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STATUS REPORT ON URBAN HYDROLOGY

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PREFACE

The process of urbanisation has been taking place for more than 6000 years. Prior to the nineteenth century, most of the urban settlements were small and functioned largely as market towns, serving the surrounding countryside. The urban growth which has taken place worldwide since the early eighteenth century may largely be attributed to the industrial revolution. From 1800 to 1950 world population grew from less than 40 million to greater than 700 million an increase of about 17 times (Johnson 1967). With this rapid expansion, the water requirement increased tremendously and consequently the hydrological problems associated with the development.

Problems of urban hydrology have been of world wide concern for several years, but there have been few compilations of background information and even fewer comprehensive investigations of specific urban situations. The new informations and data are of vital importance to the development of urban hydrology research in future. There is also an urgent need to make the best possible use of existing information. Keeping this very fact in mind M.K.Shukla Scientist B and Dr. B.Soni Scientist E of the Institute have prepared this report.

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CONTENTS

ABSTRACT

In the wake of growth and development of towns at a fast speed, the urbanisation is taking place at a very rapid rate. The constant increase in impervious area is causing high amounts of runoff in less time with the increase in runoff rate, the hydrological problems assocciated with it are also increasing. Thre is an urgent need to provide efficient civil services, water supply and drainage facilities to the people. Urban hydrological research has been taking place in several developed and developing countries from long time back. Several hydrological models have been developed to provide better estimation of runoff from urban catchments. In this report an extensive review of literature on urban hydrological modelling and catchment research has been carried out. The study showed that almost in all the countries the authentic data on long term basis is not available, specially the discharge data through urban drains. Technology transfer or information exchange programs, data on pollutant transport, snowmelt data base and validation of runoff models for water quality measurements are some of the aspects which require a deeper inside almost throughout the world.

LIST OF FIGURES

1.0 INTRODUCTION

The movement of people from rural area to urban areas is called the urbanisation. It has proceeded vary fast since the mechanisation of agriculture. Pressure of population, employment in industries, medical and educational facilities in the cities have led to the growing immigration to urban and industrialized areas in developing and developed countries alike.

Savini and Kammerer (1961) have divided urbanization into four stages:Rural,Early Urban, Middle Urban, and Late Urban. The rural stage is when the area under study is in virgin stage, under cultivation or in pasture. Quite obviously most of the earth's land surface is in this stage.Early urban land use is characterised by city type homes built on large plots with many of indigenous vegetation remaining intact.The middle urban stage concerns the construction and growth of large scale housing developments, shopping centers, schools, streets and sidewalk.The late urban stage is brought about as a result of even more development which may cause the remaining amount of vegetation to diminish to zero and land surface cover to approach a total cover of manmade structures and accoutrements.

The crisis of human settlements stem from man's failure to understand the effects of urbanisation from indifference to the consequences of his intervention in the natural environment or from his ability to take necessary preventive or corrective actions. In turn, it is urban settlements that the overburdened environment has it's most concentrated and profound influence on man (secretary general,UN,1971,Unesco press).

The urban population is increasing at a very rapid rate for example in United States the percentage of urban population has increased from 41 % of the total population in 1910 to 66 % in 1960 and is estimated to 80 % by the end of year 2000. The FRG has total population of 61 million and is expected to rise to about 68 million (10%) by year 2000. Population of Sweden will be 9.5 million by 2000 from 8.6 million (11%) in 1980.In India urban population increased to about 46.2 % during 1971 to 1981. During this period urban population of India has gone up from 109 million in 1971 to 156 million in 1981. Number of towns in India with a population over 20000 increased from 536 in 1951 to 975 in 1971. By 1991 the urban population in India is estimated to go up to 216 million and by 2001 it is estimated to go upto about 320 million.

History indicates that most of the cities and major urban centres have developed near the source of water supply principally near natural lakes and rivers. With the development of technology of dams and reservoirs, urban centres are able to get a good supply of water. ground water sources are also expanded. As urban areas continue to expand new sources of water are required to be found. This rapid concentration of population in certain areas is causing heavy demand for water for domestic, industrial and recreational purposes with the consequent increase in the construction of water supply and drainage facilities. The expenditure involved in these constructions are very heavy (e.g.av. annual cost of $ 2.5 billion for United states alone). With the increase in population demand for water is increasing tremendously. The higher water use is consequently resulting in higher urban discharges. thus the hydrological problems associated with urban population are continuously increasing. Further because of the increased residential and commercial facilities such as buildings, pavements and parking lots, the built up or impervious areas in the watershed increase, consequently magnitude and frequency of flood peaks also increase. Design of drainage facilities which do not account for this increased runoff are inadequate and may result in heavy damage and loss of property.

Modeling and catchment research for urban drainage systems is the subject singled out as having the largest gaps in knowledge in urban hydrology. Water quality aspects are accorded considerable attention because of the strong interest in environmental protection in the world. The issue has been stated as "When a city takes a bath, what do you with the dirty water?". Precipitation removes considerable amounts of particulates from urban areas. As an indication of the extent of this potential burden, it has been estimated that the 330 sq km of the City of Philadelphia, with a population of two million people, produces, in metric tons: 2,900-tons/day of pollution emissions; 780,000-tons/year of trash; 82,000-tons/year of garbage; 560,000-tons/year of incinerator residue; 24,000-tons/year of debris from inlets; and 83,000-tons/year of street sweepings. This report is prepared to give an overview of the research carried out worldwide in urban catchment research and modelling.

1.1 Urban Hydrological Cycle

A schematic representation of urban hydrologic cycle is given in fig 1.Figure is designated as pre-urban hydrological system in order to visualise the water components for a typical large sector of land prior to urbanisation as agrarian activities have only a modest effect on hydrological cycle. the complexities imposed on the system by urbanisation can be appreciated by comparing it with fig 2 which is illustrating the local water balance changes brought about by the drastic changes in land use that accompany urbanisation.

1.2 Water demand - A world wide estimate

Water is a necessity for development, though only a small portion of it is used for domestic purposes. Recent estimates by USSR State Hydrological Institute, of principle global water uses is given in the following Table (tab.1).

Continent	1970			2000		
	domestic	industrial	agril*	domestic	industrial	agril*
Europe	30	160	125	77	324	320

Asia	40	50	1300	200	360	2300
Africa	4	3	120	42	50	260
North America	40	267	206	77	920	300
South America	4	12	64	440	170	120
Australia and Oceania	1	8	12	4	22	40
Totals	119	500	1827	440	1846	3340

*-Agriculture

The relative increase of water demands to the year 2000 for mostly developing and mostly advanced continents is in the following Table (tab 2).

	Domestic	Industrial
Mostly developing continents	500-1050	700-1700
Mostly advanced continents	200-400	200-350

Note: All units in cubic km.

2.0 URBAN CATCHMENT RESEARCH AND MODELING IN U.S.A.

2.1 Urban Catchment Research

2.1.1 Introduction

Urban catchment research in USA started as early as 1948. From 1948 through 1967 The Johns Hopkins University conducted a Storm Drainage Research Project, the most comprehensive field research project to date. Over the 1948-1967 period a total of 52 different sewered catchments were gaged Data considered to be among the best accumulated during the project are available for two catchments, Northwood (19.ha) and Gray Haven (9 ha). No water quality sampling was performed. Findings from the first satisfactorily instrumented sewered catchment for ascertaining runoff water quality were reported in 1964 (Mt. Washington, Cincinnati, Ohio, 12-ha). A 1964 handbook noted a serious need for much more extensive urban drainage field research, consistent with the huge public expenditures in these facilities. The major finding soon afterward of the first Engineering Foundation conference co-sponsored by what is now the ASCE Urban Water Resources Research Council was that the acquisition of much more field data was the greatest research need in urban hydrology (Unesco,1971).

In 1969, a plan for a nationwide field data acquisition program was published.Principal benefits that were expected to accrue from an effective national program of urban storm drainage research were; (1), national criteria for more efficient and dependable planning, implementation and operation of urban storm drainage facilities, on acceptable socio-economic bases; (2), national quantification of pollution from urban storm drainage systems; and (3), resolution of the only major criteria missing for effective planning, design and operation of quantity and

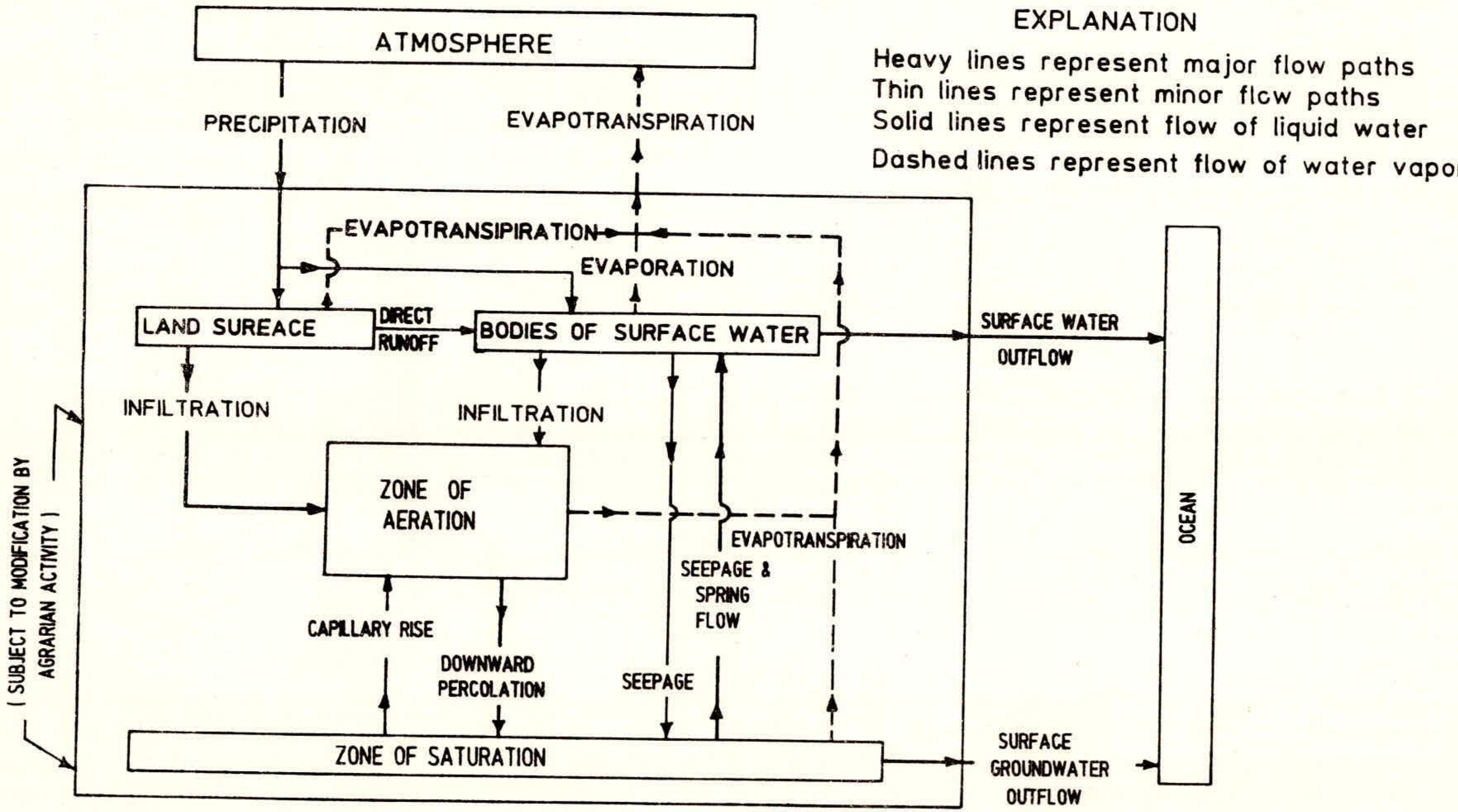

FIG. 1. PRE - URBAN HYDROLOGICAL SYSTEM .

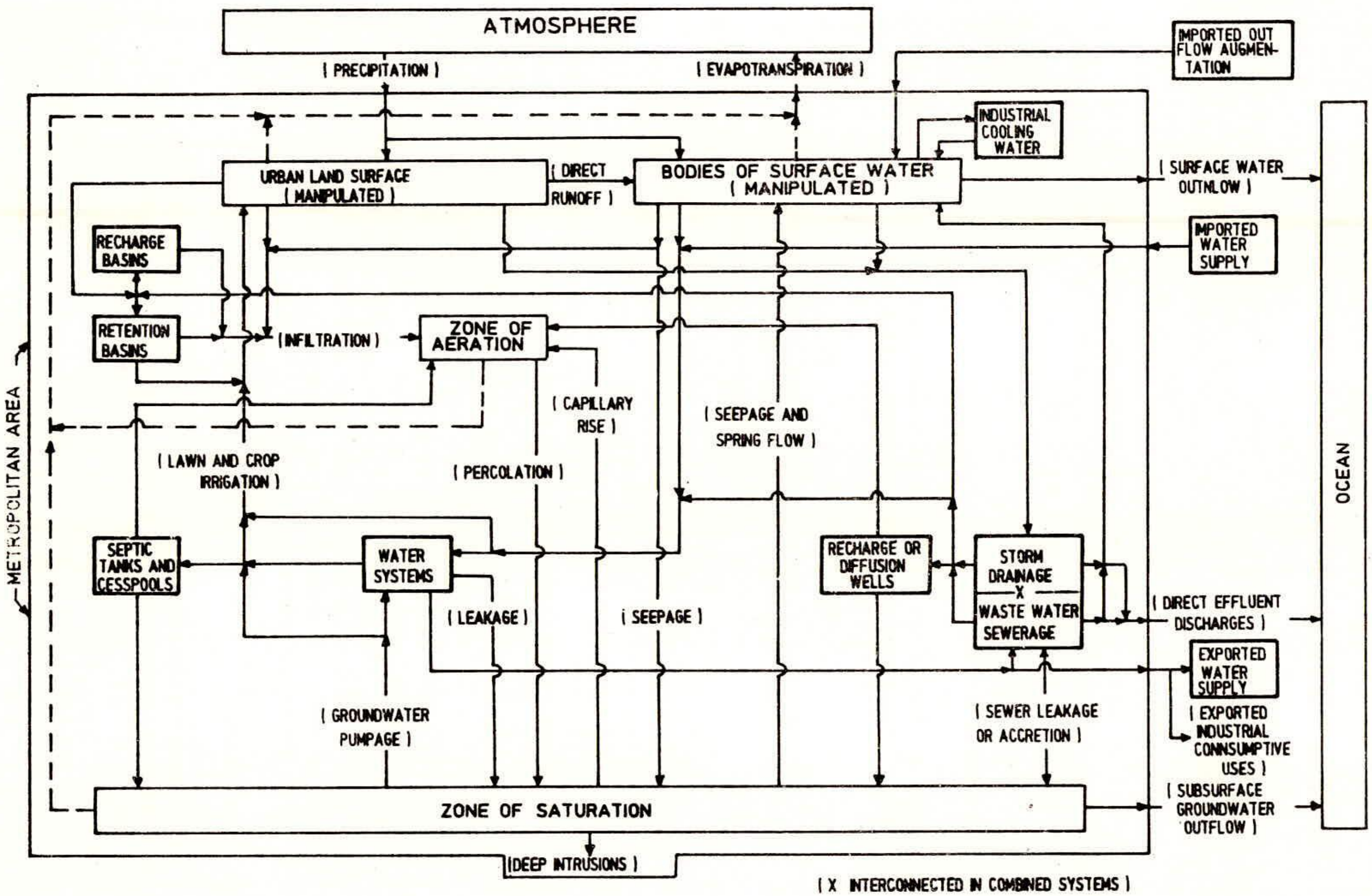

FIG. 2 URBAN HYDROLOGICAL SYSTEM .

quality exchanges between various urban water service categories. It was suggested that mathematical model development for sewered system applications has seemingly already greatly out paced the data base for model verification. There have been considerable advances in the state-of-the-art, particularly in modeling, over the past decade. However, as subjectively needs for more and better data are growing faster than such advances are taking place.

2.1.2 Water quality sampling

Water quality data has been collected on several catchments and for only a fraction of these has such data been used in model tests. Because of the rapid changes that occur in storm and combined sewer flows, a minimum sample collection interval of 3-minutes or 4-minutes is desirable and discrete samplers should be used that have a minimum of 24 containers. Systems have been developed for automatic, on-line measurement of total organic carbon and suspended solids.

2.1.3 Raingauge networks

Some of the major researches conducted in the cities of U.S.A. and their instrument network is described below.

St. Louis: From 1970 through 1975 an urban-weather research program, the world's first major field-laboratory program aimed at assessing the effect of a major urban-industrial complex on precipitation, was conducted in the St.Louis metropolitan area. Instrumentation included 250 recording raingauges. Definite inadvertent weather and precipitation modifications have been documented in initial analyses of St.Louis data and in comparisons with data from other metropolitan areas.

San Francisco: Installation of the most advanced automatic raingauge network was completed in the City of San Francisco in 1971, as part of a hydrologic and hydraulic data acquisition system. Data from 30 tipping bucket raingauges in 1/4-mm increments are recorded at a central computer as they occur, while flow levels recorded each 15-seconds are converted into discharge rates via rating curves. Unfortunately an analogous capability for obtaining water quality data was not implemented. A computer program operated off-line interpolates between raingauge network readings and prints out rainfall depths for a fine grid covering the entire city.

2.1.4 Data Bank

Not much field data is available for testing models of storm and combined sewer systems, and much of the data that is available is not of very good quality. Adding to these difficulties has been the necessity for each modeler to acquire raw field data almost independently. EPA is supporting a project by the University of Florida that is attempting to bring together data that is currently available and formulate it in a data file such that potential model developers and current model users may have ready access to the data. A tentative data retrieval format and an initial detailed inventory of potential data sources were completed by the project early in 1975.

2.1.5 Research

Walter E. Skipwsith and Walter L.Moore of University of Texas at Austin have evaluated the urban runoff by watershed simulation. Their study reported that the comparison of recorded and simulated runoff values with/without lawn irrigation for Waller Creek drainage area, gave values of 8.94, 11.52, 10.10 for 1963-64, 15.33, 1'5.95, 14.89 for 1964-65 and 10.38, 14.31, 13.34 for 1965-66 respectively.

Crippen in 1965 employed unit hydrograph methods on the sharon Creek watershed, a small 245 acre basin and found that peak discharge (Q_p) increased from 180 cubic feet/second to 250 cusec as urbanization proceeded over the several year study period.

Riggs in 1965 monitored summer and fall runoff in nine adjoining rural watersheds in the orystallin Pieclmont area of Virginia and found that low flow discharge was directly related to percentage of the drainage basin that was cleared of trees and brush and given over to pasture and hay. clearing of land along the stream channel seemed to produce a greater effect than clearing over the basin generally. The effect of clearing was negligible during periods of high discharge.

Leopold (1968) pointed out, using Brandy wine Creek in the mid-Atlantic area as an example that urbanization is accompanied by increases in short term flood peaks due to increased volumes of storm runoff from impervious surfaces and greater velocity of flow across impervious surfaces and through storm sewers. He also pointed out but did not emphasize the decrease in low flows that would and consequently loss of surface storage.

Seaburn (1969) separated direct runoff from flood hydrographs of an urbanizing stream on long island. As urbanization increased, the average annual direct runoff increased in relation to precipitation, the magnitude of short term peak flow increased, and entire hydrographs were faster.

American society of civil engineers, 1969b have reported that runoff from urban locality in united states discharging as much as 5% of annual flow of sewage, and 20 to 30% of annual volume of solids to water courses every year.

Mcpherson in his study on hydrological effects of urbanization in United States of America indicated that in general the volume of flood runoff increases with the increase in impervious areas and by the construction of storm sewers, gutters, catch basins, etc. Runoff peak flows in stream and drains, changes in timing and time distribution of direct runoff from urban areas are striking reflection on influence of urban development.

Wallace (1971) in his study in the city of Atlanta, Gorgia reported that over a period of two decade, the impervious area of the city increased from 1.7% to 31% in a 356 sq.km. catchment area. The analysis of rainfall and runoff records for a period shows that storm runoff volume has increased in dry months, base flow has decreased in wet months and peak runoff from summer storms has increased significantly.He also estimated land use in Peach tree Creek watershed at three periods. He modeled individual Peach tree Creek flow events, finding that with increasing urbanization short term flood peaks tended to increase and that time to peak tended to decrease.

Ferguson, B.K. and P.W.Suckling, in their study on changing rainfall-runoff relationships in the urbanizing peach Creek watershed Atlanta, Gorgia reported that regarding total annual flows, increasing urbanization appears to be accompanied by both increasing runoff in wet years and declining runoff in dry years. The reason of intense runoff in wet years is because large, intense rainstorms lead to large short term runoff adding to annual rainfall.

Pluhowski and Spinellau in 1978 working in the area of long island, suggested that poorly scaled sanitary sewers, located below the ground watertable, could reduce stream base flows by intercepting groundwater. The magnitude of this effect suggested by their results is uncertain.

M.H. Diskin of Israel Institute of technology, Haifa, Israel in his study on Estimation of urbanization effects by a parallel cascades model have shown that as size of the directly connected impervious area increases the relative effect of improving the stream channels decreases. The increase in peak discharge due to change in the value of storage constant is about 12%. It was clearly shown that for impervious area the peak is higher and the time to peak is much earlier than for previous areas.

Simmons and Reyholds in 1982 estimated base flow for six streams in the same area of long island, using hydrograph separation technique. The volume of base flow declined with increasing urbanization, which was attributed primarily to decreased groundwater recharge. Base flows remained unchanged in two nearby rural drainage areas during the same period.

Furguson and Sucking in 1989 presented preliminary results of annual and base flow studies on Peach tree Creek, comparing rainfall runoff relationships in early and late periods in the watershed's urbanization. This paper extends the authors' previous work by adding peak flow analysis, expanding the base flow analysis, and adding more recently available data to all studies.

The soil conservation service, 1971 (Tab 3) gives estimates of imperviousness ranges for typical urban development as follows:

Land use	% imperviousness
Low density residential	20-30
Medium density residential	25-35
High density residential	30-40
Business commercial	40-90
Light industrial	45-65
Heavy industrial	50-70

ASCE,OWRR,USGS have recognised the inadequacy of present method of analysis and design procedure adopted in urban drainage systems and in watersheds which are being urbanised. A Task force to study effect of urbanisation on runoff have been formed by ASCE with the following objectives.

a. Seek information to changes in r. o. characteristics
b. Effect of such changes on concentration of flood waters in stream channels
c. Prepare a bibliography
d. Identification of areas of research on runoff rates for flood control

Carter in his study on changes in magnitude and frequency of peak floods due to urbanisation of watersheds has concluded that effects of sewer construction, channel improvement and other features of urbanisation on peak floods were more significant than the effects of changes in percentage of impervious areas. Carter and Thomas also approved the above results.

Anderson also conducted a similar analysis and presented charts to estimate the magnitude of peak floods, which have a RI ranging from upto 100 years for watersheds in which various degrees of urban and suburban development has occurred.

Stall and Smith compared unit hydrographs derived from data obtained from two small watersheds in Champaign, Illinois. one of them was entirely agriculture and other 38.1% of impervious area. Mean basin slopes and stream channel shapes of the two watersheds were generally similar. Comparison of unit hydrograph showed that peak of the unit hydrograph of urban watershed was about four times to that of rural watersheds. Average time lag was also about four times greater for rural watershed than for urban watershed.

Espey et al. concluded that because of urbanisation the magnitude of peak discharges increased by 51% compared to those of rural watersheds and vol. of runoff/unit area of watershed increased by about 200 percent relative to unit yield of rural watersheds.

It is an substantially urbanised watershed where above study was carried out study showed an increase in total runoff wet years as urbanization increased but during dry periods a decrease occurred. This decrease can be explained only by taking into account evapotranspiration as well.

The study on effect of urbanisation on runoff for the urban watersheds of Indiana and texas was carried out. It was found that in general as a result of urbanization of a watershed, the time lag and time to peak discharge decreased by about 50%, 266% respectively whereas magnitude of the peak discharge and the frequency of peak discharge increased by about 84% & 115% respectively.

Philadelphia Project

As part of a cooperative project with the U.S. Geological Survey, the Philadelphia Water Department in 1974 completed installation, testing and initial operation of a unique field sampling and data recording, transmitting and reporting system. Two adjoining subcatchments are involved. One is a 7-ha commercial area with an average imperviousness of 69% and the other is a 33-ha residential area with an average imperviousness of 63%. Flow is measured by means of USGS flow gages in a 76-cm storm sewer of the commercial area and in a 152-cm storm sewer of the residential area just upstream of their confluence, where the flows enter the outfall sewer of the total catchment. Three tipping bucket raingauges are located on or near the subcatchments. Water quality sampler are installed near the flow meters.

During the initial tests, water quality samples were taken at one-minute intervals, but sampling frequency can be programmed at from one to fifteen minutes and sampling is commenced when pre-set flow rate magnitudes in the sewers are exceeded. Pressures in the approach and in the throat of the constriction of the flow gage were sensed by transducers at the Transmitting Station, and dry nitrogen gas is bubbled at a constant rate through connecting tubes to the two piezometer openings to maintain a constant reference pressure. Flows in excess of a pre-set magnitude are normally recorded at a one-minute interval.Water quantity and quality monitoring of streamflows and of a combined sewer catchment by Philadelphia, and the raingauge network operated by the City, were all reported.

Rochester Project

The City of Rochester, New York, is in Monroe County supported by a U.S. EPA Research and Demonstration Grant, a project for abatement and management of combined sewer overflow pollution is being conducted under the direction of the Monroe County Pure Waters Authority and the Rochester Pure Waters

District. There are thirteen combined sewer overflow outfalls involved, draining catchments ranging in size between 65-ha and 1,300-ha, and all are instrumented for automatic flow sensing and quality sampling. The samples are collected at a 15-minute interval during overflow occurrences. Rainfall is measured at ten tipping bucket raingauges distributed over the study area. A version of the U.S. EPA Storm Water Management Model is being calibrated for each catchment, using field data from the monitoring system, for use as an analytical tool to establish guidelines for the development of overflow pollution abatement master plans.

2.2 Modeling

2.2.1 Continuous daily streamflow model

The TVA daily streamflow model was designed to be used in separate studies or in applications involving studies on the effect of land use changes upon water quality transport or storm water runoff. The time unit of a day was selected for this model because of the ready availability of the daily rainfall and streamflow data. The time unit used in this model is sufficiently short that separate storm can be identified, yet sufficiently long so that data management does not become a problem. The continuous daily streamflow model is basically a simple water budget bookkeeping for the watershed. Daily rainfall is budgeted among a series of conventional cascading compartments or reservoir, it differs from some flow models in that. Outflow is not included and there is only a single soil moisture reservoir. These simplifications were made to minimize the number of parameters and interecorrelations among them. Input in the model consists of daily rainfall and streamflow and monthly evapotranspiration for analysis runs. Output from the system consists of daily, monthly, and annual streamflows and an annual allocation of the streamflow.

2.2.2 Illinois Urban drainage area simulator (Illudas)

In 1974, Terstriep and Stall of the State Water Survey Division of Illinois, USA, published the method known as ILLUDAS, now among the more widely used storm sewer design methods in the USA. In fact, it is a derivative of the TRRL hydrograph method, produced after the authors nad found that although the TRRL method gave reliable predictions of runoff from paved areas, it required a facility for computing runoff from unpaved areas if it was to be generally applicable across the USA. The procedure of this facility is first to calculate soil infiltration and storage losses, and then to develop an area/time TRRL procedure.

2.2.3 USGS model

The watershed model developed by Dawdy et.al. combines soil moisture accounting and rainfall excess components with the kinematic wave routing method. Model uses rainfall as input and routes the urban flood discharge through a branches system of pipes or natural channels. The important parameter in this model is the antecedent moisture condition, impervious surface, pervious surface etc. There are two types of impervious surfaces taken into consideration in this model, they are effective impervious surface i.e. directly connected to the channel drainage system and areas which drain to pervious area i.e. non effective impervious surfaces. The model has the option to calibrate the soil moisture and infiltration parameters for drainage basin having observed rainfall-runoff data. In the model kinematic wave theory is applied for both over land flow and channel routing and parameters are determined by applying Rosenbrok's optimization technique.

2.2.4 University of Texas Watershed Simulation Computer Programme

This model is a continuously accounting type of computer model, in this precipitation falling on the watershed is initially computered in interception storage (by vegetation and manmade structure) and is dissipated by evaporation. After interception storage is filled, precipitation continues down to the ground surface which is either impervious (contributing directly to streamflow) and pervious. Pervious area is divided as depression storage and overland flow storage. Infiltration into soil region referred to as the upper zone occurs from both overland flow storage and depression storage. Therefore, runoff in the stream channel is composed of (I) Volume of water from impervious area (II) Amount of overland flow contributing to stream (III) Volume lagged through inter flow and groundwater storage. The amount of runoff accrued in one time period PS then through a time area curve referred to as the time delay histogram. This curve, prepared from topographic maps, represents the watershed response to an instantaneous uniform rainfall and is some what analogous to the unit hydrograph concept. The inputs to this model are precipitation , pan evaporations, transpiration, stream flow, watershed physical characteristics and the constants used in infiltration, unsaturated permeability, soil moisture tension equations, size of soil zones, interflow and outflow from groundwater storage to stream.

2.2.5 Storm water management model

Storm water management model (SWMM) is a package of models linked together. It is divided into a number of blocks, namely:Executive block for control of the running and linking different blocks, Runoff block for modeling flood flows from impervious and/or pervious area, Transport block to allow overflowing manholes, back watering and flow in non uniform channels and rivers, Storage/treatment block to reduce the problem of flood and reduce pollutants and Receiving water block to study the circulation in lakes.

Natural watercourses occupy much less land area than that drained directly by systems of underground drainage conduits. It has been estimated that approximately one-sixth of U.S. "Urban Areas" (measure of metropolitan areas adopted for the 1970 census) fall within natural 100-year flood plains, whereas well over half of Urban Areas are drained by systems of underground conduits.Over the last few years urban model development has greatly intensified, with sewered catchment models perhaps eclipsing urban receiving-water model development.

2.2.6 Environmental protection agency storm water management model (SWMM)

This is a particularly comprehensive model covering both flow quantity and quality. It was developed by the US Environmental Protection Agency in the early 1970s and is being continuously updated. It has been extensively used in the USA to design sewer upgrading works particularly where these are required to control pollution. It models all the major hydrological processes but as a result becomes very unwieldy to apply.

2.2.7 Availability of Computer programme

University of Cincinnati has developed a model.The model description and the computer program are publicly available.

Massachusetts Institute of Technology has developed a model which is predominantly an analysis/design model, the current computer program is proprietary. However, a modified version developed for estimating sewered catchment and stream runoff for the master plan development of the 1000-Sq.Km County of Fairfax, Virginia.

University of Illinois Models. A user's manual with part of the computer program listing is available to the public.

University of Nebraska. A model description and the computer program listing are publicly available for quantity and quality simulation.

Dorsch Consult. Analogous in complexity and capabilities with SWMM-type models, the Dorsch Hydrograph-Volume-Method model is proprietary.

Chicago Hydrograph Method. Based on the first sewered catchment distributed model was developed, testing and application have been restricted to the Chicago area only.

Corps of Engineers (SSARR). A program description with a user's manual is available, and the computer program is available to the public. The complex Streamflow Synthesis and Reservoir Regulation (SSARR) model was designed for operational use in hydrologic engineering studies and daily streamflow forecasting for river basins and tributaries. Initial tests with urban catchment data have resulted in good estimations of daily flows, indicating a potential use of the model in urban planning applications.

Corps of Engineers (STORM). Model documentation, a user's manual, and the computer program are all available to the public. The Storage, Treatment, Overflow and Runoff Model (STORM) was designed specifically for urban runoff and quality evaluation for master planning, and normally uses several years of continuous hourly precipitation records. It is basically an allocation and accounting model and does not perform routing. Erosion yields and non-urban catchments can also be accommodated.

Carter in 1986 developed an equation for urban watershed (Washington D.C.) taking impervious factor into account

$$\frac{Q}{K} = 223A^{0.85}\ T^{-0.45}$$

where
A - Drainage area
Q - Discharge,
T - Time lag
K - Coefficient of imperviousness

$$K = \frac{0.3 - 0.3\left(\frac{I}{100}\right) + 0.75\left(\frac{I}{100}\right)}{0.3}$$

I - Percentage of imperviousness

$$\text{Time lag} = T = C\ (LS^{-0.5})^{9}$$

where
C - Coefficient reflecting the degree of urban development
L - Stream length
S - Channel slope
9 - Constant

2.2.8 Unit Hydrograph Tests

Unit hydrographs have been developed from field data for at least three-score catchments, but almost all of these were for partially sewered catchments where the streamflows measured included a significant contribution from non-sewered sectors.

2.2.9 Research on Sewerage Operations and Water Quality Models

A 29-ha portion of the Vicente Street catchment in San Francisco, Colorado State University has calibrated simple distributed models of the type tested at Purdue University using stage and rainfall data for the total 668-ha, Vicente combined sewer catchment as part of a program that is assisting in the development of automatic operational control capability for the city.Water quality modeling for systems containing rivers and reservoirs recently has been advanced through the issuance of a description of a new combination of models. The Hydrologic Engineering Center is having dynamic flow routing routines added to the model and plans to upgrade the documentation as new developments occur. A compendium two companion reports, a North American summary and a recent text, survey features of large-scale water quality models; and an annotated bibliography of models for tidal rivers, estuaries and coastal waters is available. Tidal water models have been comprehensively classified and capabilities for modeling estuary and streamflow water quality have been assessed. Aquatic ecosystem sub models have been delineated for process analysis. Effects of risk and uncertainty in the application of operations research techniques, including hydrologic modeling, have been critically reviewed at length. Stochastic generation of synthetic streamflows is still receiving the attention of researchers.

3.0 URBAN CATCHMENT RESEARCH AND MODELING IN U.K.

3.1 Introduction

Urban hydrology has taken momentum these days in U.K., although total research is increasing it less than U.S.A. (for eg). Several urban hydrologic catchments, small, total impervious parking lot draining to inlets, and catchment under urban development are under study.

3.2 Urban Catchment Research

Catchment based research in U.K. is categorized as below:

a) To provide data on rainfall and runoff areas with flow monitored at outlet and inlet.
b) Water quality studies.
c) Effect of flow on natural watercourses as a catchment urbanised.

For the study on rainfall-runoff relationships Wallingford procedure is used extensively. The study on testing of Wallingford procedure with various formulations of Rational method showed a marginal improvement by Wallingford procedure in predicting peak runoff discharges and a substantial improvement in predicting runoff volume.

At urban pollution research centre of middle sex polytechnic research on quality of urban runoff diffuse sources with urban catchments is under progress.

At Trent Polytechnic Nottingham, research on the development of a storm runoff model to predict the outfall hydrograph for day to day events on one urban catchment is under progress. A next step for this will be to develop a pollutant discharge predictive model based upon TURS.

Investigation of urban rainfall-runoff process is undertaken at the University college, London at a very small scale.

Studies on urban water balance has been conducted. Data for greater London were used to produce annual water balances for five heavily urbanised catchments. Estimates of annual runoff for rural catchments ranged from 12% to 72% of rainfall. The mean annual runoff for the rural catchment area was 15% to 44% of rainfall.

A study on runoff from pitched roofs, asphalt & chipping roofs and from asphalt roads & pavement showed that runoff was less than 100% when evaporation was low (winter season).Despite difference in slope of pitched root and flat foot the runoff was same, although from flat roof flow rate was less and runoff duration higher. This indicates that flat roof does not have much depression storage and evaporation loss.

Two studies on hydrological effects of urbanisation has also been completed. The result was a design procedure to give a runoff hydrograph appropriate for the design of storage pond.

The first published account of a storm runoff quality investigation based on systematic analysis of recorded data seems to be the work of Wilkinson who took advantage of the gauged catchment at Oxhey. He found that first flushes were not much more polluting than subsequent flows except after long dry periods.

Hedley and King investigating a combined drainage system in the Haunch Valley, Birmingham, emphasised the importance of the highly polluted initial runoff and discussed means of providing temporary storage. They also drew attention to the need to identify the separate sources of pollution and their relative significance. More recently, runoff from an urban motor way has been gauged and analysed. Motor way runoff quality was studied at Lancaster University with particular emphasis on salt dispersal.

Tucker used dilution gauging for flow measurement at Nottingham and analysed the samples to give not only the discharge hydrograph but also the concentration-time curve of polluting constituents. He also emphasised the importance of 'first flush' pollution.

The Water Research Centre is working on the Shephall catchment in Stevenage and are collecting data with the aim of devising and calibrating a mathematical model of the storm-water pollution process. They are looking at the ways in which pollutants accumulate on and are freed from urban surfaces. Also, they are studying the effects of intermittent discharges of polluted surface water on water quality and the contamination of sediments and biota in receiving streams.

Hall studied the change in shape of the derived unit hydrographs for both urban and rural catchment areas in the headwaters of the River Mole near Crawley. Whilst confirming the expected trend for lag times to decrease with urbanisation, he concluded that a simple measure of 'percentage impervious' was inadequate and that changes in the channel system and the distribution of impervious surface within the catchment should be considered. Packman followed Hall's techniques in analysing unit hydrographs in two urbanising catchments in North London. He found that non-linear effects tended to obscure the changes in lag time due to urbanisation. While the expected reduction in lag time could be observed in the initial stages of urbanisation, including the establishment of the basic sewer system, later infiltration had little extra effect.

Annual maximum instantaneous peak discharges for the Crawters brook at Hazelwick Round about a catchment area of 4.7 Sq.Km in south east England. The annual floods showed a remarkable increase with the increase in impervious area (due to urbanisation). Specially when impervious area exceeded 20% of the catchment.

3.3 Modeling

3.3.1 TRRL hydrograph method

TRRL hydrograph method is most widely used in United Kingdom. It relies upon the calculation of a runoff hydrograph from characteristics of the catchment and rainfall. A noval feature of the UK version of the method is the computation of flood hydrograph considering only runoff from paved areas directly connected to the sewer system. The rainfall input into the model is a recorded storm and the surface hydrograph is calculated using the area/time diagram for the area. The hydrograph calculated through storage is then routed, the minimum storage being the volume in the sewers occupied by water at the peak rate of runoff.

TRRL method of sewer design can be categorised as a design/ analysis model. It was developed at Road research laboratory using data collected from 1952 to 1960. Model matches the effect of reservoir type storage in practice.

Using the same assumptions as for TRRL method, King substituted simple functional relationship for design storm profile, area-time diagram and flow retention relationships. He thus gave a functional form for design hydrograph and produced a set of curves for quick evaluation of peak discharge.

Sarginson proposed that in TRRL model, the above-ground and below ground storages be treated as separated linear reservoirs in series. He also modelled the infiltration and depression storages discarding the assumption of 100% runoff from impervious surface.

Kidd in his model, deducted the depression storage and applied a loss rate to the total rainfall to give rainfall excess. Linear and non-linear reservoirs are compared and superiority of non-linear reservoir was clearly demonstrated.

3.3.2 Hydran

There are many parts of the world where the assumption of zero runoff from unpaved areas is clearly not valid and these include the tropical regions. To overcome this problem, research was undertaken in East Africa with five instrumented catchments, as a result of which the TRRL hydrograph method was modified to suit tropical conditions.

3.3.3 The Wallingford procedure

By 1975 the TRRL hydrograph method had become by far the most widely used sewer design method in the UK, and ILLUDAS filled the same role in the USA. However in the UK the emphasis had swung from the design of new sewer systems to the examination and redesign of the many inadequate and worn out sewer systems of the old towns and cities, and it was recognized that the TRRL method did not have a satisfactory facility for computing enhanced flow due to surcharge. It was also the case that the TRRL method was developed initially as a design method rather than a simulation method and it followed that although the assumption of 100% runoff from paved areas and zero from unpaved areas is quite valid for design in UK conditions, it is not valid for simulation and a procedure for calculating the percentage runoff is required.

3.3.4 Other models

Models of motor way drainage have developed a dimensionless hydrograph design method for single peaked hydrographs only with scaling factors determined from prediction equations whose coefficients have been determined from prediction equations.

Hall studied unit hydrographs for several urban and rural catchments and the changing slope of hydrograph during urbanisation. He developed a dimensionless unit hydrograph scaled by only one parameter and related this parameter to basin ratio (L/ S, where L main channel length, S main channel slope) and degree of urbanisation.

4.0 URBAN CATCHMENT RESEARCH AND MODELING IN CANADA

4.1 Introduction

Urban drainage committee under its research programme identified the need for urban water resources data particularly for urban runoff data. A survey of urban catchment carried out in 1973 indicated that there were only few instrumented catchments in Canada.

4.2 Urban Catchment Research

4.2.1 Rainfall

The measurement of temporal and spatial distributions of rainfall over large urban areas requires recording gauges network. A relatively inexpensive rainfall intensity sensor is developed (urban hydrology, 1983).

Several studies were carried out for calculating runoff from point rainfall. Such volumes obtained departed significantly from volumes obtained from intensity-duration-frequency curves. It suggests that synthetic design storms should not be used for design of storm water storage.

The areal distribution of rainfall is of interest in the design of drainage system for large urban areas. A theoretical methodology on relationship between point rainfall and areal rainfall has been proposed (for Montreal) and are correction factors were suggested.

4.2.2 Urban runoff quality

The quality of urban runoff has been studied fairly extensively and is used for model development and evaluation of impact of runoff on water quality.

Waller and Noval (1981) estimated pollutant loading from Ontario municipal source. For phosphorus, the runoff loading represented 15% of all municipal source loadings. Higher relative magnitudes of runoff loadings were found for other constituents. A study suggested unit pollutant loads for use in the assessment of urban runoff pollution at planning level.

To determine the effects of urban land use on runoff quality several research projects have been undertaken in Canada. Field investigations were conducted for improving the performance of combined sewer system and to find cost effective alternatives to sewer separation.

The study on characterization of flows in sewer systems was undertaken. In this study time varying quantity and quality of sewer flows are studied within the sewer networks.

Other investigations dealt with microbiological characterization of land drainage flows in canadian Great lakes basin. Such sources of bacteria were found to cause only minor water quality problems because of short duration and limited spatial extent of elevated micro-biological levels following runoff events.

Urban runoff data collected on the canadian catchments have been used to characterize the quality and quantity of storm water and of combined sewer overflows, to develop new urban runoff models and to verify and modify some of the existing models.

Runoff control by storages is perhaps the most widespread control measure in Canada. Among the various types of storage storm water ponds seen to be the most popular. Various aspects of storm water pond design for water quality objectives have been carried out by several researches. A lot of research was also undertaken on the thermal modeling in urban runoff and the implications for pond design. The study on bacteria in storm water and the effects of sedimentation on their levels were also conducted.

Extensive studies of urban runoff have been conducted in the Grand River basin. It was concluded that for conditions studied, urban runoff did not have a serious impact on dissolved oxygen in the river and urban runoff control measures were not justified.

Marmot Creek experimental basin was established in 1961 on eastern slopes of Rockey mountain of Alberta, Canada. Using the method of Covariance the correlation for cabin crecks sub basin was found highest for Aug.-July water year for which 11% change in flow would have been detectable. The April to June period had 7% increase in flow mainly because of a 24% increase in May. In twin Creek sub basin: a 5.5% change in annual flow, a 10% change in spring and summer flow was obtained.

4.3 Modeling

In 1973, department of Environment Commissioned a survey which indicated that practically all urban drainage design was based on rational method. In 1976 a number of modeling research projects started and runoff models were used for many planning studies. A brief description of these models is as below:

4.3.1 Queen's University Urban Runoff Model (QUURM)

The QUURM is a precipitation-runoff model developed for urban catchments. At present it is a research-oriented model undergoing further development and refinement. The QUURM model consists of two parts, the generation of inlet hydrographs and their routing through a sewer network. A single linear reservoir approach is used to generate inlet hydrographs from rainfall excess for each sub-catchment consisting of various area types. Runoff hydrographs from various sub areas form the inlet hydrographs and these are routed through the sewer network using a modified time-offset method. The time offset is calculated for an effective Manning n and a representative velocity corresponding to the average discharge is calculated for the central half of the inlet hydrograph. Model deals with runoff quantity only.

4.3.2 Subdivision Hydrograph Model (SHM)

The SHM has been developed by the Department of Civil Engineering, University of Toronto, for a particular project. It is a hybrid model incorporating some features of the Storm Water Management Model (SWMM) of the U.S. Environmental Protection Agency, the Chicago Hydrograph Method, and also some new features such as runoff routing through various types of storage. Rainfall excess in the model is calculated by subtracting the infiltration (Horton's Formula) and surface depression capacity from the actual rainfall. Overland flow and gutter flow are calculated by a stepwise procedure using the Manning equation for uniform flow. For a selected time step, the runoff flow is approximated by a successive quasi-steady state calculation in each interval. Catchbasin outflow hydrograph and storage outflow hydrographs are combined to form lateral sewer flow hydrographs, which are then routed through the sewer network using a time-offset method. The model has built-in routing functions for various storage alternatives, among which are roof storage and parking lot storage.

4.3.3 Distributed Hydrologic Model (DHM)

The DHM was developed by Shully Solomon and Associates

Limited for environmental impact assessment for the North Pickering Project. It is a distributed, continuous simulation model requiring calibration. Rainfall excess in the DHM is routed over the watershed, considering various land use and soil characteristics. Numerical solutions are based on a finite differences method.

4.3.4 Data Analysis Model (DAM)

Applications of urban runoff models require large volumes of input data, the preparation of which amounts to a significant portion of the total project cost. It is therefore desirable to simplify and computerize this part of the runoff modeling to the maximum possible extent. The DAM treats only climatological data and serves as an interface between existing data banks and both planning and design runoff models. The DAM was devised to provide input data for the STORM model of the U.S. Army Corps of Engineers. For this planning-level, a continuous simulation model using hourly precipitation and temperature data is required.

4.3.5 SWMM as planning model

To use SWMM as a planning model the number of sub catchment and transport network elements were reduced to a minimum and time step is increased. The parameters of lumped over land flow defined as spatial averages. The SWMM model was later combined with STORM model to calculate runoff quality on the basis of catchment characteristics and runoff hydrographs which have to be supplied by user. The runoff quality is calculated using SWMM algorithm. Upto ten constituents can be simulated, namely BOD, COD, suspended solids, settleable solids, coliforms, N, PO4, Cl, Pb and oil and greases. (Unesco, Vol.2).

4.3.6 Other models

A versatile storm water quantity and management model (VSQMM) was developed by lee (1981). The model consists of six basic computational modules with several options for the user.

Thomson and Sylees (1976) developed a subcatchment runoff model which is applicable to both urban and rural areas for discrete as well as continuous simulation.

For real time control of flows in combined sewers, simple runoff models were developed by Marchi et al (1982). (Urban Hydrology, 1983).

4.3.7 Simulation of Sanitary Flows

The Department of Civil Engineering, University of Toronto, has developed a parametric time-series model for sanitary flows. The model serves for planning and design of the deployment configuration of sanitary sewer networks.

4.4 Modification and Interfacing of Existing Urban Hydrological Models

The development of new urban runoff models is costly, and in some cases these new models do not have any clear advantages over the existing ones, and therefore do not advance the state of the art of modeling. Consequently, some researchers prefer to concentrate their efforts on modification and interfacing of the existing, verified runoff models. Such an approach was adopted, for instance by the Urban Drainage Subcommittee, which sponsored and directed a study primarily dealing with the modification of the Storm Water Management Model (SWMM) of the U.S. EPA. The selection of this model was based on the results of a previous study dealing with several urban runoff models.

4.5 Testing of Urban Runoff Models and Comparative Model Studies

Testing and comparative model studies are of utmost importance to model users who are attempting to select a "right" model for their application. In testing studies, the ability of a model to reproduce various runoff events observed on test catchments is evaluated.

The following urban runoff models have been tested to various extents in several Canadian studies: Dorsch HVM, Queen's University QUURM, British RRL, STORM, SWMM, University of Cincinnati UCUR, and Water Resources Engineers version of SWMM (WRE-SWMM).

The first study dealt with the HVM, QUURM, RRL, SWMM, and UCUR models. These models were applied on several test catchments and the simulated hydrographs were compared to the observed ones. The goodness of fit was evaluated in two ways. Firstly, the runoff volumes, peak flows and time to peak were considered. Secondly, the entire hydrographs were considered.

All the models performed fairly well. When comparing only the volumes, peaks and times to peak, there was no statistically significant difference in the performance of various models on most catchments. On average, about 70% of the simulated runoff volumes and peak flows, and 85% of the time to peak, were within +20% of the observed values. It should be stressed that only runoff generation on small catchments (less than 37-hectares) and simple flow routing were tested. Special features of some of the above models, such as dynamic-wave flow routing in the HVM

5.0 URBAN CATCHMENT RESEARCH AND MODELING IN FRANCE

5.1 Introduction

French research on the effects of urbanization on the water cycle has undergone a new development since 1969. This has resulted from the ever-growing complexity of urban sewerage problems: new techniques must be perfected and better adapted to the nuisances of all kinds caused by storm water disposal. Experimentation with these new techniques is necessary when existing sewer networks are extended or when new built up areas are created. It is also necessary to find new methods for sewer calculations, consistent with these new techniques and the economic problems related to the struggle against nuisances. From 1970 to 1975 there were two research goals: to bring up to date the official regulations on urban sewerage and to improve knowledge on rainfall-runoff transformations for urban watersheds by making runoff mathematical models adapted to the design of complex sewer networks.

5.2 Urban Catchment Research

By the end of 1968, six small urban watersheds, situated in the vicinity of Grenoble, had been equipped with rainfall and runoff gaging stations. In the same way three other watersheds were equipped in Montpelier by the end of 1969.

Water level in the sewer at the outlet of each watershed were indicated by float-actuated recording gauges. Rainfall was recorded with a classical tipping-bucket raingauge producing an electrical signal. Data from the experimental watersheds led to two principal types of studies: theoretical studies on urban runoff modeling on the one hand, and studies made from the viewpoint of testing and adapting the French method of drainage design on the other hand.

Theoretical studies were successful in testing various mathematical runoff models. At the same time, the Laboratoire d'Hydrologic Mathematatique (L.H.M.) studied different one-dimensional and two-dimensional mathematical models of infiltration in the zone of aeration so as to make a connection between surface water and groundwater models.

The statistical analysis of thunderstorms were aimed at the perfection of design storm models that would be used as the input for hydrological models. without design storm models there would be limited interest in the study of drainage projects for ungaged watersheds. These rainfall models do not yet take into account the spatial distribution of rain, owing to the nature of the presently available data. Studies of the sensitivity of runoff models to the definitive characteristics of thunderstorms have enabled, more particularly, the elaboration of surrogate stochastic models for the simulation of design storms. Spatial analysis of thunderstorm has been the subject of a new studies despite the lack of available data.

5.2.1 Instruments for Hydrological Measurement

Very quickly it became evident that the main problem in the advance of urban hydrology was the absence of good data. Theoretical research on modeling of hydrological phenomena has very quickly exceeded the data usually available. Unfortunately, there are as yet no rainfall and runoff gauges designed specifically for urban hydrology, nor is there any outstanding device to sample the water quality in a storm or combined sewer. The rapid changes in these variables and their random nature, and the difficult measuring conditions encountered in sewers or in urban space, have prevented definition of an ideal measurement assemblage, which in any case would probably be quite expensive.

The most widely used instrument in France is the tipping-bucket raingauge. This instrument tends to underestimate the highest instantaneous rainfall intensities (more than 60- to 80-mm/h) because of water losses, response lags, etc. Research on how to correct the information given by this instrument as well as tests of different graphic recorders has been undertaken (cylinders, unrolling tables, automatic billing of papers, etc.). Tests of punched-tape recorders have not led to very interesting conclusive results. Those of mini-tape recorders have proved quite promising. However, there has not been any important testing of electronic synchronization instruments.

Study of sewer measurement processes has shown that there is no instrument perfectly adapted to that kind of problem. The greater part of flow measurement is carried out by means of a water level measurement associated with a stage-discharge curve. Most of the time, this rating curve is established ignoring upstream or downstream conditions, for it is not very common to find hydraulic control sections at places suitable for gaging. The water-level measuring instruments in most wide use are float-actuated recording gauges or pressure-actuated recording gauges (or bubble gauges). Stage-discharge curves are generally obtained with the help of radioactive tracers or by the use of induced injections of known discharges in the case of small pipes. Tests on electromagnetic instruments measuring continuous velocity have been carried out. Some prototypes of ultrasonic flow meters and others using radioactive tracers have also been studied.

Pollution gaging is a very recent field that has been little explored and samplings are generally not continuous. There is no specific sampler adopted to that problem.

5.2.2 Urban runoff pollution - A national programme

The first experiment on urban runoff pollution began in 1977 in France. Based on the result of first study, it seemed important to estimate which component of waste water and urban runoff had the largest polluting impact on receiving waters. A committee was formed with the objectives i.e. funding out the characteristics of urban basins & sewer layout, methods of measurement and their interpretation and treatment of runoff pollution. The study was carried out in four basins two in Paris and two in South of France.

Rainfall studies: Analysis and modeling of spatial distributions of rainstorms, analysis of influences due to altitude variations, study of regional rainfall data, analysis of the effects of rainstorm travel, etc.

Runoff studies: Analysis and modeling of runoff from urban previous areas.

Water quality studies: Model and attempt to define the quality of runoff pollution.

5.3 Modeling

5.3.1 Caquot Formula for Calculating Maximum Discharges

In France, since 1949 the discharges taken into account in the analysis of storm drainage networks have been calculated by means of a statistical model developed by Caquot. The Caquot model is derived from a formula of the following type:

$$Q_p = K\ I^u\ C^v\ A^w$$

where Q_p is the peak discharge in m^3/sec., I is the average slope in m/m, A is the catchment area in hectares and C is the coefficient reflecting the degree of impermeability of the catchment. The parameters K, u,v and w are adjusted as a function of regional rainfall characteristics and the rainfall frequency considered.

5.3.2 Simulation Models

For studies concerning complex catchment areas, basin storm damping phenomena and circulatory and storage possibilities of meshed networks, simulation models have to be used to describe the physical processes involved.

Rainwater runoff simulation over a complex urban area comprises three stages: the rainfall , which constitutes the 'input' of the model; the 'rainfall-runoff' transformation over the elementary basins (subcatchments); and the composition and propagation of the flood waves from each of the elementary basins into the drainage network.

5.3.3 Hydrological Models

In order to convert rainfall intensity curves into discharge hydrographs we use the single-reservoir linear model in France, for which the characteristics time constant, K, can be calculated from the experimental adjustment made in France by Desbordes

'Muskingum-Caquot' model recommended by SOGREAH for small elementary basins, with a damping factor in the Muskingum equation of X = 0.2 and a response time, K, adjusted in such a manner that, for a given frequency, the peak discharge of the hydrograph is equal to the discharge calculated from the Caquot formula. Through this adjustment of the simulation model, on the basis of a statistical formula, it is possible to achieve design homogeneity in the drainage network between the Caquot formula, which serves for sizing the drains within the elementary basins, and the simulation study, which serves for sizing the network draining the inflows from these various elementary basins.

5.3.4 General Models

Discharge propagation in main drains can be simulated perfectly by hydrodynamic models based on the Barre de St-Venant equations. In this respect, SOGREAH constructed the CAREDAS model which is valid for both branched and meshed networks and which can also take into account pressure flow conditions . The CAREDAS model is made up of five interconnected programs: a- the model program, for preparing and checking the data defining the network; b-the Hydurb program, for the rainfall-discharge transformation of elementary basins, which can be based on a simple method if the elementary basins are small with respect to the overall catchment area; c- the Puma model, which calculates the composition and propagation of the flow of the discharge hydrographs from the elementary basins; d- the Convec program, which follows the change in pollution level in the network as a function of pollution intensity curves from the elementary basins; and; e- the Expres program for processing the results and graphically printing them with automatic plotters.

5.3.5 Optimization Model Development

For the case of a branched network draining a basin subjected to progressive urbanization, SOGREAH has developed the Abac model which associates a development design optimization program with the flood origin and propagation program so that runoff can be controlled via storm reservoirs and pipes.

6.0 URBAN CATCHMENT RESEARCH AND MODELING IN FEDERAL REPUBLIC OF GERMANY

6.1 Introduction

Urbanisation has progressed rapidly in FRG after world war II. Upto 1970 26.64 million inhabitants lived in 24 urban agglomeration areas. In recent years, extensive urban hydrological research has been taken place in FRG.

6.2 Urban hydrological research

Research on urban hydrology have revealed that local climatic conditions are undergoing profound changes in all urban centres of FRG. The study on rainfall measurement instruments have reported that measured precipitation is lower (5% to 20%) than precipitation which actually reaches the ground. A comparative precipitation measurement relative to rural surrounding in Kiel & Breman has indicated a mean increase of 10%

and 16% respectively. This study was also supported for several other areas. Studies on effect on runoff have showed that sealing of surfaces and buildings have resulted in reduced infiltration and increased runoff.

A study in the Hanover urban area on groundwater recharge has indicated that at present due to building & constructional activities, groundwater regeneration has already been reduced to amount withheld from groundwater budget by continuously artificial extraction.

A study on water quality assessment have indicated that for a mean population density of 80 to 100 inhabitants and waste water disposal of 150 liters/inhabitant, the domestic waste water built up was 5000 cu.m/ha. Assuming a mean annual rainfall (280 events) of 803 mm the annual surface runoff was around 2800 cum/ha/year (Pecher, 1974). The concentration of pollution constituents in storm water discharges from sewer systems varied but BOD_5 and chemical oxygen demand were within the order of magnitude.

A lot of research has also been under taken on effect of sewage disposal on the quality of water (surface as well as under ground). The studies showed that some amount of pollution may still exist if seepage water from solid wastes deposits infiltrates in groundwater or surface water.

Forest hydrological studies were started in Upper Harz mountain in 1948. The influence of a young forest standard of a tunnel, built in 1970 and crossing one of the basins, on the runoff process was investigated. The construction of tunnel influenced the runoff regime of the springs to a large extent.

Hobert Massing in his study on Hydrological effects of urbanization in Federal Republic of Germany has reported that while the urban area in Maichingen increased from 4 sq.km. in 1972 to 20 sq.km in 1985, the runoff coefficient also increased from 0.15 to 0.6, thereby increasing flood peak runoff of Schwippe river two fold.

6.3 Modeling

6.3.1 The hydrograph volume method (HVM)

This is proprietary model developed in Germany by Dorsch Consult of Munich. It has been used extensively also in Canada, USA and UK. The model can simulate surcharged flows and deal with ancillaries such as weir and orifice overflows making it suitable for both new design and simulation of flows in existing systems.

6.3.2 Precipitation analysis model

The intensities of and the elapsed time between two successive rainfalls are essential factors in the calculation of sewer systems. In the DG-REGDEF model precipitation records for specific events are divided into five minute intervals and subjected to a regression analysis.

A rainfall assessment programme has been developed for the city storm water discharge. This model allows local influences on storm-water runoff behaviour, and permits determination of outflow from storm water runoff behaviour to be taken into account without calculation of sewerage network.

6.3.3 Other models

Comprehensive models for surface runoff and waste water flow through sewers are also developed in FRG. In all cases differentiation is made between surface runoff models and sewerage models.

The program QQS is based on a combination of unit hydrograph procedures for the calculation of surface runoff, with an approximate solution of St. Venant's differential equation for the computation of runoff in sewer systems. It not only simulates individual precipitation events but also performs the requisite computations for a rainfall record covering up to 20 years. The more important results are: annual and monthly frequencies and duration curves of runoff and pollution load at any point of a sewer system.

Model HVM has been operational since 1966. Since then, it has been used to calculate sewer system performance for more than 40 towns and cities, in Germany, Switzerland, England, Canada and U.S.A.

Model SESIM was developed from the Storm Water Management Model and the Water Resources Engineers quality model QUAL II from the U.S. It comprises modules for surface runoff, sewer system and receiving stream, and can take into account up to 3000 drainage areas, sections and junctions, and up to 500 receiving stream sectors. This program also proceeds from St. Venant's differential equation and uses an approximation solution obtained via very small time steps.

Model HSC proceeds from St. Venant's differential equation. Quality parameters with and without exponential degradation are taken into account.

Model INKA takes surface runoff, transport in the sewer system, and water quality and pollution load into account.

The FLUT program offers the possibility of simultaneously taking into account 20 different rainfall events, allowing the determination of diversified flood curves for individual or successive rain detention basins in the sewer system. It is based on the Rational Method.

Program SBV determines the annual pollution loads discharged from sewerage outlets into a receiving stream. In addition, it simulates, via annual rainfall duration and annual rainfall frequency of an urban drainage area, the runoff rates and specific content components occurring in sewer systems. To keep the calculation within reasonable limits in spite of the large number of rainfall events involved, the runoff conditions in a sewer system are represented by fictitious runoff curves. It is based on the Rational Method.

Model KANIL is the only one written in computer language PL/1. It is based on the Rational Method. An extension of the formulations allows approximation to St. Venant's differential equation. The calculation of compound networks comprising combined and separate sewer systems is possible.

Model HHK was developed at Hanover Technical University (Keser, 1973). It is based on measurements obtained through numerous hydrological investigations in existing sewerage networks involving the most diversified system and area characteristics (elementary method).

The Niers model, serves for the determination of the influence of civil engineering measures on discharge such as, for example, detention basins and their operation.

During the years 1972-1974, the Hydraulic Engineering Institute III of Karlsruhe University developed a program which is based on the use of two linear storage cascades for impervious and non-impervious areas. This double-cascade model for built-up areas allows for the optimization of five flood discharge parameters.

Model NECKAR, simulates the processes affecting water quality. It covers biochemical degradation, sedimentation, phototrophic assimilation,the oxygen consumption of the bottom sludge in a watercourse, and the quality parameters BOD_5, BOD_N, NO_3, O_2.It is calibrated on the basis of parameter measurements in the watercourse concerned, and gives a longitudinal view of actual river pollution. A similar subject is covered by the model SAUERSTOFFHAUSHALT (Oxygen Budget).

The biocenosis model aims especially at the interrelationships in the natural self-purification of rivers. It describes processes taking place in a watercourse and contrary to Streeter-Phelps, it also analyses individual processes. As far as that is possible in a program, the aquatic nutrient cycle is simulated, and photosynthesis and weather effects are also taken into account.

A model for variated nutrient studies for forecast purposes and which also covers the influence of urbanisation was developed by Geographical Institute of Cologne University.

Some models on optimization as well as flood protection have also been developed in FRG.

7.0 URBAN CATCHMENT RESEARCH AND MODELING IN AUSTRALIA

7.1 Introduction

Although Australia is sparsely populated, it is a highly urbanised nation. Urban catchment gauging have been done to develop a better understanding of rainfall-runoff process and water quality problems.

7.2 Urban Catchment Research

For the rainfall studies, the most basic data used by urban drainage designers is a chart or formula giving the rainfall-intensity-duration-frequency data for the area. For this Bureau of Meteorology has published curves for Australian capital cities based on the longest available pluriograph records.

A study to develop a series of rainfall-intensity curves for Dandenong Creek catchment showed that for the same return period, rainfall intensities increase with elevation but only for rainfall durations in excess of one day.

Aitkeh (1973) in his study has found that use of rainfall depth-area curves may lead to incorrect conclusions. He suggested that for catchments upto about 250 Sq.Km in size an areal reduction factor to point rainfall frequency value may be appropriate to be applied.

Cullen, Resich and Beck (1978) studied water quality problems resulting from pollutant inflows to Canberra lakes. It was concluded that phosphorus was the limiting nutrient in the lakes. It was due to a small catchment which was recently urbanised.

Bliss, Brown and Perry (1979) reported on investigations of the pollution potential of storm water runoff in sydney that pollution potential of urban storm water was high and more exotic substances may cause severe degradation of water.

Bannian and Morgan (1981) suggested to design piped storwater system based upon the knowledge of energy losses in pits.

Hare (1981) in his study on magnitude of hydraulic losses produced by storm drain junctions found that maximum hydraulic efficiency was achieved when junctioin branch point was located on the down stream face of the pit.

Clark, Strods and Argue (1981) in his study for estimating gutter and pavement flows on Australian urban roads using US Bureau of Public Roads Procedure showed that above procedure over estimates gutter and pavement flow by 20% - 30% in the flow width range of 1.0 and 2.0 m. They recommended the correction factors for roadways longitudinal grades of 3% and greater.

Pilgrim and Cordey (1980) in the study on rational method for design of Urban or rural drainage have suggested for more comprehensive research on runoff coefficient and design recurrence intreval selection.

7.3 Modeling

Event Models

A number of different event models, that is, models which examine isolated rainfall-runoff events, have been tested in Australia using local data. Efforts have been concentrated on the application of overseas models to Australian conditions rather than the development of new models.

Several research projects have been directed towards testing the suitability of the Road Research Laboratory Model for urban catchments in Australia. In general, it can be said that the procedure is suitable for cities in Australia where rainfall intensities are relatively low.

The Rational Formula, applied as a statistical model, is the most widely used procedure for urban drainage design in Australia. However, only limited testing of the method has been carried out, using data from four urban catchments in Melbourne and two in Sydney. For the Melbourne catchments the results showed the statistical value of the coefficient of runoff to be lower than that generally used in design for urban catchments in that city.

The Laurenson Runoff Routing Model was originally developed for rural catchments. In contrast to hydrograph procedures, this technique assumes that a non-linear relationship exists between lag time and runoff rate. The model, with minor adaptation, has been applied by Aitken (1975) to six urban catchments and a regression equation has been derived for the main model parameter in order that it can be used for the estimation of flood hydrographs on ungaged catchments.

The Cincinnati Urban Runoff Model has been tested on two Australian urban catchments by Heeps and Mein (1974). The results showed that the model contained certain deficiencies which caused it to give less satisfactory results than either the Road Research Laboratory Model or the Storm Water Management Model.

Storm Water Management Model has been tested on only two Australian urban catchments. The testing showed that the Storm Water Management Model gave better results than either the Road Research Laboratory Model or the Cincinnati Urban Runoff Model.

In recent times, the simple linear storage model developed by Rao et al. (1972) has received limited testing and application in several urban catchment flood studies More recently, Bellingham tested Nash's hydrograph model using the regression equation developed by Rao et al. (1972) on four catchments in Brisbane. The results show a general under-estimation of catchment peaks averaging about twenty per cent.

Chapman (1969) presented the first results from the Australian Representative Basin Model. A current project which is investigating the modifications necessary to apply the Australian Representative Basin Model successfully in an urban catchment situation. So far, the testing on one catchment in Canberra suggests that good results will be forthcoming. Hydrocomp simulation programme will be tested on two Australian catchments as a part of project for Australian water resources council.

Moodie (1979) developed an urban catchment model incorporating Muskinghum, Curge channel routing method. This model, WRBHYD is suited to investigation and realignment of open channel elements of a complex urban drainage network. The model also has a capacity to represent effects of concentrated storages such as retarding basins and ornamental pools.

Black and Coder (1979) reported on use of Regional Storm water model in combination with a continuous rainfall-runoff model, for continuous or discontinuous simulation of rainfall-runoff on urbanizing catchment. The study concluded that discontinuous simulation is satisfactory for comparison of alternative drainage schemes.

Moodie (1979) described the development and calibration of two urban water quality models. One of them URBCON, simulated the transport of conservative determinants in urban drainage system based on mass balance approach. The other model, URBODO incorporated modified Streeter-Phelps equations and simulated the transport of non-conservative oxygen demanding substances in urban drains.

Bell, Brown, Coronszy and Lacey (1980) developed a mathematical model of oxygen depletion due to storm water pollutant inflow in river. This model was used to investigate in stream aeration in estuary.

8.0 URBAN CATCHMENT RESEARCH AND MODELING IN SWEDEN

8.1 Introduction

During the past 20 years hard efforts have been devoted in Sweden for the protection of rivers and lakes. About 83 % of the 8.3 million inhabitants of Sweden live in densly populated areas. Currently 75% of the urban population is surved by advanced treatment plants. Sweden has today 70,000 km of waste water pipes, 47% of which are for sanitary sewage collection , 39% for storm water collection and 14% for combined water. The various researches carried out in the country focused attention on the possibilities of a substantial reduction in storm water runoff by using different methods to infiltrate the storm water.

8.2 Urban Catchment Research

As reported by Lindh (1978), Arnatt et al. (1977), Carlsson and Folle (1977), Hollgren and Malmquist (1978), and Falk (1979) urban hydrology research has been concentrated onstorm water pollutants, modeling of storm water runoff, infiltration and flow equalization etc.

Dohlstorm (1979) made possible the derivation if intensity - duration frequency relationships standardized to the period 1931-60 for any place in country (Falk, 1979).

Arnell (1982a) made a comparison of design of sewer pipes for different types of rainfall data viz. design rainfall, measured rainfall and historicals rainfall records. The results indicates that the use of design storms gives designs that are close to those based on historical storms.

Benglsson (1981 and 1985) reported on the possible maximum rates of snowmelt in urban areas. The maximum observed flow melt flux to the base of a snowpack during 1 hr is 4.1 mm/hr. The maximum observed daily melt was 40 mm and maximum observed runoff from study plots of hard packed gravelled or grassed surfaces was 2mm/hr.

Hogland et.al (1982a) found that dust fall is an important source of storm water pollution.

In order to study the variation of soil moisture content two areas were selected.After one year the two areas were partly urbanised by covering them with impermeable sheets in such a way that in one area upper part is covered and in other area lower part is covered. It was observed that percolation increased by 300% when the area observed was lying downstream from a covered area. It was concluded that it was possible to infiltrate the runoff from the upper impervious part, in an effective balance between evapotranspiration and infiltration.

Jansson, 1917b in his study on hydrological effects of urbanization in Sweden indicated that due to leakage through conduit walls and joints, the volume of sewage water received at the sewage treatment plant is much higher than water distributed from the water work i.e. a ratio of ground 2:1 to 7.5:1.

Molmquist and Hard (1981) investigated the effects of storm water infiltration on ground water quality. The main conclusion was that storm water infiltration affects the groundwater quality only to a small extent.

In a study on water budget for the city of Lund it has been shown that all the three discharge components increased tremendously. The proportion from treated waste water, combined sewere outflow and stormwater were 80%,less than 2%, about 20% of total discharge of city on yearly basis and 15, 25 and 60% on three hour rainy period basis (Fig 4).

8.3 Modeling

Arnell (1980) described the structure, function and validation of CTH-Urban Runoff Model. It is a design analysis model and it includes infiltration, surface depression, storage, overland flow, gutter flow and retention storage.

Bengtsson (1980) reported a conversational program MAGROR, for storm water runoff. In this program surface runoff is determined from the theory of a non linear reservoir.

The sewer network models DAYL-A and DAGVL-DIFF calculate water depths under various flow conditions, including transient backwater effects and pressurized flow.

9.0 URBAN CATCHMENT RESEARCH AND MODELING IN NETHERLAND

9 1 Introduction

Inspite of the continuous growth in the population of the country and increasing population density (384 inhabitants per square km in 1970 to estimated 463 in 2000) development in water resources research has been rather tardy. However there is an enormous diversity among urban hydrological problems, which are solved adequately.

9.2 Urban Catchment Research

Urban catchment research in Netherlands is limited to the basins in the new town of lelystatt in the vicinity of Amsterdam and need with the purpose to study the relation between rainfall and urban runoff, to refine design criteria for storm water drainage, sub surface drainage system, system of open drains and to study the consequences of urbanization on water management of a polder.

Van de Ven and Ven (1982) have carried out research on urban hydrologic cycle in rural areas of polders (land with an artificial drainage) and cities. They found that urban peaks occurs early. They also pointed out that hydrologic cycle in cities and in rural areas of polders differs from similar ones (Fig 3).

To study urban hydrologic system different types of catchments areas are under investigation since 1969.

a housing area of 2 ha (covered area 44%)
a parking lot of 0.7 ha (paved area 99%)
a shopping & office area 22 ha (covered area 95%)
a unimproved building site 4 ha.
Two flat roofs area 250 Sq m and 350 Sq m.

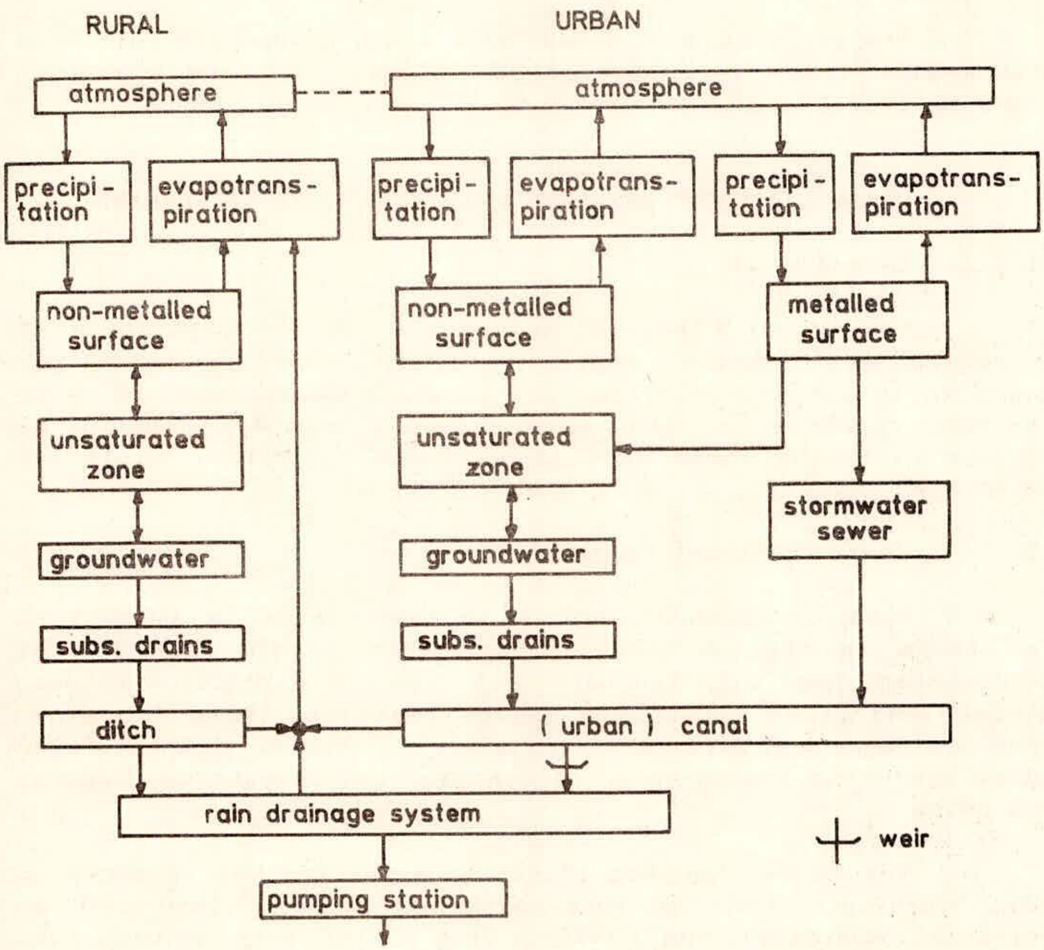

FIG. 3 URBAN AND RURAL HYDROLOGICAL CYCLE IN A POLDER AREA IN THE NETHERLANDS .

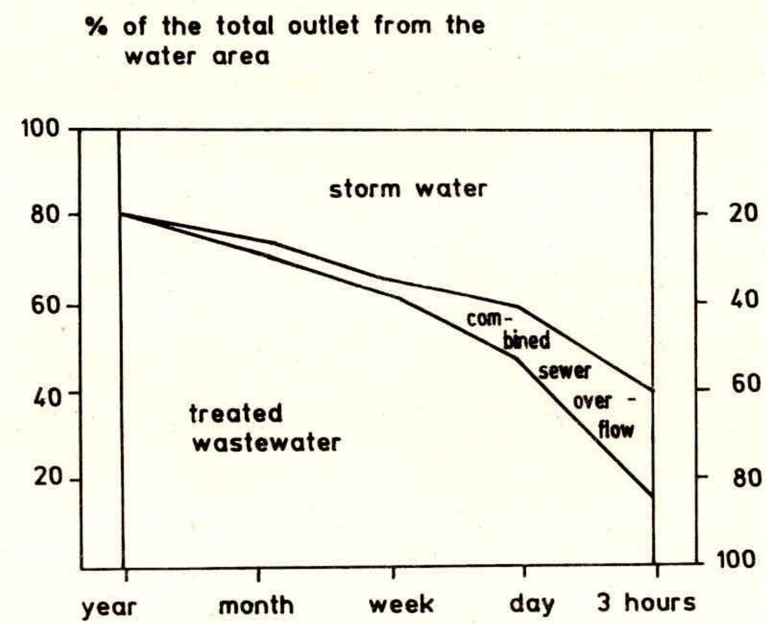

FIG. 4 RELATIONS BETWEEN DISCHARGED VOLUMES OF WATER FROM THE CITY OF LAND .

At the above sites precipitation and discharge of storm sewer, was measured continuously and is recorded. The soil moisture content of unsaturated zone in the unpaved areas is measured periodically.

The analysis of data gives following results:-

i. High correlation exists between both the total amounts of rainstorms.
ii. The measured values of discharges and groundwater levels are essentially continuous in time.

The catchment study in Neede showed peak of precipitation to peak of runoff (Translation time) about 20 min, reaction time 15 min and average runoff coefficient from 0 to 0.7.

The study on runoff from the roads in lelystad showed that surface runoff coefficients of roads will not exceed 0.2 for verges upto 5 m in width and 0.7 for verges upto 2 m in width. The contribution of the ground water flow to the runoff process exceeds the surface runoff at the verges of more than 2 m and application of sub surface drainage of the verges, besides the blanket drainage, may be alternative for ditches and open drains along roads.

A study on infiltration into pavement has indicated that the assumption that most of water from a rainstorm runs off to storm drains in designing a sewer system is not true. Water balance of parking lot covered for 99% with asphalt and bricks, only 30% of precipitation was discharged by surface drainage system. Hence infiltration is in no way negligible.

Since 1981 a national five year research programme on sewerage and water quality is going on. It's purpose is to estimate processes in sewer systems and receiving waters, to develop water quality models and optimize the design of sewerage system.

9.3 Modeling

To evaluate the transport capacity of existing/newly designed drainage control systems, Heidemaatschappij has developed two different computer programmes, classified as: Design Analysis Models. First programme deals with steady flow in closed conduits and second with unsteady flow (Slijkoord, F.)

Study on the static and dynamic simulation of water transport in a complex network system showed that static models tend to underestimate the degree of mixing in network when compared in dynamic simulation, based on a nodes and links model. (Lijklema, L and G Van Straten).

A digital model has been developed to facilitate the design of open watercourses in the new town of lelystat and Almere (J E G Bouman, E.Schultz).

Recent technological progress has simulated a hydrodynamic approach to the surface runoff problem. The dynamic equation is simplified which leads after linearization, to a diffusion type equation. As part of a model for the rainfall-runoff relation of a catchment, the hydrodynamic linear distributed model of surface runoff without internal boundary conditions consists of a cascade of linear conceptual elements (Van de Nes, Th.J.)

10.0 URBAN CATCHMENT RESEARCH AND MODELING IN SOME COUNTRIES

10.1 Introduction

This section deals with the urban catchment research and modeling for several countries which include Norway, Poland,Japan Switzerland, Scotland, USSR, Iraq, and Brazil

10.2 Urban Catchment Research

Systematic urban catchment research in Norway are carried out as part of two projects:

Project 4.2: In this project daily mean values of precipitation and discharge, graphs and tables with 5 min time resolution of significant storm events and seasonal variations of other variables are available. Statistical analysis of runoff coefficients is in progress with an objective to find out the effects of urbanisation on catchment water balance.

Project 4.7: In this project data from nine catchments, five with separate drainage systems and four with combined systems have been collected. Surface water combinations and dry weather flows are treated separately to make results for combined and separate systems. Concentration of pollution is correlated with discharge and total annual loads are analyzed against catchments characteristics such as percentage impervious area, person equivalents and catchment slopes. Surface and water loads have been found higher in combined systems.

Several preliminary studies on snowmelt phenomenon in urban areas in Norway (Oren, 1979), (Watne, 1981) had been carried out with the general conclusion that peak rate of urban runoff specially in coastal areas are greatly influenced by snowmelt.

The Research Institute on Environmental Development in Poland has reported that for a drainage area less than 50 ha, a time of concentration of duration 15 min and frequency of occurrence of floods depending upon the amount of rainfall should be used for planning and design of drainages.

Research Institute on Environmental Development Poland is also studying the influence of urban runoff on a small receiver. The study is in progress since 1981.

Ebise et.al. (1978, 1979) have carried out studies on temporary storage mechanism of benthic microorganism community on the stream beds for flushed suspended pollutants (P, N and COD) by storm runoff in Sagami river basin in Japan.

In a study in Switzerland on urban runoff from an urban area of 8.5 ha, of which 4 ha is impervious and inhabitants density of 200 in ha/ha without industries. The measured coefficient of runoff are found as 0.36 for the whole urban area and 0.78 for impervious surfaces.

· A study on widely used rational formula indicated that runoff coefficient proposed in the ordinary tables are too high for the urban areas. An experiment on different kinds of impervious surfaces (Fig 5) have shown the appropriateness of this point of view.

In a study in Scotland continuous monitoring of water level and suspended sediment concentration was undertaken in 170 sq Km Almond catchment during winter 1975-76. The study showed the sediment yields resulting from human impact were 35 t from farming and 128 t from initial excavations.

A study in Iraq considered the salt concentration in Euphrates river at different locations and time and its consequences on quality of river water and suitability for agricultural uses. The influences of drainage disposal on quality of water of river was significant.

Kuprianov, V.V. in his studies on hydrological effects of urbanization in the former USSR reported that annual runoff from urbanized territory may be greater than 10% or more, than that from rural areas. Maximum discharges of normal rainfall floods may be several times greater than in natural watersheds. As absolute volumes of flood depends on amount and intensity of precipitation as well as the extent of areas of impervious surface.

Ceferino Alvarez and Julio Sanchex of Brazil in their study on effect of urbanization on runoff on the hydrology of a sub-urban basin in Porto Alegre, Brazil reported that on application of a constant IUH (unit hydrograph method assumes there is a basin which may be typified by a constant) 1 mm, 30 min to a rainfall of 30 min and with a return period of 10 years, initially for a rural basin, and the result of an increase of upto 27 percent in the impervious area through urbanization. There is a drastic increase in peak and concentration of the volume which runoffs in a short time period, creating practical capacity problems in the storm drainage network (Fig.13).

Matti Melanen and Risto Laukkanen in their study on analysis

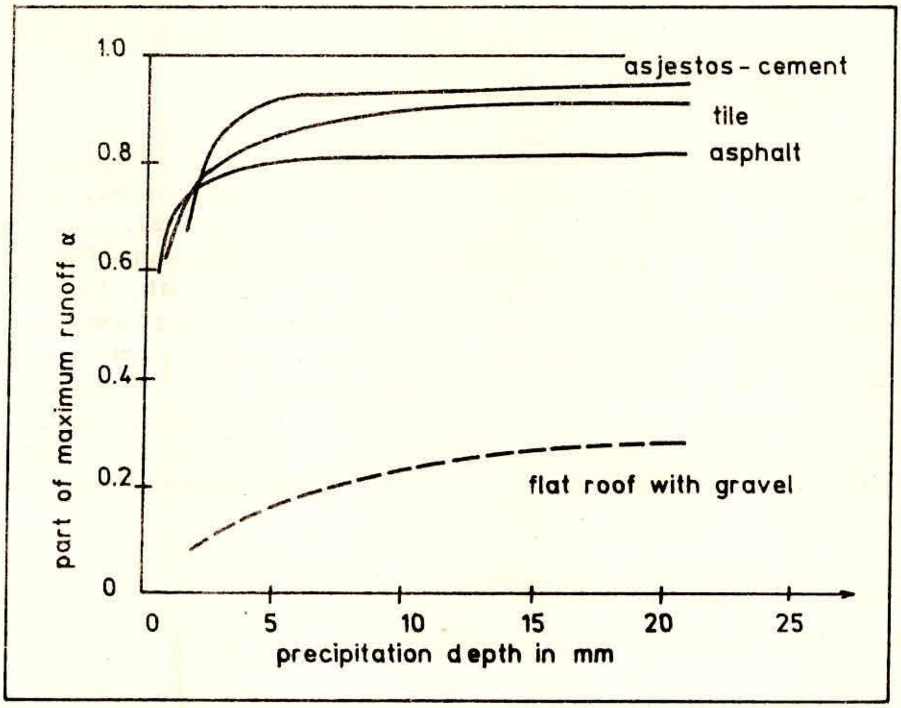

FIG. 5 RELATIONSHIP BETWEEN PRECIPITATION DEPTH,PART OF MAX RUNOFF FOR DIFFERENT KINDS OF IMPERVIOUS SURFACES .

of rainfall-runoff relationships in Finnish urban test basins have concluded that on an average, the portion of surfaces generating runoff in a urban basin may be estimated as 80-90 percent of the portion of paved (impervious) surfaces with direct assess to the storm drainage system.

10.3 Modeling

A model based on rainfall-runoff relationship of outflow and pollution of urban precipitation effluents has been developed in Poland. This model consists of three sub model namely runoff sub model, pollution of runoff and quality of water in receivers of urban storm outflows.

The model developed by Norwegian Institute for Water Research Norway (NIVA models) consists of two models: a network model, handling combined sewer and separate storm sewer systems and a waste water treatment plant model.

11.0 URBAN CATCHMENT RESEARCH AND MODELING IN INDIA

11.1 Introduction

Urban areas (towns) in India are distinguished from rural areas by the following: (1) all places with a municipality, corporation, cantonment or notified town area; a minimum population of 5000 with a density of not less than 1000 persons per square mile and three-fourths or more of the working population engaged in work outside of agriculture; and any other place which is considered by appropriate authorities to possess pronounced urban characteristics and amenities. Also, the 1971 census identified "standard urban areas" which included rural and urban populations within a fixed area with a good chance of becoming fully urbanized in two or three decades, as well as "urban agglomerations" (Unesco,1978).

11.2 Urban Catchment Research

11.2.1 Water quality

Only recently has there been a realization in India of the importance of stream and groundwater quality. Yet, water quality problems are important. For example, tannery wastes create problems for the rayon industry in Kanpur. In addition to such problems of industrial wastes and their treatment, there are two specific problems related to water quality in urban drainage design. Waste water sewerage connections are generally, made in Indian towns to less than 25% of the number of households and hence the sewer system is over designed. This leads to the accumulation of silt and sediments in the sewer. When storm runoff occurs such sewers are partially choked, leading to under utilization of their capacity and flooding. Furthermore, the low-lying areas prone to frequent flooding are often encroached upon by the poorest section of the population, and are covered with sprawling slum areas with a high density of population and meager civic amenities. Failure to provide an adequate urban drainage system seriously affects the life of these people and exposes them to potential health hazards.

Studies have also been made in academic institutions and metropolitan planning organizations concerning intensive, short duration rainfalls. For example, studies have been made of the location of the peak rainfall intensity in storm patterns and synthetic storm patterns, and a frequency analysis has been made of storm rainfall.

11.2.2 Runoff

India has one of the oldest stream-gaging networks in the world. But there has been a very great paucity of reliable data for the small drains of urban areas. While river stage measurements and other data concerning flooding are available, these pertain to the high flood levels in the rivers to which the drains discharge and generally not to the discharge in the drain itself. Realizing the importance of discharge data, attempts are being made to measure discharges in urban drains.

11.2.3 Field Research

Urban drainage design requires depth-area-duration -frequency relationship characterising storms in urban areas, particularly for small durations. Based on 5 to 23 years of data of 50 self recording raingauges, Indian Meteorological department has brought out depth-duration-frequency relationship for 15 min, 30 min, 45 min, one hr and 1 year duration.

Unesco, 1978 also reported that design of urban drainage system in India is based on rational formula because of lack of adequate continuous records of precipitation and streamflow. Yet, there is a vital need of standardization of design procedures based on engineering and economic considerations.

Ramaseshan, Unesco 1981 on research on urban hydrology reported that urban hydrologic problems of India differ from those of developed countries in several important respect as:

i. lateral rather than vertical development
ii. limited amounts of paved area
iii. Initiate interaction between urban drainage and flood control
iv. Preference for open drains over closed ones
v. limited availability of continuous records of precipitation, streamflow, and water quality
vi. low fiscal priority for drainage investment
vii. limited number of sewer connections and hence sifting of combined sewer

viii. high cost of construction and modification
ix. limited capacity of financial investment

Chakraborti,A K (1989) in his study of urban storm water runoff modeling in Rohini Delhi has indicated that

(i) the urban drainage index adopted in India is 3.5 cumec/km^2 with 35 mm/hr rainfall intensity with once in two years recurrence interval.Since the rate of urbanisation in Rohini is expected to increase from 55% to 84% the urban drainage index needs to be modified according to 5.5 cumec/km^2.

(ii) If the projected Rohini urbanisation takes place as per Rohini composite plan adding 20 sq km more area under urbanisation, projected storm runoff will be much higher than even the combined runoff of 142 cumecs from upland rural catchment plus 142 cumec additional discharge from nearby drains.

Grewal and Duggal in a study on effect of urbanisation on runoff for Ludhiana city have shown many facet problems of drainage system of the industrial and congested city of Ludhiana are described here. The plan proposed by Punjab State Pollution Control Board is discussed and its short comings are highlights. If the problems of drainage system for Ludhiana are not solved, the problems are bound to degenerate the city and make life of people measurable.

Kalwa-Panval Railway line is planned to cater transport needs in the development of new Bombay. The storm water flowing from east to west under the bridges and culverts drain catchment of hilly terrain of areas less than 25 km. These catchments belong to the small urban catchments. In this study Murthy et al indicated that the design storms derivation was made which proved satisfactory.

11.3 Modeling

11.3.1 Rational Formula

The rational formula is widely used in India for urban drainage design. Some attempts have been made to measure the peak flow from a drain and compare it with the peak storm intensity to derive the coefficient of runoff. For example, in Delhi a number of storms were gaged for peak flow in 1975 and the resulting range of coefficients of runoff was used to determine the design value. By choosing drains from essentially urban and agricultural areas, design coefficients of runoff were correlated to urbanization, such as in terms of population density. Thus, only a deterministic and not a probabilistic approach to the rational formula was adopted.

11.3.2 Mathematical Model

A nonlinear hydrologic model of the form

$$S = K1\ q^N + K2\ (dq/dt)$$

has been developed for the storage in the combined sewer and drainage system of Calcutta town, by relating the effective rainfall during a storm derived from the recorded precipitation data to the record of pumpage from the storm water pumps, using a procedure similar to that of Prasad. The parameter N was nearly constant but the parameters K1 and K2 were not constant and so they were correlated by regression analysis in terms of storm characteristics such as total rainfall excess, the duration of rainfall excess, and the time distribution of rainfall excess in terms of the time to centroid and a shape factor. The results indicated that the hydraulic capacity of the system is very inadequate, leading to frequent flooding of streets. This agrees with the fact that the design capacity provided corresponds to a 2-month recurrence interval.

12.0 DISCUSSION :

In most of the explorations for need of research in urban hydrology, following observations emerge frequently:

1. Reliable data from urban watersheds with detailed information of time and space distribution of rainfall is not available. similarly information about infiltration and evaporation from urban watersheds is also lacking, except for a few small watersheds, data for above mentioned type is not available.
2. Hydrological system analysis techniques have not been widely used for analysis of urban watershed data, nor have any general conceptual or mathematical models been developed for use in urban hydrological practice.Although several sporadic attempts have been made in these directions, the methods developed have not been tested widely.
3. Research on the effects of urbanisation on runoff from watersheds is in its early stage.

Problems of urban settlement are common to industrialised and less industrialised countries (un,1971), therefore less industrialised countries should note the difficulties experienced in developed countries in more comprehensive planning of their development that takes into account environmental considerations.One of the important observation which can be made is that the problems of urban hydrology are remarkably similar in all parts of the world.

International Hydrological decade/ UNESCO subgroup on Effects of Urbanization on the Hydrological Environment has arrived at following conclusions:

1. More metropolitan-scale water-balance inventories and their analysis should be undertaken as a means for improving overall water resources planning and management, and follow-on inventories should be made periodically to document change and to provide a better understanding of the hydrological effects of progressive urbanization.
2. The interrelation and interdependence of water and waste water and the competition and conflict between multiple jurisdictions have intensified with the growth of metropolitan areas. The variety of uses for water in metropolitan areas are continually enlarging, particularly for recreational purposes and for esthetic enhancement. Thus, hydrological surveys of urban areas should be updated frequently and regularly.

Urbanisation substantially alters precipitation-runoff relations compared with those for natural drainage. Despite a number of studies that have been made the time/space relations of the urban runoff process are not still very well qualified. The increase in the impervious area that accompanies urbanisation tends to reduce volumes of infiltration and evapotranspiration of a catchment. Surface detention storage characteristics can be drastically changed. All these factors collectively change the surface runoff regime, a change which is often reflected in an alteration in the amount of groundwater recharge.Stil there are large gaps existing in urban hydrological research and modelling and data colllection. A summary of hydrolodical research and modelling is presented in Tab 4 (ASCE,1983).

Ramaseshan, 1981 pointed out that urban hydrologic problems of India differ from those of developed countries in several important respect such as lateral rather than vertical development, limited amounts of paved area, Initial interaction between urban drainage and flood control, Preference for open drains over closed ones, limited availability of continuous records of precipitation, streamflow and water quality, low fiscal priority for drainage investment, limited number of sewer connections and hence shifting of combined sewer, high cost of construction and modification and limited capacity of financial investment.

Although it is a fact that most problems and effects in technologically and economically advanced countries are very similar, very few generalities on hydrological effects of urbanisation on a national scale can be drawn. As an example, it has been demonstrated in a number of countries that urbanization increases the local contribution of direct runoff volume and that systems of storm drainage conduits result in greater direct runoff peaks with shorter rise times than for pre-urban conditions. A source of importance in generalization is the fact that, world-wide, the field of urban hydrology is almost devoid of modern research investment and that there has been relatively little study to date of the effect of human settlements upon natural hydrological conditions.

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