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URBAN STORMWATER MANAGEMENT: EUROPEAN EXPERIENCE

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1.0 INTRODUCTION

A large majority of European countries are highly urbanized and a further progress of urbanization is predicted. It is estimated (15) that the European urban population will increase by 50% during the period from 1970 to 2000. High concentrations of population in relatively small areas (urban land use typically represents 5%-7% of the total land area) lead to increasing exploitation of natural resources and dramatic changes in the hydrological cycle. Of these changes, only the problem of urban stormwater is dealt with in this presentation.

Although the first European attempt to address the stormwater problem dates back to the last century (29), full scale investigations of urban stormwater and of its management have been conducted only during the last two decades. The actual practicing of stormwater management has taken place during recent years and only in those countries which have virtually completed the control of point sources of water pollution.

The main objective of this presentation is to highlight some interesting developments and achievements in the European stormwater management. Most of the information presented here refers to stormwater management practices in France, Germany, Norway, Sweden and the United Kingdom. It is believed that, among European countries, these five countries are the more advanced in the management of urban stormwater.

2.0 SEWERAGE SYSTEMS IN EUROPEAN COUNTRIES

In all the surveyed countries, both combined and separate sewerage systems are used. The combined sewerage system, which serves for conveyance of both municipal sewage and stormwater, is rather common in European cities, particularly in older areas. Contrary to the Canadian practice, even some new systems are built as combined. Among the reasons for building new combined sewers, one can name lower costs (3), consistency of new additions with the existing system (3), and pollution control (23). The last argument was used in German practice in areas where high pollution of stormwater is expected and would damage the receiving waters. By using a combined sewerage system with holding tanks, pollution input to the receiving waters is smaller than that from the separate system.

The separate sewerage system consists of sanitary and storm sewers. The sanitary sewers are typically built as gravity sewers, some experience with pressurized and vacuum sewers was reported in the United Kingdom (3) and Sweden (3). The storm sewers typically carry all the surface runoff and outflow from foundation drains. The majority of the new developments in the surveyed countries are served by separate sewers.

The design of new storm sewers is based on the return periods of 1 to 5 years. Exceptionally, the drainage of intensively developed areas is designed for return periods of 10-20 years, and major schemes in the United Kingdom are designed for 50-100-year storms (3).

3.0 STORMWATER CONTROL STRATEGIES

A variety of stormwater control strategies has been reported in the European literature. The discussion of these strategies starts with quantity aspects and is followed by water quality considerations.

3.1 Controls of Stormwater Quantity

Various forms of storage are basic tools for controlling the quantity and distribution of stormwater inflows into sewerage systems and, eventually, into the receiving waters. The storage facilities reported in the literature include detention ponds, drainage discharge channels, storage trenches, retention tanks, oversized sewers, parallel sewers and storage tunnels.

Detention ponds have been used extensively in the design of drainage for New Towns of Milton Keynes and Stevenage in the United Kingdom. In Milton Keynes (5), the predevelopment runoff peak flow was maintained by means of a series of wet-dry and wet-storage ponds. Some of these reservoirs were built on-stream using low earth embankments, others were built off-stream. An example of the latter type of reservoirs is shown in Fig. 1.* The detention ponds built in Stevenage were called balancing water meadows. A number of these facilities has been built, with the largest one having a storage capacity of 12 acre-feet. These detention ponds were found effective in attenuating the runoff flows. The accumulated water is discharged over a period of up to 20 hours after the end of the storm.

Recently, a commission for the design of balancing storm tanks has been established in the United Kingdom. Some of the commission's findings are summarized in Fig. 2 which schematically outlines a procedure for the design of balancing tanks (3).

Another type of stormwater storage was reported in Norway (see Fig. 3) (8). In this case, stormwater is stored in a trench filled with rocks (the porosity is about 35-40% of the total volume). Stormwater enters this storage through a concrete pipe, with open joints, located at the top. The facility is drained through a large pipe, with open joints, located at the bottom. After construction, the trench is covered with soil. This type of underground storage is relatively inexpensive and allows further use of the land above the storage facility.

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* Figures are attached at the end of the paper.

The attenuation of stormwater discharges by oversized and parallel sewers was reported in Germany and Sweden (3). The effectiveness of such facilities is increased, in some cases, by installing throttling weirs at the sewer outfall.

The use of tunnels for stormwater storage was reported in Sweden (3) and Norway (11). One such system is currently under construction in Norway. This tunnel will serve the cities of Oslo, Barum and Asker, located on the shore of the Oslofjord. The tunnel is three metres in diameter and 40 kilometres long. The tunnel storage capacity is about the daily dry weather flow volume. It is expected that the utility of this storage system will be maximized through a proper operation. Operational controls will include two pumping stations, two overflows and five control gates in the system. Sewer overflows will be completely eliminated in the summer when the receiving water body is used most intensively for recreation. Overflows occurring during the fall and spring seasons will receive primary treatment prior to their discharge into the Oslofjord.

Other cases of operation of large combined sewerage systems to maximize the in-system storage were reported in France (3) and Germany (3). Extensive, looped sewer systems are particularly suitable for this purpose.

Stormwater holding tanks are very common in the European practice, particularly in the case of the combined sewerage systems. In these systems, the main function of the holding tanks is to reduce the volume and frequency of sewage overflows. These tanks will be further discussed in the following sections.

3.2 Stormwater Pollution Controls

Contributions of the urban stormwater to pollution of surface waters and the groundwater have been recognized and studied in many European countries. Extensive research studies have been conducted in Germany, Sweden and the United Kingdom.

Combined sewer overflows are considered in all the surveyed countries as a major source of water pollution which should be controlled. Although no national policies on the overflow control were reported, the problem of overflows is addressed in various recommended codes of practice (   ), or in recommendations of provincial or regional water authorities.

The basic tool in controlling overflows are holding tanks. These tanks typically perform a twofold function - eliminate overflows during minor storm events, and provide primary treatment for sewage flows exceeding the tank capacity. The sewage accumulated in the tanks during the period of overflows is returned to the wastewater treatment plant when flows subside.

The design of holding tanks for combined sewer overflows has been established in the German and British practice. In the German practice (23), the design of holding tanks is based on the mixing ratio. The tanks are designed for five times the dry weather flow (DWF) and specified minimum detention times (15-20 minutes). Flows exceeding the tank capacity overflow to the receiving waters. The design approach, based on the mixing ratio, has been criticized because the procedure underrates the local precipitation situation and overemphasizes actual wastewater runoff (23). A new procedure, based on a critical areal rainfall (see Fig. 4), has been introduced. In this context, the critical areal rainfall is a function of the receiving stream discharge, wastewater runoff from the sewer system and, possibly, the long-term depth of local precipitation in summer (2).

In the British practice, the size of the holding tanks is usually based on a two-hour detention of the difference between the 3 DWF and 6 DWF (29).

Pollution control effectiveness of the holding tanks depends also on the capacity of the interceptors and the sewage treatment plant. Interceptor capacities as high as 5 DWF have been reported (3). Many sewage treatment plants are designed for partial treatment of the flow equal to 5 DWF. The full (secondary) treatment capacity is typically 2 DWF (23).

Overflows from holding tanks are rarely treated. Among the treatment processes used, screening and disinfection were reported (3).

Overflow regulators controlling the overflow quality were studied in the United Kingdom (25). With the exception of a few demonstration projects, these regulators are not commonly used in the practice (3).

The quality of urban surface runoff has been extensively studied in Germany, Norway, Sweden and the United Kingdom. It is recognized that urban runoff contributes not only to the pollution of surface waters, but also to the pollution of the groundwater. The latter case is of particular concern in Germany where artificial recharge with surface water is used in water supply schemes. Road runoff was found to be an important source of pollution in groundwater. Large pollution loads of hydrocarbons, heavy metals and sodium chloride were reported in road runoff (23). Frequent accidents involving tank trucks carrying potential pollutants, in particular petroleum products, have caused severe environmental damage in recent years. Therefore, oil separation basins are provided along some transit highways in such critical areas, as the valley of the Ruhr River (23).

Various approaches to the characterization of pollution in urban runoff were reported, ranging from estimates of annual pollutant loads to studies of the sources of pollution.

Annual unit pollutant loads were reported for a number of catchments in Norway (26). The reported loads of nutrients agreed fairly well with the Canadian data. The loads of Suspended Solids and BOD (Biochemical Oxygen Demand) exceeded the Canadian data by several hundred percent.

The sources of pollutants in urban runoff were studied in Sweden (21). Among these sources, the atmospheric fallout, corrosion of building materials, traffic and population were considered. The population and traffic were the main sources of suspended solids, chemical oxygen demand, lead and phosphorus. Most of the nitrogen quantities originated in the fallout. The presence of zinc and copper was explained by fallout and corrosion. In general, the runoff quality improved with the increasing distance from the city centre.

Treatment of urban surface runoff is not practiced to any large extent in the surveyed countries. Where local conditions dictate control of runoff quality, either a combined sewerage system with holding tanks is used (23), or stormwater settling tanks are constructed. Such tanks are designed in Germany for retention times in the order of 10-20 minutes for the peak of the first in-rushing runoff wave (23). The tanks are often equipped with oil traps. Complete emptying of the tanks and sludge removal after rainfalls are recommended.

Improvements in the water quality of urban runoff passing through the balancing water meadows (described earlier) were reported in the United Kingdom (3).

Other pollution control considerations applicable to both combined and separate sewerage systems include street sweeping, sewerage system maintenance and snow disposal.

Streets are swept in the surveyed European countries fairly often. Downtown areas may be swept even several times a day, the suburban streets are swept about once every two weeks. In the Scandinavian countries, the removal of sand and grit by sweeping in the spring is considered to be particularly important. Although street sweeping is done mostly for aesthetic reasons, the sanitary and pollution control effects of street sweeping are recognized. Studies of the effects of street sweeping on the surface runoff quality were conducted in Sweden (20). Some of their findings are summarized in Fig. 5.

The maintenance of sewerage systems includes cleaning of sewers, catchbasins and holding tanks.

Cleaning of sewers during dry-weather periods was reported in France and the United Kingdom (3). High pressure flushing is most common.

Catchbasins are installed at sewer inlets in all the surveyed countries. Some British studies show that catchbasins are a significant source of pollution (9, 22). This source can be controlled by regular cleaning of catchbasins. The reported frequency of cleaning is once or twice a year. Suction devices are used for that purpose.

Stormwater holding tanks are maintained regularly. In most cases, solids are removed after every rainfall.

Snow removal and snowmelt quality are of particular interest in the Scandinavian countries. In combined sewerage systems, high chloride concentrations caused by snowmelt runoff interfere with the operation of sewage treatment plants (disturb biological treatment). Drainage effluents from storm sewers contain large quantitites of chlorides and may cause environmental damage to the receiving waters. No solutions to these problems are forthcoming. A partial remedy is obtained by restricting the use of deicing compounds.

4.0 ANALYTICAL TOOLS FOR STORMWATER MANAGEMENT

Although the first simulation models applicable to urban drainage design were developed in Europe nearly 20 years ago, complex simulation models dealing with various aspects of stormwater management were introduced only recently. Consequently, the European experience with design/analysis models is much more extensive than the experience with planning and water quality models. A large number of simulation models were reported in the surveyed countries and most of these models were used in the practice. In countries like Norway and the United Kingdom, a single simulation model (developed under government sponsorship) is commonly used in drainage design. A wide range of simulation models developed mostly by engineering companies is used in Germany.

In the following, a brief description of various approaches to simulation of urban stormwater management systems is given.

4.1 Rainfall Analysis

Rainfall data are used in stormwater management simulations in a variety of ways. In some cases, runoff flows from a catchment or storage reservoir are determined directly from the analysis of rainfall data. Two such procedures were reported. The British Flood Studies Report (24) gives a procedure for deriving flood frequency curves directly from the rainfall data. This procedure was subsequently modified for urban conditions (12).

A similar procedure was developed in Germany for catchments with storm holding tanks (23). The outflow from the tanks is calculated without considering details of the sewer network.

Another use of rainfall data is in conjunction with various runoff or stormwater management models. The following types or rainfall data inputs are used:

(a) actual rainfall (or precipitation) data
(b) base rainfalls
(c) design storms.

Actual rainfall data are used in continuous simulation done for planning studies. This type of rainfall input is used by the Norwegian Model NIVA (26) and the QQS Model of Dorsch Company (10). Both models translate the rainfall record into runoff flow and pollutant flow records. These latter records are then subject to frequency analysis and used further in planning and design of drainage systems. A computer model which prepares rainfall input data from conventional rainfall records was developed in Sweden (4).

The concept of base rainfalls has been developed in Norway (18). Actual rainfall events are replaced by equivalent block-rainfall events of constant rainfall intensity. These block-rainfalls are then classified into a number of groups according to their intensities and durations. Finally, base rainfalls are established, as rainfalls of mean intensity and duration, for each group. These base rainfalls are then used in detailed simulations and their use results in significant computer cost savings as compared to the costs of simulations for all the actual events. The neglect of the interevent time seems to be an obvious shortcoming of this procedure.

Design storms are used commonly in the European practice. In some cases, design block rainfalls of specified return period and duration are used in conjunction with the Rational Methods, or its variations (6, 14).

Design storm hyetographs are used in design and analysis of drainage systems. The complexity of such design storms varies. Relatively simple procedures define the temporal rainfall intensity distribution which is then applied in conjunction with local rainfall intensity-duration-frequency curves. In the United Kingdom, the design storms have been derived this way by a government agency and are readily available to users (30).

In more complex procedures, such as for example, the analysis of rainfall data for the City of Hamburg (1), the random characteristics and spatial distribution of rainfall are also considered.

An extensive research of the design storm concept has been undertaken in France. Approximate methods were developed to determine the return periods of the runoff peak and volume produced by a design storm (7).

4.2 Simulation of Urban Catchment Hydrology

Computations of urban runoff are done separately for impervious and pervious areas. Excess rainfalls are computed by considering rainfall losses. This excess rainfall is then distributed in time.

On impervious areas, only a constant initial loss (wetting loss and depression storage) is typically considered. The overland flow hydrograph is produced by using such approaches as linear and non-linear reservoirs, unit hydrograph, or the Kinematic wave. Calculation for pervious areas proceed in a similar way, except for considering another loss-soil infiltration. Many models use the Horton equation to approximate soil infiltration rates. A model developed at the (British) Institute of Hydrology uses statistical data from many catchments to account for losses on the pervious area (28). Some of the models used in Germany (e.g. Dorsch models QQS and HVM) consider evaporation and soil moisture conditions in calculation of rainfall losses on pervious areas (23).

In many cases, the losses on both impervious and pervious areas are accounted for by constant runoff coefficients.

4.3 Flow Routing in Drainage Systems

The approaches to flow routing vary from simple time off-set methods to numerical solutions of the St. Venant equations. Many models, particularly in the countries with older sewer systems, include sewer surcharging and pressurized flow in their models. The selection of a routing model is typically based on a compromise between the accuracy of computations and the associated costs of such computations.

Sophisticated flow routing models (often proprietary) account for such hydraulic conditions and structures as flow reversal, looped sewers, backwater effects, weirs, orifices, tidegates and in-line and off-line storage facilities.

Finally, some interesting observations from recent publications on flow routing are listed. Kidd (13) drew attention to the fact that, for flows with Froude numbers about two or higher, the solutions of the St. Venant equations do not describe the actual flow conditions. In that region of Froude numbers, the underlying assumptions of St. Venant equations are violated and other approaches have to be used.

The lack of data on energy losses at sewer junctions seems to defeat the accuracy and sophistication of the dynamic wave routing procedures. A further research on junction energy losses was recommended (27).

4.4 Water Quality and Pollution Control Considerations

Quality aspect simulations include simulation of the constituent flow in sanitary sewage and surface runoff, routing of constituents through storage and treatment facilities and, eventually, water quality simulations in the receiving water body.

Dry weather flow and surface runoff quality are typically simulated by simulation models. The dry weather flow is characterized by a flow pattern and composition derived from land use. The surface runoff quality is described either by average concentrations, or calculated from catchment characteristics, pollutant accumulations and runoff flow rates (10). Most models deal with only a few basic constituents, such as BOD and suspended solids.

The routing of constituents is based on advection and mixing. Other quality reactions, such as constituent decay in the catchment or during transport, are rarely considered (23).

In storage facilities, only settling is considered in quality computations.

Simulation of treatment is included in the NIVA model (17) which makes it possible to evaluate, over a long time period, the performance of a sewage treatment plant during the dry and wet weather. The periods of wet weather are of particular interest, because the plant becomes overloaded and the treatment effectiveness is reduced. Optional treatment facilities simulated by the model include the primary clarifier, aeration tank, secondary clarifier, flocculation and coagulation unit, retention basin, and overflow regulators. An optimization subroutine built into the model designs the least-cost combination of storage and treatment for any specified pollutant loads to be disposed of into the receiving waters.

Other treatment models for urban stormwater are under development in Germany (23).

Simulation of water quality in the receiving waters is included in several models. In many cases, such simulations are done separately from the runoff simulations.

5.0 CONCLUSIONS

Management of urban stormwater has become widespread in the European drainage practice only in recent years. In many countries, extensive research on stormwater management is currently underway and new results and advances can be expected in the near future.

Combined sewerage systems are rather common in European cities. The problem of overflows from such systems is typically solved by storm holding tanks with return flow to the waste treatment plant.

Separate sewerage systems are built in new urban areas. Under favourable conditions, runoff peak flows are attenuated by storage in detention ponds or other facilities. Exceptionally, these storage facilities are designed as settling basins (with or without oil traps), in order to reduce the pollution loads discharged into the receiving streams.

For evaluation of stormwater management alternatives, a large number of simulation models developed in Europe as well as in the U.S.A. are used. The European experience with stormwater modelling is particularly extensive in the field of design/analysis models.

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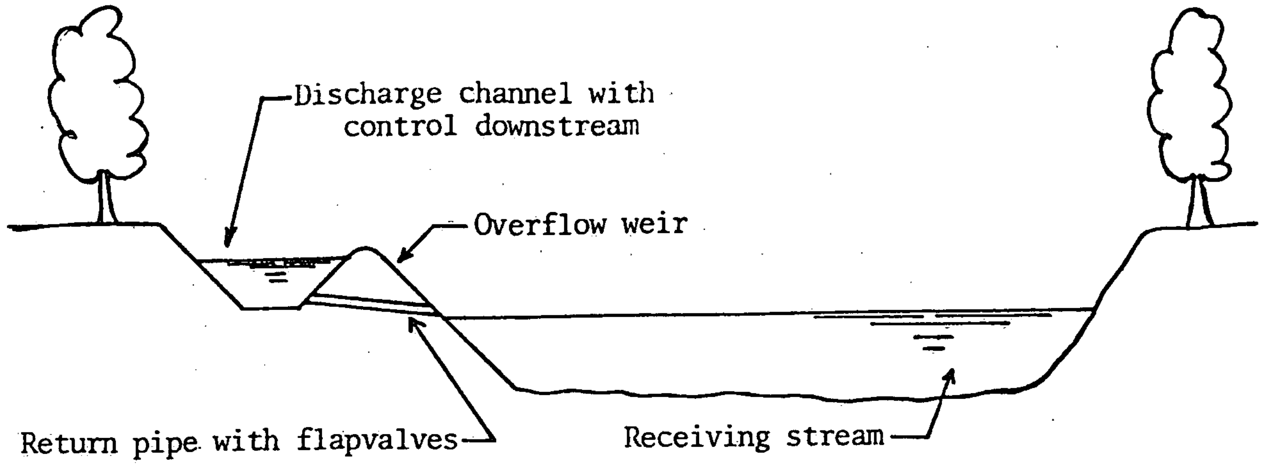

Fig. 1. Off-Stream Storage of Urban Runoff(After ref.5) .

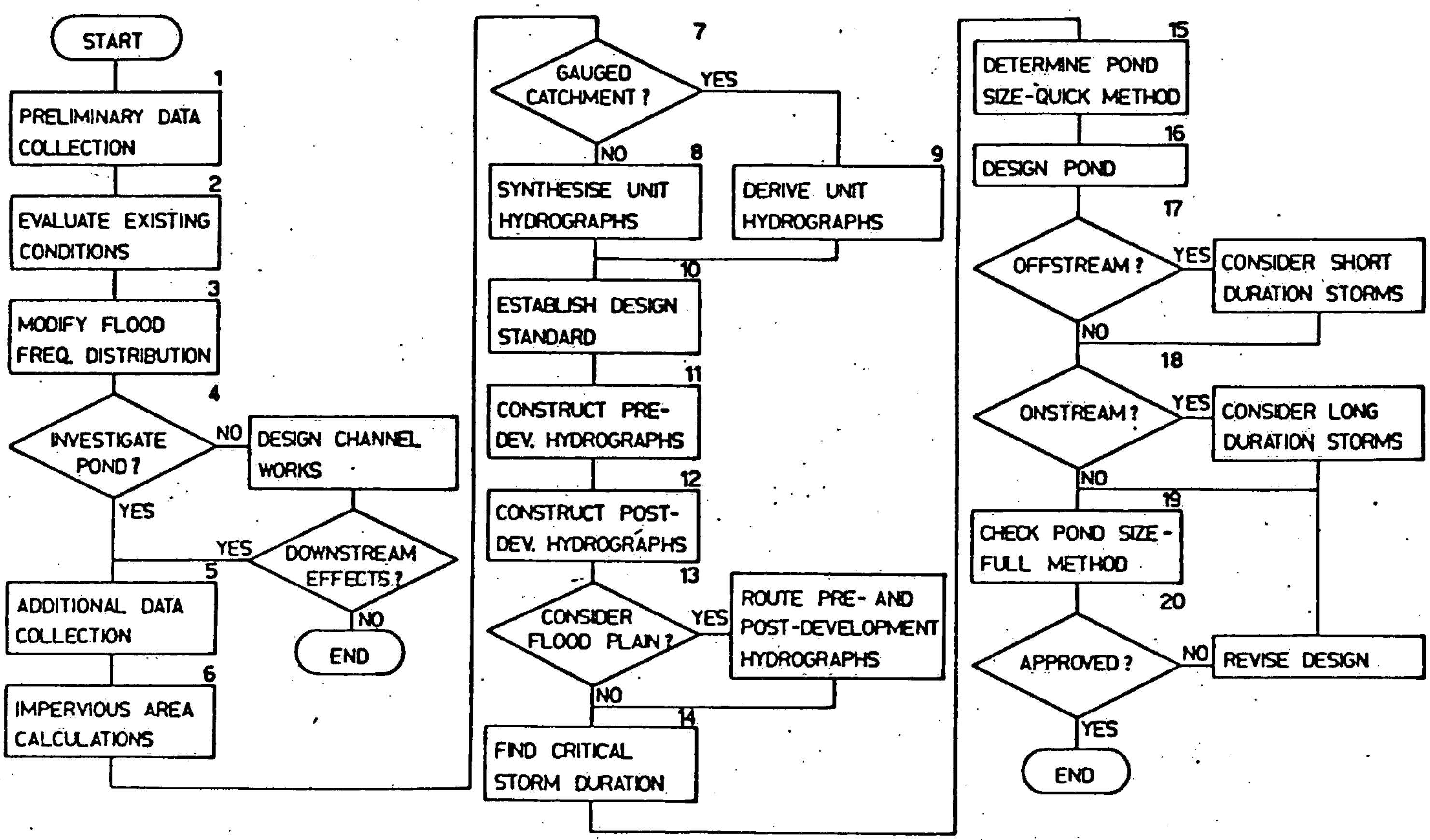

Fig.2. Flowchart for Design Procedure for Stormwater Ponds(After Hall et al., Urban Strom Drainage,Pentech press,London,1978).

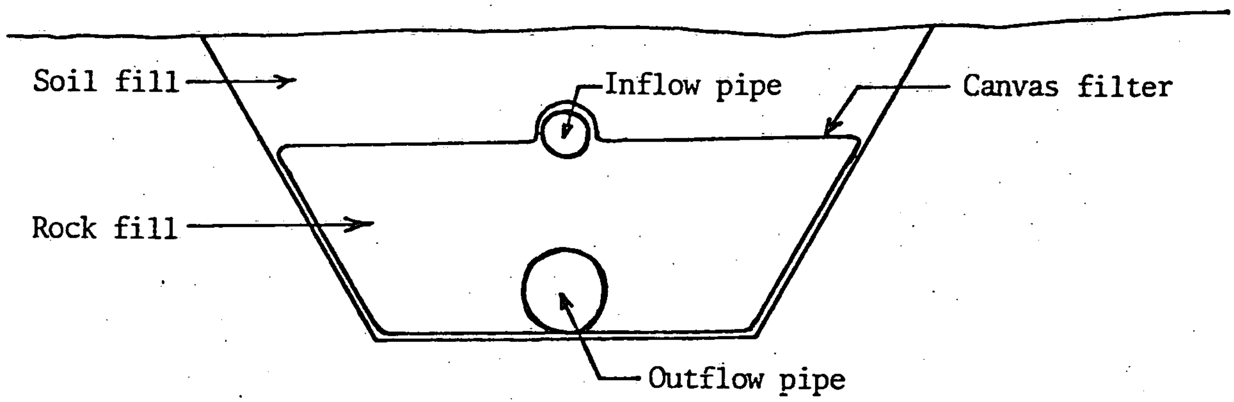

Fig. 3. Urban Stormwater Storage Reservoir(After ref.8) .

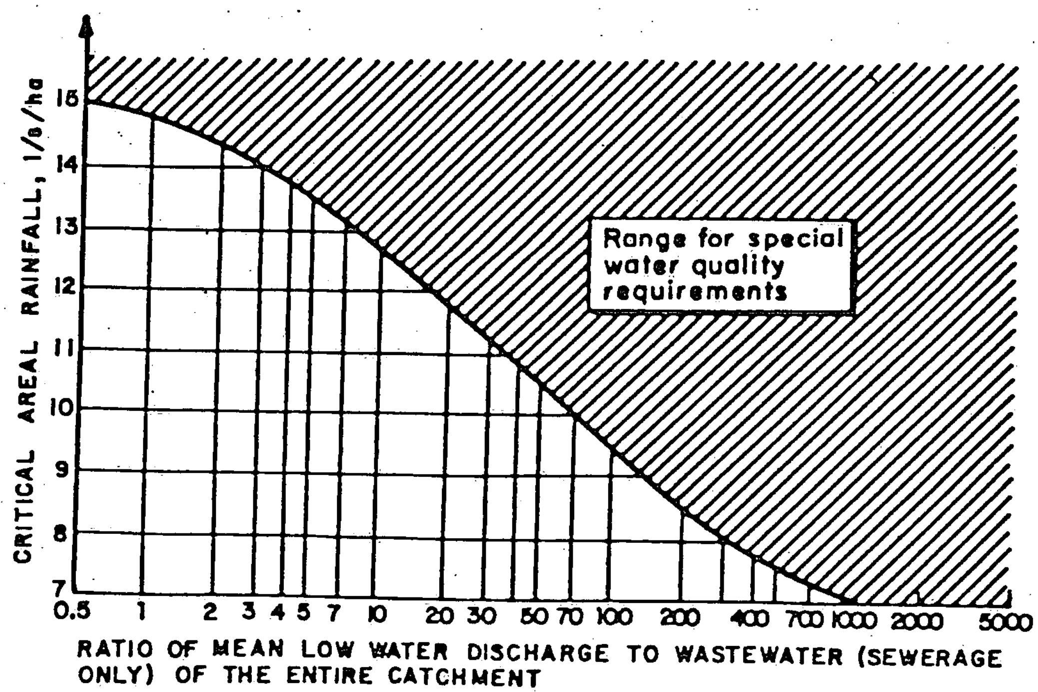

Fig.4. Design Critical Areal Rainfall for Storm Holding Tanks(After ref.23).

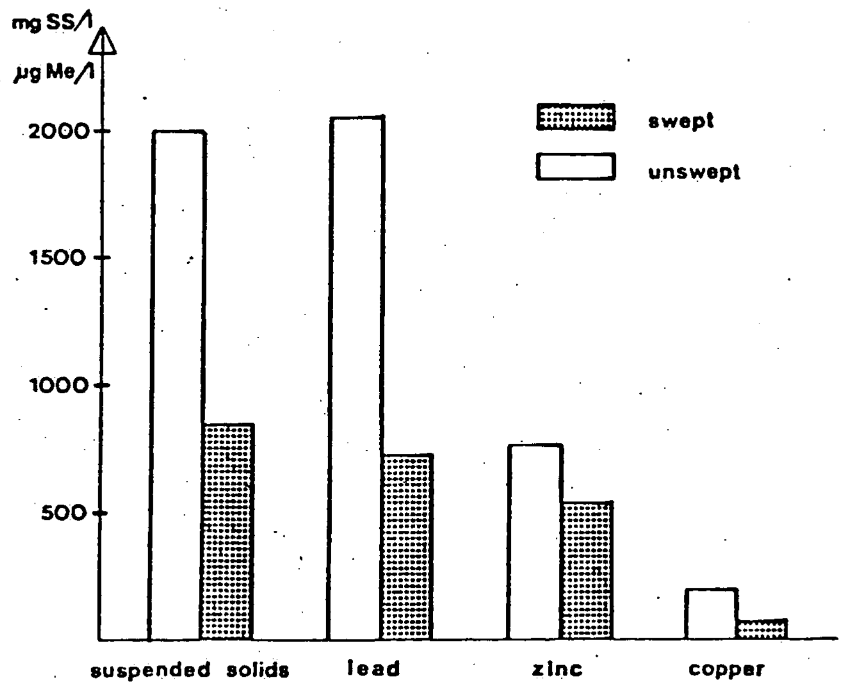

Fig. 5. Effects of Street Sweeping on Pollutant Quantities in Urban Runoff (After ref. 20) .