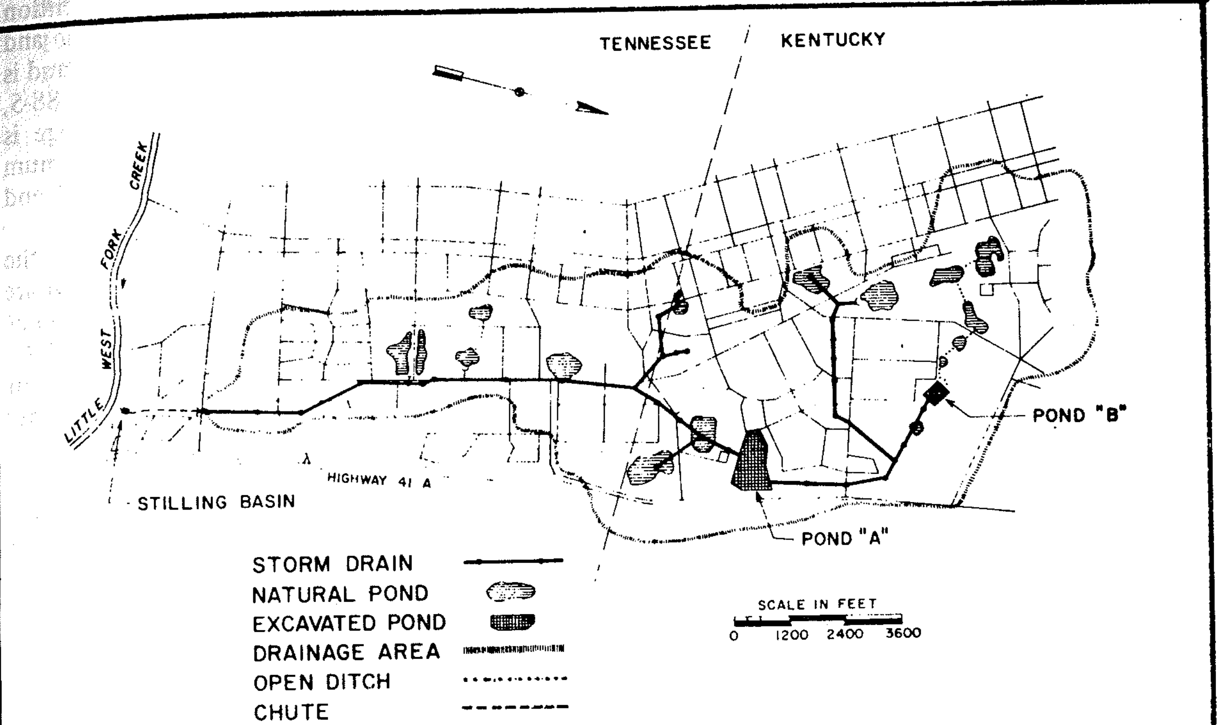
Fort Campbell is located on the Kentucky-Tennessee state line about 50 miles northwest of Nashville, Tennessee. The total area of the cantonment is about 6,000 acres and the region has gently rolling terrain with thick clay overlying cavernous limestone formations.

Planned expansion of Fort Campbell onto 2,000 acres initially led to preliminary drainage designs embodying an all-gravity system having an estimated cost of $3,370,000. This system was to replace a previous series of sinks using 6-in. to 8-in. diameter metal-cased shafts constructed through the clay soil into voids in the underlying limestone. These were unreliable in disposing of runoff, creating hazards in builtup areas, including family housing.

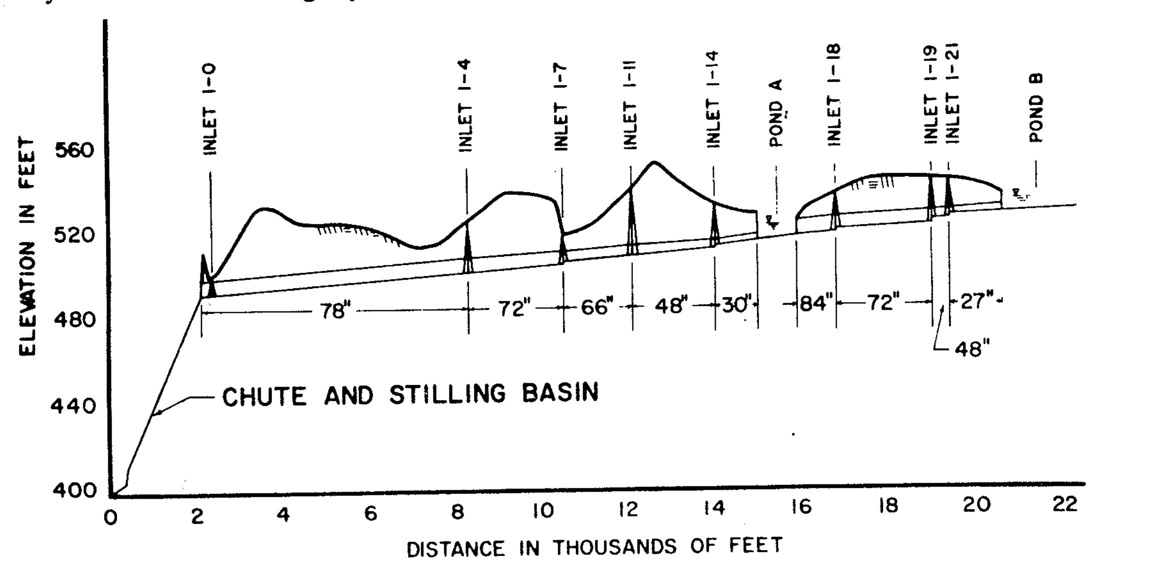
Alternative studies for providing stormwater drainage included the use of detention storage. This system, combined with the use of some open channels instead of closed conduits, was adopted and built at a cost of $2,000,000. Final design was by the Mobile District of the Corps of Engineers.

Significant reductions in pipe sizes were made possible by the use of temporary detention storage, as shown in Figure 19, Profile of Main Trunk Sewer. For example, the inflow pipe to one pond is 84 in. in diameter, while the outflow pipe from the pond has a diameter of only 30 in.

Without the use of ponding, a 90-in. diameter outflow pipe would have been required, together with corresponding increases in pipe sizes all the way downstream from the pond. The outflow pipe from the



a. layout of storm drainage system



b. profile of main trunk sewer

FIGURE 19 PROFILE OF MAIN TRUNK SEWER

pond is 13,000 ft in length and the total cost of the pipeline, and that upstream at a second pond, was reduced by over $1,000,000.

The total storage volume of each pond is about 130 acre-feet. Pond A is approximately 1,200 feet long and from 400 to 800 feet wide. Pond B is smaller in area – about 600 ft x 400 ft – but the average depth is greater.

Figure 20, Inflow-Outflow Hydrograph for Pond A, was developed. Similar hydrographs were developed for other ponds in the system.

To restrict the rate of runoff entering the system, most inlets were constructed with a short control pipe. Critical flow with inlet control was assumed when the control pipe is flowing partially full; flowing full, the discharge was computed by the conventional orifice formula. The capacity of the long pipes draining Ponds A and B assumed friction control plus an entrance loss of 0.1 of the velocity head.

Routing: The adopted drainage system was checked for its stormwater routing characteristics using a 50-year frequency rainfall. No flooding of any facilities was predicted. The depth and duration of more frequent ponding was determined by routing a 1-year event through the system. Table 16, Comparison of Hydrographic Data for Storms of Various Frequencies, gives ponding data for storms of 1, 10, and 50-year frequency.

The United States Army has published a technical manual on the use of detention ponds in the drainage of airfields and heliports. It is identified as TM 5-820-1, and is also used by the U.S. Air Force as AFM 88-5, Chapter 1. The use of detention storage is encouraged in the manual – for maximum application "consistent with operational and earth-grading requirements."

Details of the hydraulic design of the surface drainage system at Fort Campbell are given in a paper, *Hydraulic Design of the Fort Campbell Storm Drainage System,* by L.G. Leach and B.L. Kittle of the Corps of Engineers South Atlantic Division. This paper appeared in Highway Research Record No. 116 published in 1966 by the Highway Research Board. This entire section of the report is taken principally from the Leach &

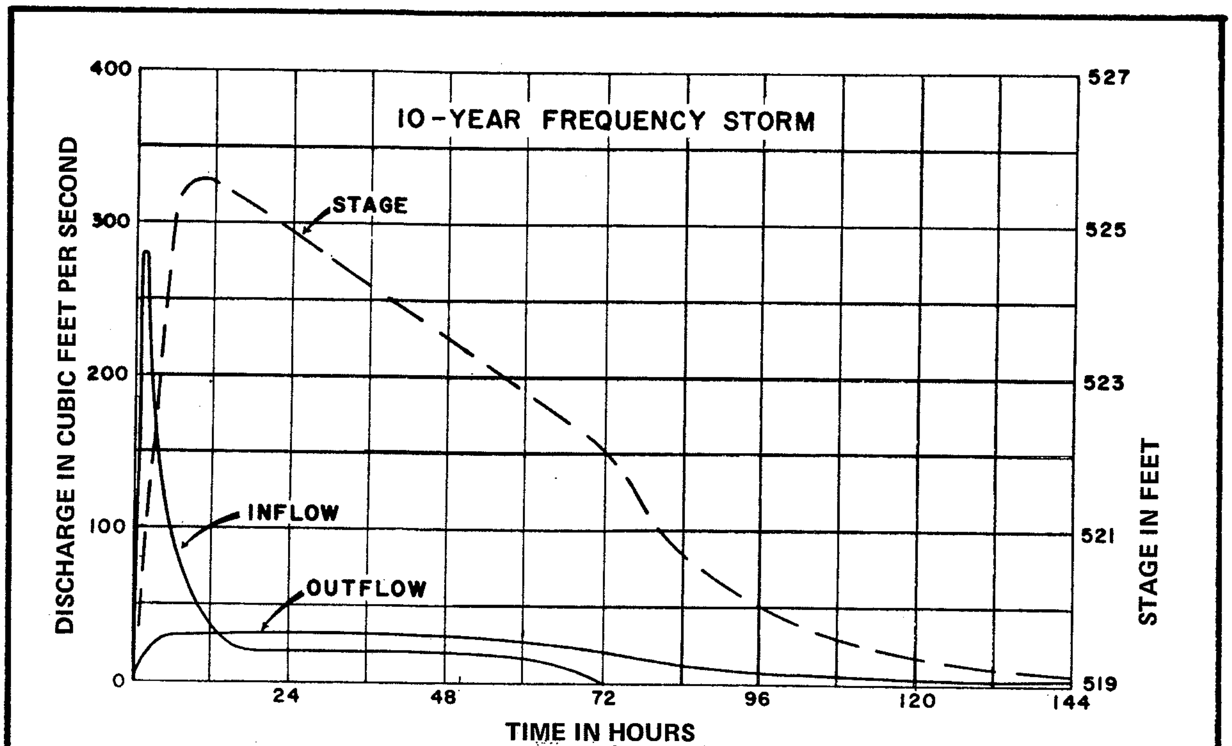


FIGURE 20 INFLOW-OUTFLOW HYDROGRAPH FOR POND A

TABLE 16
COMPARISON OF HYDROGRAPH DATA FOR STORMS OF VARIOUS FREQUENCIES

Area No.	Drainage Area (acres)	1 – Year				10 – Year				50 – Year			
		Max. Inflow (cfs)	Max. Outflow (cfs)	Max. Pond Elev.	Pond Time (hr.)	Max. Inflow (cfs)	Max. Outflow (cfs)	Max. Pond Elev.	Pond Time (hr.)	Max. Inflow (cfs)	Max. Outflow (cfs)	Max. Pond Elev.	Pond Time (hr.)
1	198.6	63.5	40.0	539.0	6.5	103.5	63.6	539.9	12.5	137.5	77.0	540.7	13.0
6a	372.0	165.0	18.7	536.4	30.0	270.0	22.3	538.9	72.0	347.0	23.8	540.0	96.0
7	38.4	29.3	16.0	541.8	4.5	31.0	18.4	642.9	8.0	38.9	19.6	543.5	10.5
8	31.9	15.3	6.1	539.2	6.0	25.2	12.1	539.8	10.0	31.6	14.8	540.2	12.0
9	44.3	17.4	7.4	543.2	6.0	28.6	8.2	544.2	12.5	36.4	8.6	544.6	42.0
10	61.5	40.2	26.7	539.2	4.5	64.2	32.9	540.0	9.0	79.8	34.8	540.5	10.0
11	39.9	25.0	7.0	537.9	6.5	40.2	7.8	538.7	12.0	49.8	8.0	539.1	18.5
12	47.9	30.4	12.7	529.8	6.0	49.1	18.3	531.0	10.5	61.3	20.0	532.0	11.5
13b	244.7	180.0	19.6	521.8	137.0	270.0	32.0	525.6	192.0	333.0	36.0	528.2	219.0
14	100.0	40.8	12.5	539.3	10.0	66.3	20.6	540.4	17.5	85.0	23.0	540.8	21.0
15	66.2	26.2	7.9	537.9	6.5	42.6	9.0	538.6	18.5	54.6	9.0	539.4	25.0
16c	19.3	14.2	14.2	–	–	22.9	22.9	–	–	28.6	28.6	–	–
17	87.2	58.4	50.0	531.2	4.5	93.5	62.0	534.7	10.0	116.2	68.0	535.1	10.0
18c	24.9	17.3	17.3	–	–	27.8	27.8	–	–	35.0	35.0	–	–
19	257.0	97.8	26.2	521.0	13.5	132.5	37.0	523.9	21.0	172.9	41.0	525.4	33.0
20	5.4	3.7	1.9	520.8	3.5	5.9	2.6	521.0	5.5	7.2	3.3	521.5	8.5
21b	32.0	14.6	11.7	516.9	5.0	22.7	17.4	517.8	9.0	29.8	18.4	519.0	10.0
22b	32.7	22.2	9.8	511.1	10.0	37.1	19.9	512.2	13.0	49.7	22.5	513.4	16.5
23	208.0	87.6	26.2	512.1	18.5	144.7	39.0	513.6	19.0	185.0	46.2	514.7	25.0
24	54.6	30.4	7.7	522.6	6.0	50.0	8.8	523.9	15.5	62.3	9.2	524.3	21.0
25c	23.3	10.0	10.0	–	–	16.5	16.5	–	–	20.8	20.8	–	–

Notes: a. Includes areas 2 through 6
b. Includes discharge from upstream area
c. No ponding in these areas

Kittle paper. The figure and table are direct copies from the paper.

A reply to an inquiry made in 1971 revealed that the system had performed in a very satisfactory manner during the eight years that it had been in operation.

Chain of Lakes
Village of Hoffman Estates, Illinois

Hoffman Estates, a Cook County community in Metropolitan Chicago, initiated a stormwater detention program about 15 years ago. The decision to use detention storage was primarily an economic one, because detention of runoff would reduce the required sizes of various drainage facilities needed. At the present time, there are 17 ponds which have permanent pools of water ranging in size from 0.5 to 10 acres. These have storage capacities of from 3 to 80 acre-feet. There are numerous smaller storage facilities of various types – dry basins, parking lot detention, and detention in buried culverts.

The earliest portions of the village were all developed by Hoffman Rosner Corporation. The existing drainage from a 700-acre tract flowed under the tollroad through a 30-inch corrugated metal pipe and a 15-inch tile underdrain located nearby. This flow passed through a forest preserve and thence into a tributary of Salt Creek.

The agricultural land in its natural state had several natural retention basins, where stormwater collected and was retained in swamp-like areas until it could flow from the area through the culvert and farm tile. Most of these farm ponds were generally in the locations later selected for the detention ponds. Considerable portions of these swamp-like areas were underlain with thick layers of peat and, therefore, were unsuitable as building sites. This determined their ultimate use as open lands for recreation and enhancement of the local environment.

While Hoffman Rosner did not own all of the 700 acres involved, they decided that this area would ultimately be developed and that they should build a storm runoff system which would be adequate to serve the entire 700 acres when completely developed, regardless of who the developer might be. To drain the entire area with conventional drains would have required a structure under the tollroad of 750 cubic feet per second flow capacity. Such a sizeable box culvert would have been quite costly, traffic flow on the tollroad would have been detoured and it would have been difficult to secure sufficient headroom for this structure. Because the land beyond the tollroad is very flat and swamp-like, handling the peak runoff would have required the dredging of drainage ditches for a mile or more.

The storm drains, due to their length and size, would have been expensive, and providing cover material over lines of such size would have been a problem in the prevailing flat terrain. On the other hand, it was reasoned that if detention sites could be selected in the areas of natural retention where soils were not suitable for building, the amount of excavation needed to provide detention ponds and their ultimate cost should be minimal. If such ponds were dug to depths sufficient to discourage growth of moss and cattails at low water level the resulting water areas could be pleasant additions to the landscape and should have considerable recreational value. Because the peat areas were generally much larger than would be needed for retention ponds, adequate adjacent land would be available for normal park purposes, and the ponds could then become an integral part of the park system.

Based upon these findings, Hoffman-Rosner engineers set out to design a series of ponds with their outlets sized so that the drainage could be handled through the existing 30-in. culvert and 15-in. tile under the tollway. The locations of the detention lakes and the approximate boundaries of each sub-basin in the "Highlands West" watershed portion of the development are shown in the map, Figure 21, Highlands West Subdivision. The area of each sub-basin and the sequence of flow routing is given in Table 17, Watershed Areas. Storage volumes, depths, surface areas, water elevations, outlet sizes and flow capacities, and type of pond (wet or dry) are given in Table 18, Details of Retention Pond Design.

The area was developed in phases with Areas B and C-2 being the first to be developed. Highland Lake and the adjoining park lay over an extensive peat bed and were drained through storm sewers to the low-lying area located where Jones Lake now stands. From this point, the water was allowed to flow through farm tiles and overland through undeveloped land to the outlet under the tollroad.

Next to be developed was the A-1 area. Here a 10-acre lake was excavated with the waste material being used to fill some of the lower areas to the southwest which now lie in the park. This lower area was also used for a waste dump for excess building materials and dirt during the construction of the homes. Perforated underdrains were placed throughout the area for proper drainage following rainstorms. After the construction was completed, topsoil was placed over the entire area and the banks of the lake and the park area were seeded.

Drainage from the Highpoint Lake passed through an 18-in. storm sewer to the eastern edge of the area then being developed, which was approximately 1,200 feet to the east. At that point normal flow entered a farm tile and ultimately reached the outlet under the tollroad while storm runoff passed overland, through the undeveloped area, to the same outlet.

Later, when Area D was developed, the Twin Lakes were established in areas underlain with peat. The storm sewer system

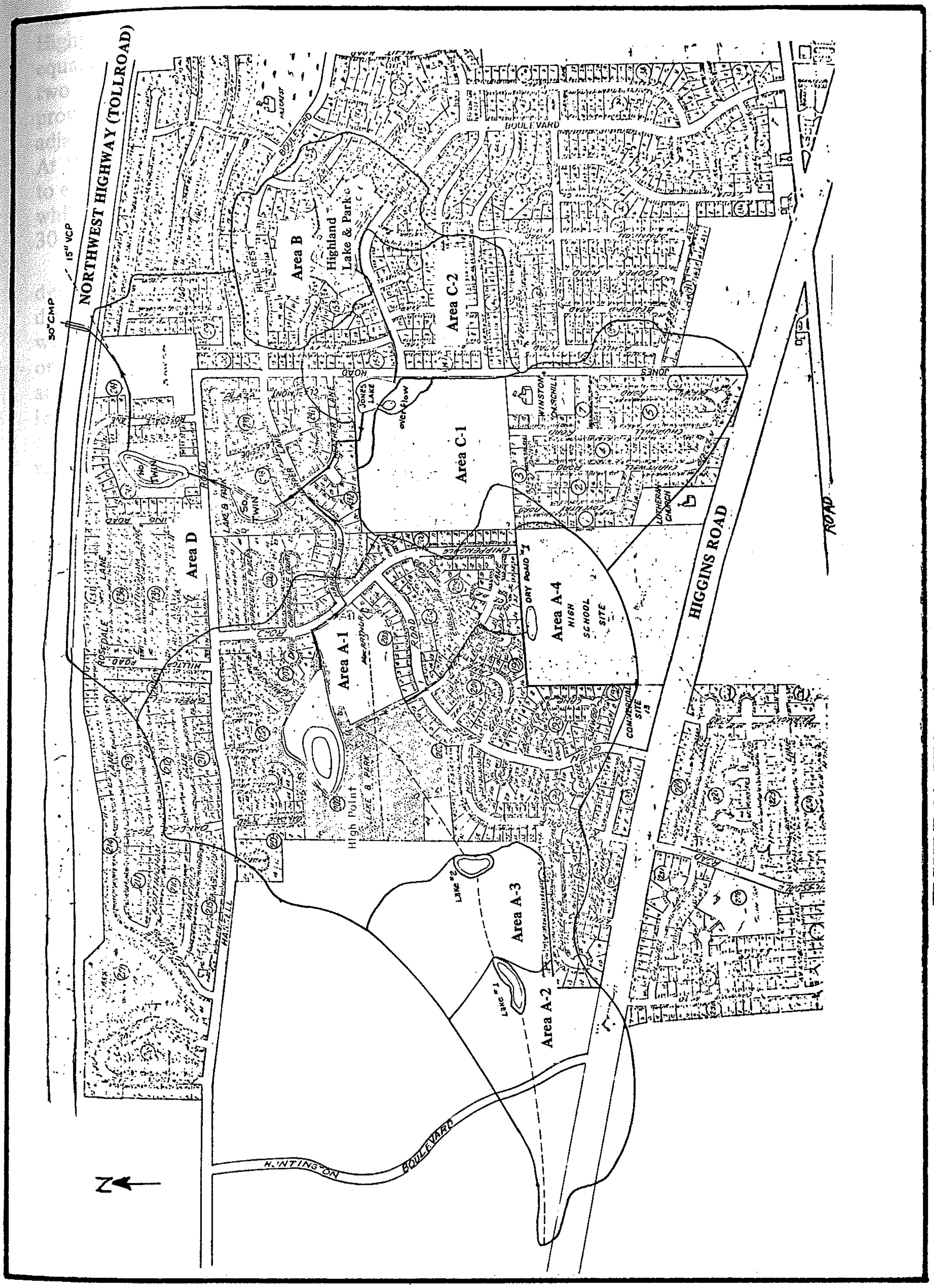


FIGURE 21 HIGHLANDS WEST SUBDIVISION
HOFFMAN ESTATES, ILLINOIS

TABLE 17

WATERSHED AREAS
"HIGHLANDS WEST" RETENTION PONDS
HOFFMAN ESTATES, ILLINOIS

Area (Identification)	Drainage Area (acres)	Runoff Coefficient For Developed Area	Pond of Original Storage for Runoff	Outflow Later Passes Through These Ponds
A – 1	217	.35	Highpoint	Twin Lakes
A – 2	55	.41	Lake No. 1	Lake No. 2 Highpoint and Twin Lakes
A – 3	35	.41	Lake No. 2	Highpoint and Twin Lakes
A – 4	33	.42	Dry Pond No. 1	Highpoint and Twin Lakes
B	50	.35	Highland	Jones Lake (lower level) and Twin Lakes
C – 1	105	.35	Jones Lake (upper level)	Jones Lake (lower level) and Twin Lakes
C – 2	45	.35	Jones Lake (lower level)	Twin Lakes
D	160	.35	Twin Lakes	none

TABLE 18

DETAILS OF RETENTION POND DESIGN – "HIGHLANDS WEST"
HOFFMAN ESTATES, ILLINOIS

Pond Name	Type of Pond	Maximum Depth of Normal Pool (ft)	Size of Area Original Service (acres)	Inflow From Other Area (acres)	Normal Pool Size (acres)	Normal Pool Elevation (ft)	Flood Pool Elevation (ft)	Flood Storage Capacity (acre ft)	Outlet Size	Outlet Capacity CFS	Design Capacity For 100-yr Flood (acre ft)
Highpoint	Wet	7	217	123	10.0	779.0	784.0	50.0[1]	18"CP	3.5	50.5
Lake No. 1	Wet	4	55	–	1.2	784.0	786.5	3.2	16"CP	3.0	8.4
Lake No. 2	Wet	4	35	55	1.0	779.0	783.5	5.1	27"CP	12.0	
Dry Pond No. 1	Dry	0	33	–	0.2	812.0	817.0	1.5	12"VCP	6.5	1.5
Highland	Wet	4	50	–	4.0	780.0	784.0	20.0	15"CP	5.0[2]	5.0
Jones Lake (Upper Level)	Dry[3]	4	105	–	0.4	778.4	785.0	9.5	15"CP	5.0	10.9
Jones Lake (Lower Level)	Wet	3	45	155	1.4	778.0	783.0	8.0	30"CMP	8.0	7.1
Twin Lake – South	Wet	4	70	540	3.5	775.0	780.0	19.5	36"CMP	Equalizer	27.0
Twin Lake – North	Wet	4	90	610	4.0	775.0	780.0	22.0	27"CP	15.0	

Outlets under Tollway – 30" CMP – Cap. 12.0 CFS
– 15" VCP – Cap. 3.0 CFS

[1] An additional 50 acre feet (or more) of overflow storage is available before water reaches within one foot of floor level.
[2] Controlled by valve to 3.0 CFS.
[3] Has small permanent pond, balance of overflow on play field.

was then extended to connect the outlet from Highpoint Lake to the South Twin Lake. An equalizer pipeline was provided between the two Twin Lakes and a 27-in. outlet was provided to carry the water to a point adjacent to the 30-in. pipe under the tollroad. At this point, the normal flow was permitted to enter the 15-in. farm tile under the tollroad while the flood flows were carried to the 30-in. pipe.

In short, the design as ultimately developed followed the pattern prior to development. The series of lakes provided were located in the general vicinity of the original retention areas. The lakes and the accompanying park-like areas were developed into desirable assets for the residential community and are used extensively today as recreational facilities. By utilizing small-size drains to carry the outflow to the ultimate outlet under the tollroad, the cost of the drainage system was greatly reduced from the estimated cost of a conventional drainage system.

To provide an additional safety margin, the ponds were designed to hold a minimum of one foot more water than the runoff from the 100-year rainfall before houses would be flooded. The system has worked as anticipated by the designers and is a satisfactory method of controlling runoff from this 700-acre area. The only serious problem was encountered in Area C-1 where the retention pond that was planned originally was not built. That detention pond is now under construction and, while it is somewhat undersized, it should alleviate the flooding conditions which have occurred there.

The ponds and adjacent park areas are used for recreation. Some have been stocked with fish and others now have ducks inhabiting them. Others are used as parts of golf courses, and some, located near buildings, enhance aesthetic values.

The most serious problem to date is preventing land developers from deviating from the original master drainage plan, as was done in the C-1 area. An overall master plan was developed for the entire sub-watershed, and only by following this plan will adequate drainage be obtained. Control by the Metropolitan Sanitary District of Greater Chicago will help coordinate such plans in the future.

There have been maintenance problems. Children playing at pond outlets have stuffed sticks and debris into the outlet pipes causing blockages and reduced flow. Objects thrown into the pond have had similar effects. Ready access to each outlet should be available to operating personnel and a manhole should be installed downstream of each outlet to aid in cleaning operations. Ice plugs forming in sewer pipes during the winter and spring can also be cleared more easily with such provisions.

Slow drainage of ponds can kill grass and shrubs. It is important to incorporate design features to prevent this from happening.

On small ponds where the slopes are steeper than 3 1/2 horizontal to 1 vertical, maintenance is difficult and the ponds become a safety hazard for small children unless they are fenced. Ponds having gentle side slopes cause no problems of this type and are not fenced.

Siltation during construction of the subdivision was also a problem and it is advised either that the pond be dredged after construction is terminated or that measures be taken to control erosion.

Suggestions by the developer for facility design are: (1) limit the construction of impervious area to the assumed area upon which the original design of the detention facilities was based; (2) provide emergency spillways through streets, etc., to handle abnormal flows; (3) use outfalls larger than required by calculations, and provide for control of flow rates to permit rapid drainage when needed; (4) construct banks of ponds with gentle slopes for safety and ease of maintenance; (5) provide for erosion and siltation control; and (6) install a manhole downstream of each outlet to simplify clearing of debris in outlet pipes.

In conclusion, Hoffman Estates has experienced no serious difficulty with stormwater detention facilities. The ponds are economically advantageous. They are extremely useful for controlling stormwater drainage and reducing flooding, and they provide significant recreational and aesthetic benefits.

That proper engineering pays off was evident in 1972 when the general area had 3.5 inches of rainfall in 45 minutes on August 23rd and six to seven inches in a two-hour period two days later. According to the land development company (Hoffman-Rosner Corporation) only a handful of flooding complaints were registered by the 8,000 homeowners, and none in any of their newest developments.

Indian Lakes Estates
Bloomingdale, Illinois

Indian Lakes Estates is a single-family residential development located in the Village of Bloomingdale, northeastern DuPage County, Illinois. It includes 1/2-acre residential lots, two 18-hole golf courses and a clubhouse. The drainage system, designed by Bauer Engineering, Inc. (Chicago), was put into operation in 1969. It serves 400 acres of gently rolling watershed. Much of the area was formerly swampy and had no well-defined natural drainage channels.

Two basic alternative designs were investigated. One required the construction of a 72-inch diameter sewer to carry the surface runoff from the watershed to Salt Creek. This would have entailed constructing 7,000 feet of precast concrete pipe across farm land owned by a party who objected to having this sewer constructed on his property.

The alternative chosen involved constructing small-diameter sewer lines on the Estates to connect with an old existing farm drain built of 16-inch diameter field tile. Engineering investigations and calculations showed that this drain, much of which was in poor condition, had a capacity for handling about 0.01 in./hr. (0.25 in./day) of runoff. This flow rate is extremely small compared with the capacity of the alternative design involving the 72-inch sewer. The rate is small enough to permit treatment of the stormwater runoff when desired or required at some future date. Also, this slow discharge rate would not contribute to rapid rises in the water levels in Salt Creek.

The estimated costs of constructing the two alternative drainage systems indicated a net saving of $370,000 in favor of a system incorporating the farm drain tile with on-site detention lakes. A tabulation of estimated costs is given in Table 19, Comparison of Estimated Costs.

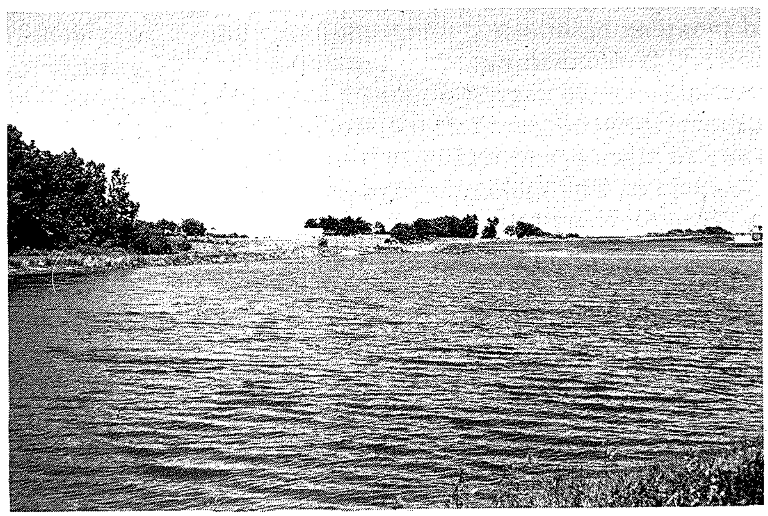
The hyetograph of the largest recorded rainfall in the history of Chicago was used as the design runoff. The difference in mass diagrams constructed for both the uncontrolled runoff and the controlled runoff situations was used to estimate the detention storage volume required. This was computed to be a volume equivalent to 3.0 inches of water spread over the 400-acre watershed. This amounts to 100 acre-feet of water stored over 17 acres of water surface at an average depth of six feet.

Figure 22, Indian Lakes Estates, contains photographs of (a) an existing permanent, variable-depth lake on the golf course area; (b) a new permanent excavated lake at a lower level, created in a swamp, to collect surface runoff and to provide additional

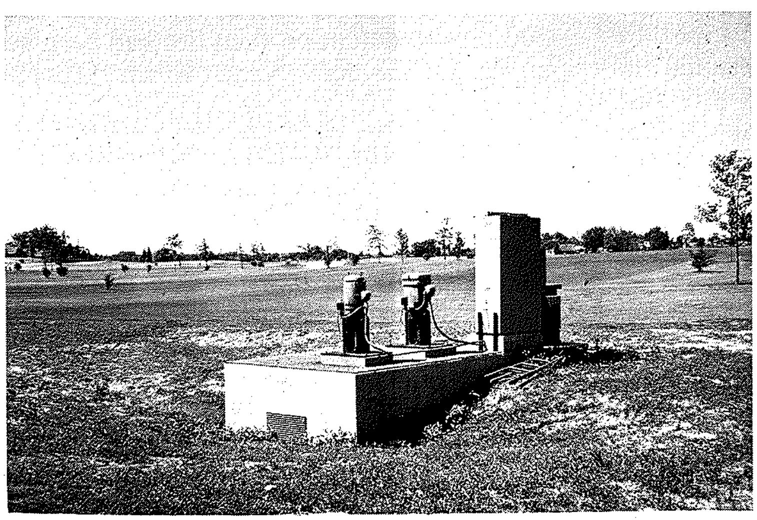
TABLE 19
COMPARISON OF ESTIMATED COSTS – INDIAN LAKES ESTATES

Item	Costs of 72-inch Sewer System	Costs Using Farm Drain with Detention	Savings Using Detention System
Piping (Installed)	$ 500,000	$ 40,000	$ 460,000
Pumping Station	0	50,000	(50,000)
Excavation for Lakes	0	100,000	(100,000)
Contingencies	100,000	40,000	60,000
TOTALS	$ 600,000	$ 230,000	$ 370,000

a. View of the upper detention lake on the golf course area.



b. Lake created from swamp located in lower area where surface runoff collects. Dike constructed from peat excavated from the swamp is shown on the far side of the lake. A portion of a residence can be seen at the upper right of the photo.



c. Pumping station located in shallow basin from which water is pumped to the upper lake on the golf course. Water enters this basin by gravity flow from the lake excavated in the swamp area during periods when the surface runoff into the lower lake causes the lake level to rise above the horizontal grating at the outlet.

FIGURE 22 INDIAN LAKES ESTATES

storage through a 5-ft rise in its water surface; and (c) a pumping station designed to pump excess runoff from the low-lying excavated lake to the upper lake. An 18-in. diameter two-way flow force main was constructed between the upper lake and the pumping station; and a 12-in. diameter existing storm sewer between the low-lying lake and the pumping station. Small-diameter sewers permit gravity discharge of excess stored runoff from both the upper and lower lakes into the existing farm drain.

Two additional interconnected, small lakes located on the golf course drain excess stored runoff into a different storm sewer, separate from the system described above.

A total of 40 acre-feet of runoff can be stored in the upper lake, and the lower lake and pumping basin can store an additional 60 acre-feet. If filled to capacity, the upper and lower lakes would require about 12 days time to drain the 100 acre-feet of stored water down to the permanent five-foot average water depths. The maximum flow capacity of the farm drain system controls the rate of outflow from the upper and lower lakes. This maximum flow rate is, in turn, dependent upon water levels in Salt Creek where the system discharges.

In summary, the man-made collection lake, located in a peat bog, is an example of how a liability was converted into an asset. Not only does this lake constitute an important component of the detention storage system for handling stormwater runoff, but it enhances the aesthetic appeal of this residential area. This has resulted in higher sales prices for the abutting lots. But most important, by detaining the surface runoff at the site, flow rates into Salt Creek were minimized, thereby sparing property owners along the creek, and its tributaries, from flood waters that would otherwise have been cast upon them.

By incorporating on-site detention facilities into the design and construction of the surface drainage system of this subdivision, about $370,000 in construction cost was saved. This amounts to 160 percent of the actual construction expenditures.

APPLICATIONS

Key engineering personnel of municipalities, sanitary districts, urban drainage and flood control districts, and engineering design firms in the United States and Canada were surveyed in 1972. A total of 230 completed questionnaires were received from public agencies and 40 completed questionnaires were received from engineering firms.

Of the 230 questionnaires completed by public agencies, 99 reported that detention facilities exist in their jurisdictions, while 109 reported that they had none in their area. Twenty-two respondents did not answer this question.

Ownership of the facilities and the land was reported by 58 respondents to be by public agencies, while 66 jurisdictions reported private ownership of facilities, and 12 jurisdictions reported ownership by others. Of the 1,410 detention facilities reported, 29 percent were identified as parking lot facilities, 14 percent were in parks, 7 percent were on rooftops of buildings, 2 percent were on schoolgrounds, and 48 percent of the facilities were listed under the "other" category. Apparently, the respondents were using this category for ponds and basins located in open spaces of various developments other than parks or schools. A tabulation of the responses is shown in Table 20, Number of Detention Facilities.

One public agency reported that about 200 on-site detention facilities had been built in its jurisdiction. Areas which promoted

TABLE 20
NUMBER OF DETENTION FACILITIES

Type of Detention Facility	Number
Rooftop	100
Parking Lot	400
Park	200
Schoolground	30
Other	680
Total	1,410

Source: Survey of 230 Public Agencies

detention ponds had many such facilities; and areas like Denver, Chicago and Montgomery County, Maryland, each reported over 100 facilities in their respective jurisdictions. Other areas with many detention ponds include Jefferson County, Kentucky (102), Buffalo, New York (200), and Suffolk County, New York (101). These six areas had a total of about 710 installations. The remaining 700 installations were reported by 93 other jurisdictions.

Engineering firms across the country were also surveyed. Of the 40 replies, it was found that 34 firms had designed a total of 602 stormwater detention facilities. One firm had designed 120, of which 70 were on parking lots. Parking lots were the most commonly used installation accounting for 184 detention facilities. Table 21, Design of Detention Facilities, gives a tabulation of the number of various types of facilities reported.

TABLE 21
DESIGN OF DETENTION FACILITIES

Type of Detention Facility	Number
Rooftop	95
Parking Lot	184
Ponds in Parks and Playfields	120
Ponds on Schoolgrounds	18
Ponds in Residential Areas	146
Underground Tanks	20
Other	18
Total	601

Source: Survey of 40 Engineering Firms

Geographically, most of the detention facilities were located in areas that encourage the use of detention facilities for surface drainage. Five firms located near Denver, Colorado, accounted for the design of 238 facilities, and five engineering firms in the Chicago, Illinois, area accounted for 207 projects. In both instances the use of stormwater detention facilities is either required or strongly recommended by local jurisdictions.

A total of 556 of the 601 on-site stormwater detention facilities were built in areas where such facilities were required, or encouraged, by local public agencies. Only 45 of the facilities were constructed in areas where they were not encouraged.

On-site detention facilities are in widespread use, although their use is more prevalent in areas where the concept is recommended or required. It was found that on-site detention ponding is practiced in many urban areas primarily for the purpose of reducing the frequency and extent of local flooding. Approximately 1,400 such facilities were reported by local public agencies to be in use or in the planning stage. Detention ponding in open spaces is the most prevalent practice. The use of parking lots was reported in 400 instances. Detention of runoff on rooftops and in park areas is implemented less frequently. Although public agencies often own the land and facility, seldom do they bear the total cost of providing the facility.

Relatively few jurisdictions require detention storage or other means of limiting stormwater runoff rates, except by the disconnection of roof drains from sanitary sewers. The greatest advantage besides reducing flooding and pollution problems, was said to be improvement in the aesthetics of urban areas.

The biggest environmental problems foreseen were mosquito breeding, algal growth and displeasing appearances of empty detention ponds. Maintenance and operation was clearly identified as a major problem of concern to public agencies.

CHAPTER 5
PREVENTING AND REDUCING FLOODING

By reducing peak stormwater runoff flows to the level that the sewer systems can handle, on-site detention of stormwater runoff can reduce flooding caused by sewer surcharging and can also reduce the frequency of pollution caused by combined sewer overflows. If practiced widely, it can also protect against major drainage system (river) flooding by detaining the water until capacity exists for the system to handle the runoff. These are the goals of the systems described in this section.

On-site stormwater detention programs are emphasized in at least two areas of the United States where it is either promoted, or required, under the leadership of regional authorities.

In the Denver region, the Urban Drainage and Flood Control District has not adopted any legal requirements for on-site detention, but its guidance has promoted the adoption of on-site detention requirements by communities located within its jurisdiction.

The Metropolitan Sanitary District of Greater Chicago, in 1971, adopted requirements for on-site detention of stormwater. The requirements were established by amending the District's sewer permit ordinance. The requirement for on-site detention by the District required all municipalities within its jurisdiction (Cook County) to adopt the concept, and has influenced neighboring jurisdictions to adopt similar requirements and techniques in their local stormwater management programs.

Skyline Urban Renewal Project
Denver, Colorado

General Requirements and Criteria – In the planning of its 80-acre Skyline Urban Renewal Project in downtown Denver, the Denver Urban Renewal Authority (DURA) took action in 1970 to require private developers to temporarily store (on-site) stormwaters directly falling on their properties. The purpose was to detain the local runoff to reduce the surcharging of the storm drainage system in the downtown area until such time as tributary areas had been drained. A land-use map of the Skyline Urban Renewal Project area is shown in Figure 23, Skyline Urban Renewal Project. To implement this requirement, DURA published and distributed to potential redevelopers a set of criteria outlining requirements for on-site detention of stormwater. The criteria includes requirements and suggested means for detaining rainfall in both new construction and in renovation of buildings. In general, three types of on-site detention facilities are included: rooftop ponding, ponding in plazas, and ponding in open spaces and grassed areas.

Flat roofs obviously provide a storage area that does not conflict with vehicle traffic and pedestrians. The associated costs and inconvenience are minimal because:

a. roofs in the Denver area are presently designed for a snow load equivalent to the weight of, approximately, six inches of water, and
b. horizontal roofs need to be constructed to be water-tight to prevent leaks from ponding that often occurs unintentionally during rainstorms.

A detention ring for installation around a standard roof drain has been designed for rooftop ponding. The hydraulic characteristics of the ring limit the maximum flow rate tributary to the storm sewer system. The detention ring can be designed for such variable factors as roof slope, roof area, and maximum rainfall intensity and duration. It is safe for use in large storms with high intensities of rainfall, such as the 100-year rain, because the water can flow over the ring into the roof drain, thus preventing any unsafe structural load.

Elevated plazas and parking lots can be designed so that the runoff contribution is limited to a pre-determined rate, with storage being provided by placing surface drainage inlets, with orifice regulators or other flow restricting devices, in depressions. Pedestrian inconvenience can be minimized by careful selection of walkway and drain locations. The

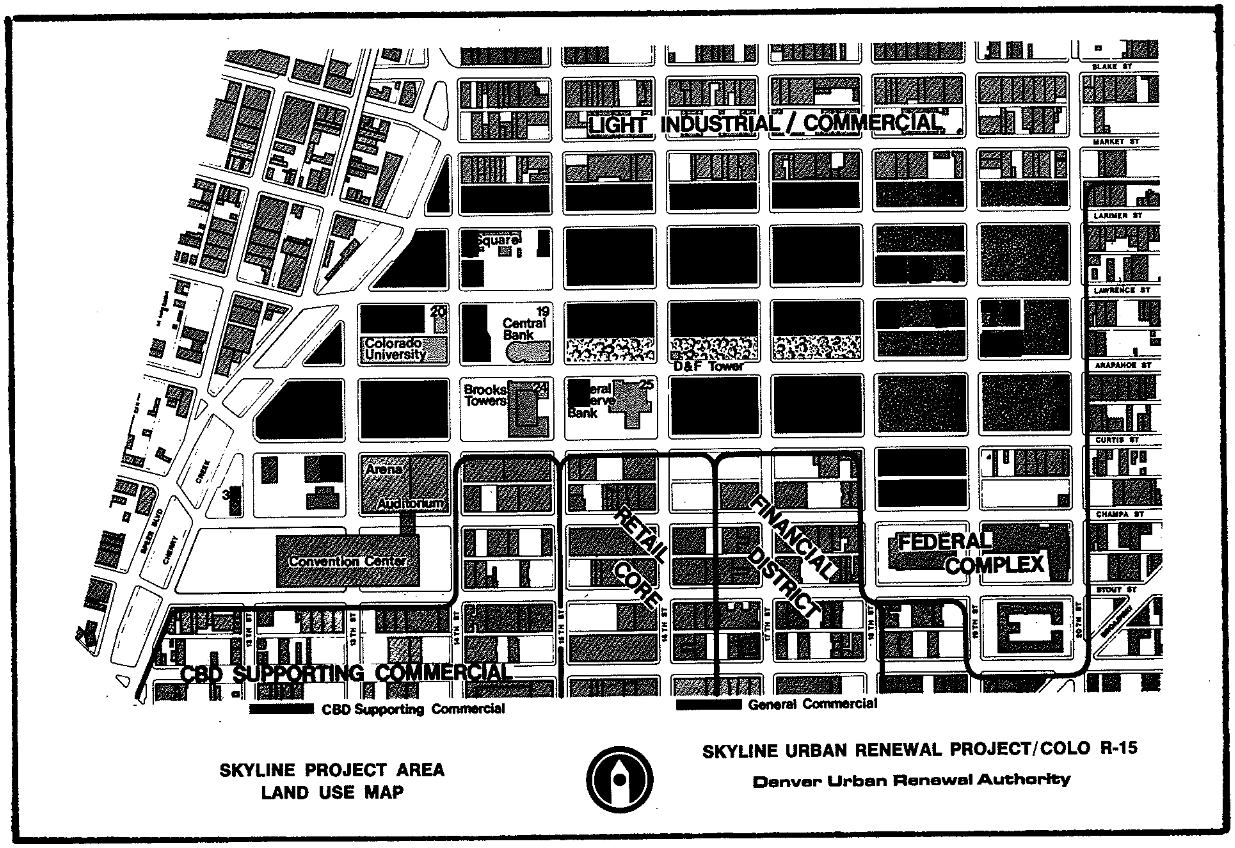


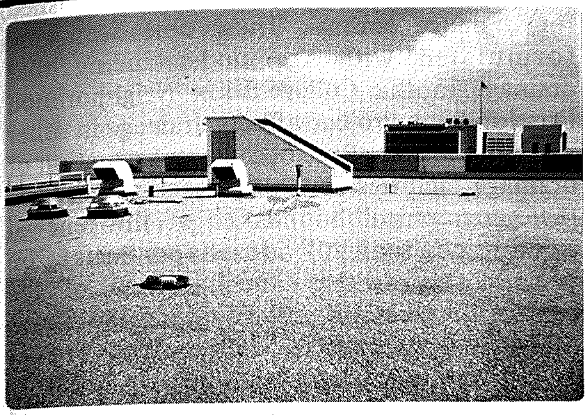
FIGURE 23 SKYLINE URBAN RENEWAL PROJECT

depth of storage required will depend on the total area being drained, the design storm characteristics, and the selected outflow rate.

Drains on roofs of buildings and in plaza areas are designed in accordance with the Denver Building Code; however, the peak drainage rate is limited to comply with the Denver Urban Renewal Authority site drainage criteria. These criteria limit the runoff from roofs of all buildings to 0.5 inch per hour, when the stored rainfall is discharged to the storm sewer. This can be related to gallons per minute or cubic feet per second on a direct basis. The inlet to the drain leaders are to be designed to limit ponding on the roof during a 100-year rain to three inches of depth at the discharge point, with the maximum discharge of 0.5 inch per hour. Actually, the water depth at the inlet to the drain may exceed three inches due to the slope of a relatively flat roof toward the drain. Figure 24, Rooftop Detention, contains photographs of ponding rings installed on the roof of the new Prudential Office Building in Denver.

Elevated plazas may be designed to drain at a rate of one inch per hour for the total plaza area. It is preferred that elevated plazas drain directly to the storm sewer. No drainage from private areas, including roofs, plazas, etc., are permitted to cross over public rights-of-way. If there are special problems related to a particular development in meeting the criteria, reasonable modifications in requirements are approved provided that compensatory storage is provided elsewhere on the site.

The criteria pertain to two distinct types of ponding based on the area and the use. One type is that of elevated plazas, pedestrian malls, arcades and other extended flat areas in which a minor amount of ponding at designed locations would not cause serious inconvenience. For these areas, the design has assumed a rate of runoff of one inch per hour, which should result in a maximum water



a. ponding rings installed around roof drain conductor heads, Denver

b. close-up of rainfall ponding ring and conductor head

FIGURE 24 ROOFTOP DETENTION

depth of 0.75 inch during a 10-year return-frequency rainfall.

The other category includes roofs of buildings, structures, parking lots, and other areas where a greater depth of ponding can be tolerated. For these areas, the design has assumed a rate of runoff of only 0.5 inch per hour. During the ten-year return-frequency rainfall, this would result in a ponding depth of approximately one inch. During a 100-year rainfall event, the ponding depth would not exceed three inches.

The assumed maximum rates of runoff (specified in the criteria), in inches per hour, are given in Table 22, Maximum Release Rates, in units which may be more familiar to architects and others. Also shown is the maximum accumulated depth of ponding that could be expected to occur for each of the two runoff rates specified.

To incorporate the above detention criteria in rooftop drainage systems, it is necessary to limit the flow rate of the rainfall into the downspouts or storm sewer inlets. This can be accomplished on rooftops by installing a weir-type device at the drain conductor head. A sketch of a roof drain detention ring is shown in Figure 1. This device also provides for overflow at the 3 or 4-inch level, depending upon the height of the device. On paved surfaces in plazas, orifice plates can be installed below the grating or perforated plates covering storm sewer inlets. These detention devices delay the storm runoff in the project until the peak has passed; yet, they allow for a more economical and realistic design of the storm sewer system throughout the entire project.

The Denver Urban Renewal Authority requirements for the design of roof drains differ from those set forth in the plumbing section of the building code of the City and County of Denver in that detention of rainfall is not required by the latter code. The requirements for the design of the downspouts are the same in both cases. This

TABLE 22

MAXIMUM RELEASE RATES – RUNOFF AND PONDING DEPTH

Inches/hour	cfs/acre	cfs/1,000 sqft	gpm/100 sqft	Accumulated Depth for 10-Yr Rainfall
1	1	0.023	1.04	3/4 inch
1/2	0.5	0.012	0.52	1 inch

assures that the discharge capacities of rain leaders designed under the DURA criteria will be more than sufficient to discharge the peak flows of the water stored on rooftops as well as any water that may overflow the roof drain detention devices.

Construction in the Skyline region is progressing rapidly. Of the eleven major building developments initiated, all but one was scheduled to be completed in 1973. The rooftops and plaza areas of these buildings are used for detention storage in accordance with the criteria described. In another area of Skyline Project, a park, three blocks long and one-half block wide, was constructed. Its surface was depressed below adjacent street elevations and designed to detain rain water falling directly on the park property.

Summary: The entire Skyline Urban Renewal Project provides for on-site detention of rainfall in new construction and in the renovation of old buildings as well. Being almost a city within a city, the Skyline Project is an excellent example of successful application of the concept and techniques of on-site detention of stormwater to help solve existing problems of stormwater management in the central business district of a large urban area. Furthermore, the obvious success and the relative ease with which detention of rainfall was incorporated into the renewal developments is concrete evidence that it is feasible to secure cooperation from land developers and builders, even in central business district projects, in providing for stormwater drainage.

College View Neighborhood Development Project – Denver

Part of the renewal work needed for the College View rehabilitation area was for improvement of the stormwater drainage system. Located in southwest Denver, this predominately residential area of 579 acres has three drainage ditches. The program for controlling stormwater includes stormwater detention, flood plain zoning, and multiple use of drainage areas. Construction of the stormwater drainage system, recreational facilities and other improvements is now underway.

A set of major objectives was established for drainage control. These objectives were formulated with the understanding that drainage in the College View Neighborhood Development Project affects drainage in other parts of Denver. But, because construction of drainage facilities for this project is limited to the geographical boundaries of the renewal area, control of drainage must be accomplished within the confines of the project area. Major objectives of the storm drainage works in the College View Project include the following:

1. design discharges should not exceed previous (that is, pre-redevelopment) discharge rates for rains of the same frequency;
2. efforts should be made to keep discharge rates at historic levels, that is, pre-urban levels;
3. multi-means and multi-purpose concepts, including park development of drainage ditches, should be used to increase benefits and reduce costs;
4. on-site ponding should be used to both reduce the peak flow requirements of the system and to improve water quality;
5. on-stream ponding should also be used as much as possible;
6. a 100-year rainfall frequency should be used for the drainage system design, if feasible – otherwise provision should be made to protect property against the runoff flows of a 100-year rainfall event by means of flood-proofing;
7. where base flows are adequate, permanent pools should be developed for park and recreational purposes; and
8. all drainage ditches are to be flood plain zoned.

Objective number four indicates the desirability of utilizing on-site storage. A 1971 study for development of one of the drainage ditches in the project area, the West Evans ditch, called the use of ponding relatively new; and it was concluded that this method could significantly improve runoff characteristics for urban basins. The report recognized five types of ponding:

1. rooftop ponding,
2. plaza and parking lot ponding,
3. open space and grassland area ponding,
4. recreational-field ponding, and
5. other types of ponding as described in the Denver Regional Council of Government's publication entitled *Urban Storm Drainage Criteria Manual.*

The various methods of stormwater detention were viewed as being practical if designed properly. Landscaping of lawns and other open spaces to include relatively small depressions in the ground surface to retard the runoff was recommended as was the use of ponds and basins in recreational areas.

Evaluations of planned future land use were made to determine the expected runoff and the amount of ponding necessary for surface drainage control. Four land use categories were described and restrictions were placed on the amount of development of land area in each land-use category. For example, in commercial developments an equal amount of area must be provided outside the buildings as the floor area inside the buildings. This means that as much as 50 percent of the developed land area can be used for ponding.

The design of the West Evans Ditch calls for the use of ponding wherever practical, except for streets and land already developed. Due to limited space, detention storage in the flood plain is kept to a minimum. A "wet" detention reservoir is included at the downstream edge of the project. This permanent pond of varying water depth is designed to reduce discharge rates to, or below, pre-redevelopment discharge rates.

Other ditches in the Project area are being developed with multiple-use features, including recreation, such as bicycle trails, playgrounds, and picnic grounds.

Summary. The College View Project is evidence of the economic feasibility and practicality of improving stormwater drainage systems in connection with renewal of urban neighborhoods. In this renewal project, initial planning called for improving the area aesthetics and recreational use of large portions of the land designated for stormwater control.

The project described above is an excellent example for study by urban planners and designers, particularly those engaged in urban renewal activities.

Denver's East Harvard Gulch Project

The East Harvard Gulch Project for flood and erosion control in southeastern Denver solved the problems of flooding and erosion with methods that are aesthetically pleasing and compatible with area land use. The drainage basin had long been a problem for the neighborhood and the entire city. Urbanization of the basin increased stormwater runoff to such an extent that rainfalls of 1-year frequency caused flooding. Steep grades contributed to high runoff flow rates and channel erosion.

Major encroachment on the channel's flood plain had occurred prior to the enactment of city zoning laws to protect the flood plain. Infringement on the channel was so intensive that the defined channel ended about 4,000 feet from the South Platte River. To reach the River, flood waters have regularly flowed down a major business street.

With help from neighborhood citizen groups, a $2.3 million general obligation bond issue was passed in a city-wide election and financed by a city-wide sales tax.

Channel improvements were proposed to extend from the South Platte River to Colorado Boulevard, a distance of three miles, through a heavily urbanized area. Thorough hydrologic studies and efficient engineering designs were required. Careful concern for aesthetics and compatibility with local land-use were recognized as important considerations for obtaining the greatest benefits.

Directives were given to the project engineer that the benefits of the project should be the maximum possible with the limited funds available. The synthetic unit hydrograph method was used to determine the design flood for the project. Hydrologic studies were undertaken for recurrence intervals of 2.5, 5, 10, 25, 50, and 100 years and the final choice was based on the cost estimates of preliminary designs. The 25-year flood was subsequently chosen as the design basis for the project. However, freeboard clearance has since allowed larger floods to be passed safely.

Five basic criteria for the project were:

1. The last 4,000 feet of the channel, which had been intensely encroached upon, had to be built underground to prevent interference with existing commercial activities and to avoid placing limitations on future city planning.
2. Project cost could not exceed the $2.3 million bond issue.
3. New construction on 20 acres of state-owned property which borders the channel should result in an aesthetically pleasing park area and open space for the citizens.
4. Channel construction must be on city right-of-way whenever possible to avoid the added cost and problems of land and building acquisition.
5. All new construction must be designed not only to reduce the flood hazard and erosion problems but also to improve neighborhood aesthetics as a means of encouraging new well-planned buildings and landscaping.

As a result of these criteria, the final design was prepared with the following features:

1. The 4,000-foot underground conduit was designed as a 12-foot diameter concrete culvert. Alternate designs included an equivalent cast-in-place concrete box culvert and a prestressed concrete box culvert. Bidding on all three alternatives resulted in the choice of the cast-in-place concrete box culvert. The design called for the conduit to have open channel flow at all flow rates. The conduit has a progressively steeper slope as it approaches the river, following the natural terrain and providing velocity acceleration. Air breathers are provided approximately every 330 feet. These increase conduit efficiency by allowing rapid expulsion of air during a period of increasing flows and admission of air during times of decreasing flow. Each air breather can also release water to the street above should the conduit become blocked or surcharged. The main safety control on the culvert capacity limitation was a specially designed inlet.

A model of the hydraulics of the inlet was prepared and studied at Colorado State University. Inflows were to be limited to 2,100 cfs, and maximum velocity in the conduit was to be 21 fps.

2. An inlet to the conduit was designed to accelerate as well as limit the flows into the conduit. Any excess flow would be routed to the river along a paved street.

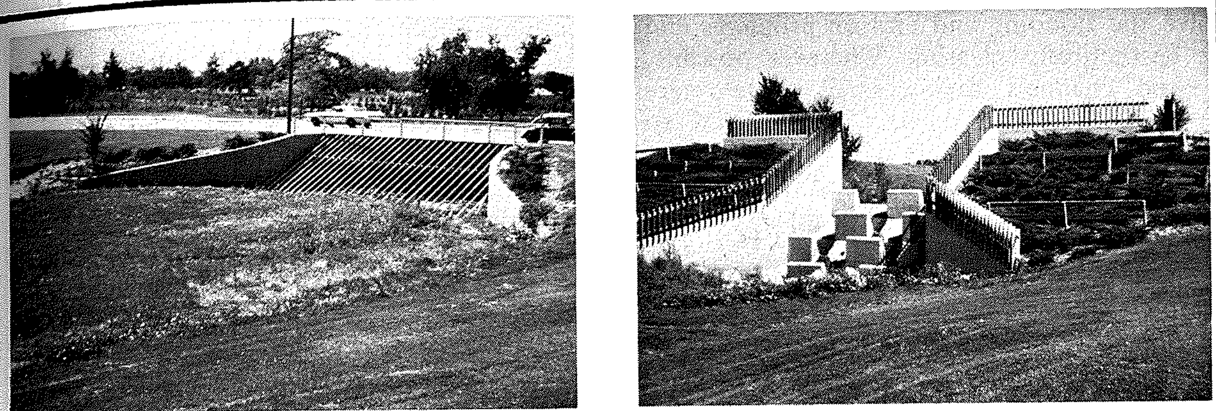
3. A detention basin was installed upstream from this inlet on the state-owned property. The detention basin was designed to handle high water flows that would spill over a low side-channel spillway into the basin – to be released when water levels recede. Figure 25, East Harvard Gulch Project, shows the energy dissipator and inlet to the box culvert.

The detention pond was designed to reduce peak flows from 1,970 cfs to 1,600 cfs by storing about 12 acre-feet of water during flood stages. Besides serving for stormwater detention, a permanent pond was constructed for recreational purposes and to enhance area aesthetics.

4. Upstream from the detention basin, a concrete spillway was built with an energy dissipator. This reduced the energy of the approaching runoff flow and the slope of the downstream channel bed, allowing it to be planted in grass, with maximum flow rates of 7.5 fps. This was done to reduce erosion of this channel and to provide a scenic area. Figure 25 (b) shows the energy dissipator.

5. Upstream from the spillway, a 0.5-mile long high-velocity concrete channel was constructed. A narrow channel was needed because of the limited right-of-way owned by the city.

6. A slow-flow grassed channel was designed for the last portion of the channel improvement, upstream of the high-velocity concrete channel. A grassed channel was chosen because it fit in better with



a. inlet to box culvert

b. energy dissipator

FIGURE 25 EAST HARVARD GULCH PROJECT

neighborhood aesthetics, was less expensive, and the slow flow would increase the time of concentration of runoff flows and decrease downstream peak flow rates. This section would also provide channel storage, further reducing peak flows downstream.

7. All bridges (there are 21 bridges crossing the East Harvard Gulch) were designed to withstand the full dynamic force of high-velocity flows that may result from a blockage or a flood much larger than the design flow. This would cause local flooding instead of passing the flow downstream rapidly – which would cause a major flood in the more densely populated areas downstream. For the bridges constructed over the grass channels, freeboard was kept to a minimum, and on some bridges freeboard was eliminated altogether. In this region, the objective was to create local ponding of water behind the bridges during any storm larger than the design storm without losing the bridges.

Furthermore, all bridges were built with streamlined shapes to reduce the debris collection problem.

8. Collapsible trash racks are used at the entrance of both the enclosed conduit and at the high-flow concrete channel. They were designed to be collapsible to prevent unnecessary local flooding problems that would result from plugged racks.

Construction took place in three stages, progressing from the downstream end to the upstream end. This was done to insure that sufficient water-carrying capacity existed downstream prior to making upstream improvements which would produce increased flow rates. Extensive excavations were required. Cuts of 22 feet deep were made in streets for box culvert construction. Disposal of some of the 120,000 cubic yards of excess earth was accomplished by regrading the state-owned land and filling private lots along the construction route. The remainder was saved for future city projects. Broken concrete from other city projects was recycled to the project for underground emergency barriers to control erosion during unprecedented events. Construction was completed in 1967, in time for Denver's wettest year in history.

Summary: The East Harvard Gulch flood control project in southeastern Denver solved problems of flooding and soil erosion with a variety of experimental techniques. In 1969 the facility handled peak runoff flows of 2,000 cfs and functioned very well. The project was limited in funds provided by a bond issue, and limited by the constraints of intensive encroachment on flood plains. In some areas, land developments totally occupied the normal channel, causing the runoff flows to use the streets as channels.

It was decided that this project had to solve the flooding and erosion problems and be aesthetically pleasing. Wherever possible, grassed channels having small slopes were used. Baffled chutes were constructed to dissipate the high energy of the runoff flows produced by differences in elevation along the channel length. Detention storage of high flows was provided for on state-owned property in a park-like setting. Local ponding of flows above the 25-year design rainfall was encouraged by bridge construction with little or no freeboard above the water surface. Laboratory model studies were conducted to test the functioning of an enclosed conduit inlet in order to produce a design which would optimize the efficiency of the conduit.

Boulder, Colorado

The problems resulting from stormwater runoff in Boulder, Colorado are accentuated by the hilly terrain and the city's location in the foothills of the east slope of the Rocky Mountains. Because of this location and the terrain, stormwater runoff from both the mountains and the urban area can cause great damage due to both the high velocities and the large volumes of runoff flows. Boulder has adopted the use of on-site stormwater detention along with other means for managing runoff.

The City of Boulder recognizes two distinct parts of the drainage system. One is the major drainage system consisting of all natural drainage channels, paths and outfalls; the other is the secondary (collection) system which receives stormwater runoff from the minor storms and conducts as much of it as its capacity permits into the major system.

Design criteria were adopted by the city for the flood-handling characteristics of the two types of drainage systems. All components of the major system are to be designed to handle the 100-year rainfall event. The secondary system components are assigned design rainfall requirements according to land use and property value. In high-intensity use and high property valuation areas, a 10-year return period is used for the design rainfall. In single-family residential subdivisions, the 2-year rainfall is used; and in other areas within the city, a 5-year return period is specified.

The maximum allowable release rate of stormwater from temporary storage in detention facilities is computed by either of two methods. In one method, the pre-development runoff flow-rate is used as the maximum allowable rate. The Rational Formula is used to compute the permitted release rate. Values of C and i are obtained from standardized information provided by the city in the form of graphs and a table. The other method sets the limit on the allowable release rate based upon the percentage of various types of land use areas planned within the proposed development. Information concerning the determination of permitted release rates was given in Chapter 3.

Detailed design instructions are given by the city for computing detention storage volume requirements. Several techniques are available for providing on-site detention facilities. Of these, rooftop storage is considered one of the best alternatives where building design lends itself to this method. Other methods include detention in depressed areas in parking lots or landscaped areas, and collection of runoff in wet wells which are used to recharge the ground water table through release of the stormwater.

Examples of stormwater management facilities in Boulder are shown in Figure 26, Detention Facilities – Boulder, Colorado. Figure 26a shows a series of low check dams installed across a stream to control flow velocities of the mountain stream. Figure 26b illustrates the use of the open space of an apartment building complex for detention of stormwater. Storm sewer inlets with restricted capacities are installed in low spots in grassed areas and in parking lots.

Enforcement of the rules for stormwater detention is accomplished by means of subdivision regulations, building regulations, and a fee system.

In a new development that requires land subdivision, plat approval is contingent upon including facilities for on-site detention of stormwater. In a case where only a building permit is required, the developer must include on-site stormwater detention in the plans

a. check dams across a stream, through an urban area in Rocky Mountain foothills

b. storm sewer inlets in grass areas restrict inflow rates

FIGURE 26 DETENTION FACILITIES – BOULDER, COLORADO before a building permit is issued. In all cases, drainage design must be done by a registered engineer and plans are checked by the city hydraulics engineer.

Opposition to the requirement for detention storage came from architects who complained about the added design restriction – and from builders who would submit plans for detention storage facilities, but would not actually build these facilities. An educational program explaining the advantages of on-site stormwater detention overcame the objections of architects. Inspection of buildings prior to final construction approval resolved the problems with the builders.

An added method of securing compliance for the use of on-site detention is a fee system by which a service charge is levied monthly against every lot to pay for upgrading the public stormwater drainage facilities. The service charge is based on the flow rates of runoff from each lot draining into the system. Two factors used in computing the annual fee for a specific piece of real estate are the square feet of area and the computed coefficient of runoff. Boulder specifies a formula for calculating the fee as explained in Chapter 2. In many cases, it is beneficial to a landowner to reduce runoff to lower his service charge.

Boulder has adopted a flood plain zoning ordinance which forbids development of buildings and most other permanent structures within the limits of the flood plain of a 100-year rainfall event. Permitted in the flood plain areas are recreational facilities, wildlife preserves, agriculture, open pit mining, utility transmission lines of some types, and certain commercial and industrial uses such as material-loading facilities and railroad rights-of-way.

Summary. The initial results of Boulder's program to control stormwater runoff by means of on-site detention have been good. Flooding from rainfalls of the 2-year and 5-year frequency in problem areas of the older parts of the city have been greatly reduced or eliminated. Maintenance of nuisance areas after small rainfalls has also been reduced greatly.

Five basic steps followed in setting up Boulder's program to manage runoff are:

1. development of a set of criteria in the areas of policy, law and design;
2. development of a complete master plan for every drainage basin involved, giving the proper direction for the assignment of priorities;
3. adoption and enforcement of necessary ordinances to provide flood plain zoning, management, and flood insurance until the program is completed;
4. provision of a financing program to allow program implementations; and
5. provision for multi-purpose use of drainage areas for open space, green belts, detention storage of runoff, and recreation – including bike paths, horse riding trails and play areas.

Metropolitan Sanitary District of Greater Chicago

Because of the flat topography of Metropolitan Chicago, the area has poor natural drainage. The rapid pace of urban development has compounded existing flooding problems and caused significant increases in flow rates and volumes of stormwater runoff which must be handled by the natural waterways.

Concern for flood control in the metropolitan Chicago area began in the early 1900's when the flow of the Chicago River and the Calumet River were reversed away from Lake Michigan. Continued concern for flood control resulted in the request by the Metropolitan Sanitary District of Greater Chicago that builders and developers voluntarily provide temporary storage of rainfall on parking lots, roofs and open spaces. This program, begun in about 1967, fell far short of controlling the added runoff resulting from increased urbanization. More stringent requirements were obviously needed and the MSD, which has jurisdiction over sewer systems in all of Cook County, initiated a program aimed at developing effective management of runoff.

Following the adoption of a resolution passed by the Board of Trustees of the MSD, an amendment to the District's Sewer Permit Ordinance was adopted to require provision of stormwater detention facilities as a prerequisite to obtaining a sewer connection permit. This requirement, which applies to new construction in unsewered and separately-sewered areas within the District's jurisdiction, became effective January 1, 1972. The action was based upon the fact that there would be further aggravation of flooding problems and creation of new flooding problems if steps were not taken to provide for additional stormwater detention in new land developments.

Basically, the resolution adopted by the district was a "policy statement for flood control." It contained a request that the Governor of Illinois direct the appropriate State department to: (1) establish a flood control program for the state based upon the principle of detaining stormwater runoff at or near its source; (2) regulate and control stormwater flows that pass from one county to another by establishing maximum flows at county lines; and (3) regulate and control stormwater runoff from all improvements in the drainage basin that are ahorized (including federal, state and local road improvements) through the issuance of permits by the State Department of Public Works and Buildings, by requiring that permittees construct and maintain storm detention facilities capable of storing runoff from the storm of record.

The amendment to the Sewer Permit Ordinance is not an attempt to solve the flood problem in total. Actions under the amendment must be coordinated with other programs – such as better management of floodplain areas, construction of detention reservoirs to replace some of the lost storage potential, and provision of storage for the runoff issuing from existing developments. The District is now constructing reservoirs to help alleviate flooding caused by existing developments.

The District has also undertaken a major planning effort in conjunction with the U.S. Soil Conservation Service. This includes the preparation of detailed plans for implementation of flood control projects throughout the Chicago Metropolitan Area. Neighboring counties and states are being included in this planning work.

Prior to adoption of the amendment to the Sewer Permit Ordinance, a subcommittee of a specially-appointed Blue Ribbon Committee studied the proposed action. In addition to recommending adoption of the amendment, the Subcommittee urged the establishment of a Flood Control Coordinating Committee which would act to set responsibility, budgets and policy for flood control improvements on a region-wide basis. In addition, the Subcommittee recommended the establishment of Basin Steering Committees to develop the planning of flood control facilities within the respective drainage basins.

The essence of the findings of the Subcommittee was that the natural waterways in the Chicago area are very restricted in their capacities to discharge water and that their carrying capacity for the average annual flood is approximately 0.022 cfs/acre of tributary drainage area. Based upon this capacity of the natural waterways, the District staff prepared the details of the amendment.

Computations are based upon the Rational Formula for determining the two critical factors in providing detention storage; namely, (1) the "release rate" that is allowed for off-site discharges, and (2) the "volume of on-site detention storage" to be provided.

The maximum release rate is the equivalent of the runoff from a 3-year return frequency storm occurring on an undeveloped site having a runoff coefficient of 0.15 for use in the Rational Formula. The rainfall frequency rain occurring on an undeveloped National Weather Service Technical Bulletin No. 40. The time of concentration guidelines were prepared by the staff of the District. These, generally, conform to the standards of the U.S. Army Corps of Engineers.

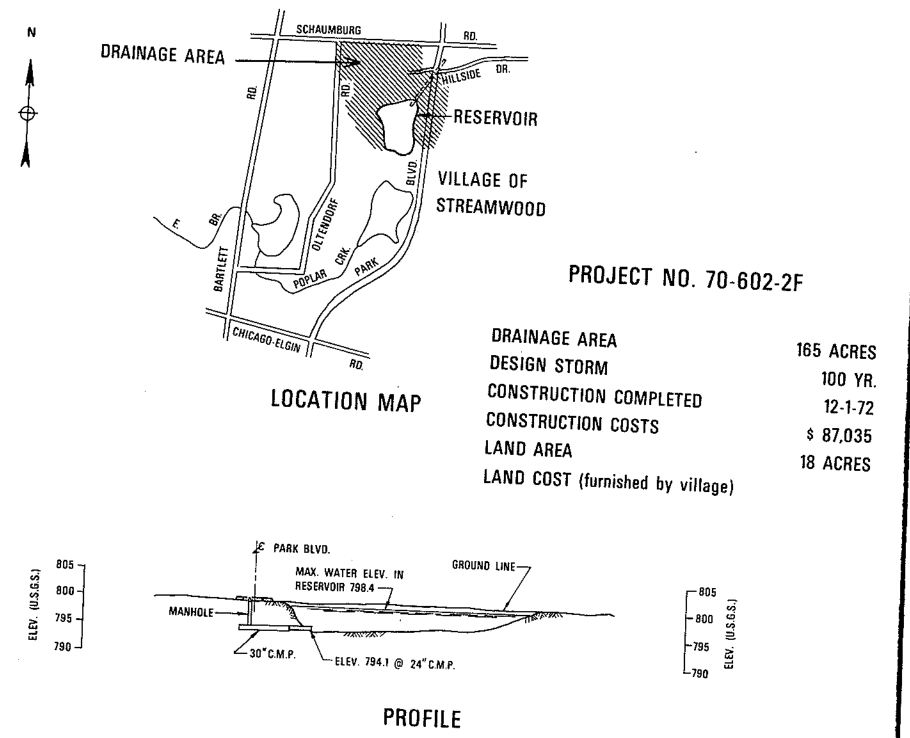
Detention storage volume requirements are calculated based upon the runoff from the 100-year design rainfall on the "fully-developed" site, diminished by the volume of runoff computed using the permitted release rate. A formula for calculating the required "live detention storage" is included in the amendment.

The amendment provides an exclusion when dealing with small parcels of land – under five acres for commercial developments, under 10 acres for residential, and residential development between five and 10 acres where the impervious area is below 60 percent of the total area of the site.

An information pamphlet has been developed for use by architects, engineers, etc., to meet the requirements of the ordinance. This information is reproduced in this report in Appendix D.

In addition to requiring the construction of on-site detention facilities for new developments, the MSD has also constructed or financed large detention reservoirs to handle the runoff from existing problem areas. Examples of such facilities are shown in Figure 27, Detention Facilities, Metropolitan Sanitary District of Greater Chicago. The standard event used for design is the 100-year rainfall. The MSD usually financed construction costs, although the land was most often furnished by the local government.

Melvina Ditch Detention Reservoir. An example of a large-scale municipal multi-purpose stormwater detention facility is the Melvina Ditch Detention Reservoir (Figure 27f) constructed by the MSD at a cost of $892,000. This project is unique not only in terms of its size and multi-purpose nature but because it has a pumping station rather than gravity outflow from the reservoir. The basin, which is 21 feet deep, covers 11.5 acres and has a capacity of 165 acre-feet of storage. It serves a four-square mile drainage agea, principally residential, and was designed to accommodate a 10-year rainfall event. Actually, it is the 100 cfs capacity of the downstream ditch which limits the flood protection potential of the reservoir. Planned improvements of this ditch and construction



a. Hillside Park retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

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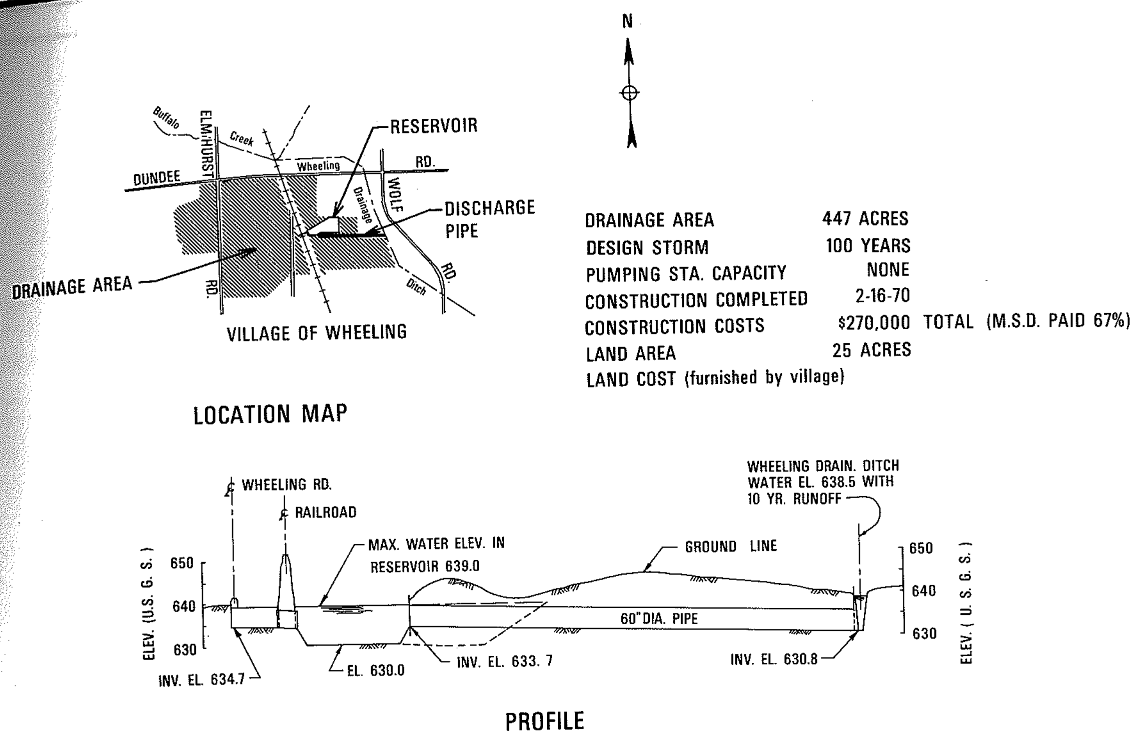
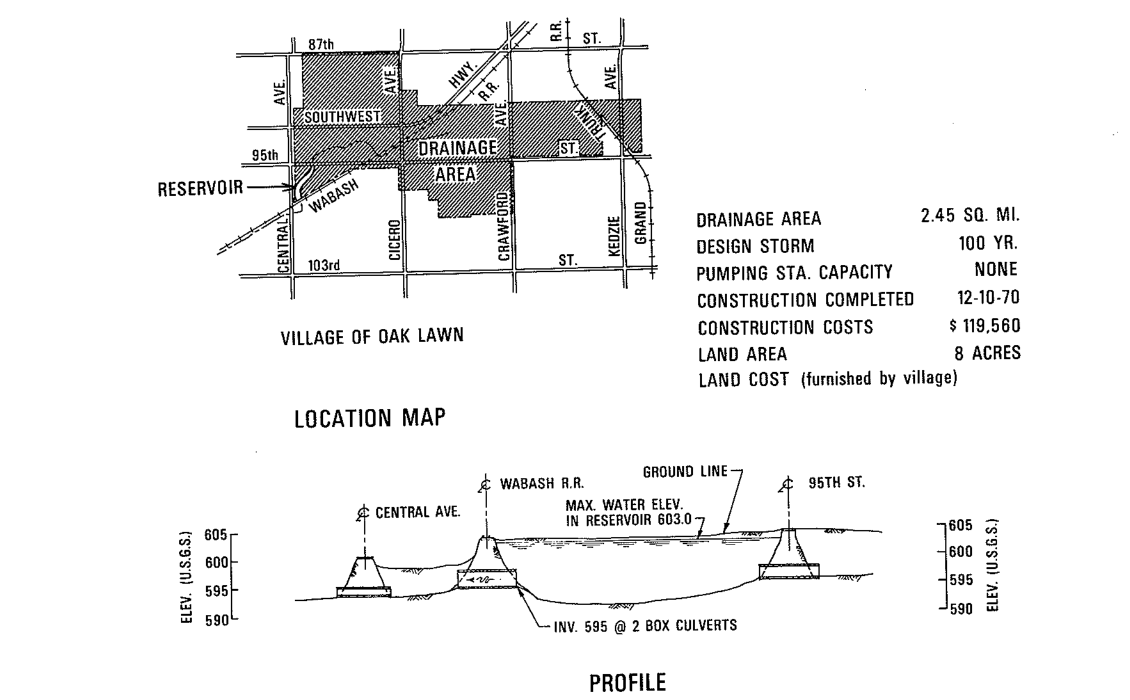
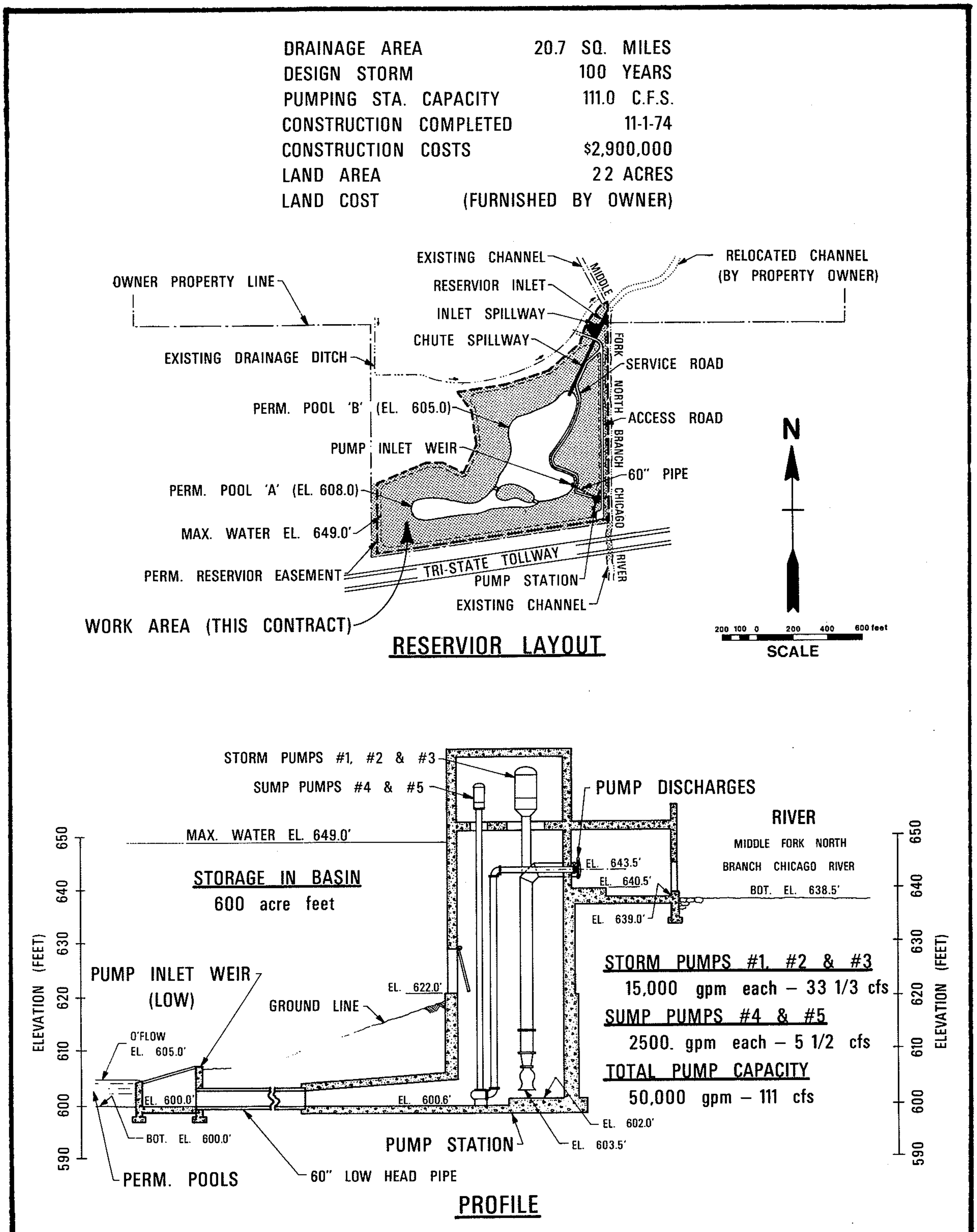


b. Heritage Park West retention reservoir



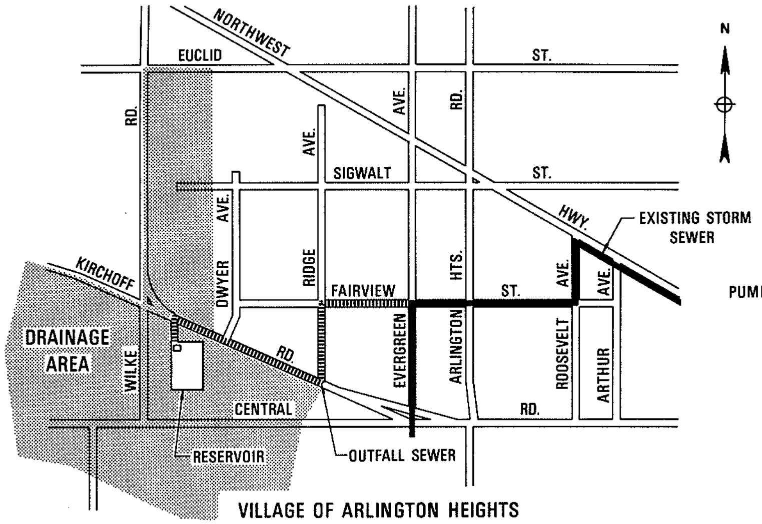
c. Oak Lawn retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

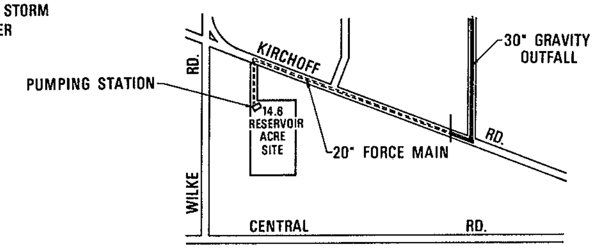


d. Middle Fork North Branch of the Chicago River reservoir

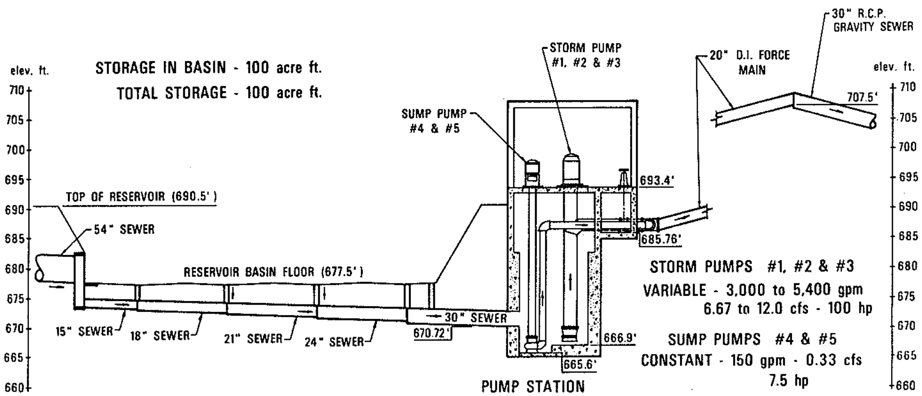
FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO



LOCATION MAP



RESERVOIR LAYOUT

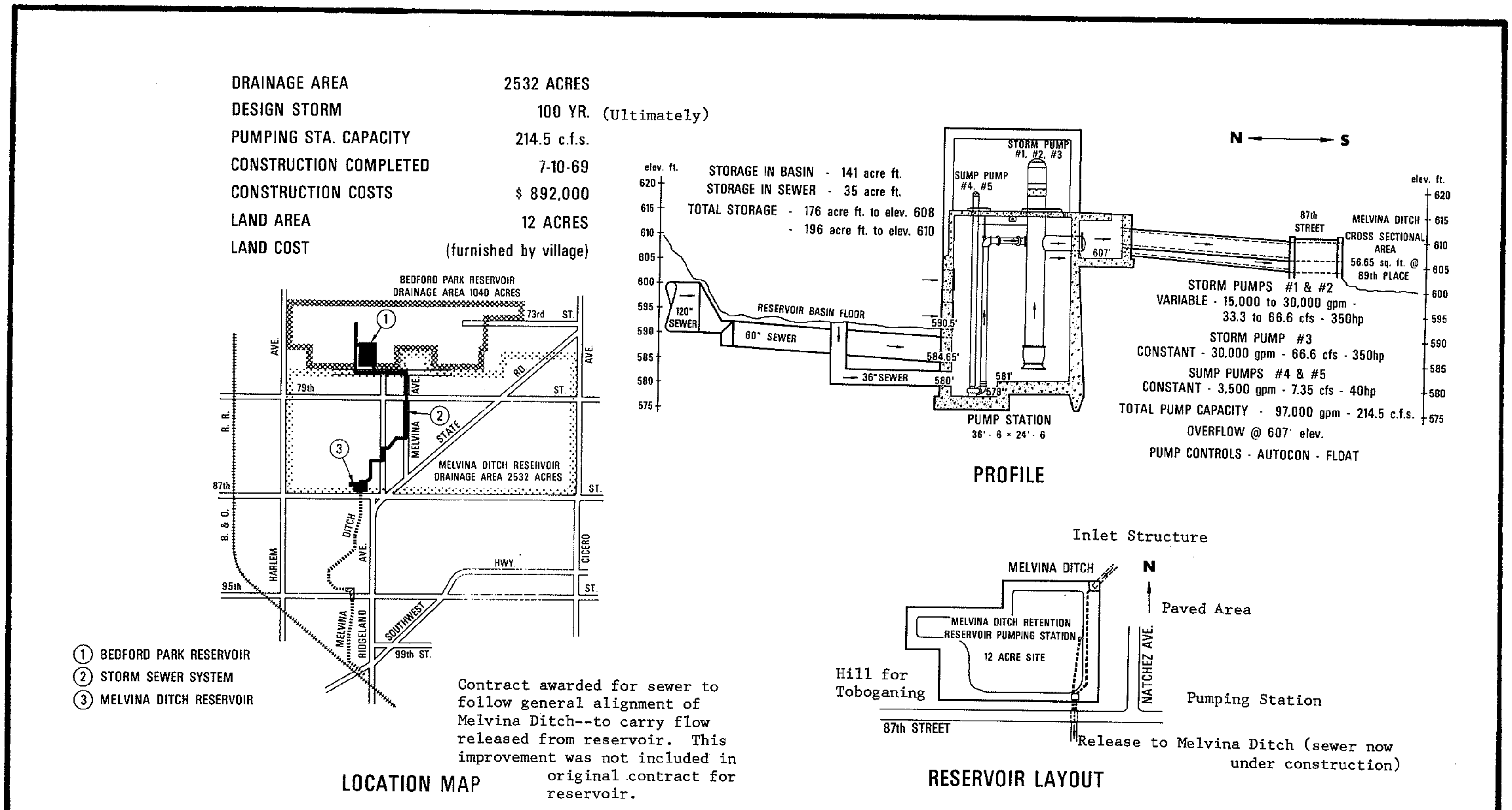


PROFILE

DRAINAGE AREA	717 ACRES
DESIGN STORM	100 YR.
PUMPING STA. CAPACITY	36.7 c.f.s.
CONSTRUCTION COMPLETED	
CONSTRUCTION COSTS	$ 871,000
LAND AREA	14.6 ACRES
LAND COST	$ 232,000

e. Wilke-Kirchoff retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO



f. Melvina Ditch retention reservoir

FIGURE 27 DETENTION FACILITIES – METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

of an additional reservoir upstream will enable this system to accommodate the runoff from a 100-year rainfall.

The basin was dug out of a clay soil which provides a tight seal. The bottom is grass, and the grassed sides with 4:1 slopes are enclosed with an 8-foot chain-link fence. The pumping station, located at one corner of the basin, contains three 66 cfs pumps and two 7.5 cfs low-flow pumps. These pumps could empty the full basin in 12 hours; however, because of downstream flow limitations, a period of 24 hours is currently required. After most rains, the basin is pumped dry in four to six hours.

Storm sewers draining the tributary area carry the runoff into the basin through a concrete inlet structure located at a corner of the basin, remote from the pumping station. Upon being discharged from the inlet into a sloping concrete chute, the flow is directed to a 100 x 200-ft concrete-paved area installed to prevent erosion of the basin bottom. At low flow, the runoff drops through a grate in the inlet structure and is guided to the pumping station through a 60-inch diameter underground pipe. This allows low flows to by-pass the basin, leaving it dry during low-flow periods. This enhances the multi-purpose use of the facility.

A reverse-crown concrete roadway, located in the bottom of the basin, extends from the basin inlet structure to the intake of the pumping station. This serves as a roadway for maintenance trucks and as an erosion prevention channel for runoff inflows that exceed the low-flow capacity of the underground pipeline. When the basin begins to fill, the paved areas become completely submerged; and, with further increase in water depth in the basin, the inlet structure is also submerged.

The detention basin was designed to serve as a recreation facility in addition to its primary function of reducing local flooding. Steps were constructed down the basin side slope for access to the basin bottom. Winter activities include tobogganing and skiing on a large earth mound constructed in one corner of the basin, using excavated materials. The concrete-paved area in the basin is flooded during winter months to serve as an ice-skating rink. During summer months, it is used for volleyball, basketball and general play. All recreational activities are supervised by the South Stickney Township Park District under an agreement between the Park District and Sanitary District for use of the property for recreational programs.

The reservoir was built as part of a cooperatively-financed general drainage improvement in the area. When completed, the improvement will consist of: (1) storm sewers upstream of the reservoir provided by the South Stickney Township Road District at a cost of $4.5 million; (2) the Melvina Detention Reservoir and downstream channel modifications provided by the Sanitary District at a cost of $1.9 million; and (3) downstream channel modifications provided by the Village of Oak Lawn, at a cost of $500,000. Without these improvements, programs for street paving with curb and gutter, elimination of roadside ditches, and general upgrading of neighborhood conditions would have been impossible.

Since the completion of the Melvina Detention Reservoir no flood damage has been reported downstream or upstream of the facility. Recently, this basin took runoff from a 10-year rainfall event lasting for six hours, with the pumps inoperable. There was no downstream damage. It is estimated that this detention basin cost about one million dollars less than it would have cost to construct large storm sewers to an adequate outlet located about two miles downstream.

Analysis of Program Effectiveness. An analysis of the effectiveness of the MSD program was made in July, 1972, by the Sanitary District staff. Prior to January 1, 1972, the date that the amendment to the Sewer Permit Ordinance became effective, it was estimated that there existed a total runoff detention deficiency of 35,044 acre-feet. It was estimated that the cost of providing the needed detention capacity would be about $5,500 per acre-foot or a total cost of $192,742,000.

In the three-year period, 1969-1971, immediately preceding the requirement for land developers to provide detention facilities, an average of 1,181 acre-feet of detention capacity was added annually. During this period, other land development (where detention facilities were not provided) produced an increase in stormwater detention deficiencies estimated to cost about $6,500,000, annually, for correction.

For the period of January 1, 1972, to June 28, 1972, a total of 570 sewer permits were approved, representing developments that served a population of 40,926. The construction produced 1,305 acres of impervious area. A total of 253 acre-feet of detention was provided, leaving a net detention deficiency of only 74 acre-feet estimated to cost $407,000. If these results are extrapolated for the entire year (1972), the net added detention deficiency would require expenditures of about $815,000 for correction, compared to $6,500,000 estimated average annual costs that would have been required to correct detention deficiencies created annually in the preceding three years. This shows conclusively that the program has been very successful in reducing the rate at which flood hazards are being added annually by urban development. The MSD keeps accurate records of new developments, impervious area, detention capacity required for a 3-inch stormwater runoff, and the amount of detention volume provided. This is done for each of the nine drainage basins that affect the operations of the District.

Summary. The Metropolitan Sanitary District of Greater Chicago assumed an active role in stormwater management in the 1950's, although the District has had interest in controlling flooding since the early 1900's. Modern techniques employed and planned by the MSD include detention of stormwater runoff in large surface reservoirs, underground tunnels and on individual land developments. On-site detention of runoff is required for obtaining sewer connection permits in new developments exceeding specified acreages.

The MSD is building detention basins to reduce flooding in existing developed areas. Preliminary results of a recent amendment to the District's Sewer Permit Ordinance are very encouraging. Most aboveground detention facilities have been designed for multiple-purpose use. This has added to their desirability and acceptance by residents of nearby communities.

Arlington Heights, Illinois

Arlington Heights is a Village of 73,000 population located in Cook County, Illinois, all of which falls within the jurisdiction of the Metropolitan Sanitary District of Greater Chicago. Therefore, the rules of the MSD, including the requirements and provisions of the District's Sewer Permit Ordinance, are applicable to the Village. In addition, the MSD has encouraged municipalities in their jurisdiction to adopt local legislation requiring on-site detention of stormwater in new developments. This encouragement led to the adoption of a stormwater detention ordinance in Arlington Heights. The District is also urging local governments in Cook County to develop master plans for stormwater management for review and approval by the District.

Arlington Heights requires that detention facilities meet the MSD requirements and criteria in order to obtain village approval of any plat submitted for subdivision of land. The requirement for on-site detention of stormwater is coupled with a village flood plain ordinance which has met the approval of the MSD. With the backing of the District, the ordinance has operated satisfactorily and it has the flexibility to allow the details of storage to be planned jointly by land developers and the village engineering department.

About 12 major detention facilities have been built, or are in the planning stage, in Arlington Heights. The largest, costing $1.1 million and providing 100 acre-feet of storage, is the Wilke-Kirchoff Retention Reservoir which is being constructed in cooperation with the MSD of Greater Chicago. The 100-year rainfall was used in designing the facility which will serve a 717-acre drainage area. The reservoir will be emptied by pumping, using three pumps having a capacity of 5,400 gpm, and two 150-gpm sump pumps. Other detention facilities in Arlington Heights include the use of tennis courts and permanent ponds located in residential complexes.

Figure 28, Detention Facilities, Arlington Heights, contains photographs of a permanent pond in an apartment complex. This is a multi-purpose detention facility as is evidenced by the children shown readying a pole for fishing. Also shown is a photograph of a tennis court at an apartment complex. The stormwater inlet and the open flow channel can be seen at the bottom of the ponding area. The grassed slopes along the sides of the tennis courts, which form the sides of the detention pond, are flat enough to permit power mowing.

Residents of Arlington Heights seem to prefer the use of permanent ponds for stormwater detention because of the aesthetic appeal. In agreement with this, village officials feel that permanent ponds require less maintenance than do dry basins.

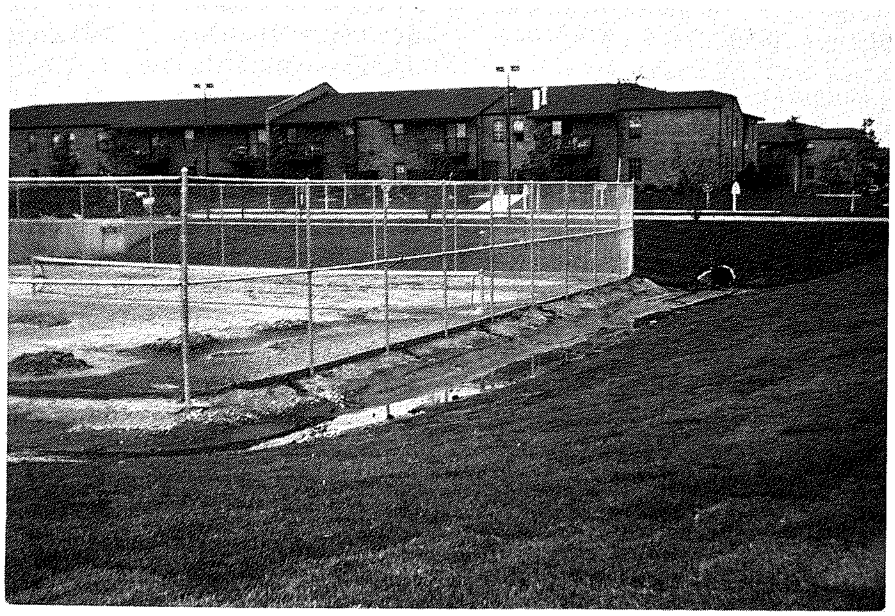
Maintenance responsibilities of the village for publicly-owned detention facilities are limited to maintaining the structures, while the Park District provides the ground maintenance, such as the grass mowing. A unique feature of one permanent-type detention pond is a wind-actuated stirrer which aerates the water, thus reducing the opportunity for algae growth.

Summary. Arlington Heights, a large village in Cook County subject to the regulations of the MSD of Greater Chicago, has passed ordinances concerning flood plain zoning and on-site detention of stormwater to combat problems of flooding from surface runoff in the village. The ordinance on stormwater detention is not detailed and can be administered flexibly. This makes it possible for the village engineering department to work with land developers in planning and providing stormwater detention facilities. Such cooperation has worked well.

The only major difficulty that the village engineer has reported in administering the village's stormwater detention program is with the use of runoff formulas, such as the Rational Formula, that do not allow for the relatively-low infiltration that occurs during intense rainfalls. During these periods, the runoff rate can be much greater than the values computed using the Rational Formula.

a. detention pond in residential area

FIGURE 28 DETENTION FACILITIES – ARLINGTON HEIGHTS, ILLINOIS



b. stormwater runoff is collected on a tennis court

FIGURE 28 DETENTION FACILITIES – ARLINGTON HEIGHTS, ILLINOIS

Mount Prospect, Illinois

The Village of Mount Prospect, Illinois has a population of 50,000 persons and is located in Cook County, within the jurisdiction of the Metropolitan Sanitary District of Greater Chicago. In response to the requirements for stormwater detention adopted by the MSD, the village passed an ordinance in 1971 requiring on-site detention of stormwater.

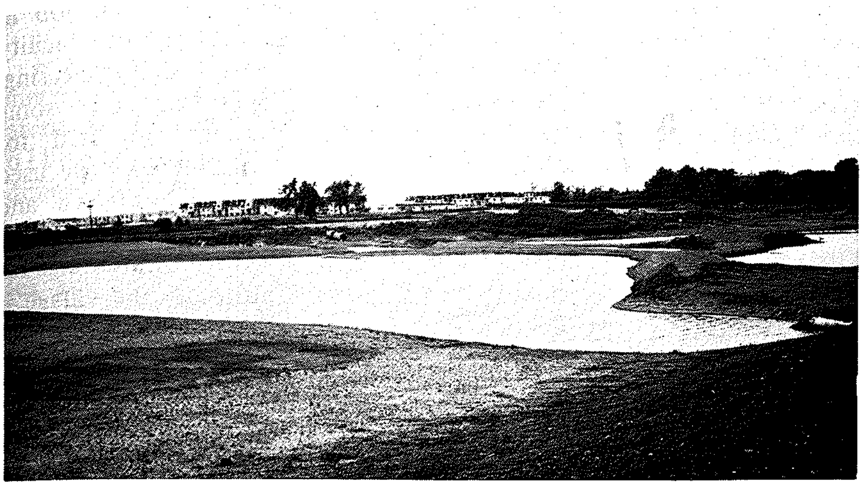
This ordinance generally follows the criteria set down by the MSD, but is more stringent in that it requires on-site detention for all commercial and industrial developments, regardless of size. Residential developments must exceed five acres to require detention storage; whereas, the district's requirements generally stipulate 10 acres for residential developments. Storage may be of any suitable type, as long as the basic criteria are fulfilled.

Residential developments have turned to the use of permanent ponds in open spaces for temporary storage of stormwater on development sites. These ponds serve multiple purposes such as boating, fishing, swimming, and ice-skating. They also improve the aesthetics of these land areas.

The largest of these permanent ponds is known as Clearwater Park. It has a storage capacity of about 178 acre-feet and controls the runoff from a 780-acre tributary drainage area. The pond was constructed in conjunction with a new housing development by means of the joint efforts of the village, park district and land developer. It is owned by the village and the park district. Figure 29, Detention Facilities, Mount Prospect, shows part of the pond, which maintains a permanent level of water. This beautifully landscaped pond is in direct contrast to the other photograph which shows a detention facility that was constructed by excavating a basin on three adjacent residential lots.

A total of about eight detention ponds in residential areas have been constructed or are in the planning stage in Mount Prospect. For some, ownership will be turned over to the park district, while for others the facility will remain the responsibility of the developer. If proper maintenance is not performed to control weeds, the village will perform the maintenance and charge the owner.

Commercial and industrial developments of all types and sizes, from gasoline stations and hamburger stands to large commercial



a. Clearwater Park detention pond

b. detention basin on three residential lots

FIGURE 29 DETENTION FACILITIES – MOUNT PROSPECT, ILLINOIS

developments, must provide on-site stormwater detention for the 100-year design rainfall. The use of storage in large sewers is discouraged and is expensive, and sheet flow to the streets is not allowed. Architects have been wary of rooftop storage. As a result, commercial developments have turned to the use of parking lots for stormwater detention.

Because of the possible disadvantages of rooftop storage, as seen by local architects, few such facilities have been built. The village, however, views rooftop storage as a desirable detention method and has information describing the safety features of rooftop storage and cost reduction attributable to the use of smaller roof drain leaders. Part of this savings can be used to provide better waterproofing for rooftops. Structural designs do not need to be altered, since the maximum storage of three inches of water is equivalent to a live load of only 15 pounds per square foot. The local building code specifies that roofs shall be designed for a minimum live load of 30 pounds per square foot.

Part of the flooding problem in Mount

Prospect is caused by the surcharging of sewers from high water levels in the local creeks. To alleviate this problem, the Division of Water Resources Management of the State of Illinois has begun to dredge the creeks, removing obstructions and debris and increasing flow capacities up to 100 percent. Deep tunnel storage of combined sewer overflows and the construction of a new treatment plant near O'Hare Airport are also proposed by the MSD of Greater Chicago to solve the flooding and pollution problems.

Summary. In Mount Prospect, completed detention facilities are doing their job in meeting design criteria, although one facility was not built to be aesthetically pleasing. Permanent ponds in open spaces of some residential developments are used for stormwater detention. Parking lots are used for storage of rainfall in commercial and industrial developments. Architects are cautious about using rooftops of buildings for detention of rainfall, although the village is encouraging the use of this method.

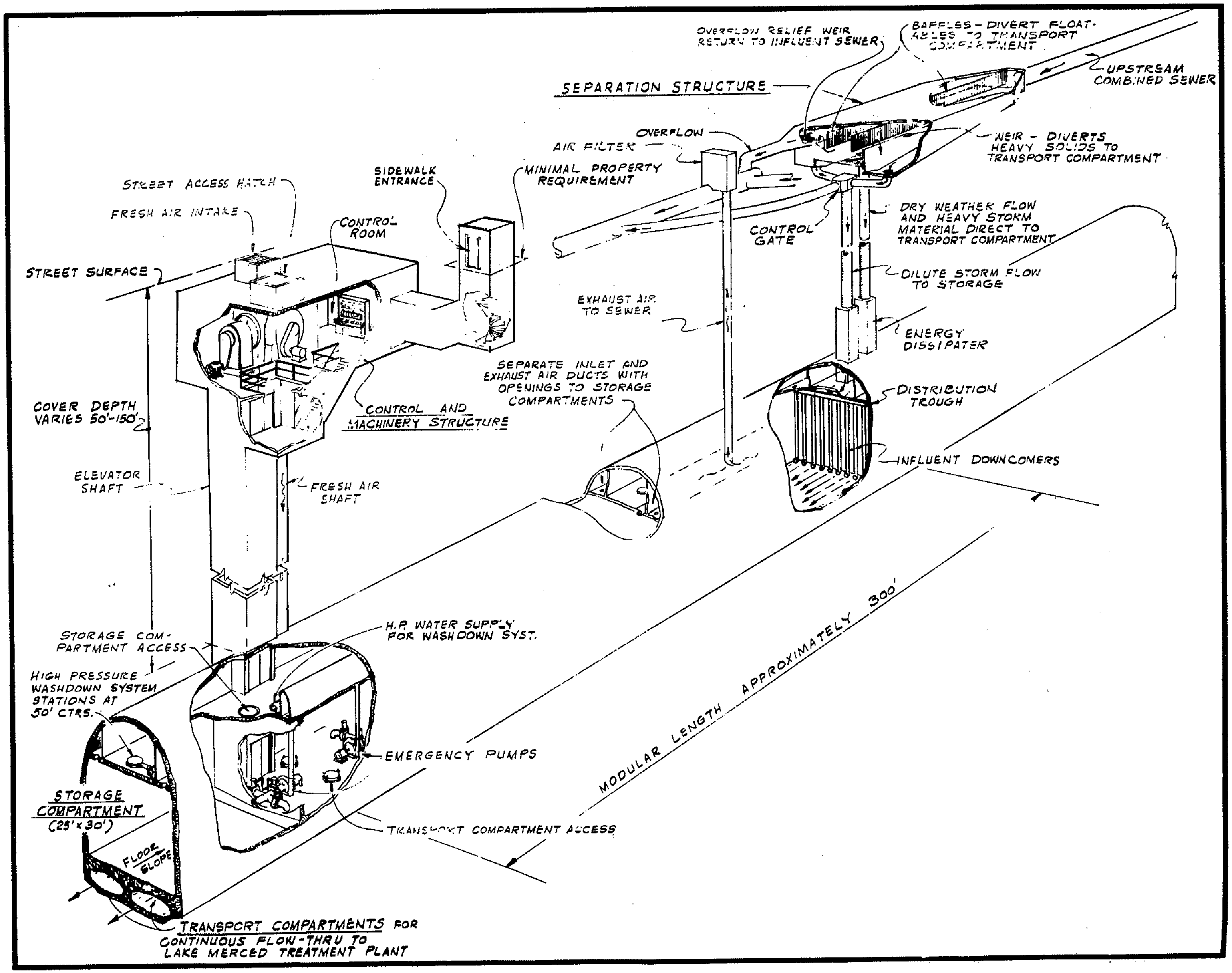


FIGURE 58 TUNNEL PERSPECTIVE

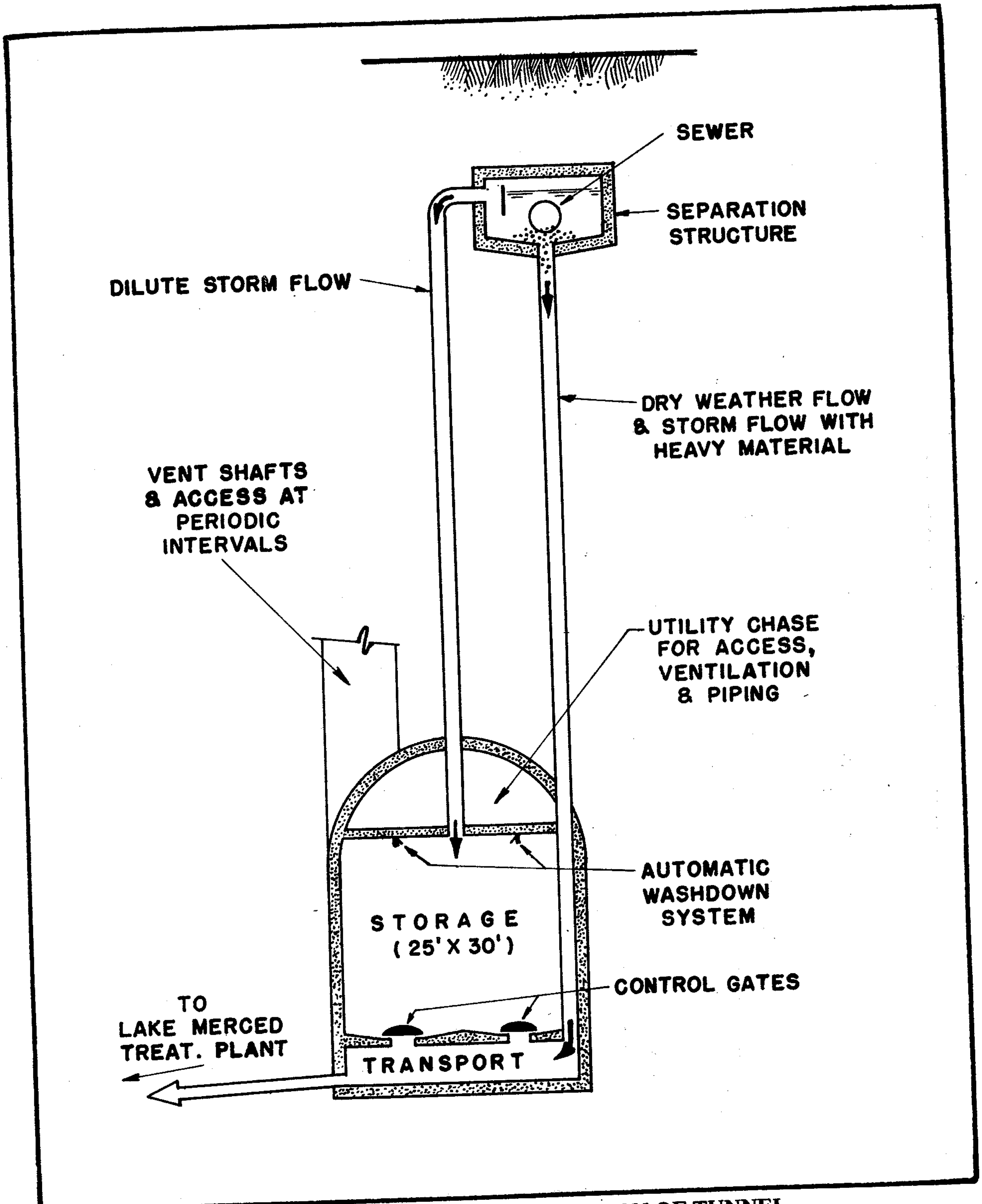


FIGURE 59 SCHEMATIC SECTION OF TUNNEL

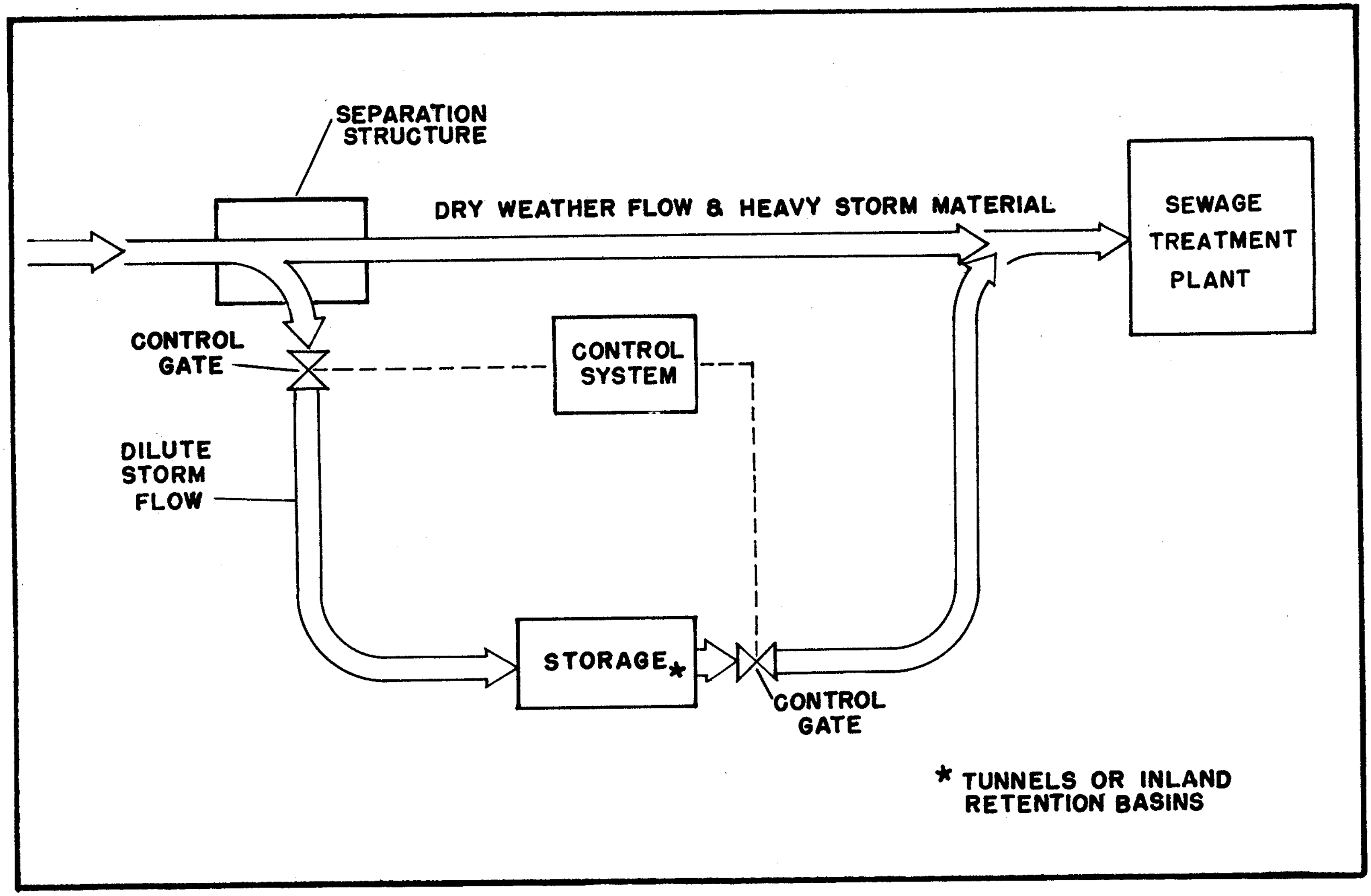


FIGURE 60 SCHEMATIC DIAGRAM OF WET WEATHER CONTROL

outfall. Included in the tank compartments will be a spray system to wash the interior surfaces of the tanks. A forced air ventilation system will provide air exchange which will exhaust into the interceptor sewer for release at the treatment plant. Control will be unattended and automatic through the master control system.

Upstream basins will be operated in much the same manner. Sanitary flow will be contained in the sewer and routed on to the sewage system downstream. The internal features of the tanks are similar in concept to the shoreline tanks except that the outlet will be a gravity sewer, with a controlled flow rate, to reenter the existing sewer downstream. The individual tanks will each have a spray system for cleaning interior surfaces and an exhaust ventilation system. Figure 61, Inland Basin Perspective, is an example of the structure.

The system will interconnect all storage facilities. This will allow a transfer of treatment capacity to service those areas with the greatest need during periods of non-uniform rainfall over the city.

Such interconnection will minimize the probability of multi-overflow occurrences at locations which cannot be prevented where zones are not interconnected. The interconnection of the city drainage and storage system will allow the selective interception of runoffs from the cellular high intensity rainfall patterns, which would otherwise result in multiple overflows at different locations and times; such cellular patterns have been observed.

Storage interconnection will also allow some judgment to be exercised in controlling overflows in those areas of higher dilution or lower priority receiving water usage. This can be accomplished through the allocation of treatment capacity to areas of sufficient storage to contain overflows while allowing stressed areas, which would overflow in any event, to overflow under controlled conditions. This situation is the reverse of the above-noted cellular pattern event.

This system employs interconnection and the optimization potential resulting from unattended automatic storage and transport control and allocation. There is a corollary potential for minimizing the total emissions during wet weather. The use of storage during the light to medium rainfall occurrences is maximized thus attenuating the resultant higher flow rates to utilize the full treatment facility to maximum capacity over an extended duration. As the size or volume of storage increases, the fraction of the infrequently used storage increases. Comparison of the percent of time that various volumes are used with the total storage volume indicates that a fairly sharp decrease in frequently-used volume occurs at (about) the storage volume required for four overflows per year.

It is proposed to construct a pilot inland detention basin for the purpose of making a full-scale model study to develop firm operating procedures. This study is expected to:

1. make it possible to set up operational rule tables for the facility under selected treatment rates and varying rainfall occurrences.
2. determine the maintenance requirements of the detention facility;
3. confirm the effectiveness of the separation structure in causing solids and floatables to bypass the storage compartments;
4. develop the most effective ventilation scheme for basins to minimize odors, health problems, hazards, etc.; and
5. give guidance toward refining cost estimates of proposed detention facilities.

Because the Master Plan is predicated upon reasonably-efficient separation structures to deliver expeditiously most of the solids and floatables in wet weather flows to the treatment facility, there is no apparent reason to assume any significant treatment effects due to temporary detention in the storage facilities. Further, such temporary detention is to be of relatively short duration.

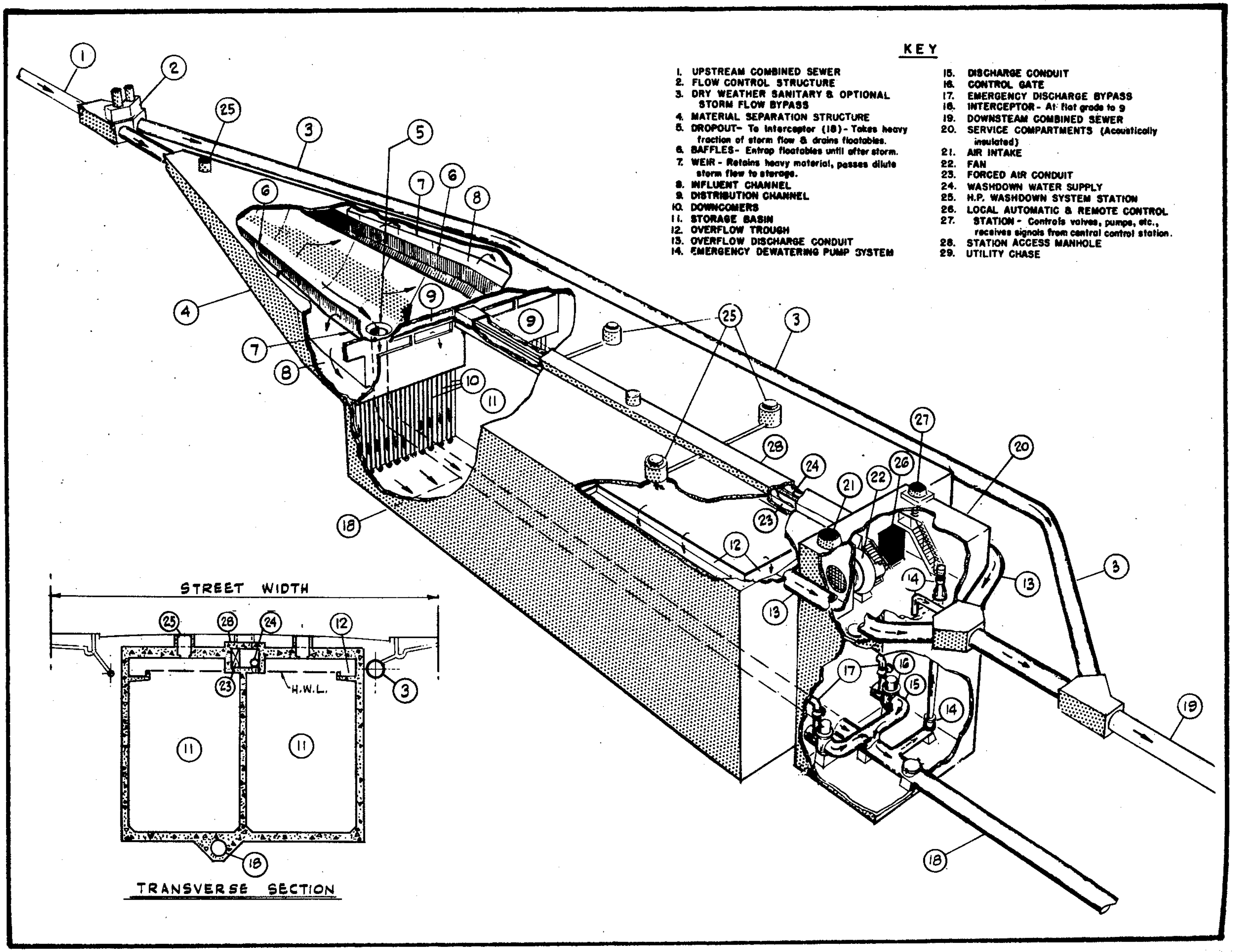


FIGURE 61 INLAND BASIN PERSPECTIVE

AUTOMATIC CENTRAL CONTROL SYSTEMS

The uncertainty of uncontrolled overflow is increased with the number of separate control and treatment systems under consideration. Without central control and interconnection of the drainage and storage systems, the same facilities for storage and treatement that would limit overflows to eight per year would experience from 24 to 128 overflows depending on the pattern of rainfall events in a given year. An automatic controls system is clearly an essential and vital element of the Master Plan.

Storage and treatment are further interrelated in determining the amount of time the control system has in which to respond to each individual rainstorm. A light rainfall of relatively short duration may be diverted to storage and released at a low rate to effect the best possible removal efficiency. Conversely a high intensity rainfall of long duration will require that the treatment plant respond as quickly as possible to the full operational mode. The detention time available for each of the alternatives *A* to *D*, when the single new 1,000 MGD treatment plant is operating at full capacity, is as follows:

Alternative	Storage Capacity (millions of cuft)	Time to Drain Storage at 1,000 MGD Rate (HRS)
Existing	0	0.25 - 0.50
A	9	1.6
B	18	3.2
C	33	5.9
D	56	10

An additional storage volume of approximately 2 million cubic feet is also available at the treatment plant in bringing the plant up to full operational status. This storage system capacity plus the transportation time to deliver the flow to the plant represents the maximum time period available to the treatment plant for responding to wet weather conditions.

This maximum response time must be reduced for control system design because if the total storage is allocated at the beginning of the rainfall the whole system would lose its flexibility to store for a subsequent increase in rainfall intensity above the treatment rate.

WET WEATHER CAPITAL COSTS

Table 40, Comparison of Wet Weather Cost vs. Accomplishments, presents a comparison of wet weather capital costs versus accomplishments for the four alternate schemes proposed under the Master Plan. It should be noted that the costs are in 1974 dollars (based upon 7.5% annual increase over 1970 estimates).

Inadequate Sewers – Savings and Costs The San Francisco studies indicated that the estimated total cost of replacing all of the sewers in the city which are inadequate to carry designed storm flows to be $150 million. Construction of upstream storage basins in any of the alternative wet weather plans will restore one-third of the inadequate sewers to adequate and will reduce the cost for replacement to $100 million. Clearly the cost of the storage has reduced the cost for replacement or supplementation of inadequate sewers by about $50 million.

FINANCING PROGRAM

The studies include financial programming for the construction, maintenance and operation of the Master Plan. A program for various possible bond issues was developed to cover the city's portion of the capital costs of the total wastewater management program. Various overflow control schemes were evaluated. A matrix of capital costs for the combined Dry-Wet Weather Programs is given in Table 41, Program Costs (1974, Million Dollars) for Combined Dry-Wet Weather Programs. These are based upon the following variables and assumptions:

1. average annual number of wet-weather overflows (Alternates A to D);
2. the level of dry-weather treatment essential to meet long-range policy requirements;
3. time period required for completion of each phase or the various programs;
4. the available assistance from various Federal and State grant programs;
5. six (6) percent interest rate;

TABLE 40
COMPARISON OF WET WEATHER COST VS ACCOMPLISHMENTS

	EXIST. COND.	ALTERNATE A	B	C	D
Cost (Wet Weather) - $ Millions		$333	$396	$522	$665
Per Annun - Average					
Number of overflow occurrences	82	8	4	1	0.2[a]
% Reduction[b]		90	95	99	99+
Duration in hours	2.5	2	2	3	4
% Reduction		-	-	-	-
Total Hours	205	16	8	3	1
% Reduction		92	96	99	99+
Vol. of untreated overflow discharge (billions of gallons)	6	.8	.4	.1	.02
% Reduction		88	96	98	99+
Vol. of treated discharge (billions of gallons)	38.8	44.1	44.4	44.7	45
Days receiving H_2O exceeds bact. standards	171	40	20	5	1
% Reduction		77	88	94	99+
Suspended solids (million lbs.)	42	14.3	13.2	12.4	12.1
% Reduction		66	68	70	71
COD (millions lbs.)	126	81.2	80.9	80.6	80.5
% Reduction		35	36	36	36
Grease (millions lbs.)	10.8	3.5	3.4	3.3	3.3
% Reduction		68	69	69	69
Flotables (millions lbs.)	0.5	0.3	0.3	0.3	0.3
% Reduction		30	32	33	34
Nitrogen (millions lbs.)	10.4	9.7	9.7	9.7	9.7
% Reduction		7	7	7	7
Phosphate (millions lbs.)	5	1.4	1.4	1.4	1.4
% Reduction		71	71	71	71

[a] 0.2 equivalent to "once per 5 years" frequency.
[b] from "Existing Condition".

The costs hereon are capital costs.

TABLE 41
PROGRAM COSTS (1974, MILLION DOLLARS) FOR COMBINED DRY-WET WEATHER PROGRAMS

	WET WEATHER ALTERNATIVES			
	A	B	C	D
WET WEATHER COSTS	$ 333	$ 396	$ 522	$ 665

COMBINED DRY-WET WEATHER COSTS

DRY WEATHER PROGRAM	LEVEL OF TREATMENT	WET WEATHER ALTERNATIVES			
		A	B	C	D
SCHEME I (Most economical)*	1	$375	$438	$564	$707
	2	416	479	605	748
	3	463	526	652	795
SCHEME II (S.E. effluent to ocean)	1	406	469	595	738
	2	458	521	647	790
	3	505	568	694	837
SCHEME III (S.E. & N.P. effluent to ocean)	1	417	480	606	749
	2	469	532	658	801
	3	516	579	705	848

* "Most economical" means - Optimized staging of facilities to meet wet weather requirements with least duplication of dry weather costs.

6. the present worth of each scheme based upon 1974 project costs; and
7. assumed uniform annual project-life increments of capital cost expenditures.

Facilities, costs and funds required for the comprehensive wastewater management program are summarized in Table 42, Comprehensive Wastewater Management Program – Facilities, Costs and Funds Required. All of these cost figures assume a maximum of Federal and State grant funds. Further, they take into consideration the city's financial limitations and other constraints. The costs include replacement of sewers approaching failure because of age, corrosive deterioration or changes in the necessary conditions of soil support.

In addition to the capital costs, maintenance and operation costs are summarized in the report. These will vary with the level of dry weather treatment and with the degree of completion of various phases of the Master Plan.

The dry weather maintenance and operation costs will vary from $4.7 million (1974 dollars) for first level treatment at the individual plants up to $7.5 million (1974 dollars) for second level dry weather treatment at the individual plants. These costs

TABLE 42
COMPREHENSIVE WASTEWATER MANAGEMENT PROGRAM
– FACILITIES, COSTS AND FUNDS REQUIRED –

Treatment

I. Dry Weather Facilities

a)	Cost	136.0 million
b)	Less 80% Grant Funds	-108.8 million
c)	Net City Funds Required during Program Period	27.2 million
d)	Funds Available	65.0 million
e)	Net Remaining Funds	37.8 million

II. Wet Weather Facilities

		Alt.A	Alt.B	Alt.C	Alt.D	
a)	Cost	333.0	396.0	522.0	665.0	million
b)	Less 80% Grant Funds	-266.4	-316.8	-417.6	-532.0	million
c)	City Funds Required during Program Period	66.6	79.2	104.4	133.0	million
d)	Funds Available	37.8	37.8	37.8	37.8	million
e)	Net Funds Required during Program Period	28.8	41.4	66.6	95.2	million

Transport

		20 Year Program	30 Year Program
I.	Costs		
	a) Inadequate Sewers	66.7 million	100 million
	b) Replacement Sewers	75.0 million	112.5 million
	c) Total Transport Costs	141.7 million	212.5 million
II.	Funds Available	6.0 million	6.0 million
III.	Net Funds Required during Program Period	135.7 million	206.5 million

may be reduced to $7.2 million (1974 dollars) by consolidation of facilities. The additional costs of wet weather treatment to first level effluent will range from about $0.1 million (1974 dollars) for a single wet and dry weather plant to $1.1 million for a separate wet weather facility. If second level dry weather treatment (the most probable in the opinion of the report) is implemented and the plants are consolidated, then the maintenance and operation costs are $7.0 million (1974 dollars) during a 20-year to 30-year wet weather construction period. This assumes a dry-weather program of about 5 years length.

The maintenance and operations costs are expected to be as follows:

Annual Maintenance and Operation Cost

Dry and Wet Weather Treatment	$7,300,000
Culverts and Catchbasins	280,000
Sewers	1,500,000
Outfall	90,000
Total	$9,170,000/Yr

The $7.3 millionis an optimum cost figure based upon the wet weather treatment alternatives and the dry weather treatment levels.

No Federal or State grant funds are available for annual O and M costs. In 1971, the city adopted a sewer service charge based on water consumption. It is anticipated to generate about $13 million (1974 dollars).

Separate costs for the maintenance and operation of detention basins and tunnels are not available in the study report.

SUMMARY OF ADVANTAGES OF DETENTION STORAGE

The preceding discussion, some of which is taken verbatim from the excellent studies of the Department of Public Works of the City and County of San Francisco, has touched upon and explained the many advantages and basic role that detention storage has in the best type of master plan for the sewerage of the area. This will minimize the pollution of storm overflows into the Bay and the Ocean.

To recapitulate, these advantages are: (1) the supplementation of a proposed single sewage treatment plant with a capacity of 1,000 MGD (equivalent to a rainfall rate capacity of 0.10 inches per hour) by significant storage capacity provided in the various watersheds of the city; (2) proper distribution and location of the storage in each sub-watershed, particularly in the upper watershed, can (through attenuation of outflow from such storage) restore to adequacy, for runoff transport, the capacity of many of the currently inadequate sewers downstream from the location of such storage facilities; (3) detention basins have the potential for flushing the downstream conveyance system by deliberately timed release of storage during portions of the day (this may reduce maintenance costs in the lower portions of the system); (4) the location of detention basins at sites within the city where surface waters currently accumulate, can decrease public inconvenience attributable to surface pondage; and (5) the judicious location and use of crosstown tunnels for storage can have the important additional advantages of such tunnels being used for interconnecting many watersheds.

With central control of diversions from subbasin to subbasin by means of such gravity tunnels, a high intensity rainfall over a subbasin can in part be diverted to adjacent undertaxed subbasins. Highly centralized control of diversion of flows from potentially overcharged basins to undercharged basins will make it possible to utilize to the best advantage all of the sewerage facilities of the area instead of sporadically concentrated overusage in smaller parts of the total area.

The report's consideration of the capital and maintenance and operations costs of the Master Plan indicate its economic feasibility with maximum Federal and State grants for the capital construction costs. O and M costs, not eligible for annual governmental grants, can be borne locally under current local sewer service charges. If less than the maximum Federal and State grants towards capital costs becomes available, the Master Plan can still be implemented under an extended construction schedule.

APPENDIX G
LIST OF UNPUBLISHED REPORTS PREPARED IN THE STUDY BY TEAM MEMBERS, CONSULTANTS AND SYMPOSIUM PARTICIPANTS

(Note: Published reports of members of the study team are included in the bibliography.)

DETENTION STORAGE IN URBAN DRAINAGE, A CASE STUDY AND ANALYSIS

J. J. Anderson
Watermation, Incorporated, St. Paul, Minnesota:March 1973:28 pp

MONTGOMERY COUNTY POLICY FOR ON-SITE DETENTION OF STORMWATER RUNOFF

W. E. Bell
Montgomery County, Maryland Department of Environmental Protection, Rockville: November 28, 1972:5 pp

DESIGN METHODS FOR THE DESIGN OF DETENTION FACILITIES

E. L. Claycomb, L. A. Muller
Fraiser & Gingery, Consulting Engineers, Englewood, Colorado:1973:17 pp

DETENTION STORAGE AS AN ELEMENT OF FLOOD CONTROL AND STORM DRAINAGE

T. K. Dieffenderfer
City of Boulder, Colorado:1972:8 pp

LEGAL ASPECTS IN COLORADO OF ON-SITE DETENTION STORAGE OF URBAN STORMWATER RUNOFF

T. T. Grimshaw
Calkins, Kramer, Grimshaw & Harring, Denver:1973:11 pp

RETENTION PONDS – OPERATION AND MAINTENANCE PROBLEMS

J. W. Hossack
Village of Hoffman Estates, Illinois:April 13, 1972:7 pp

TRUCKING TERMINAL, CONSOLIDATED FREIGHTWAYS, INCORPORATED, ST. LOUIS, MISSOURI

S. W. Jens
Reitz & Jens Consulting Engineers, St. Louis, Missouri:1972:4 pp

EARTH CITY ST. LOUIS COUNTY, MISSOURI, STORMWATER DETENTION STORAGE

S. W. Jens
Reitz & Jens Consulting Engineers, St. Louis, Missouri:1972:35 pp

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F. B. Laverty
Pasadena, California:July 14, 1972:3 pp

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C. Mallory
Hittman Associates, Columbia, Maryland: 1973:26 pp

ANALYSIS OF QUESTIONNAIRE SURVEYS OF STORMWATER DETENTION PRACTICES

H. G. Poertner, J. Reindl
Bolingbrook, Illinois: 1972:12 pp

PROGRAMS FOR REMOVING CONNECTIONS OF ROOF DOWNSPOUTS FROM SANITARY SEWERS

H. G. Poertner, J. Reindl
Bolingbrook, Illinois: 1973:25 pp

APPLICATIONS OF ON-SITE STORMWATER DETENTION

H. G. Poertner
Bolingbrook, Illinois: 1973:97 pp

PROVISIONS OF STATUTES, ORDINANCES, BUILDING CODES, AND REGULATIONS FOR ON-SITE DETENTION OF RUNOFF

H. G. Poertner
Bolingbrook, Illinois: 1973:15 pp

INVESTIGATIONS OF NEW METHODS OF STORMWATER DETENTION

John Reindl
University of Wisconsin – Milwaukee, Department of Civil Engineering: 1973:21 pp

BIBLIOGRAPHY ON DETENTION STORAGE OF STORMWATER RUNOFF

John Reindl
University of Wisconsin – Milwaukee, Department of Civil Engineering: 1973:8 pp

LEGISLATION RELATING TO ON-SITE DETENTION OF URBAN STORMWATER RUNOFF

W. J Shoemaker
Shoemaker and Wham, Attorneys, Denver, Colorado: 1972:10 pp

SUMMARY OF REMARKS – ON-SITE DETENTION OF URBAN STORM WATER RUNOFF

W. W. Smith, Jr.
Fairfax County, Virginia Department of County Development, Fairfax: November 28, 1972:6 pp

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T. H. Stauffer
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APPENDIX H
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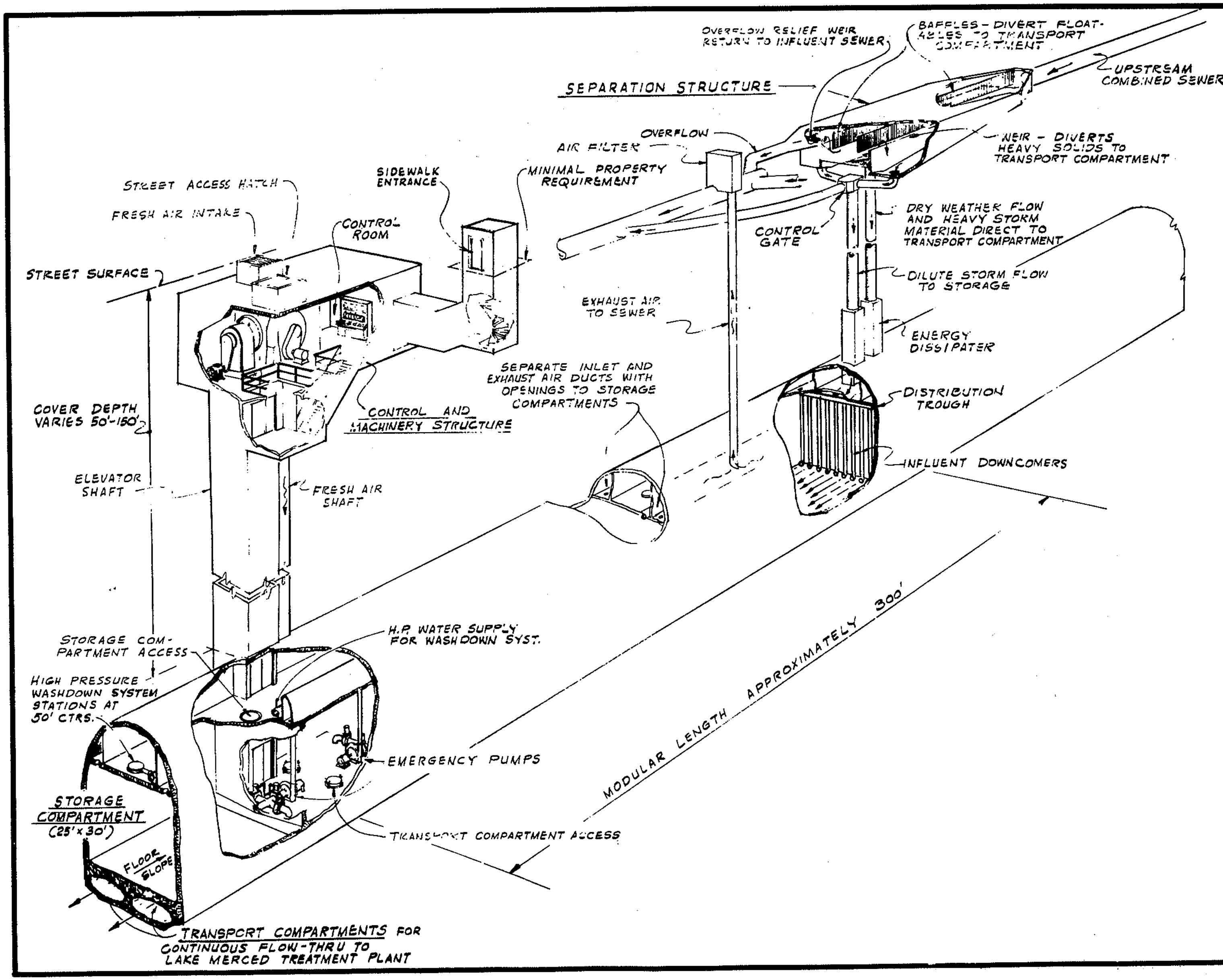

FIGURE 58 TUNNEL PERSPECTIVE

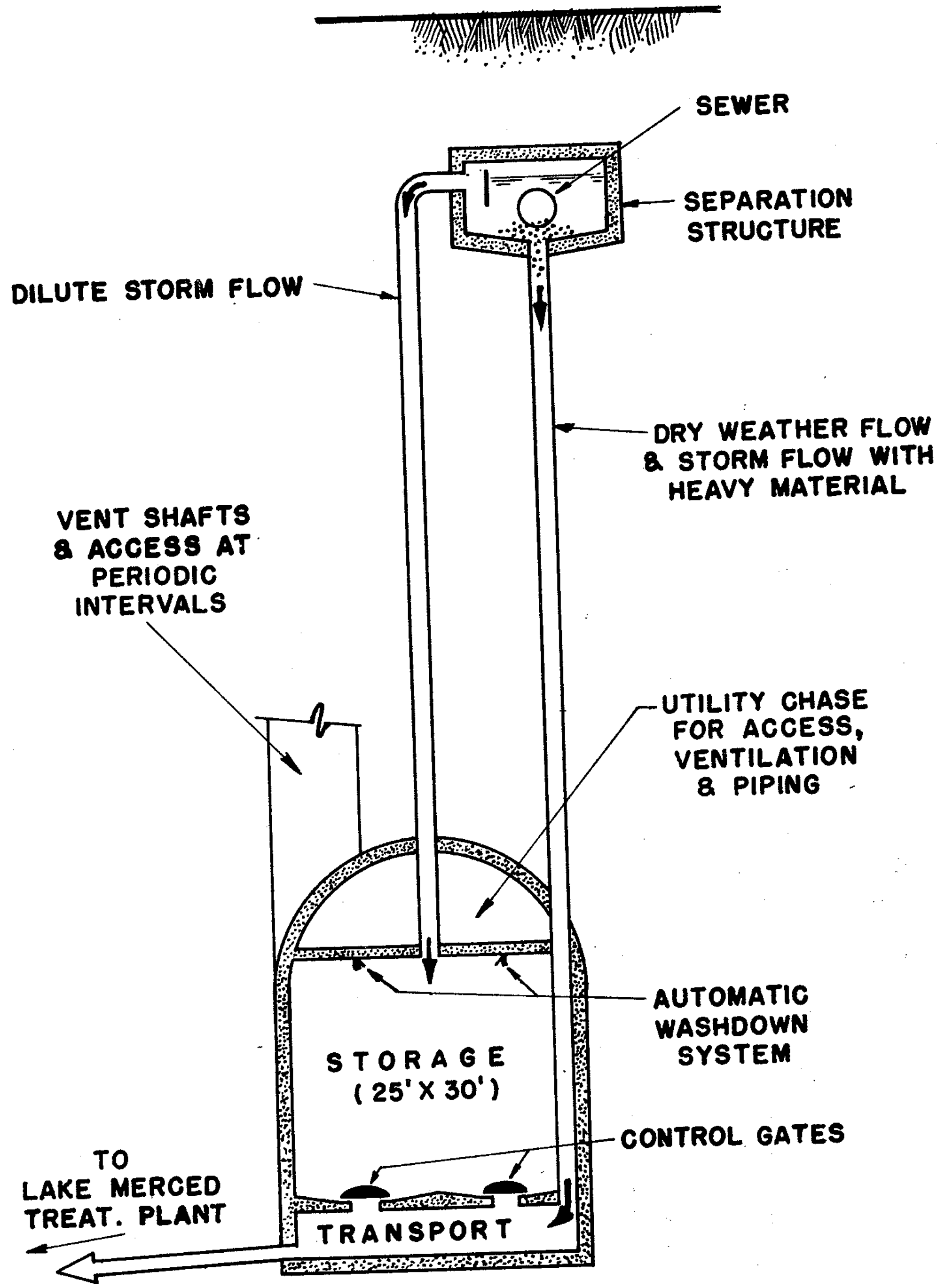

FIGURE 59 SCHEMATIC SECTION OF TUNNEL

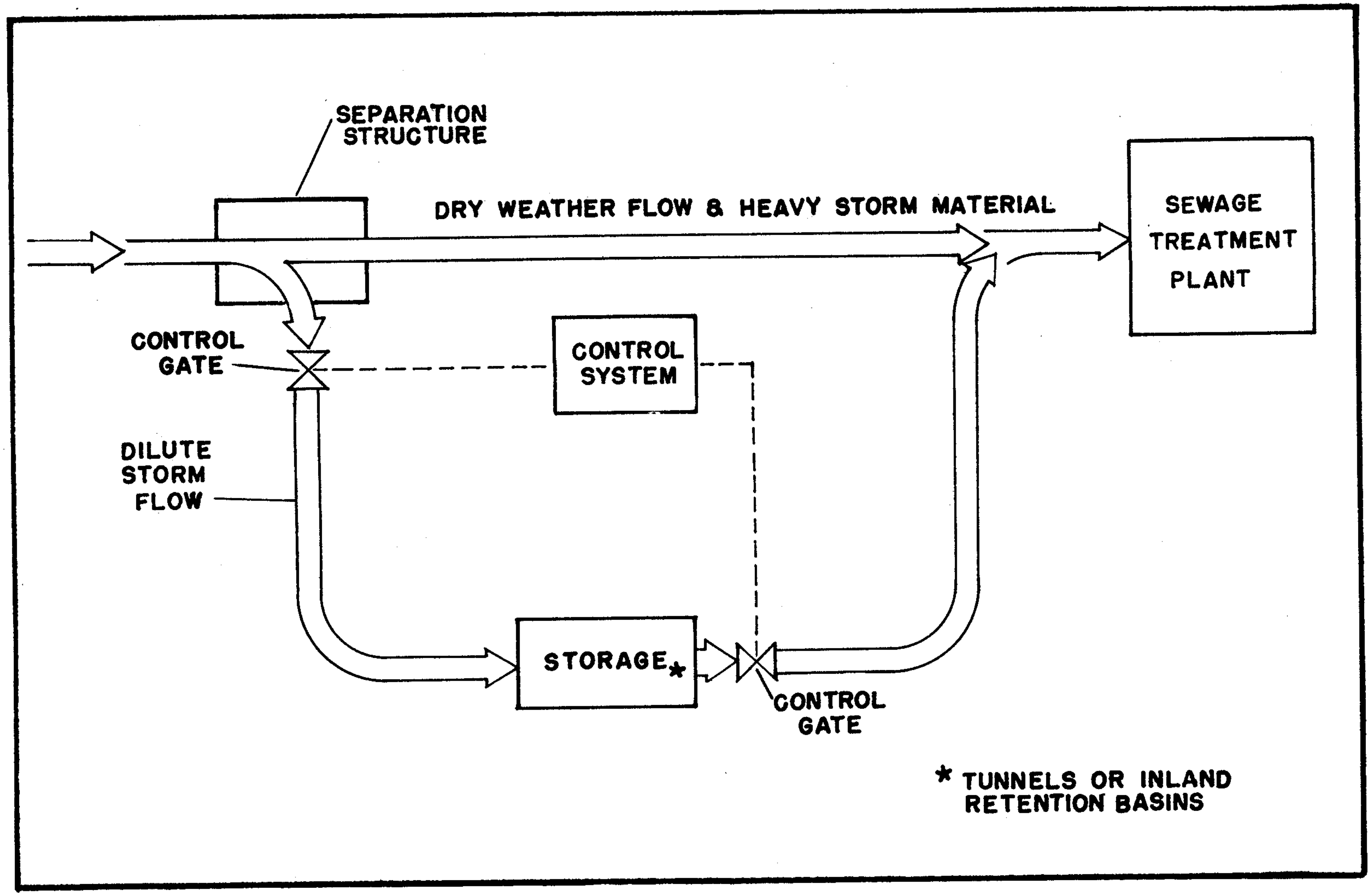

FIGURE 60 SCHEMATIC DIAGRAM OF WET WEATHER CONTROL

outfall. Included in the tank compartments will be a spray system to wash the interior surfaces of the tanks. A forced air ventilation system will provide air exchange which will exhaust into the interceptor sewer for release at the treatment plant. Control will be unattended and automatic through the master control system.

Upstream basins will be operated in much the same manner. Sanitary flow will be contained in the sewer and routed on to the sewage system downstream. The internal features of the tanks are similar in concept to the shoreline tanks except that the outlet will be a gravity sewer, with a controlled flow rate, to reenter the existing sewer downstream. The individual tanks will each have a spray system for cleaning interior surfaces and an exhaust ventilation system. Figure 61, Inland Basin Perspective, is an example of the structure.

The system will interconnect all storage facilities. This will allow a transfer of treatment capacity to service those areas with the greatest need during periods of non-uniform rainfall over the city.

Such interconnection will minimize the probability of multi-overflow occurrences at locations which cannot be prevented where zones are not interconnected. The interconnection of the city drainage and storage system will allow the selective interception of runoffs from the cellular high intensity rainfall patterns, which would otherwise result in multiple overflows at different locations and times; such cellular patterns have been observed.

Storage interconnection will also allow some judgment to be exercised in controlling overflows in those areas of higher dilution or lower priority receiving water usage. This can be accomplished through the allocation of treatment capacity to areas of sufficient storage to contain overflows while allowing stressed areas, which would overflow in any event, to overflow under controlled conditions. This situation is the reverse of the above-noted cellular pattern event.

This system employs interconnection and the optimization potential resulting from unattended automatic storage and transport control and allocation. There is a corollary potential for minimizing the total emissions during wet weather. The use of storage during the light to medium rainfall occurrences is maximized thus attenuating the resultant higher flow rates to utilize the full treatment facility to maximum capacity over an extended duration. As the size or volume of storage increases, the fraction of the infrequently used storage increases. Comparison of the percent of time that various volumes are used with the total storage volume indicates that a fairly sharp decrease in frequently-used volume occurs at (about) the storage volume required for four overflows per year.

It is proposed to construct a pilot inland detention basin for the purpose of making a full-scale model study to develop firm operating procedures. This study is expected to:

1. make it possible to set up operational rule tables for the facility under selected treatment rates and varying rainfall occurrences.
2. determine the maintenance requirements of the detention facility;
3. confirm the effectiveness of the separation structure in causing solids and floatables to bypass the storage compartments;
4. develop the most effective ventilation scheme for basins to minimize odors, health problems, hazards, etc.; and
5. give guidance toward refining cost estimates of proposed detention facilities.

Because the Master Plan is predicated upon reasonably-efficient separation structures to deliver expeditiously most of the solids and floatables in wet weather flows to the treatment facility, there is no apparent reason to assume any significant treatment effects due to temporary detention in the storage facilities. Further, such temporary detention is to be of relatively short duration.

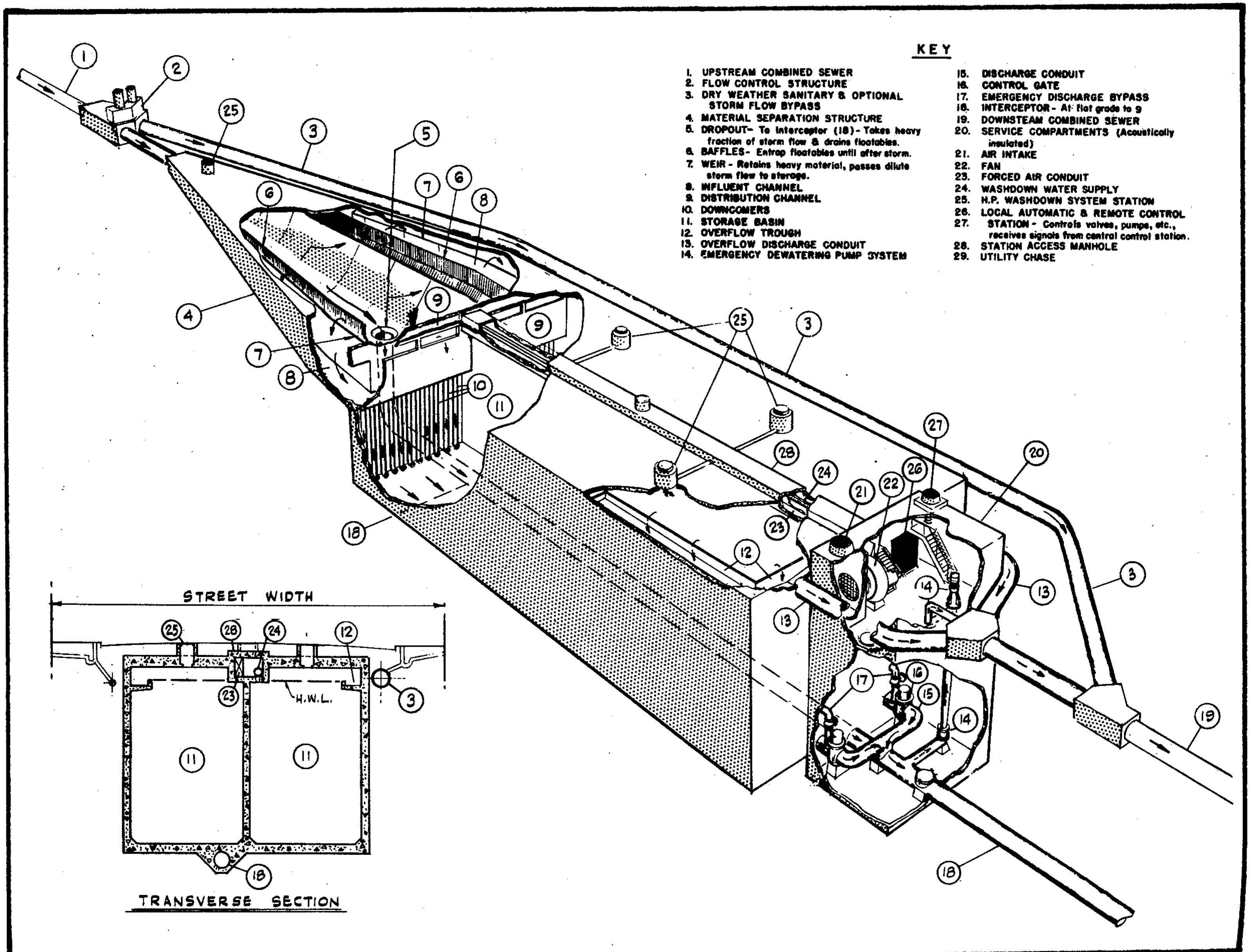

FIGURE 61 INLAND BASIN PERSPECTIVE

AUTOMATIC CENTRAL CONTROL SYSTEMS

The uncertainty of uncontrolled overflow is increased with the number of separate control and treatment systems under consideration. Without central control and interconnection of the drainage and storage systems, the same facilities for storage and treatement that would limit overflows to eight per year would experience from 24 to 128 overflows depending on the pattern of rainfall events in a given year. An automatic controls system is clearly an essential and vital element of the Master Plan.

Storage and treatment are further interrelated in determining the amount of time the control system has in which to respond to each individual rainstorm. A light rainfall of relatively short duration may be diverted to storage and released at a low rate to effect the best possible removal efficiency. Conversely a high intensity rainfall of long duration will require that the treatment plant respond as quickly as possible to the full operational mode. The detention time available for each of the alternatives *A* to *D*, when the single new 1,000 MGD treatment plant is operating at full capacity, is as follows:

Alternative	Storage Capacity (millions of cuft)	Time to Drain Storage at 1,000 MGD Rate (HRS)
Existing	0	0.25 - 0.50
A	9	1.6
B	18	3.2
C	33	5.9
D	56	10

An additional storage volume of approximately 2 million cubic feet is also available at the treatment plant in bringing the plant up to full operational status. This storage system capacity plus the transportation time to deliver the flow to the plant represents the maximum time period available to the treatment plant for responding to wet weather conditions.

This maximum response time must be reduced for control system design because if the total storage is allocated at the beginning of the rainfall the whole system would lose its flexibility to store for a subsequent increase in rainfall intensity above the treatment rate.

WET WEATHER CAPITAL COSTS

Table 40, Comparison of Wet Weather Cost vs. Accomplishments, presents a comparison of wet weather capital costs versus accomplishments for the four alternate schemes proposed under the Master Plan. It should be noted that the costs are in 1974 dollars (based upon 7.5% annual increase over 1970 estimates).

Inadequate Sewers – Savings and Costs The San Francisco studies indicated that the estimated total cost of replacing all of the sewers in the city which are inadequate to carry designed storm flows to be $150 million. Construction of upstream storage basins in any of the alternative wet weather plans will restore one-third of the inadequate sewers to adequate and will reduce the cost for replacement to $100 million. Clearly the cost of the storage has reduced the cost for replacement or supplementation of inadequate sewers by about $50 million.

FINANCING PROGRAM

The studies include financial programming for the construction, maintenance and operation of the Master Plan. A program for various possible bond issues was developed to cover the city's portion of the capital costs of the total wastewater management program. Various overflow control schemes were evaluated. A matrix of capital costs for the combined Dry-Wet Weather Programs is given in Table 41, Program Costs (1974, Million Dollars) for Combined Dry-Wet Weather Programs. These are based upon the following variables and assumptions:

1. average annual number of wet-weather overflows (Alternates A to D);
2. the level of dry-weather treatment essential to meet long-range policy requirements;
3. time period required for completion of each phase or the various programs;
4. the available assistance from various Federal and State grant programs;
5. six (6) percent interest rate;

TABLE 40
COMPARISON OF WET WEATHER COST VS ACCOMPLISHMENTS

	EXIST. COND.	ALTERNATE A	B	C	D
Cost (Wet Weather) - $ Millions		$333	$396	$522	$665
Per Annun - Average					
Number of overflow occurrences	82	8	4	1	0.2[a]
% Reduction[b]		90	95	99	99+
Duration in hours	2.5	2	2	3	4
% Reduction		-	-	-	-
Total Hours	205	16	8	3	1
% Reduction		92	96	99	99+
Vol. of untreated overflow discharge (billions of gallons)	6	.8	.4	.1	.02
% Reduction		88	96	98	99+
Vol. of treated discharge (billions of gallons)	38.8	44.1	44.4	44.7	45
Days receiving H_2O exceeds bact. standards	171	40	20	5	1
% Reduction		77	88	94	99+
Suspended solids (million lbs.)	42	14.3	13.2	12.4	12.1
% Reduction		66	68	70	71
COD (millions lbs.)	126	81.2	80.9	80.6	80.5
% Reduction		35	36	36	36
Grease (millions lbs.)	10.8	3.5	3.4	3.3	3.3
% Reduction		68	69	69	69
Flotables (millions lbs.)	0.5	0.3	0.3	0.3	0.3
% Reduction		30	32	33	34
Nitrogen (millions lbs.)	10.4	9.7	9.7	9.7	9.7
% Reduction		7	7	7	7
Phosphate (millions lbs.)	5	1.4	1.4	1.4	1.4
% Reduction		71	71	71	71

(a) 0.2 equivalent to "once per 5 years" frequency.
(b) from "Existing Condition".

The costs hereon are capital costs.

TABLE 41
PROGRAM COSTS (1974, MILLION DOLLARS) FOR COMBINED DRY-WET WEATHER PROGRAMS

	WET WEATHER ALTERNATIVES			
	A	B	C	D
WET WEATHER COSTS	$ 333	$ 396	$ 522	$ 665

COMBINED DRY-WET WEATHER COSTS

DRY WEATHER PROGRAM	LEVEL OF TREATMENT	WET WEATHER ALTERNATIVES			
		A	B	C	D
SCHEME I (Most economical)*	1 2 3	$375 416 463	$438 479 526	$564 605 652	$707 748 795
SCHEME II (S.E. effluent to ocean)	1 2 3	406 458 505	469 521 568	595 647 694	738 790 837
SCHEME III (S.E. & N.P. effluent to ocean)	1 2 3	417 469 516	480 532 579	606 658 705	749 801 848

* "Most economical" means - Optimized staging of facilities to meet wet weather requirements with least duplication of dry weather costs.

6. the present worth of each scheme based upon 1974 project costs; and
7. assumed uniform annual project-life increments of capital cost expenditures.

Facilities, costs and funds required for the comprehensive wastewater management program are summarized in Table 42, Comprehensive Wastewater Management Program – Facilities, Costs and Funds Required. All of these cost figures assume a maximum of Federal and State grant funds. Further, they take into consideration the city's financial limitations and other constraints. The costs include replacement of sewers approaching failure because of age, corrosive deterioration or changes in the necessary conditions of soil support.

In addition to the capital costs, maintenance and operation costs are summarized in the report. These will vary with the level of dry weather treatment and with the degree of completion of various phases of the Master Plan.

The dry weather maintenance and operation costs will vary from $4.7 million (1974 dollars) for first level treatment at the individual plants up to $7.5 million (1974 dollars) for second level dry weather treatment at the individual plants. These costs

TABLE 42
COMPREHENSIVE WASTEWATER MANAGEMENT PROGRAM – FACILITIES, COSTS AND FUNDS REQUIRED –

Treatment

I. Dry Weather Facilities

a)	Cost	136.0 million
b)	Less 80% Grant Funds	-108.8 million
c)	Net City Funds Required during Program Period	27.2 million
d)	Funds Available	65.0 million
e)	Net Remaining Funds	37.8 million

II. Wet Weather Facilities

		Alt.A	Alt.B	Alt.C	Alt.D	
a)	Cost	333.0	396.0	522.0	665.0	million
b)	Less 80% Grant Funds	-266.4	-316.8	-417.6	-532.0	million
c)	City Funds Required during Program Period	66.6	79.2	104.4	133.0	million
d)	Funds Available	37.8	37.8	37.8	37.8	million
e)	Net Funds Required during Program Period	28.8	41.4	66.6	95.2	million

Transport

			20 Year Program	30 Year Program
I.	Costs			
	a)	Inadequate Sewers	66.7 million	100 million
	b)	Replacement Sewers	75.0 million	112.5 million
	c)	Total Transport Costs	141.7 million	212.5 million
II.	Funds Available		6.0 million	6.0 million
III.	Net Funds Required during Program Period		135.7 million	206.5 million

may be reduced to \$7.2 million (1974 dollars) by consolidation of facilities. The additional costs of wet weather treatment to first level effluent will range from about \$0.1 million (1974 dollars) for a single wet and dry weather plant to \$1.1 million for a separate wet weather facility. If second level dry weather treatment (the most probable in the opinion of the report) is implemented and the plants are consolidated, then the maintenance and operation costs are \$7.0 million (1974 dollars) during a 20-year to 30-year wet weather construction period. This assumes a dry-weather program of about 5 years length.

The maintenance and operations costs are expected to be as follows:

Annual Maintenance and Operation Cost

Dry and Wet Weather Treatment	$7,300,000
Culverts and Catchbasins	280,000
Sewers	1,500,000
Outfall	90,000
Total	$9,170,000/Yr

The $7.3 millionis an optimum cost figure based upon the wet weather treatment alternatives and the dry weather treatment levels.

No Federal or State grant funds are available for annual O and M costs. In 1971, the city adopted a sewer service charge based on water consumption. It is anticipated to generate about $13 million (1974 dollars).

Separate costs for the maintenance and operation of detention basins and tunnels are not available in the study report.

SUMMARY OF ADVANTAGES OF DETENTION STORAGE

The preceding discussion, some of which is taken verbatim from the excellent studies of the Department of Public Works of the City and County of San Francisco, has touched upon and explained the many advantages and basic role that detention storage has in the best type of master plan for the sewerage of the area. This will minimize the pollution of storm overflows into the Bay and the Ocean.

To recapitulate, these advantages are: (1) the supplementation of a proposed single sewage treatment plant with a capacity of 1,000 MGD (equivalent to a rainfall rate capacity of 0.10 inches per hour) by significant storage capacity provided in the various watersheds of the city; (2) proper distribution and location of the storage in each sub-watershed, particularly in the upper watershed, can (through attenuation of outflow from such storage) restore to adequacy, for runoff transport, the capacity of many of the currently inadequate sewers downstream from the location of such storage facilities; (3) detention basins have the potential for flushing the downstream conveyance system by deliberately timed release of storage during portions of the day (this may reduce maintenance costs in the lower portions of the system); (4) the location of detention basins at sites within the city where surface waters currently accumulate, can decrease public inconvenience attributable to surface pondage; and (5) the judicious location and use of crosstown tunnels for storage can have the important additional advantages of such tunnels being used for interconnecting many watersheds.

With central control of diversions from subbasin to subbasin by means of such gravity tunnels, a high intensity rainfall over a subbasin can in part be diverted to adjacent undertaxed subbasins. Highly centralized control of diversion of flows from potentially overcharged basins to undercharged basins will make it possible to utilize to the best advantage all of the sewerage facilities of the area instead of sporadically concentrated overusage in smaller parts of the total area.

The report's consideration of the capital and maintenance and operations costs of the Master Plan indicate its economic feasibility with maximum Federal and State grants for the capital construction costs. O and M costs, not eligible for annual governmental grants, can be borne locally under current local sewer service charges. If less than the maximum Federal and State grants towards capital costs becomes available, the Master Plan can still be implemented under an extended construction schedule.

APPENDIX G
LIST OF UNPUBLISHED REPORTS PREPARED IN THE STUDY BY TEAM MEMBERS, CONSULTANTS AND SYMPOSIUM PARTICIPANTS

(Note: Published reports of members of the study team are included in the bibliography.)

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APPENDIX H
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PRELIMINARY DESIGN REPORT, URBAN STORM DRAINAGE, MODEL CITIES–DENVER, STUDY AREAS A, C, D & G

Wright-McLaughlin Engineers
Denver, Colorado:January 1971:120 pp

URBAN STORM DRAINAGE CRITERIA MANUAL: DENVER REGIONAL COUNCIL OF GOVERNMENTS

Wright-McLaughlin Engineers
Denver, Colorado:1969:2 vol.

MASTER PLANNING FOR STORM RUNOFF FOR NEW NORTH/SOUTH AND ENVIRONS – STAPLETON INTERNATIONAL AIRPORT

Wright-McLaughlin Engineers
Denver, Colorado:November 1969:39 pp

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History of Public Works in the United States, 1776-1976, Special Pre-Publication Price—To be mailed on or about Jan. 1, 1976	$10
APWA Emblem, lapel clutch pin, tietack, or charm	$ 5

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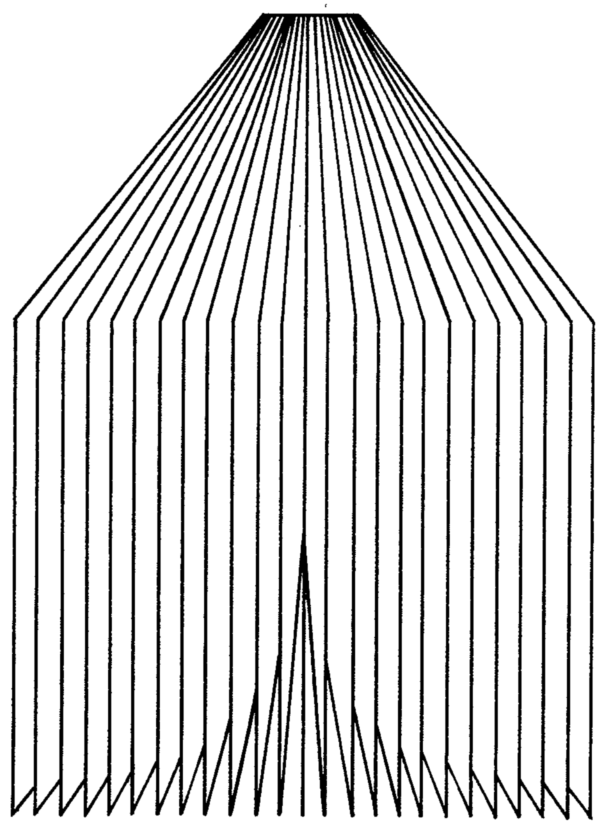

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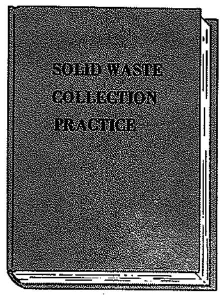
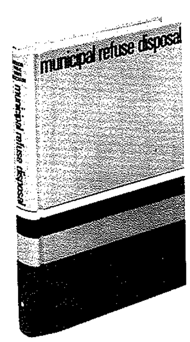


SOLID WASTE COLLECTION PRACTICE
New 1975 Edition

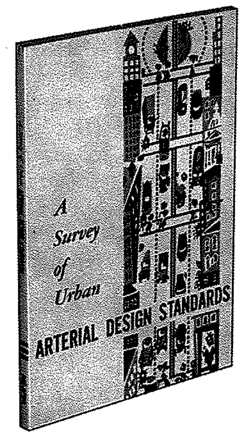
The most authoritative text in its field. Originated in 1941 as *Refuse Collection Practice,* and revised in 1958 and 1966, this widely acclaimed source of information has now been renamed and updated to meet the needs of today's challenging solid waste collection field. Five knowledgeable solid waste men examined data from 675 questionnaires to make *Solid Waste Collection Practice* the most comprehensive source of information possible. $16 to APWA members – $20 to non-members.



MUNICIPAL REFUSE DISPOSAL

A comprehensive analysis of the methods cities can use to cope with the mounting waste disposal crisis. It tells how refuse can be disposed of without polluting the environment – or recycled into useful materials. It discusses the mechanical, chemical, management, cost, public health, and public relations aspects of all disposal methods – a how-to-do-it manual on landfilling, incineration, composting, and resource recovery. 1970, 538 pp., illus., cloth, indexed, bibliography, typical ordinances. $12 to APWA members – $15 to non-members.

A SURVEY OF URBAN ARTERIAL DESIGN STANDARDS



Municipal engineers will find good use for this book as a basis for local standards, a reference, and a guide to further information. It reports the standards and practices of 24 urban areas, including lateral clearance, curvature and grade, corner radii, lane width, medians, curb and gutter, roadway width, driveways, sidewalk and border, and right-of-way. 1969, 91 pp., illus, tables. $4 to APWA members. $5 to non-members.

ACCOMMODATION OF UTILITY PLANT WITHIN THE RIGHTS-OF-WAY, STATE-OF-THE-ART

Special Report 44. Based on an APWA Research Foundation study, this Special Report contains information from field interviews in 20 metropolitan areas, a comprehensive mail survey of practices in 22 municipalities, traffic delay tests in 16 areas, and a literature search. 1974. 160 pp., 31 tables, illus., 6 appendices. $10 to APWA members – $12.50 to non-members.

ACCOMMODATION OF UTILITY PLANT WITHIN THE RIGHTS-OF-WAY, MANUAL OF IMPROVED PRACTICE

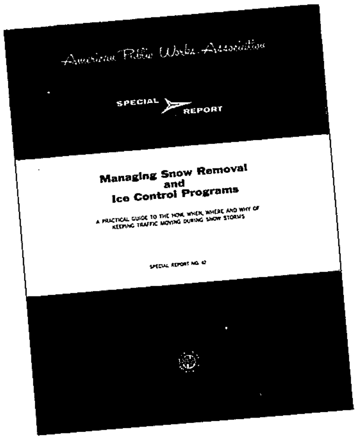
To be used in conjuction with *Special Report 44,* this manual was published jointly by APWA and the American Society of Civil Engineers (ASCE). It replaces ASCE Manual 14, published more than 30 years ago. 1974. 102 pp. $8 to APWA members – $12 to non-members

PRACTICES IN DETENTION OF URBAN STORMWATER RUNOFF

Special Report 43. Based on a study conducted for the Office of Water Research, U. S. Dept. of the Interior, this report covers such areas of stormwater management as local flooding, pollution from combined sewer overflows, and problems associated with the beneficial use of stormwater. A must for public works officials facing problems that could be alleviated through better stormwater management. 1974. 231 pp., 42 tables, 7 appendices, and bibliography. $10 to APWA members – $12.50 to non-members

MANAGING SNOW REMOVAL AND ICE CONTROL PROGRAMS

Special Report 42. A practical guide to the how, when, where, and why of keeping traffic moving during snowstorms. This unique manual contains selected informa-



tion presented by public works officials at the annual North American Snow Conferences. It covers the planning necessary before the storm, all facets of snow fighting and ice control, and the evaluation and rating of performance after the storm. In addition, a special section presents an analysis of the data gathered from 120 snow belt cities and counties that will be most helpful to public works men. 1974. 168 pp., 32 tables. $8 to APWA members – $10 to non-members

RAIL TRANSPORT OF SOLID WASTES

Special Report 40. This study by the APWA Research Foundation offers a feasible solution to the growing shortage of landfill sites in urban areas. It shows how compacted wastes can be hauled by rail to distant sanitary landfills at a price that competes with disposal costs being paid by many municipalities. *Rail Transport of Solid Wastes* evaluates the various factors and processes which could be integrated into a complete system. A wealth of data is presented in 64 tables and 28 figures. Photographs show how the system is being put to work in a Minnesota region. Twenty-three state and local governments, the Penn Central Railroad, and the Environmental Protection Agency sponsored this feasibility study by APWA. 1971. 150 pp. $8 to APWA members – $10 to non-members

FEASIBILITY OF UTILITY TUNNELS IN URBAN AREAS

Special Report 39. This comprehensive study of the technical, legal, and economic aspects concludes that utility tunnels are justified in high density urban areas. Although current technology can settle the unresolved technical problems, further research is needed to prove economic feasibility and general benefit to the public. Much of the research was conducted under contract by Stanford Research Institute. Engineers, lawyers, planners, administrators, and educators will find the report a valuable reference. 1971. 167 pp., 13 tables, 34 figures, bibliography, glossary. $8 to APWA members – $10 to non-members

PUBLIC WORKS COMPUTER APPLICATIONS

Special Report 38. This is designed to extend the use of computers beyond their application in the public works field. It weighs the problems, approaches, and opportunities of further computer use in terms of feasibility; process character; equipment design, acquisition, and placement; economic factors; and training of personnel. 1970. 143 pp., illus., glossary, references. $8 to APWA members – $10 to non-members

MOTOR VEHICLE FLEET MANAGEMENT

Special Report 37. What's the best time to replace a piece of equipment? *Motor Vehicle Fleet Management* takes the guesswork out of that problem – and scores of others related to equipment management. The report provides a total equipment management system based on standards and exception reporting, standard interval maintenance (PM), parts inventory and warehouse control, physical and performance specifications, optimum utilization and replacement, and instrumentation to monitor performance and standards. It shows how to plot costs of capital shrinkage and operating, maintenance, and downtime into a combined cost that reveals break-even point, earnings (savings), and replacement point. 1970. 101 pp., illus., glossary, equipment codes and standard factors, sample purchase descriptions and master specs. $8 to APWA members – $10 to non-members

PUBLIC WORKS INFORMATION SYSTEMS

Special Report 36. With few exceptions, management information systems for local public works organizations are not very far advanced. Cost accounting, work reporting, and facility inventory systems are fragmentary and produce data that cannot be used for interagency comparisons. This report will help to remedy those shortcomings. The cost accounting, data gathering, performance evaluation, and data processing systems developed during the project provide the basis of better local information systems as well as a statistical reporting service. 1970. 147 pp., figures, tables, and exhibits; 5 appendices including universal accounting system. $8 to APWA members – $10 to non-members

LOCAL PUBLIC WORKS ORGANIZATIONS

Special Report 35. Some 1,000 jurisdictions in the United States and Canada were surveyed for this report on the organization and administration of public works. The analysis of their replies tells when and how public works departments are established and how functions such as engineering, sewerage, refuse, parks, etc. are distributed. It gives characteristics of department heads, key assistants, and other personnel – a profile including age, education, experience, and salary. Departmental procedures, labor relations practices, and trends in organization also are covered. 1970. 168 pp., 88 tables, representative organizational charts. $8 to APWA members – $10 to non-members

VEHICLE CORROSION CAUSED BY DEICING SALTS

Special Report 34. A 28-month study by APWA in Hennepin County, Minn., showed that deicing salt can cause up to 50% of vehicle corrosion. Inhibited salt has less corrosive effect on bright metal parts but does not appreciably retard corrosion of auto-body steel. 1970. 75 pp., illus., tables. $8 to APWA members – $10 to non-members.

RESOURCE RECOVERY FROM INCINERATOR RESIDUE

Special Report 33. An analysis of factors that affect economic recycling of ferrous metals and other inorganic material contained in municipal incinerator residue. 1970. 35 pp., illus., tables, references. $4 to APWA members – $5 to non-members

HOUSEKEEPING FOR PUBLIC BUILDINGS

Special Report 32. The total cost of cleaning and maintaining an average office building usually equals the original construction cost within 20 years, and the largest share is for sanitation/housekeeping. This report gives custodial supervisors methods of reducing housekeeping costs while raising standards of sanitation. 1968. 25 pp., standard work times, workloads, contracts. $2.40 to APWA members – $3 to non-members

URBAN DRAINAGE PRACTICES, PROCEDURES AND NEEDS

Special Report 31. Summarizes data from 627 United States and Canadian communities on administration, regulation, and financing of drainage facilities. Discusses research and capital needs. 1966. 54 pp., 22 tables, bibliography. $2.40 to APWA members – $3 to non-members

SNOW REMOVAL AND ICE CONTROL IN URBAN AREAS

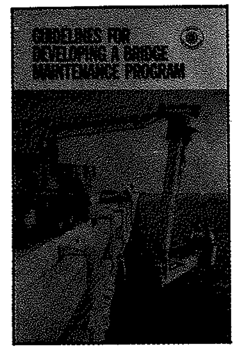
Special Report 30. Discusses methods of measuring cost and performance, chain of command, equipment strategy, snow ordinances, hiring private contractors, operations manuals, communications, and public information. 1965. 126 pp., illus., tables. $8 to APWA members – $10 to non-members

CENTRALIZED MAINTENANCE OF PUBLIC BUILDINGS

Special Report 28. Centralized maintenance can reduce manpower needs and improve service. This book tells how to do it, with examples from cities of various sizes. 1964. 37 pp., suggested ordinances. $5

GUIDELINES FOR DRAFTING A MUNICIPAL ORDINANCE ON INDUSTRIAL WASTE REGULATIONS AND SURCHARGES

Special Report 23. This is a guide for municipal officials who are considering the adoption of regulations and surcharges for the acceptance of industrial-waste discharges. It is not a substitute for engineering or legal consultation but rather a compendium of experiences that reveal the form and content of an ordinance. Revised 1971. 20 pp., $3



GUIDELINES FOR DEVELOPING A BRIDGE MAINTENANCE PROGRAM

Provides local public works officials with guidance for developing a viable bridge maintenance program. In addition to general information, the publication also includes guide specifications with related discussion on such topics as repairing concrete masonry with shotcrete, grouting reinforcing steel in old concrete, resetting existing steel expansion devices, and much more. 28 pp. $4 to APWA members – $5 to non-members

FINANCING AND CHARGES FOR WASTEWATER SYSTEMS

This 60-page report on sewer charges describes and analyzes the theory and practicality of how to charge the two broad groups served by the wastewater system – users and property. It should be particularly helpful to agencies adopting new rate structures in accordance with guidelines set forth by the USEPA. This is required by the 1972 amendments to the Water Pollution Control Act to receive federal funds for water pollution control projects. 1973. $2 to APWA members – $4 to non-members

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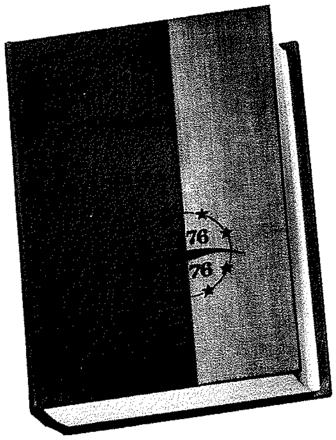


HISTORY OF PUBLIC WORKS IN THE UNITED STATES - 1776-1976

Scheduled for publication January, 1976, as part of the U. S. Bicentennial celebration, this book has been supported by the Federal Government in the form of Public Law 92-54, enacted by Congress and signed by President Nixon. It documents the role played by public works in U. S. development during the nation's 200-year history. The book is being produced by a special APWA committee with several prestigious public and private organizations cooperating. $15

EQUIPMENT MANAGEMENT MANUAL

One of the most comprehensive compilations of information on equipment management, the manual is being published in two parts; one available now and the other expected to be available in 1976. Part I, produced by the APWA Research Foundation, consists of six segments: Spec Writing-Hardware, Replacement Analysis, Parts Inventory Control, Preventive Maintenance, Management Information Systems, and APWA Data Bank Standards. Part II is a joint project of the Research Foundation and the Institute for Equipment Services. Comes in three-ring binder for easy updating. Part I (including binder) $15   Part II $10

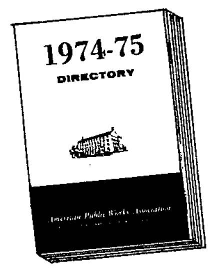
PROFESSIONAL EDUCATION IN PUBLIC WORKS/ ENVIRONMENTAL ENGINEERING AND ADMINISTRATION

This handbook for establishing university centers and programs describes various ways universities can make a greater contribution in meeting the country's critical needs for professionally educated public works engineers,

technologists and administrators. It was prepared for the guidance of universities, professional societies, government agencies, foundations and private enterprises interested in creating the necessary education/training and research capabilities. 1974. 71 pp. $5

PROCEEDINGS OF THE 1973 INTERNATIONAL PUBLIC WORKS CONGRESS AND EQUIPMENT SHOW

A compilation of articles from THE APWA REPORTER, the 121-page book contains 42 adaptations of papers presented during technical sessions of the 1973 Congress, held in Denver, Colo., Sept. 15-20. Also featured are the banquet address by J. E. Dube, former Minister of Public Works, Canada; and opening session talks. Most articles presented with pictures, maps, charts and other graphics. $10



APWA DIRECTORY

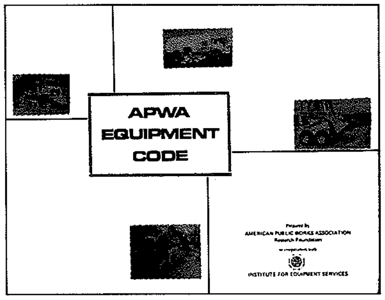
This is an encyclopedia of information on the American Public Works Association, listing all members, past and present officers, chapters, award recipients, institutes, committees, foundations, and much more. Everything you want to know about APWA is between these pages. APWA members ordering the Directory before publication receive it free of charge. Otherwise, $15

PUBLIC WORKS CONSTRUCTION INSPECTION

This important in-service training course is now revised, updated and ready to be administered at the local level. Subjects included in the course are asphalt paving, concrete construction, water mains and appurtenances, stormwater and sanitary sewers, plans and specifications, inspection duties and records, surveying and staking, and soils and foundations. Course can accommodate from 20 to 100 students at a time. 1974. $15

APWA EQUIPMENT CODE

This publication is part of the APWA Equipment Service Program and Data Bank (Research Project 70-1). It identifies important characteristics of motorized equipment, allowing meaningful comparisons of similar types of equipment such as gasoline vs. diesel engines or standard



vs. automatic transmissions. This publication is a must for agencies hoping to upgrade equipment management. $3

PROCEEDINGS, ENGINEERING UTILITY TUNNELS IN URBAN AREAS

With the findings of *Special Report No. 39,* representatives of utilities, government agencies, engineering firms, and contractors met to discuss what must be done to promote the construction of utility tunnels. Organized by the Engineering Foundation and co-sponsored by APWA and its Institute for Municipal Engineering, the conference covered systems compatibility and safety, design problems, foreign experience, operating and maintenance procedures; and financing, legal, and right-of-way considerations. 1971. 135 pp. $10

UNIFORM PUBLIC WORKS ENGINEERING CONSTRUCTION FORMS

Forms are titled "Invitation for Bids," "Instructions to Bidders," "Proposal," "Form of Agreement for Engineering Construction," and "General Conditions of Contract for Engineering Construction." Prepared jointly by APWA and Associated General Contractors of America. $1.00 a set

APWA Emblem – The letters "APWA" are in gold on a background of rich blue enamel. Available in four styles; lapel clutch, pin, tie tack and charm. $5 each.

No-Charge Publications

Individual copies of the following publications are free Write to APWA for prices of bulk quantities.

DYNAMIC TECHNOLOGY TRANSFER & UTILIZATION

A joint effort by APWA and Indiana University, this publication is based upon a year-long study conducted under a contract with the Research Incentive Group of the National Science Foundation. The study was designed to examine the manner in which new technology is introduced, mechanisms most effective in implementing improved technology, and to develop a program to spur the use of new technology by public works agencies. 1974. 77 pp.

GUIDELINES FOR DESIGN AND CONSTRUCTION OF CURB RAMPS FOR THE PHYSICALLY HANDICAPPED

Attractive two-color pamphlet contains a wealth of information on how to make it easier and safer for handicapped persons to negotiate city streets. Nine drawings and photographs complement the text. 12 pp. 1974.

GUIDELINES FOR DEVELOPING URBAN TRANSPORTATION SYSTEMS

Concentrating on the four most basic and commonly used elements of urban transportation – rail rapid transit, bus, major streets and freeways, and related terminals – this pamphlet assists officials at all levels of government to initiate new urban systems and improve existing ones. 1973.

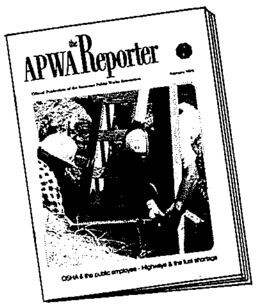
GUIDELINES FOR RETAINING CONSULTANTS TO PROVIDE ARCHITECTURAL AND ENGINEERING SERVICES

Here are new guidelines for public agencies to use in selecting consultants for architectural and engineering services. Recognizing the importance of using sound procedures that will instill the confidence of the public in this sensitive area, APWA's Institute for Municipal Engineering, through its Committee on Consultants, created this sound procedure to assist local officials charged with this important responsibility. 1973.

NEWSLETTERS

Newsletters of the Institutes for Solid Wastes, Municipal Engineering, Transportation, Water Resources, and Equipment Services.

Members of APWA Institutes receive the quarterly *Newsletters* and up-to-the-minute reports to the profession. For membership information write to APWA.



THE APWA REPORTER

Public works men keep abreast of their profession with THE APWA REPORTER, the monthly journal of important technical developments. Association and chapter news, and a wide variety of helpful features. Regular columns are devoted to new publications and positions available. Write to APWA for membership information.

CHAPTER PUBLICATIONS

Many of the Association's chapters publish standard construction specifications and other publications. For a current list, write to APWA.

Order the following publications from the Government Printing Office, Washington, D.C. 10401.

WATER POLLUTION ASPECTS OF URBAN RUNOFF

An APWA study of the causes and remedies of water pollution from surface drainage. Street refuse – litter – and catch basins were found to be potential major sources of pollution. The report evaluates the efficiency of street cleaning methods and the limitations of com-

monly used equipment. 1969. 272 pp., $1.50. Order number WP-20-15.

PROBLEMS OF COMBINED SEWER FACILITIES AND OVERFLOWS

The effects and means of correcting combined sewer overflows and separate storm and sanitary sewer discharges were inventoried nationally by APWA in 1967 and compiled in this report. 1967.189 pp., $1. Order number WP-20-11

CONTROL OF INFILTRATION AND INFLOW INTO SEWER SYSTEMS

A survey by APWA of 212 public jurisdictions in the United States and Canada produced 20 recommendations for corrective action other than relief sewers or enlarged treatment plants. 1970. 121 pp., $1.25. Order number 11022 EFF 12/70. The companion volume, *A Manual of Practice,* covers methods of correction. 1971. 131 pp., $1.25. Stock number 5501-0053

SURVEY OF FACILITIES USING LAND APPLICATIONS OF WASTEWATER

An onsite survey of 100 land application facilities utilized for municipal and industrial wastewater treatment conducted by APWA in 1971. The report summarizes results of the survey and provides information on foreign practices. EPA 4301/9-73-006.

THE SWIRL CONCENTRATOR AS A COMBINED SEWER OVERFLOW FACILITY

A hydraulic and mathematical model study was conducted in 1971-72 by APWA to develop design information for use of the swirl concentration principle for the regulation of combined sewer overflows. A simple geometric shape, without internal moving parts was found to offer a high degree of solid removal efficiency from the overflow. Full model reports are given and a simplified design approach explained. 1972. 179 pp., $2.25. Order number EPA-R2-72-008

HIGH PRESSURE COMPACTING AND BALING OF SOLID WASTE

A large commercial press was modified by APWA to determine design parameters for the high-pressure compaction and baling of solid wastes. Design considerations and performance for the equipment are given. 1972. 163 pp., $1.75. Order number SW-32d

FEASIBILITY OF COMPUTER CONTROL OF WASTEWATER TREATMENT FACILITIES

This report and manual of practice gives design information for several types of regulators and reviews new devices which promise to limit the pollutional impact from combined sewer overflows. 1970. 77 pp., $1.00. Stock number 5501-0145.

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___ Practices in Detention of Urban Stormwater Runoff	10.00	12.50
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___ Rail Transport of Solid Wastes	8.00	10.00
___ Feasibility of Utility Tunnels	8.00	10.00
___ Public Works Computer Applications	8.00	10.00
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