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PRESENT STATUS OF URBAN HYDROLOGY

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PREFACE

With the increasing Urbanisation and rapid development of cities, the problem of urban hydrology have become more complex. The Land Surface modifications due to urbanisation produce changes in the magnitude of runoff volume. The hydrological problems associated with urbanisation are the continuously increasing demands for various uses, changes in physical environment that alter the natural water balance and the disposal of wastes that alter the natural streams and ground water. At present one of the present problem of urbanisation is that the quick disposal of storm water from the inhabited areas.

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 information 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.

In this report, the present status of urbanisation in developed and developing countries, urban hydrologic cycle , software related to urbanisation problems, and sanitation in urban areas etc. have been reviewed. This review has been carried out by **Dr. (Mrs.) Rama Devi Mehta, Scientist 'B', Hydrological Information System Division** of the Institute.

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Director

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 associated with it are also increasing. There 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.

The present status of urbanisation in developed and developing countries, software related to urban problems, Sanitation in urban areas, Reuse of water in urban areas, etc. have been reviewed here. Problems in modelling Urban watersheds and comparative study of different models by different scientists have been also highlighted.

Contents

List of Tables

List of Figures Page No.

1.0 INTRODUCTION

The history of urban hydrology is not very old. The co-ordinating council in 1970 decided to form a sub-group on the effects of urbanisation on the hydrological environment, supported by UNESCO, to assist the working group and to investigate more intensively industrial and urbanisation aspects. Urban Hydrology is defined as the interdisciplinary science of water and its inter relationships with Urban man (Jones, 1971). It is a relatively young science, the bulk of its knowledge has accumulated since the early 1960's in Western countries. Again, the urban hydrology is the study of the hydrological processes occurring within the urban environment. However, further consideration of the hydrological cycle of an urban area, depicted in Fig. 1 & 2 reveals the inadequacy of this simplistic conception. The natural drainage systems are both altered and supplemented by sewerage. Despite the continuing increase in the extent of major towns and cities, in many countries the land occupied by the urban population is often less than 2% of the total area (Atlas of India, 1987). The concentration of human activities intensifies local competition for all types of resources; among the most vital of which is water. As Schneider et. al. (1973) have noted, water is both an artery and a vein to urban life.

Water has been identified as the trigger of war in the next millennium, an extremely serious statement, which despite critical voices nevertheless highlights the intimate links between water and power. Degradation of land and water resources caused by poverty-related factors like high demographic pressure on natural resources, lack of know-how and financial means to deal with resource degradation, can also aggravate the outcome of high order effects like armed conflicts.

Water is also employed extensively in urban areas for the disposal of wastes. In the initial stage of urban development, septic tanks are employed for the disposal of domestic wastes. As the urban area grows, foul sewerage system discharging to sewage treatment works are installed, and the treated effluent is returned to local water sources or even the ocean. It results the rapid creation of large impervious areas, producing noticeable drainage problems. The Science of urban hydrology was born out of the necessity to understand and control these problems. 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 is 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 high 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. Designs of drainage facilities, which do not account for this increased runoff are inadequate and may result in heavy damage and loss of property.

Urban development in India is presently going through a very dynamic stage. In the first forty years of the century, the country was still a fully agarian society and its proportion of urban population was less than 12%. India's urban population growth between 1981 and 1991 with 36.19% was higher than the decadal growth of the 1960s and 1970s, but -- most relevant-- the rate of growth has been much higher in urban than in rural areas. Particularly important are the fact that the urban population increased almost ten times between 1901 and 1991, and the number of urban settlements doubled in this period. Since the beginning of this century, the urban population has steadily increased by 217 million in 1991. Among the urban areas, the small towns are somewhat stagnating while the 23 metropolitan cities (as per the 1991 census) stand out very prominently as they accommodate about one third of the total urban population. The largest of these, i.e. Bombay (12,6 million), Calcutta (11.1 million), Delhi (8.5 million) and Madras (5.5 million) account for nearly one fourth of all urban population. The urban population has been reached nearly 320 million or approximately 33% by year 2000. From the urban population in many cities, 30-40% of the citizens alone resides in slums and squatter settlement, but in India's industrial capital Bombay, already 40% of the population live in slums. The National commission on Urbanization (1988) estimated that some 75 million will be living in slums and under conditions of multiple deprivation -- non-availability of affordable land, illegal land tenure, deficient environment and Kutcha shelter in near future. As a reason for this gloomy picture of an urban India of slums it is stated that nearly 60% of households cannot afford a conventional puccha house and the lowest income group, some 10 – 15 % of the population, cannot even afford a serviced site. By 2020 more than 50% of India's population is expected to live in urban areas, thus the age old image of India as a rural nation will be a matter of the past. A rapid concentration process of population in larger towns, cities and metropolitan areas compounds this picture, and it is projected that in year 2080 India will already have some 18 metropolitan cities. (Singh & Steinberg, 1996)

At the same time, India's urban future poses an unprecedented challenge for planners and city managers. As the country enters in an era of economic growth, economic liberalisation and prosperity, the cities seem not yet ready to accommodate the growing population, to provide work and services and environmental infrastructure for all, and access to critical inputs of land, affordable finance, and construction technologies need to be resolved.

2.0 LITERATURE REVIEW

Several authors, including Savini and Kammerer (1961), Leopold (1968), and Hall (1973) have described the changes in flow regime, which occur when an initially rural catchment area is subject to urbanisation. Ramaseshan (1983) has given the progress on Urban Hydrology since 1979 in India. The particular aspects of urbanisation which exert the most obvious influence on hydrological processes are the increase in population density and the increase in building density within the urban area. The consequences of such changes are outlined in the Fig.3.

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. But Selvalingam (1987) said that ' it allows only the determination of the discharge hydrograph peak'. Limitations include the inadequacy to account in large catchment for pipe routing or variations in rainfall intensity, contributing area and rate of contribution. The further drawback in this method is the lumping of all physical factors into two parameters (runoff coefficient and time of concentration) which makes parameters estimation subjective and is generally found to be simplistic to permit actual discharge to be adequately predicted from observed rainfall.

In the recent past much research has gone into the development of digital simulation models which can aid in the design, evaluation and management of the urban drainage system. At present, there are several models available and Selvalingam et.al. (1987) have presented two such models, the runoff routing model (RORB) and the Storm Water Management Model (SWMM). They applied these models to a tropical catchment (partly urban area) in Singapore and concluded that the SWMM model is a good replacement for the rational model used currently and can be incorporated without much difficulty to simulate urban drainage system in developing countries.

A N.I.H. technical note TN-49 (Goel & Soni, 1988) 'Storm drainage estimation in Urban areas" has been reviewed the various urban drainage models developed in different countries with their merits and demerits. The present practice of urban runoff estimation in India has been examined and the necessity of recording & maintenance of hydrological data for urban areas has been emphasised in this note. They have described some specific models and runoff estimation practices in India.

Chakraborti, A.K. (1989) in his study of urban storm water runoff modelling 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% so the urban drainage index needs to modify 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 cumec from upland rural catchments plus 142 cumec additional discharge from nearby drains.

Nancy & Troutman (1989) have given the Regression Models for Estimating Urban Storm – Runoff quality and quantity in the United States. Urban Planners and managers need information about the local quantity of precipitation and the quality and quantity of storm runoff, if they are to plan adequately for the effects of storm runoff from urban areas. As a result, linear regression models were developed for the estimation of storm – runoff loads and volumes from physical, land-use, and climatic characteristics of urban watersheds throughout the United States. Based on mean annual rainfall, three statistical different regions were delineated to improve linear regression models for total storm rainfall and total contributing drainage area. Impervious areas, land-use and mean annual climatic characteristics were also significant explanatory variables in some linear regression models. Models for dissolved solids, total nitrogen, and total ammonia plus organic nitrogen were the most accurate models for most areas, whereas models for suspended solids were the least accurate. The most accurate models were those for the more arid western United States, and the least accurate models were those for areas that had large quantities of mean annual rainfall. Buttle (1990) has given the effects of Sub urbanization upon snowmelt runoff. Chakraborti, A.K. (1991) has also studied the urban storm water runoff projection.

In recent years, water policy official, faced with growing water demands, have explicitly addressed demand management strategies. Rate structures have been infrequently used as a management tool, as opposed to the traditional methods of education and conservation programs. Michael L. Nieswiadomy (1992) has given two purposes. The first is to estimate urban water demand in the United States using the most current American Water Works Association (AWWA, 1984) survey of 430 (of 600 largest) U.S. utilities. This water demand model will explicitly incorporate the impact of conservation program, something few other studies have done. The second purpose is to test if consumers respond to average prices (AP) or marginal prices (MP) using Shin's model (1985). A problem, which has received very little attention in the economic literature, is the impact of conservation and public education programs on water demand. A similar problem persist with public education programs that encourage people to save water, which may convince people to conserve water out of a sense of public duty. But if the plea for conservation is not accompanied by an increase in water rates, the plan is likely to fail in the long run. For example, in Tuscon in the 1970s, a " Beat the Peak" (conservation) campaign was successful in decreasing per capita use for a few years. However, a few years later, use increased back to its previous level because real water rates did not rise. Martin et.al. (1984, p. 66) state, in summarising the Tuscon situation, " Major decreases in water use per capita occur only where a major price increase is accompanied by major public awareness of the action surrounding the passage of the increased price schedule."

Another N.I.H. technical report TR (BR) 124 (Shukla, 1994) entitled ' Effect of Urbanisation on Runoff Hydrograph' has made some attempt to find out the effect of change in impervious area on the run off peak and time to peak using a deterministic model "Kingen" for the Palam urban drainage basin a sub basin of Nazafagarh drainage basin, New Delhi.

The recent decentralisation act, the Nagarpalika Act (Amendment 74 to the Constitution) of 1994, factually placed greater responsibilities and urban management tasks in the hands of the Urban Local Bodies (ULBs) or municipalities. These tasks involve town planning, land use planning, socio- economic development planning, poverty alleviation programmes, development of roads and bridges, water supply, sanitation and solid waste, and the provision of various other services and amenities.

The Nagarpalica Act and its decentralization initiatives come at a time that the new economic policies demand improved capabilities for urban and financial management at local levels of government, supported by state and central level institutions. The decentralization of urban management also calls for new roles and the involvement of the private sector, non- – governmental organizational (NGOs) and the community at large. Municipal administrations will not only benefit from a participatory approach and the active involvement of these urban stakeholders, but also have no better alternative to pro-active partnerships with these urban actors. A dialogue with the private sector, non-governmental and community-based organizations (NGOs / CBOs), and the community will enable the mobilization of far greater resources for urban investments and help in managing the cities is a better way. (NHB, 1992).

The recent shift of economic policy towards liberalization gives way to assume that there will be a gradual withdrawal of the public sector, and a growing role of private sector, NGOs and community involvement. These issues have been taken up by the 2nd United Nations Conference on Human Settlements (HABITAT II) in 1996 which have influence on India's urban policy for start of the next century (Das and Gupta, 1994; Ministry of Urban Development, 1994)

Chau (1995) presents the development of a computer – aided design (CAD) and drafting package (DRAINAGE) for medium sized municipal storm – water drainage systems. The computer package for flow prediction and drainage design applies the Colebrook equation and the rational method to route pipe flows through tree-type drainage network, automatically adjusting drainage pipe diameters to fulfil flow requirements and backwater effects. The program outputs are written as DXF files, which can be read and displayed readily as drawings of drainage layout plans and longitudinal profiles in an AutoCAD environment. Drainage replaces the time-consuming conventional method for designing storm – water drainage networks.

A comprehensive and wide-ranging "The 1999 world water week " in Stockholm took place with the Stockholm water symposium. At the 1999 symposium, " Urban stability through Integrated Water- related management"; over 800 delegates from 101 countries analysed the problems and sought constructive strategies to secure a stable, yet dynamic and creative urban situation.

Professor Asmal challenged delegates to view the cities of the future as "complex, dynamic, living entities with water as their precious lifeblood, social justice as their compass for growth and prosperity, and science and technology as their engines for progress." His speech dedicated to the multi-faceted role of women in water and related issues, touched on the interlinkages between poverty, the lack of clean water and basic sanitation services, social problems, and the need for radically new and innovative ways to view and address the water crisis of the cities. The challenge for delegates through the week-in workshops, general sessions, meetings, and other events- was, how to avoid the collapse of cities and livelihoods in the growing urban and peri-urban areas due to water supply and sanitation problems or due to unemployment when severe water pollution forces industries to close down. Nine symposium workshops focussed on key issues related to this challenge. Topics included water reuse, urban flood mitigation, water-waste-energy management, non-technical challenges of urban water management in developing countries, long –term water supply and sanitation solutions, urban areas in the upstream/ downstream basin context, sustainable sanitation, and interaction between urban and peri-urban areas. Symposium delegates concluded that urban stability requires – apart from the need to tackle challenges within the city – societal ability to cope with both unavoidable floods and water pollution enormous in developing countries, in fact threatening economic development of mega cities. A whole set of barriers besides the financial ones stand in the way of minimising pollution loads. At the same time, rapidly growing cities tend to destroy their own water sources by " paving over" or polluting existing reservoirs. New sources further and further away are getting insurmountably costly to develop. Water reuse is therefore a natural way out, although in the long term limited by the soil and water salination that develops in response. (Stockholm Water Front, 1999)

3.0 URBANIZATION IN INDIA: AN OVERVIEW

The important highlight of 1991 census in India is the unprecedented rapid growth of urban population. The rise of percent during 1981-91 is the highest in any decade in the century. During this period urban population of India has gone up from 159 million in 1981 to 217 million in 1991. This rise of 58 million is largely a result of the mass rise of the population in class I cities. The general trend of urban population and its distribution for the country in different classes of cities to total urban population along with the estimates for 2001 census is given in the following table.

Table 1: Trends of urban population and their distribution

Years	Population (in millions)	Classes of cities to total urban population					
		I	II	III	IV	V	VI
1901	25.61	22.9	11.8	16.5	22.1	22.4	6.3
1911	25.58	24.2	10.9	17.7	20.5	19.8	7.0
1921	27.69	25.3	12.4	16.9	18.9	19.0	7.4
1931	32.97	27.4	12.0	18.8	19.0	16.3	5.6
1941	45.00	35.4	11.17	17.71	16.29	13.38	3.45
1951	62.00	41.77	11.08	16.73	14.02	13.20	3.22
1961	79.00	48.37	11.89	18.53	13.03	7.23	0.95
1071	109.00	52.41	12.15	17.36	12.04	5.24	0.80
1981	159.00	56.51	12.35	13.63	10.69	5.11	0.72
1991	217.61	62.50	13.65	13.10	8.05	2.07	0.63
2001	320.00	70.60	12.85	9.33	4.67	2.15	0.45

* Figure for 2001 is estimated figure. Source: Compiled from Census Reports,

Despite in long urban history, India remains one of the less urbanised countries of the world. It was around one-sixth urban at the time of independence in 1947. The 1991 census recorded over one –fourth, to be precise 26.1%, of the total population as urban (Table 2). The corresponding figure for the world was 45% in 1990 (United Nations, 1991, p. 107). The less developed countries together recorded 37% of their population as urban. In absolute numbers, however, India's urban population is the world's second largest after that of China. It is projected to grow to over 300 millions, nearly one–third of the total, in the year 2001. All this represents the magnitude of urban management situation even when the country is at a relatively low level of urbanization. (Krishnan and Singh, 1996)

Table 2: India: Urbanization and related indicators, 1951 – 1991

Census	No. of Towns/ urban Agglomerations	Urban Population (in millions)	Urban population as % of the total	Annual growth rate during the preceding decade				
				Urban population	Urban natural increase	Gross national production	Agricultural production	ndustrial roduction
1951	2,845	62.4	17.3	-	-	-	-	-
1961	2,365	78.9	18.0	2.3	*	3.9	4.0	7.1
1971	2,590	109.1	19.9	3.2	*	3.2	2.5	6.1
1981	3,378	159.1	23.3	3.8	1.9	3.2	2.0	4.4
1991	3,768	217.6	26.1	3.1	2.0	5.3	3.6	7.8

* Source: Census of India, 1991 and Government of India, 1991, S-1 and S-3

* Means data not available

Wide regional differences in urbanisation level are not unexpected in a country like India with a subcontinental disposition marked by great heterogeneity in resource base, development stage and historical experience at regional level. Among the 452 districts of the country, excluding 14 districts of Jammu & Kashmir, where the 1991 census could not be taken due to disturbed conditions, 6 districts were entirely urban and 10 wholly rural. In nearly three-fourths of the total districts, percentage of urban population was less than 25%. In 1991 census, almost half of the districts, were at an urbanisation level, which was lower than the national average of 17.3% in 1951 census.

Relatively speaking, South India is more urban than its northern counterpart (Fig. 4). The former is coastal, characterised by a greater degree of commercial agricultural in cotton, oilseeds, sugarcane and plantations crops, and marked by comparatively higher level of industrialisation. North India is predominantly agricultural. Herein Punjab and West Bengal are more urbanised than the national average. Urbanisation level of different states (Table 3) is significantly related to their per capita income (r = 0.69), share of income generated in the secondary sector (r = 0.77), the income share of tertiary sector (r =0.9) and economic growth rate (r = 0.59).

Table 3: India - Urbanisation level, 1991, 1951 and 1901 by states and union territories and spacing of towns / urban agglomerations in 1991.

India/ States/ U.T's.	Percentage of Urban Populations			Mean Distance (in Km.) between towns
	1991	1951	1901	1991
India	26.1	17.2	10.8	31
States				
Andhra Pradesh	26.8	17.4	9.7	39
Arunachal Pradesh	12.2	0	0	98
Assam	11.1	4.3	2.3	32
Bihar	13.2	6.8	4.0	31
Goa	41.0	-	-	13
Gujarat	34.4	27.2	22.3	32
Haryana	24.8	17.1	12.4	24
Himachal Pradesh	8.7	6.5	4.0	34
Jammu & Kashmir	*	14.1	7.4	60
Karnataka	30.9	23.0	12.6	30
Kerala	26.4	13.5	7.1	20
Madhya Pradesh	23.2	12.0	8.7	34
Maharashtra	38.7	28.8	16.6	35
Manipur	27.7	0.5	25.4	29
Meghalaya	18.7	9.7	2.8	61
Mizoram	46.2	0	0	33
Nagaland	17.3	1.9	3.1	46
Orissa	13.4	4.1	2.5	39
Punjab	29.7	21.7	12.4	22
Rajasthan	22.9	18.5	15.1	43
Sikkim	9.1	2.0	0	32

Tamil Nadu	34.2	24.4	14.2	24
Tripura	15.3	6.7	3.7	26
Uttar Pradesh	19.9	13.6	11.1	22
West Bengal	27.4	23.9	12.2	25
Union Territories				
Andaman & Nicobar Island	26.8	25.2	0	98
Chandigarh	89.7	0	0	11
Dadra & Haveli	8.5	0	0	24
Daman & Diu	46.9	-	-	8
Delhi	89.9	82.4	52.8	16
Lashadweep	56.3	0	9	3
Pondicherry	64.1	-	-	9

- Source: Census of India, 1991, pp. 19,51 & 52. and census of India, 1981, pp. 34-38 and 573 – 584.,
- Means data not available.,
- Mean distance was arrived at by assuming that every town/urban agglomeration has a tributary area of equal size, hexagonal in shape. The procedure adopted was to divide the area of a state by the number of towns/urban agglomerations located in it. Distance between the centres of any two such adjacent hexagons was adopted as the mean distance.

3.1 Urban land for the poor

Urbanisation is defined (Rugg. 1972) as the concentration of people in urban settlements and the process of change in land use occupancy resulting from the conversion of rural lands into urban, suburban and industrial communities.

Urban anatomy is also affected by external factors such as the capabilities of the transportation media and the degree of trade relationship with the surrounding region and other areas. To remedy the week position of the poor, the Indian Government has, over the years, devised a number of institutional interventions, which are implemented through organisations at national, state and local levels. The role of public institutions in making land and land development rights available to the urban poor has consisted of three basic forms of intervention. Institutions have directly acquired land for housing and sites and services projects, which they have attempted to deliver or affordable prices. They have made low cost finance available to families and other institutions to develop land. They have legitimised irregular land occupation in squatter settlements and illegal sub-divisions and assisted in their improvement. Apart from these specific means for low income settlements, public institutions are responsible for planning and regulating the use of land in cities, redistributing in society the individual rights and public property (for which they have also resorted to large scale evictions and demolition of informal settlements). Public institutions have made use of a large number of legislative, fiscal and policy instruments to perform their functions.

In the case of land supply to the poor, the back-bone of policy and practice has been direct intervention by public institutions in assembling land for projects through expropriation under the Land Acquisition Act of 1894. However, institutional efforts have never really matched the requirement of plentiful and cheap land supply. But the situation was never so bad as in the last decade, not only is there a growing resistance to compulsory acquisition but the 1984 amendments to the Act required public institutions to mobilise larger sums of money within shorter periods for acquiring land. That is not an easy matter considering the poor financial condition of most institutions. So, with a few exceptions, land supply through this method is virtually at a standstill. Again, barring a few exceptions, application of the Urban Land (Ceiling and Regulation) Act, 1976 has so far not yielded land for the poor.

But the last decade still stands out as a period when there has been a substantial increase in legal land occupation by the poor. This has become possible through the new widely accepted popular practice of regularising tenure in informal settlements. Thousands of poor families in Indian cities have got access to legal tenure and better infrastructure. The practice has been extrapolated into State and National Policy (Banerjee, 1994). Within the broad framework of facilitating or enabling strategies the state is expected to look after the interests of the poor. What envisaged is that in addition to direct intervention in providing land and shelter where possible or absolutely necessary, public institutions would enable legitimate access to land through financing, through tenure regularisation and improvement of informal settlements and through laying down conditions for the operation of the land and housing market. There is also a stress on increasing the supply of urban land and rationalising its use. In essence all national policy documents of the last decade take a similar stand. They are the Report of the Task Forces on Housing and Urban Development (Ministry of Works and Housing, 1983), the Seventh and the Eighth Five Year Plans (Planning Commission, 1985, 1991), Report of the National Commission on Urbanisation (Ministry of Urban Development, 1988) and the National Housing Policy (Ministry of Urban Development, 1994). In addition, state governments such as Madhya Pradesh and Maharashtra have their own housing policies with a similar approach. (Mitra, 1990a).

3.2 Small-Scale urban Infrastructure

Small-scale urban agriculture, which is possible to arrange on very limited area of a densely polluted city, is also an option. In Botswana, the " Sanitas Wall" has been developed to use gray water from households for growing crops for consumption. In tight urban environments, a concrete (or sunbaked clay) wall is built with two-compartments. One compartment is filled with sand, and the other with compost where plants grow and are irrigated with household gray water. A wall three meters high and three meters long is enough to absorb the average volume of grey water from one household. Another small-scale agriculture solution is the so-called permanent growing strips. Instead of ploughing, soil is ripped in permanent strips to which rainwater is concentrated to take the crops through drought periods. The amount of water for irrigation is significantly lower than in normal agriculture yet yields an astonishing 10 to 25 times more grain per hectare than from traditional agriculture.

By seeing the benefits and contributing knowledge in the search for safe and efficient technical solutions, the scientific community has an important role to play in further developing aquaculture, pond systems, and irrigation with wastewater, and newer types of small-scale, gray water-fed agriculture in urban and peri-urban agriculture. Of course, local knowledge is necessary regarding safety, construction, water quality standards, and consumption restrictions.(Stockholm Water Front, 1999).

3.3 Pricing of water supply in Indian cities

Water supply is one of the statutory functions of municipal bodies in India. This is provided in the Municipal Acts of all the states, except Jammu & Kashmir, Karnataka and Goa (Government of India, 1989, pp. 28 – 55). Safeguarding public health is obligatory for them and protected water supply is one of the imperatives for this.

The history of piped water supply in Indian cities is now a century old. Individual municipal bodies initially installed their own independent systems. After independence, these were deemed as unequal to the task of meeting the water demands of rapidly increasing urban population. The sixties saw a distinct change in institutional arrangements when state level water supply and sewerage boards were established to produce water and maintain its supply. Subsequently this job was entrusted to the Public Health Engineering Department in several states. Uttar Pradesh went for two separate autonomous bodies, Jal Nigam (water supply corporation) and Jal Sansthan (water supply board) to do capital works and water supply respectively. Similar other arrangements, such as constitution of autonomous city level water supply boards as in Bombay, were also made. The task of within –the – city distribution of water, maintenance of the system and collection of water charges generally remained with the municipal bodies.

Notwithstanding all these institutional innovations, water supply in most Indian cities is in a crisis situation. About one – fourth of the city population have no access to piped water supply. Only one in every sixteen cities is in a position to provide piped water in quantity, which satisfies the norm of around 200 lpcd as recommended by the N.I.U.A. (1989). The daily per capita supply of water is 142 litters against a demand of 231 litters (National Institute of Urban Affairs, 1989, p.25). Water supply is not only restricted to a few hours but is also quite erratic in its schedule. Generally it operates at a low pressure. People have to often resort to alternative unhygienic modes, such as handpumps, wells and tanks to obtain water.

Municipal bodies in Indian cities devote 12.8 % of their revenue expenditure to water supply (National Institute of Urban Affairs, 1989, p.63). This is next to their expenditure on sanitation (19.8%). As against this, their non-tax revenue, that is the income from rents and prices of created assets, fees/ fines, and user charges, among which water supply is one item are barely 4.9 % of the non-tax revenue. Since municipal bodies are statutorily required to follow the principle of surplus budget, wherein revenue is to exceed expenditure, their returns from water supply must be far too short of expenditure on it.

Water tariffs differ widely among cities in India (Table 4). Most of the cities charge less than Rs. 1.00 per kl. for domestic use of water supply. The charges for commercial and industrial use of water are generally three to four times higher. In Rajkot, charges for domestic use of water are Rs. 2.40/ kl .; in Madras, domestic water is supplied free upto 30 kl. Delhi is noted for one of the lowest charges of Rs. 0.35/kl upto 25kl of domestic water supply. Generally water charges are common for different cities/towns in a state despite glaring differences in their cost of production. By rough estimates, it could be said that expenditure on water supply is around two times the revenue earned in most Indian cities.

Table 4: Tariffs for domestic water supply in some major cities of India: 1990

City	Tariff (Rs. Per kl.) for the lowest slab	Tariff (Rs. Per kl.) For other slabs
Rajkot	Rs. 2.40	Rs. 2.40
Hyderabad	Rs. 1.50 upto 25 kl.	Rs.1.75 for 25 – 50 kl. Rs. 2.00 for 50 – 100 kl. Rs. 2.25 for 100kl. And above
Ahmadabad	Rs. 1.50	Rs. 1.50
Puna	Rs. 1.30 to Rs. 2.00	Rs. 1.30 to Rs. 2.00
Jaipur	Rs. 1.25 upto 15 kl.	Rs. 1.50 for 15 – 100 kl. Rs. 2.00 for above 100 kl.
Shimla	Rs. 0.90 upto 100 kl.	Rs. 1.20 for above 100kl.
Jabalpur	Rs. 0.80	Rs. 0.80
Agra	Rs. 0.75	Rs. 0.75
Kanpur	Rs. 0.75	Rs. 0.75
Lucknow	Rs. 0.75	Rs. 0.75

Calicut	Rs. 0.75	Rs. 0.75
Bombay	Rs. 0.60 to Rs. 1.00	Rs. 0.60 to Rs. 1.00
Baroda	Rs. 0.60	Rs. 0.60
Panaji	Rs. 0.50 to Rs. 1.00	Rs. 0.50 to Rs. 1.00
Pondicherry	Rs. 0.50	Rs. 0.50
Chandigarh	Rs. 0.48 upto 25 kl.	Rs. 0.60 for 25 –50 kl.
		Rs. 0.78 for above 50 kl.
Bhopal	BMC*	Rs. 0.45
PHED**	Rs. 0.33	Rs. 0.33
Delhi	Rs. 0.35 upto 15 kl.	Rs. 0.70 for above 25 kl.
Amritsar	Rs. 0.35 upto 15 kl.	Rs. 0.50 for above 15 kl.
Banglore	Rs. 0.35 upto 10 kl.	Rs. 0.45 for 10 to 25 kl.
		Rs. 0.75 for 25 to 50 kl.
		Rs. 2.00 for 50 to 75 kl.
		Rs. 3.00 for 75 to 100 kl.
		Rs. 4.00 for above 100 kl.
Indore	Rs. 0.35	Rs. 0.35
Gwalior	Rs. 0.33	Rs. 0.33
Gandhinagar	Rs. 5.00 upto 20 kl.	Additional Rs. 0.35/kl upto 40 kl.
		Additional Rs. 0.50/kl above 40 kl.
Kohima	Rs. 5.00 per tap	Rs. 5.00 per tap
Trivendrum	Free upto 9 to 22.5 kl.	Rs. 0.75/kl for above
Madras	Free upto 30 kl.	Rs. 1.00 for 30 to 50 kl.
		Rs. 2.00 for above 50 kl.

Source: Chandigarh Administration , Chandigarh.

Katko (1989, p.ix) believes that water supply should be seen as a part of the city infrastructure rather than a social service. Cost recovery should be seen as one of the key requirements for sustainable development in water supply and sanitation.

4.0 MODELLING IN URBAN WATERSHEDS

Modelling of urban watersheds is complicated by the complexities of the hydrologic system brought about by urbanisation, model scale, and client diffusion. Techniques for hydrologic analysis of rivers and urban streams are at a stage of development far beyond those for local drainage. The intention here is not to downgrade the importance of stream hydrology but to highlight a portion of urban hydrology that has received inadequate attention relative to its recent environmental and economic importance. A common error has been to assume that methods, techniques, and tools developed for river basin hydrologic analysis can be transferred more or less intact to the urban scene. Present database reflects this because it has much more data on stream flow fed by partially urbanised areas than it has on fully sewered catchments.

Historically, urban settlements have been drained by underground systems of sewers that were intentionally designed to remove storm water as rapidly as possible from occupied areas. Substantial departures from that tradition are required by new national priorities: enhancement of urban environments, conservation of water resources, and reduction in water pollution. Although there is universal agreement that the planning and development of drainage systems and floodplain management programs should be co-ordinated and integrated. Prospects for accommodation diminish rather than improve because of an increasing concern over water quality considerations in sewered systems and a contemporary neutrality or indifference on water quality matters by agencies dealing predominantly with floodplains primarily because of external legal constraints. It is ironical that much of the flooding problem as well as the water quality problem could possibly be countered more effectively on the land feeding urban watercourses.

Another dimension is the kind of model needed for a particular function. There can be substantial differences between model requirements for planning, design, and operation. In the design of urban water systems, occasionally the assertion is made that the totality of a jurisdiction should be subjected to detailed modelling. Most of Indian major cities have dozens and even hundreds of storm water drainage catchments with cumulative conduit lengths.

The hydrologic system of a typical large sector of land prior to its urbanisation is represented schematically in Fig. 5. Complexities imposed by urbanisation can be appreciated by comparing Fig. 6, an urban hydrologic system schematisation, with its preurban counterpart (Mc Pherson & Schneider (1974)). Hydrologic effects of changes in land and water use associated with the progressive stages of urbanisation from 'preurban' to 'late urban' have been traced by Savini and Kammerer (1961). Fig. 6 is a simplified summary of water quantities in the urban hydrologic system, in which 'water systems' is intended to include treatment and distribution facilities of public systems and self-supplied industrial process systems. Because only a small percentage of industrial cooling water is from groundwater sources, only surface water withdrawals and returns of this type are represented in Fig. 6. Provision of flow detention storage for overland runoff is considered to be a part of 'storm drainage'. The term 'manipulated', used twice in Fig. 6, would include runoff management, such as occurs in the deliberate provision of local storage, of the 'urban land surface', and recreation, transportation, flood control measures, and property value enhancement in connection with 'bodies of surface water'. In striking contrast to rural catchments, essentially all our metropolitan areas are constantly undergoing dynamic change. Thus modelling of runoff encounters not only involvement with projections of future change but must rely on data often acquired under continually changing field conditions.

4.1 Modelling objectives

Modeling objectives vary widely, from storm sewer design to management of local runoff to river basin planning. Each objective requires a different approach to modeling. Current difficulties in modeling involve inherent nonlinearities in most methods of processing inputs for linear models, problems of storm definition, interconnection of urban catchment areas, and shortage of detailed rainfall-runoff water quality data for calibration. Despite handicaps, progress has been made in modeling urban watersheds and will continue to be made.

Capturing and/or diverting storm water for recreational and aesthetic enhancement, for use as a water supply supplement, and for meeting the zero pollution goal of Public Law 92-500 (October 18, 1972) all require or imply the employment of

some degree of detention and/or retention storage. Such storage would have to be added to existing systems and included in new systems at substantial cost.
In comparison with design and planning, objective functions stand out in bolder relief in operations: minimised flooding of properties, minimised quality degradation of receiving water bodies, maximised recreational and aesthetic opportunity, or maximised water supply use. Whereas process mastery is vital for flexibility in design and planning of project alternatives, the control mode can be, and probably must be, approached in a much more pragmatic fashion. . Of course, detailed rainfall-runoff quality modelling based on real field data is both desirable and logical. However, such exercises are meaningful only to the extent that they contribute towards development of hard criteria for satisfying the objective functions. The real test of performance effectiveness occurs in basements of buildings and in contaminant levels of receiving water bodies, and it is there that system sensitivity analysis should be concentrated. That is, sensitivity analyses of flow control capability may be misleading unless they yield improved insight on response sensitivity for the objective functions.

4.2 Some major modelling difficulties

Human life is seldom threatened by the flooding of urban drainage facilities. Because the principal local detrimental effects of flooding are damage to the below-ground sections of buildings and hindrance of traffic, the consequences of flooding range from clearly assessable property destruction to annoying inconvenience. It follows that provision of complete protection from flooding can only rarely be justified. Instead, facilities are designed that will be overtaxed infrequently. The major question in the analysis/design of drainage systems is the choice of storms to be used. Storm definitions used for deriving river basin extremes such as 'reservoir design floods' and 'spillway design floods' are irrelevant because urban sewer systems are expected to be overtaxed much more frequently than major river structures whose failures could be catastrophic. From this standpoint the mean frequencies of occurrence of flow peaks and volumes and quality constituent amounts are the issue, not the frequencies of the input rainfall, and if it were possible to arrive at statistical series for discharge quality independently of rainfall, we could vastly simplify the storm characterisation issue.

A further complication arises in the delineation of the urban catchment areas. Complications in determining drainage divides in storm-sewered areas result from the changes in natural topography usually associated with the initial plating, grading, and building of the network of streets in a given area. Cut-and fill techniques are commonly employed to establish uniform land gradients amenable to engineering procedures. Grading, and the street system functions as a series of interconnected and intersecting channels that can transcend natural topographic boundaries obliterate often minor upland drainage features.

In addition, storm sewer systems are often interconnected between urban basins, and under certain runoff conditions, flow from one catchment area spills over into the storm drain of an adjacent catchment through the interconnection.

The ultimate solution for the problem of abating pollution from urban storm sewer discharges and combined sewer overflows is the treatment of such flows prior to their release into receiving waters. Capturing, transporting, and treating all discharges/overflows unattenuated would require gigantic collection sewers, pumping stations, and treatment facilities, all of which would be used less than the equivalent of about an hour a day on the average over a typical year.

5.0 URBAN SURFACES AND RUNOFF

As the land surface is developed for urban use, a region is transformed from the natural state to a totally manmade state. New structures add large amounts in impervious areas to the watershed, which in general increase slopes and considerably diminish the water storage capability. As the area covered by structures approaches 100%, the amount of vegetation, natural surface and infiltration will all approach zero.

Fig. 7 schematically illustrates the two extremes: a natural watershed and a totally urbanised watershed. The vegetation intercepts part of the rain falling into the natural watershed, and the remainder falls on the ground, is stored in depressions and begins to penetrate the soil. As the vegetation and the soil become saturated, the excess rainfall begins to run off the surface; subsurface flow has also begun. However, since the subsurface flow is slower than surface runoff, it will take longer before the subsurface flow contributes to the streamflow.

Saturation and consequent surface runoff occur relatively rapidly in the urban watershed, since storage and infiltration have been reduced to practically zero. Incoming rainwater quickly fills any depressions and becomes readily available for surface runoff. Subsurface runoff is virtually non-existent and most excess rainfall augments streamflow.

From the study it can be inferred that as impervious area is increasing the runoff peak is also increasing. The runoff is taking place at a faster rate from impervious areas and that is why more than one hydrograph peaks are occurring. The total volume of runoff taking place from the urban area is about 80% of total runoff taking place from the entire area.

5.1 Modelling of runoff from urban areas

Urban drainage design requires depth-area-duration- frequency relationship characterising storms in urban areas, particularly for small duration. 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 hour and 1 year duration.

N.I.H. status report SR-15 'Status report on Urban Hydrology' (1992) has described the different following models of runoff from Urban areas used in different parts of the world:

- University of Texas Watershed Simulation Computer Programme.
- Conceptual Model of Urban Hydrologic System.
- The Rapid City Runoff Model.
- TRRL Hydrograph Model (developed at Road Research Laboratory using data collected from 1952 to 1960).
- USGS Model (Watershed Model).
- Hydrocomp Simulation Program-Fortran.
- Storm Water Management Model.
- Continuous Daily Streamflow Model
- ILLUDAS (Illinois Urban drainage area simulator)
- Environmental Protection agency storm water management model (SWMM).

- Queen's University Urban Runoff Model (QUURM)
- Subdivision Hydrograph Model (SHM)
- Distributed Hydrologic Model (DHM)
- Data analysis Model (DAM)
- SWMM as planning model

Shukla and Soni(1993) described the Urban catchment research and modelling in U.S.A., U.K., Canada, France, Germany, Australia, Sweeden, Netherland and India.

The rational formula is commonly used in India to estimate the design peak flow in an urban watershed. Also the Hydrologic model, ILLUDAS has been implemented and used for the analysis and design of urban drainage system in India. The most widely known of the computer based urban rainfall runoff model is the storm water management model (SWMM). In this model, the runoff block is concerned with the derivation of runoff hydrographs and their associated pollutant loadings. The transport block routes both the hydrographs and the time variations of individual pollutants through the sewerage system.

Illinois urban drainage model is the testing record for an U.S. adoption of the British Road Research Lab Method. The model is based on digital model and used for hydrologic design of storm drainage system. The choice of which method is the most appropriate among the several models available is hardly straightforward. A clear distinction must be drawn between design methods and simulation methods.

5.2 Flood and pollution control problems of urban areas

The internal and external drainage problems are clearly intimately related, they have traditionally been considered in isolation, the former being the concern of the municipal engineer and the latter that of the land drainage or river engineer. Fig. 8 illustrates the design procedures applied by both groups.

Four distinct steps may be identified in the design procedure. Firstly, the degree of protection to be provided by the works, i.e. the tolerable frequency of flooding, must be identified. With regard to internal drainage problems, flooding is defined by the conditions under which the sewers have insufficient capacity to carry away the peak flow rate. Although reverse flow may occur at road gulley and manhole covers may lift, the drainage network rarely fails in the structural sense of the term. However, in treating external drainage problems, the structural integrity of the works forms a fundamental design consideration. In case, the design frequency, or its reciprocal, the return period should ideally be based upon an economic analysis. (Hall, 1984).

Once the tolerable flooding frequency has been determined, the second step in the procedure of Fig. 8 involves the acquisition of the appropriate rainfall information for design purposes. The 'design storm' may consist of an average rainfall rate corresponding to a specified storm duration, or a storm profile showing the variation of rainfall intensity with time throughout the event. In any design application, the type of meteorological information depends primarily upon the method of flood estimation that is adopted in the third step of the procedure.

Having constructed the design storm, the third step in the procedure consists of the transformation of the rainfall into runoff. There are three important aspects of this transformation:

(i) the proportion of the total volume of rainfall that appears as surface runoff,

(ii) the manner in which the runoff volume is distributed in time, i.e. the shape of the flood hydrograph, and

(iii) the relationship between the frequency of the design rainfall and the frequency of the resultant peak rate of flow.

The final step in the procedure involves the determination of the size of channel or conduit required to carry away the estimated peak flow rate. For sewer system, design tables giving the capacities and flow velocities for pipes of a given diameter and roughness laid at a specified gradient are available for use in unsurcharged flows (Hydraulics Research Station, 1977). With regard to external drainage problems, structural measures, such as flood alleviation channels and storage ponds, have invariably been chosen as the most appropriate devices to mitigate the effects of urbanisation. However, with enlarged channels, care is necessary to ensure that the original flooding problem is not simply passed further downstream. In addition, where several flood storage ponds are constructed within a catchment area, the designer must ensure that these ponds should accommodate the full amount of flood. Recent experience in the United States has tended to indicate that engineering works alone may not be completely successful in reducing flood losses. A variety of non-structural measures, including land use controls, floodproofing and insurance programmes, have been instituted in an effort to avoid heavy expenditure on projects which fail to achieve their objectives. White (1975) has presented a comprehensive review of the factors, which enter into the development of optimal policies for the reduction of flood damages.

5.3 Impact of urbanisation on water quality

The various hydrologic and hydraulic variables, which affect water quantity in a basin also, influence system, water quality. Velocity, depth and cross-sectional area along a stream are directly related to the underlying geology. Runoff also contributes inorganic and organic constituents. Changes in water quantity such as flood peaks or droughts cause dilutions of the constituents to vary and alter water quality.

6.0 URBAN SYSTEMS ANALYSIS AND PROBLEM SOLUTION

Problems of Urban and human settlement systems in India have reached a critical dimension calling for holistic new approaches to problem solving within an increasingly technological society, with a view to ensuring a matching of the ends, ways and means at various decision levels as described by the National Housing Policy of 1994 (Ministry of Urban Development). Many urban problems are insoluble, not because of their inherent characteristics but because of the inadequate manner in which they have been defined, analysed and how solutions are being sought (Catanese, 1972). Scientific urban systems analysis helps in arriving at a correct qualitative and quantitative definition of the problems in terms of conditions, environments, measure of effectiveness, inter-relationships, human values and priorities. It gives a frame of reference through which better solutions may be discovered. However, rarely such an approach is adopted in the conventional urban planning process, which may be one of the reasons for the deteriorating condition of shelter and urban services.

One of the reasons for deteriorating shelter conditions in India is the mis-match between the housing and services supply through the formal system (i.e. conventional planning and design process), and the affordability constrains, and growing need for housing and services, particularly of the poorer households. In this connection, it is worthwhile to examine whether the enormous growth of slums is due to the mis-match between the formal ' physical planning structure' developed by a planner, the economic base structures' of a city and the 'demographic distribution structure', which tends to take a shape which is in line with the 'economic base structure' of a city. Thus, it may be more a problem of optimal location of facilities and residential land uses rather than a problem of enforcing planning regulations, as done normally by the various planning authorities.

Urban systems analysis is the breakdown of the urban systems into their physical, political, economic and social parts with the aim to understand their nature, function and inter-relationships, to determine their problems, and to seek solutions to these problems, which are inter-dependent (Catanese, 1972). To ensure problem solution it is desirable that decision and actions outlined by the National Housing Policy (NHP) are based on such urban systems analysis. NHP as a course of action adopted and pursued by a government should be judged on the 'ends' and policy 'goals' pursued and on the appropriateness and effectiveness of the 'ways' and 'means' used. The ways in which the means are used to achieve the policy goal defines the policy strategy. In the context of severe scarcity of resources, it is essential to use them in the most cost-effective way ensuring compatibility between the ends of ways and means. As mentioned earlier, each set of actors in the housing development system, dealing with planning, design, construction and finance has differing and often conflicting interests and viewpoints. This need to be resolved by adopting an appropriate 'value scale' for the multi-dimentional solutions which ensure a matching between the policy goal (say: supply of adequate shelter for all), the means or policy instruments (say: the way or the defined role in which the policy instruments are to be used). A system based approach facilitates clarity among such inter-linkages and interactions in housing and human settlement development. It assists in reaching policy decisions ensuring the above compatibility at each system level, with the consequent benefit of improved performance of the housing and urban services delivery system, as this will also avoid the working of various actors at cross purposes. (Chakraborty, 1996)

6.1 Analysis of urban infrastructure

The term infrastructure is very wide and includes a variety of goods and services like water, drainage, sewerage, sanitation, transport, telecommunication, health and education. At present, there is an acute shortage of all urban infrastructure facilities. The reasons for the same are follows:

Firstly, though the government at all levels have been taken the responsibility for production as well as supply of urban services, in practice due to limited resources available with the government, there has developed a huge gap between demand and supply. Secondly, no attempt was made to entrust some activities to the private sector or to recognise its role in provision of urban services.

The huge potential exists for private investment only if the urban sector is deregulated. The economic and internal rates of returns are quite high in urban projects to make private investment remunerative. But it ordains that private sector has freedom to fix prices and recover project costs with profit. This calls for host of urban policy reforms.

Traditionally in India, it has been viewed that the provision of urban infrastructure fulfils a basic human need and users cannot be denied access to urban services. It was also believed that water, roads, sewerage, electricity, etc. being capital intensive with long gestation period and uncertain returns on investment private sector will not be interested. Mistrusting relationship between government and private sector was also innate in the economic planning process that unless government intervenes, private sector monopolies will emerge and which will jeopardize the interests of consumers. On all these counts, the government took upon itself the total responsibility to provide all urban services. In practice, because of limited resources available with the government, unremunerative pricing and in some cases free supply of services, high overhead costs there has developed a huge gap between supply and demand for various urban services in all towns.

The shortages in provision of urban infrastructure are serious in towns of all types and sizes. A recent All-India survey shows that only 56% of households have access to treated water supply. Nearly 16% and 21% still depend on handpump and well respectively for their water supply requirements and the balance draws water from unsafe sources. Only 12% of the towns have underground sewerage system. The rest of the towns have open surface drains for disposal of wastewater. In most of the towns there are open rubbish dumps as there is no arrangement to properly dispose off 120 million kgs of household solid waste.

The current situation in the cities is one of big vicious circles. The consumers are not willing to pay more because the service levels are so poor, both in terms of quality and quantity. As users are not willing to pay, the financial position of the agencies is week and they are neither able to improve neither quality nor quantity. This also makes the agencies depend too much on the government for grants and subsidies. The private sector role in water supply is directly related to the method of supply. As per All India survey, non-official agencies are responsible for 28.5% of the total water supply in India. The details of break up as per source is as follows:

Table 7.: Source of Water as per Agency

Agency	Source of Water Supply (%)
Government	71.47
Non-Government	
Agencies –	2.79
Community	0.52
Charitable Trusts	25.22
Others	
Total	100.00

Source: NSSO, 1990

If we take the method of water supply, through Handpump/Tubewell, Pucca Well, Tank/Pond, 64.58% to 81.13% of the water is made available by non-government agencies. The supply of water through tankers is again dominated by government agencies (79%). The details are given in Table 8.

Table 8: Source of Water Supply as per Method of Supply (%)

Method of supply	Government	Non-government	Total
Tap	86.87	13.12	100.00
Hand-Pump/Tube well	35.42	64.58	100.00
Pucca well	17.86	81.13	100.00
Tank/Pond	26.96	73.04	100.00
Tankers	79.05	20.95	100.00

Source: Kundu, 1991, p.214

7.0 SOME DEVELOPED URBAN HYDROLOGY MODELS

7.1 Urban Runoff Volume Model

Viktor Arnell (1982) has estimated the runoff volumes from Urban areas by the equation $Q = a\,A\,\Sigma\,(P_e - b)$, where Q is the runoff volume, a is the part of the total area A contributing to runoff, P_e is the rainfall amount for a single event, and b is the initial rainfall losses. For the evaluation of a and b, rainfall/runoff measurements were made in five areas of sizes between 0.035 km^2 and 1.450 km^2. By linear regression analysis of rainfall volumes versus runoff volumes, the initial rainfall losses were found to vary from 0.38 mm to 0.70 mm for the different areas. The parts of the areas contributing to runoff were found to be proportional to the impermeable parts of the areas. The equation is applicable in urban areas with well-defined paved surfaces and roofs and with a negligible amount of runoff from permeable areas. This model describes the evaluation of the initial rainfall losses (b) and the part of the areas contributing to runoff (a) for five areas where rainfall/runoff measurements were made.

7.2 Management of Urban Non-Point Source Pollution Model (MUNP)

Public Law 92- 500 has mandated the need for evaluating the impact of non-point source pollution on receiving water quality, primarily through Section 208 Areawise Planning. The Management of Urban Non-Point Pollution (MUNP) model developed by

Roger & McCuen(1978) has estimated the accumulation of eight non-point pollutants on urban streets, their removal by both rainfall and street sweeping operations. The model can simulate the following pollutants: total solids or sediment-like material, volatile solids, five-day biochemical oxygen demand, chemical oxygen demand, Kjeldahl nitrogen, nitrates, phosphates, and total heavy metals. The simulated results can be used for investigation of non-point pollution management alternatives. The model is capable of reflecting variation in such diverse factors as physical and chemical characteristics of accumulated pollutants, land use characteristics, rainfall characteristics, street sweeper characteristics, roadway characteristics, and traffic conditions. By using mean estimates of many input variables for large segments of a city, the MUNP model could be used to point source pollution alone. If the results indicate that non-point pollution loadings are sizeable and require further analysis, the MUNP model could be used to define the specific nonpoint source pollution areas within a city. Hypothetical locations and actual rainfall data for Washington D.C. were used to demonstrate some capabilities of the MUNP model.

The objective in the formulation of the MUNP model was to simulate the actual physical processes of pollutant accumulation and removal while linking these processes in a manner that is assumed to be occurring in the real world. Thus, the basic structure adopted for the MUNP model is presented as a simple flowchart in Fig. 9. The model uses hourly precipitation, land use, watershed, roadway, traffic, and street sweeper data to continuously simulate the accumulation of eight pollutants on urban streets, their removal by rainfall, and their removal by street sweeping operations. The eight pollutants involved are: total solids or sediment-like material, volatile solids, five-day biochemical oxygen demand, chemical oxygen demand, Kjeldahl nitrogen, nitrates, phosphates, and total heavy metals. MUNP is capable of reflecting variation in such diverse factors as physical and chemical characteristics of accumulated pollutants, land use characteristics, rainfall characteristics, street characteristics, roadway characteristics, and traffic conditions. It also concluded that under good operating procedures and conditions occurring over an extended period of time, street sweepers could remove approximately 50% of the pollutants accumulating on urban streets. Actual removal percentages vary considerably with the type of pollutant, the frequency of street sweeping, the type of street sweeper, and the forward speed of the street sweeper. The statement "good operating procedures and conditions" means frequent sweepings on smooth, uncracked pavement by vacuumized street sweepers operating at slow forward speeds. Since "good operating procedures and conditions" are rarely found, any model that assumes a constant street sweeping efficiency should adopt a more realistic removal efficiency of 33%.

7.3 Urban Runoff Digital Computer Model

This model has been developed by Sanguan Phamwon and Yu-Si Fok and M. ASCE in 1977. The estimation of flood peaks from runoff of urban watersheds by digital computer models has gained popularity recently because of speed and accuracy advantages obtained from computers. The methods used for flood peak estimation vary in complexities, e.g., from utilising the simple rational formula to the complex dynamic equation of flow. Many models have been developed and utilised; each has its own merits and works satisfactorily at least for its own locality. It is an another digital computer model for urban runoff simulation utilising the kinematic wave approximation of the dynamic equation of flow for water routing and utilising appropriate infiltration curves for determination of pervious area supply rates to its runoff. The available hydrological data of Hawaiian small urban watershed are utilised to check the model adaptability. The model utilises hypothetical design storms for new storm drainage system designs and evaluates existing storm drain systems. The dynamic equations of flow utilise the continuity equation and the momentum equation while the kinematic wave equations consist the continuity equation and the simplified version of the momentum equation. The simplified momentum equation can be obtained from a consideration that for a fairly steep slope terrain, only the friction and gravity components are important so that the momentum equation becomes $S_0 = S_f$.

General Features of the Model -

This computer model consists of the following main features: a subroutine PAVED to compute surface runoff hydrographs for paved areas from input storms; a subroutine SUPPLY to compute grass area supply rates, i.e., the rates of excess water after subtracting infiltration water which contributes to surface runoff from pervious areas; a subroutine GRASS to compute surface runoff hydrographs for pervious areas from grass area supply rates; a subroutine GUTTER to compute gutter flow hydrographs from combined hydrographs of paved areas and pervious areas; a subroutine SEWER to compute sewer flow hydrographs. The computation procedure will be repeated for each subwatershed. A general algorithm for this computer model has been shown in fig. 10.

7.4 Urban storm runoff model

The problems of stormwater drainage have increased in proportion to the rate of growth of urban areas. Major hydrologic effects of urbanisation include: increased peak rate and volume of runoff, and reduced response time, and reduced hydrograph-base length. The high cost of storm sewers, drainage channels, and flow detention structures requires adequate estimates of runoff for the best stormwater system design. One method of estimating runoff is to use computer models based upon the mathematical equations describing the physical process being studied.

Edward et.al (1977) have given the above-mentioned model where the rainfall-runoff process is complex with many interrelated components. Attempting to precisely model all components of the process is complicated and expensive, so to simplify the modelling process, components are approximated. The computer model used in this study is based upon simplifications of infiltration and surface runoff. Rainfall input to the model is considered as several discrete pulses of rain and is assumed uniform over the watershed. A watershed is presented as a series of cascading planes and channels. Each plane is assumed to have uniform surface and subsurface characteristics.

A computer program is formulated to calculate the response of a watershed to a specified rainfall event. The model can be used to compute flows for the following elements: overland flow on a rectangular surface, open channel flow in a trapezoidal channel, and free surface flow in a circular conduit. Watershed geometry is represented by combinations of these geometrical segments. The computer model parameters are estimated from information obtained from topographic maps, aerial photographs, soil surveys, property development records, watershed reconnaissance, and other hydrologic data sources. Input data are utilised by the computer model to sequentially compute the outflow hydrograph from each segment. Outflow from one segment may become inflow to another segment. Fig. 11 is a flow chart of program KINGEN and provides a brief outline of the computational logic utilised by the model.

A flow routing model based upon the kinematic equation was used to simulate overland flow and free surface flow in trapezoidal or circular-shaped channels. Kinematic routing does not have the capability to account for backwater effects; applications must be limited accordingly. Routing of flows was based upon the hydraulic characteristics of the surface or channel. Computation of infiltration losses on pervious surfaces was based upon a parametric decay-type function. The most sensitive of infiltration parameters had physical significance. The original study using these infiltration components listed appropriate parameters for a wide range of soil types. Runoff from a 67,000-m^2 (165-acre) urban watershed was simulated using the computer model. The complex geometry was represented by a series of cascading planes and channels. Storm sewers within the watershed were simulated as free surface flowing circular conduits.

It is concluded that this physically based model was satisfactory for predictive purposes. The greatest challenge to using the computer model is to adequately estimate the rainfall excess available for surface runoff. An objective means of estimating the initial moisture content from antecedent precipitation and climatic data would be very useful. Further refinements of the routing components would be justified only with an improved method of estimating infiltration.

7.5 QUURM - A realistic urban runoff model

QUURM, (Queen's University urban runoff model), a mathematical model which simulates urban storm runoff for any given rainfall pattern, is described (Watt & Kidd, 1975). A realistic and design oriented model QUURM employs the n-linear reservoir model to generate inlet hydrographs from the rainfall excess for each area type for each subcatchment. These inlet hydrographs are combined and routed through the sewer system using a modified time offset or progressive average-lag method. The model has been applied successfully to an urban catchment in Kingston, Ontario, Canada.

Increasing attention has been directed recently to the necessity for the development of better techniques for the prediction of urban storm runoff for the purposes of planning, design and operation of storm-water conveyance structures. As a result, a number of "mathematical models" have been developed (Terstriep and Stall, 1969; US Environmental Protection Agency, 1971; Kidd, 1972; Papadakis and Preul, 1972).

Most of these models can be used only for the analysis of existing sewers or trial designs. The model " Queen's University urban runoff model", hereinafter referred to as QUURM is suitable for these purposes but, in addition, it can be applied at the planning level because of its simplicity and its minimal data requirements.

QUURM was applied to ten rainfall events, which occurred during the summers of 1972 and 1973. These events represent all the significant storms for which complete rainfall and discharge records are available.

The Queen's University urban runoff model, QUURM, is a relatively simple model with a limited number of parameters. It provided good simulation of storm events on two catchments; the simulation results on one catchment are included herein. Increased complexity can only be justified either by more precise input data or more measurements of the individual processes (e.g., sewer routing, inlet hydrographs, etc.)

QUURM, in common with many other models, employs Horton's equation to determine infiltration. This did not lead to significant error for the events tested. In fact, there may not be a significant contribution from pervious areas for many cases of storm sewer design. Nevertheless, research is continuing towards the incorporation of a better infiltration submodel into QUURM.

7.6 Road research laboratory model (RRLM)

RRL model has been developed and extensively used in Great Britain. Some experience with this model in North America was described by Terstriep and Stall (1969), Stall and Terstriep (1972) and Papadakis and Preul (1973). The original model version was described by Watkins (1962) but the computer programme used in this study was obtained from the University of Florida.

The RRL Model considers only runoff generated on impervious areas and neglects the contributions from pervious areas where infiltration and detention are usually high.

The depth of rainfall is reduced by a factor to account for surface storage. In this study, this factor was taken equal to 0.9. The resulting effective rainfall data are then applied over the impervious area directly connected to the sewer system. This are is characterized by a curve of contributing area vs the time of travel. The curve is usually linearized by connecting the point representing the total contributing area and the origin with a straight line and such a simplified approach was used in this study for each subcatchment. The time of travel generally consists of the inlet concentration time is usually obtained as for the travel time in the sewer. The inlet concentration time is usually obtained as for the Rational Method by an empirical estimate, as was done in this study, or by using the linear kinematic-wave solution for the overland flow, as done by Terstriep and Stall (1969). The time of travel inside the sewers is calculated for the full-bore velocity derived from the Colebrook-White formula.

The inlet hydrograph is derived by combining the effective rainfall hydrograph with the contributing area vs time diagram.

After adding the time-lagged upstream hydrographs the resulting hydrograph is routed through main sewers using storage routing based on a linear reservoir concept.

The design version of the model deals with surcharging by automatically increasing the would-be-surcharged pipe diameter.

7.7 Storm water management model (SWMM)

The SWM model has been developed under the sponsorship of the U.S. Environmental Protection Agency (EPA) and has been widely used in North America. The computer programme for the model has been obtained from the University of Florida and EPA, detailed description of the model was given by Metcalf and Eddy, Inc. (1971).

The SEM model considers the urban drainage basin to consist of a series of rectangular sub-basins with a various degree of imperviousness. The precipitation input onto these sub-catchments is taken as the precipitation reduced for the infiltration rates computed from the Horton equation. The rainfall excess over the detention depth is routed over the rectangular sub-basin using a linear kinematic wave approximation. The overland flow does not commence until the surface depression storage is filled.

However, the model user has an option to specify the portion of the impervious area, which is assigned the zero storage resulting in immediate runoff. In this study, this portion was taken to be the entire area which is identical to the value supplied by the model in default of a prescribed ratio.

The gutter flow is calculated using the Manning equation and storage routing. The flows reaching the point of interest at any particular time are added to produce the inlet hydrograph. These inlet hydrographs are then routed through the major sewer pipes. The routing procedure is based on the continuity and normalized flow-area relationship calculated from Mannings's equation for uniform flow. The stability of the numerical scheme is improved by an iterative procedure, with up to four iterations used. If surcharge occurs, the volume of surcharge is calculated, stored at the point of surcharge and fed back into the system when the sewer capacity permits.

The computational procedure above represents the Runoff Block of the SWMM as used in this study. The use of the Runoff Block only was found adequate for the studied watersheds.

All model parameters except those which can be derived directly from the map of watershed were taken to be equal to the "default values" recommended by the model builders (Metcalf and Eddy, Inc., 1971).

7.8 University of cincinnati urban runoff model (UCURM)

The UCUR model has been developed at the University of Cincinnati under a grant from EPA. There are no indications that the model was applied for practical design. The application of the model in comparative studies was reported by Papadakis and Preul (1973) and Heeps and Mein (1972, 1974). The model was described in detail (including the computer programme) by Preul and Papadakis (1972). The computer programme for the model as used in this study was obtained from EPA, Washington, and revised in co-operation with the original model builders.

The UCUR model assumes the drainage basin divided into either wholly pervious or wholly impervious sub-catchments. On the pervious sub-catchments, the infiltration is estimated from Horton's equation modified for field conditions and shifted by the time offset method described by Preul and Papadakis (1972) is the initial rainfall intensity is less than the initial infiltration capacity.

The depression storage is described by an empirical relationship allowing the overland flow to begin before the depression storage is filled. Thus the rainfall excess producing the overland flow is obtained by subtracting the infiltration and depression storage suply from the rainfall. The overland flow simulation is based on an empirical formula expressing the depth of flow at the end of the overland flow plane as a function of the instantaneous and equilibrium detention storage depths.

The gutter flow is calculated by adding the lateral inflow integrated along the gutter to the flow entering the upstream end of the gutter.

The routing of hydrographs through laterals as well as main sewers is accomplished by time-lagging the hydrographs. The time lag equals the travel time calculated for a weighted average velocity, where the flow rate is the weighting factor. A simplification of this procedure was proposed by Heeps and Mein (1972). In their proposal, the weighted average velocity is replaced by the velocity corresponding to the centroidal discharge of the hydrograph. Such a procedure was used in this study only for the Calvin Park catchment. Surcharging is treated by allowing the discharge to exceed the full-bore flow rate in surcharged pipes.

7.9 University of Texas watershed simulation computer program

The University of Texas watershed simulation program is a continuously accounting type of computer model. This simulation program, written in Fortran, is a modified version of the Stanford Watershed Model IV, and utilises several of the processes of the Stanford model. However, in developing the University of Texas model, Calborn attempted to associate it more closely with the steps in the natural hydrologic process that was done in the Stanford model. The University of Texas model also has a more flexible calculation interval than the Stanford model, ranging from one minute to one day.

A diagram of the physical processes as described by the University of Texas simulation program can be seen in Fig. 12. As indicated, precipitation falling on the watershed is initially captured in interception storage. Interception storage is that amount of precipitation intercepted by vegetation and man-made structures. This water never reaches the earth's surface and is dissipated by evaporation. After interception storage is filled, precipitation continues down to the ground surface. Two classes of ground surface are present here, impervious area, which contributes directly to streamflow, and pervious area.

Moisture is removed by evaporation from interception, overland flow, depression and upper zone storage. That amount of runoff accrued in one time period is then lagged 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 somewhat analogous to the unit hydrograph concept.

One obvious input to the University of Texas watershed simulation computer model is precipitation. This may be either accumulative or rate (inches/hour) using any time increment desired, ranging from one minute to one day. Other inputs include measured pan evaporation and some measure of transpiration, both being input as monthly totals. For the purposes of statistical analysis with the simulated flows, recorded streamflow in the form of mean daily flows or actual measured hydrographs may also be input. Other inputs describe watershed physical characteristics. Some of these watershed characteristics are areas, location (latitude and longitude), and time-delay histogram. Other watershed parameters involve quantities which are less well defined and cannot be measured, such as constants in the infiltration, unsaturated permeability and soil moisture tension equations, sizes of the various soil zones and recession parameters for interflow and outflow from groundwater storage to the stream.

The values of these parameters were adjusted by trial and error to match the recorded hydrograph peaks and volumes of runoff. In addition to the above parameters, some estimation of initial soil moisture conditions in the watershed must be made for the initial year of the simulation period.

8.0 COMPARATIVE STUDY OF RAINFALL-RUNOFF MODELS IN URBAN AREAS

Sharma et.al. (1973) defined the relative generation performances of five linear rainfall excess-direct runoff models, which are compared for several urban watersheds with varying degrees of development. The five models considered are the single linear reservoir, the Nash model, the double routing method, the linear channel-linear reservoir model and the instantaneous unit hydrograph (IUH) obtained by the Fourier transform method. The IUH always gives the best regeneration performance among the four conceptual models tested. The optimised single linear reservoir constant differs from the theoretical time lag value, but is related to the latter, and for each watershed varies from storm to storm. For large watersheds the Nash model gives the best regeneration performance among the four conceptual models tested. The model parameters for each watershed are found to vary from storm. The quality of regeneration for larger basins is less than that found for the smaller basins.

The assumption of the linearity of the rainfall excess-direct runoff process (hereafter referred to as the rainfall-runoff process) forms the basis of several commonly used methods in urban hydrology. Linear conceptual and/or mathematical models of the rainfall-runoff process have been used successfully in recent investigations of small experimental impervious watersheds (less than 1acre in area).

As several linear conceptual models can be formulated by appropriate combinations of linear elements such as the linear reservoir and the linear channel, the question of comparative suitability of any of these models to simulate the urban rainfall-runoff process arises. The work reported herein deals with an investigation of the relative regeneration performance of some of the commonly used linear hydrologic system models is an attempt to select an appropriate model to simulate the rainfall - runoff process in a given urban watershed.

Marsalek et. al. (1975) have given the comparative evaluation of three Urban runoff models, namely, the road Research Laboratory Model (RRLM), the Storm Management Model (SWMM) and the University of Cincinnati urban Runoff Model (UCURM). These were examined by comparing the model-simulated hydrographs with the hydrographs measured on several instrumented urban watersheds. This comparison was done for the hydrograph peak points as well as for the entire hydrographs using such statistical measures as the correlation coefficient, the special correlation coefficient and the integral square error. The results of the study indicated that, when applying the three selected non-calibrated models on small urban catchments, the SWM model performed marginally better than the RRL model and both these models were more accurate than the UCUR model. On larger watersheds, the comparison between the SWM model and the other two models would be likely even more favourable for the SWM model, because it has the most advanced flow routing scheme among the studied models. Uncalibrated deterministic models for urban runoff, such as RRLM, SWMM and UCURM yielded a fairly good agreement between the simulated and measured runoff events on typical urban catchments of small size. The main advantage of the RRLM is its simplicity since it can be applied without a computer. The SWMM is, on the otherhand, much more general versatile and is being continuously refined and improved. The SWM model has the most advanced routing scheme among the considered methods. The accuracy of flow routing becomes particularly important when studying large watersheds.

Soni and Shukla(1992) have made a study on intercomparison of Urban watershed models. In this report, some of the common urban drainage models like SWMM, Illinois urban drainage area simulator model, SCS Tr-55 procedure, USGS model, Wallingford model, Road Research Lab method and TVA model have been discussed and a comparative study has been made regarding the suitability of the model. Several good comparison of RRL, SWMM has been reported here. The SWMM is the model with best performance but at the expense of large computer storage and time requirements.

Out of the various models, the SWMM simulations were marginally better than those by RRL and both these models were more accurate than UCCRM with all models applied in an uncalibrated version. The choice of model largely depends on the type of problem and input data availability. The more complex design problem, the more sophisticated technique required to obtain the solution.

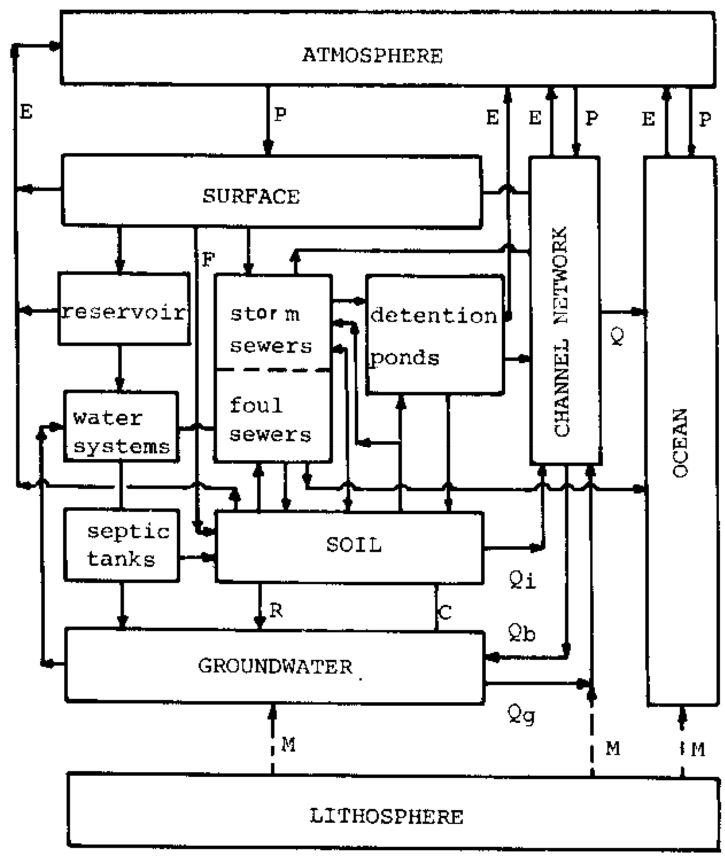

FIG. 1 THE URBAN HYDROLOGICAL CYCLE

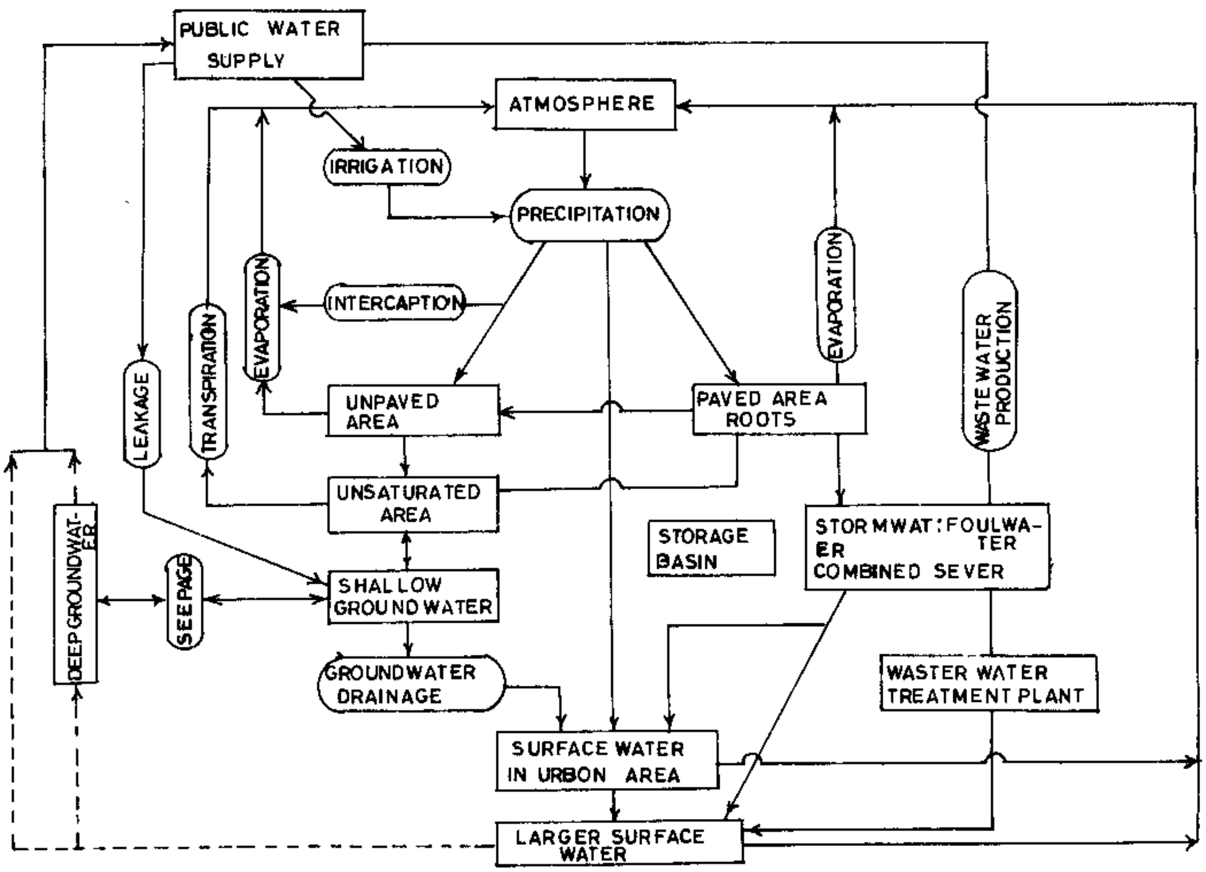

FIG. 2. PATHWAYS OF THE WATER IN URBAN AREA

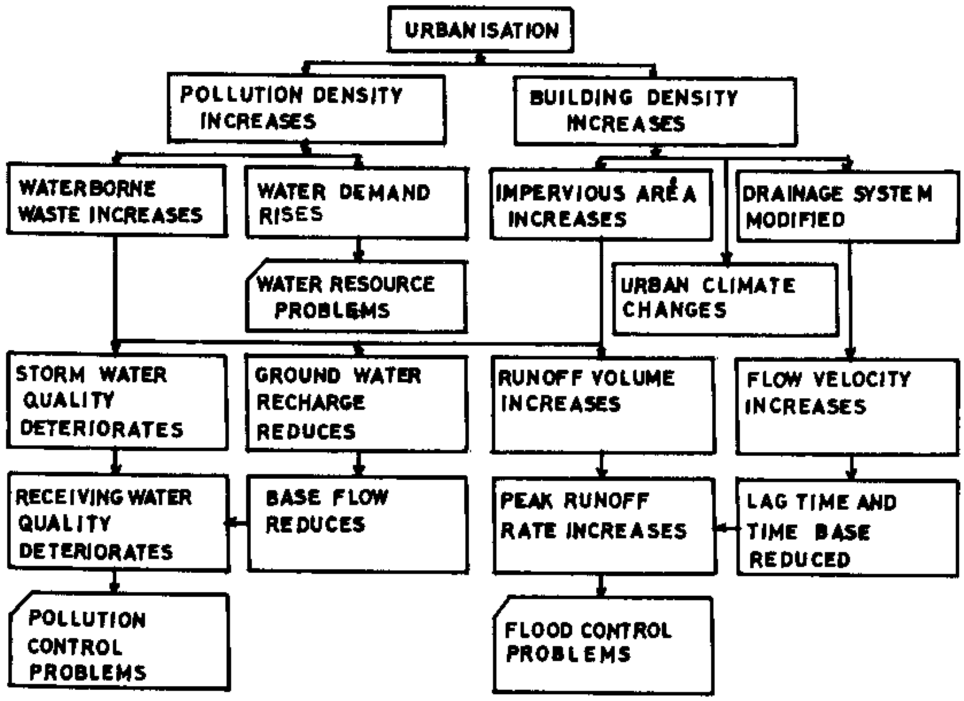

FIG. 3: THE EFFECTS OF URBANISATION ON HYDROLOGICAL PROCESS

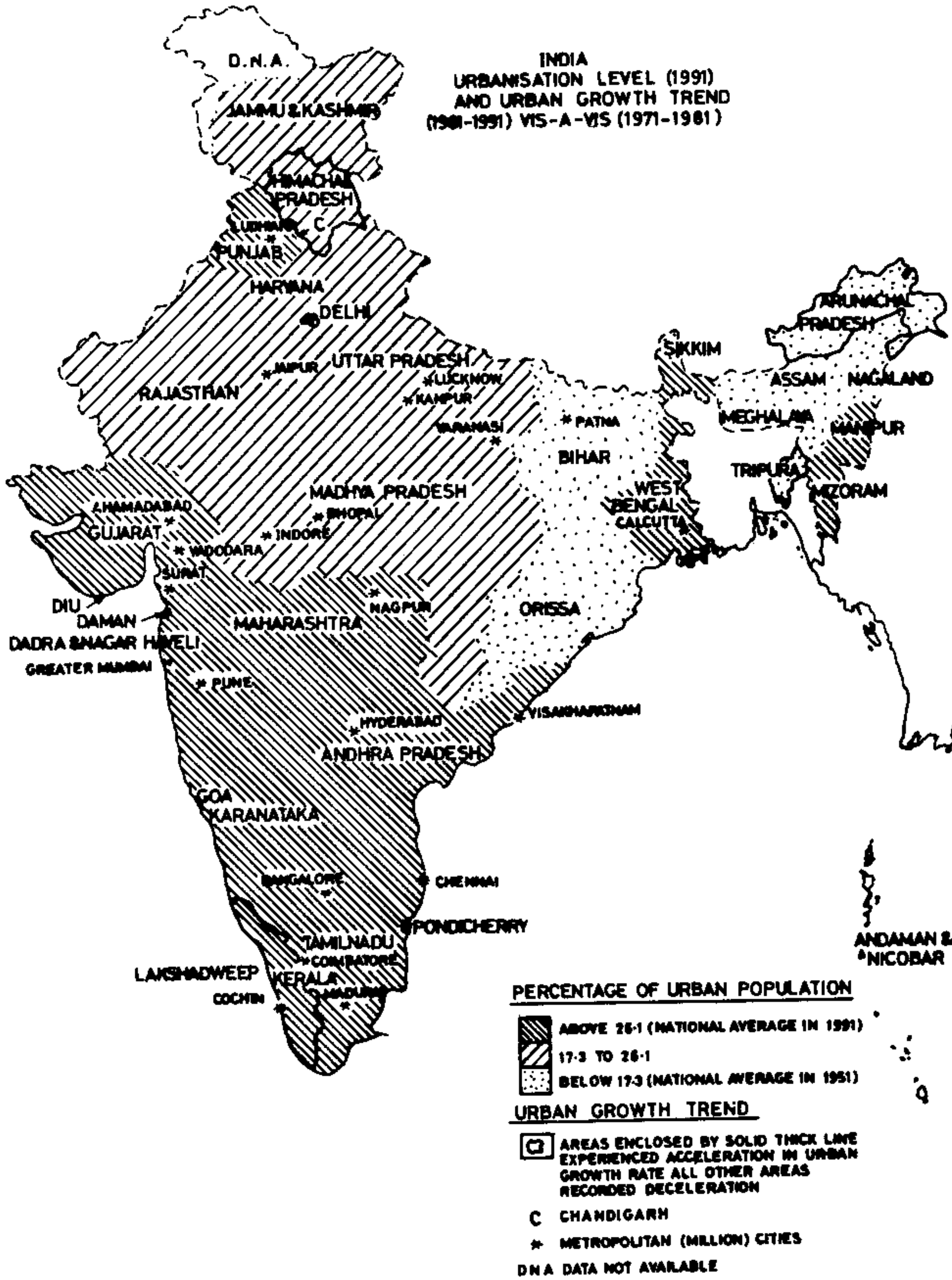

FIG. 4: INDIA; AREA AND POPULATION BY STATES/UNION TERRITORIES

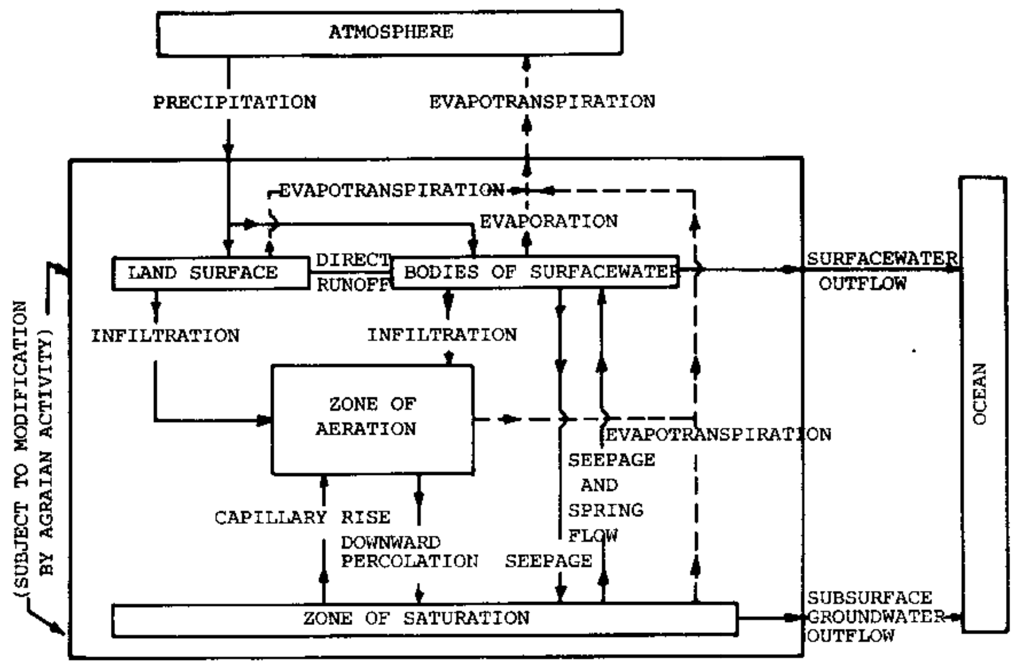

Fig. 5 Preurban hydraulic system from Cohen et al. (1968) showing major flow paths (heavy lines), minor flow paths (thin lines), flow of liquid water (solid lines), and flow of water vapor (dashed lines).

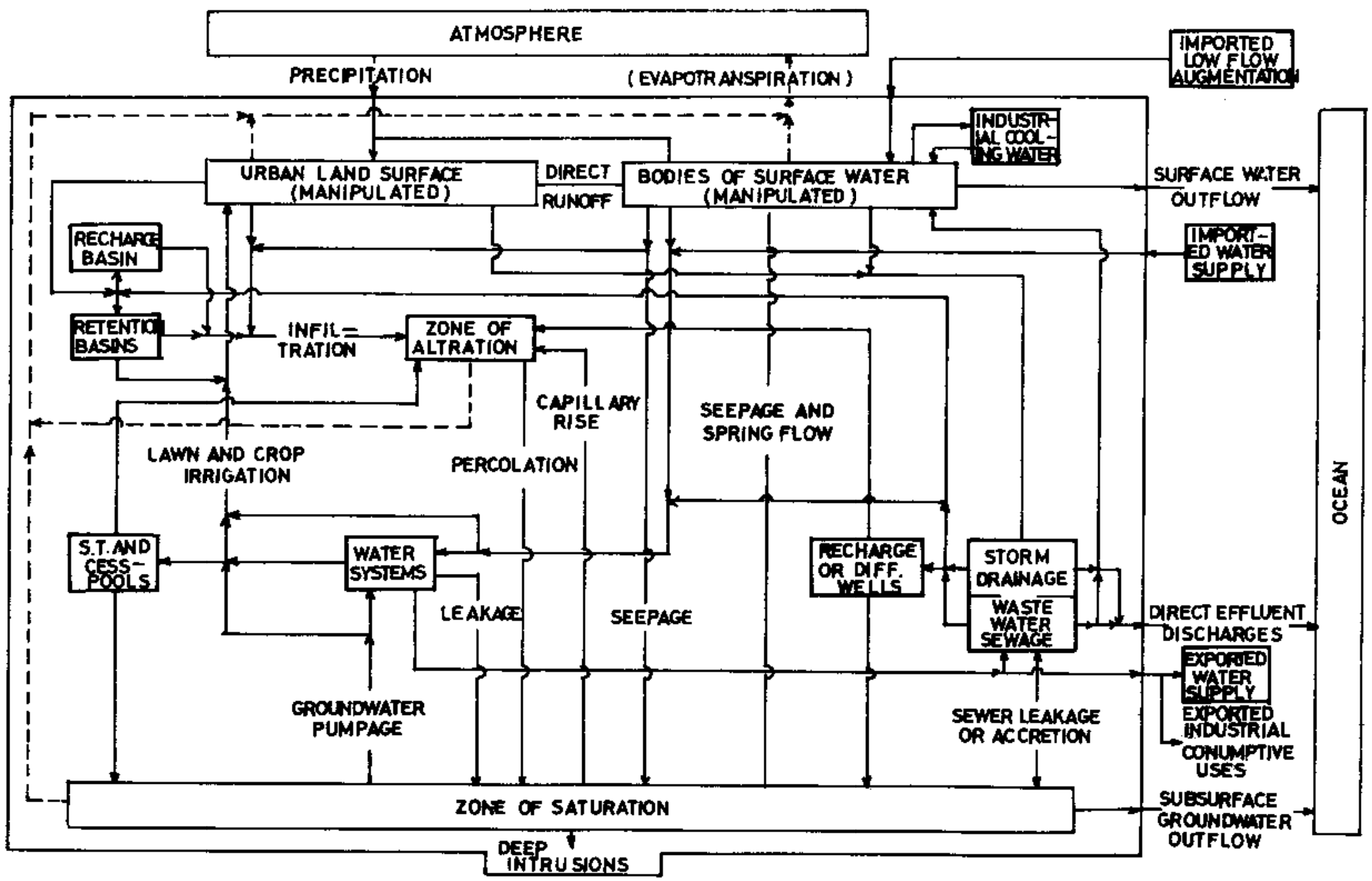

FIG. 6 URBAN HYDROLOGIC SYSTEM ADAPTED FROM FRANKE AND McCLYMONDS (1972)

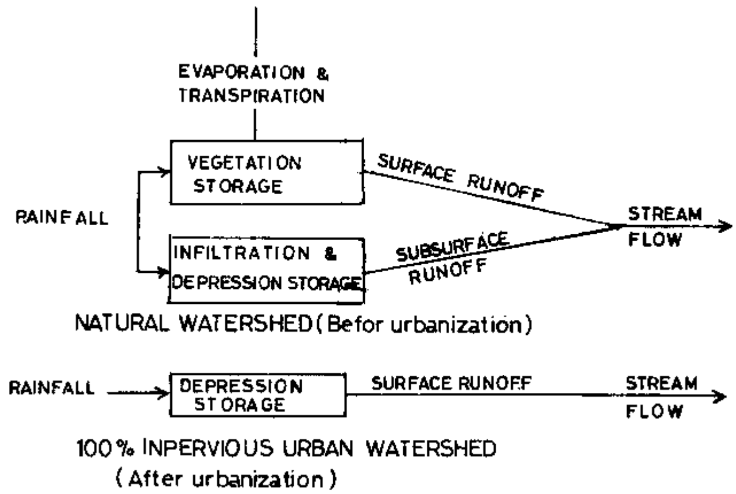

FIG. 7. COMPARISON OF NATURAL AND URBAN WATERSHED

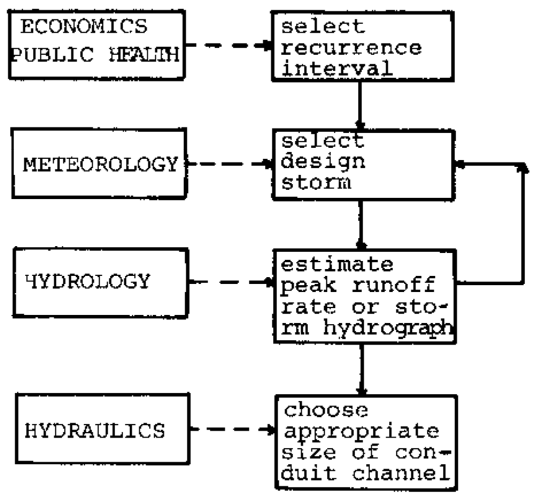

Fig. 8 Design procedure for drainage problems

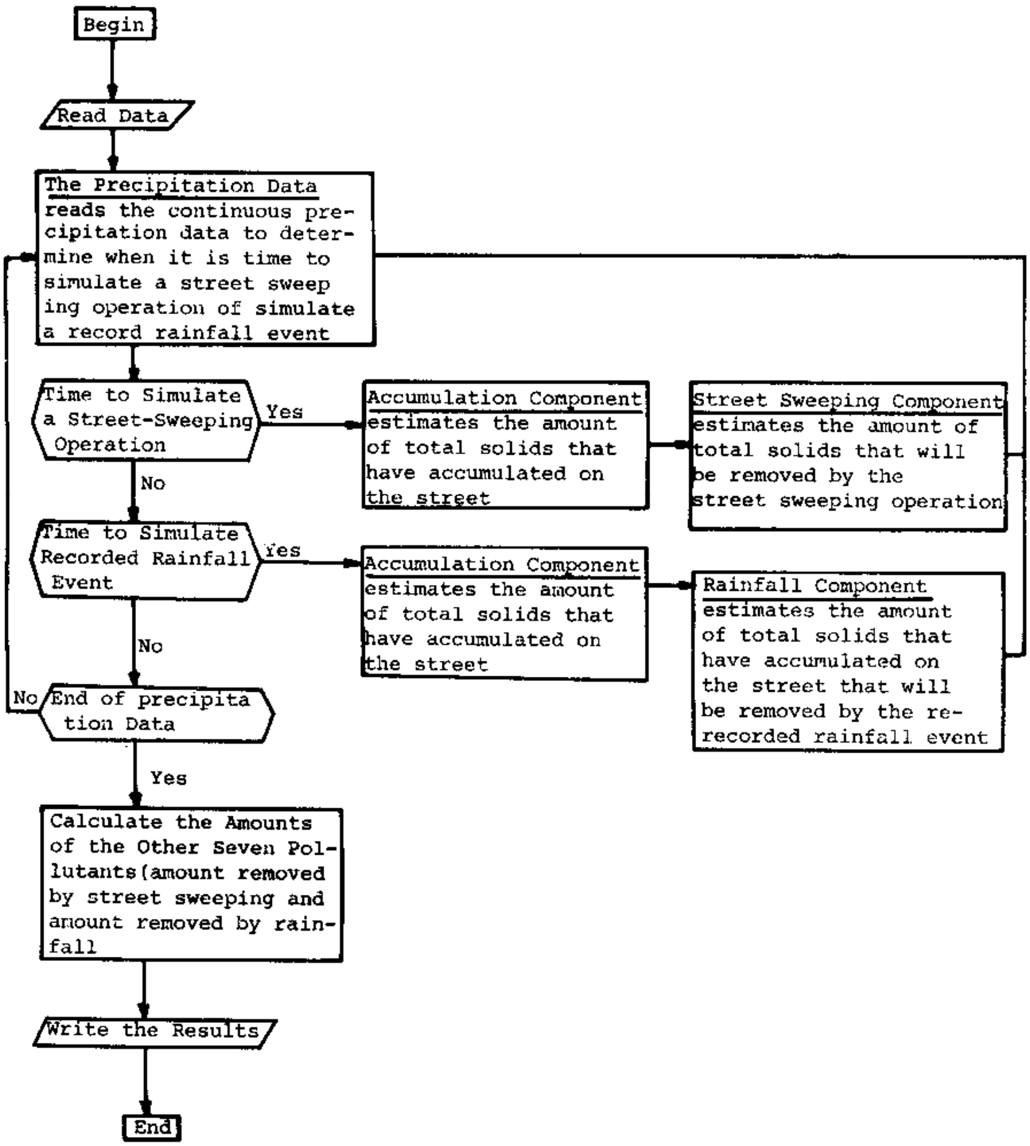

Figure 9 A Flowchart of the Basic Structure Adopted for the MUNP Model

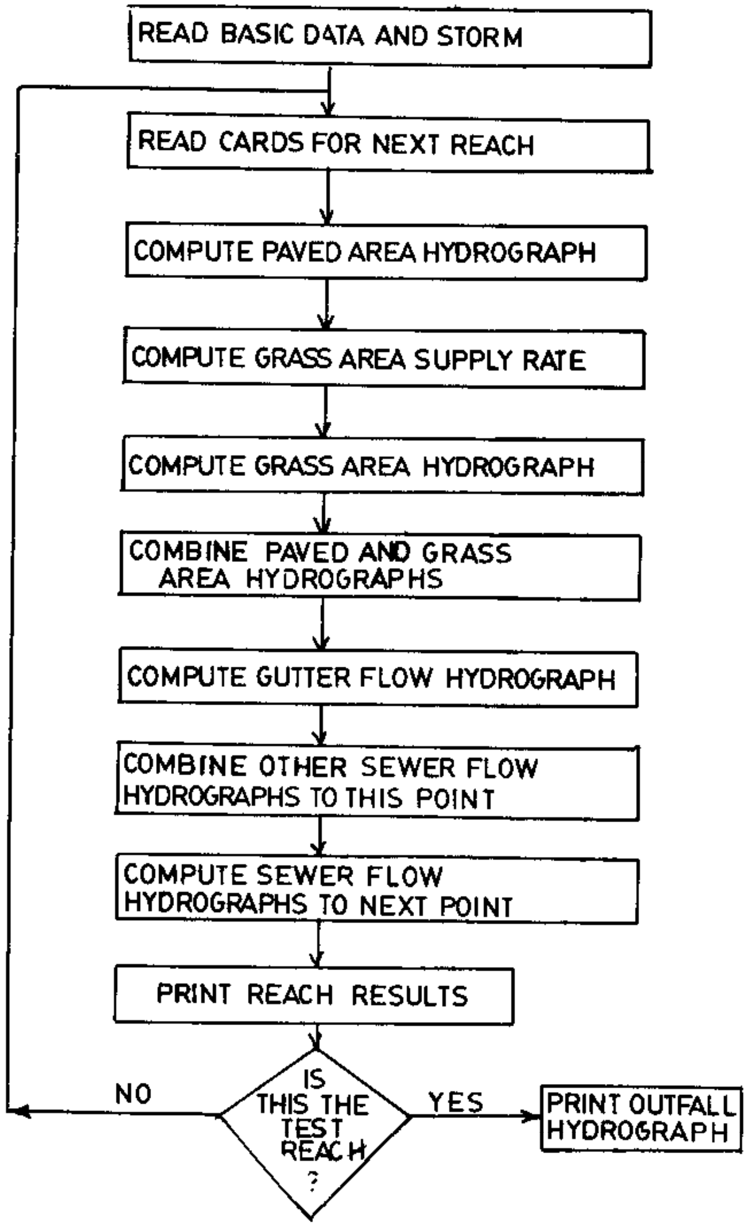

FIG.10 FLOW CHART FOR URBON RUNOFF DIGITAL COMPUTER MODEL

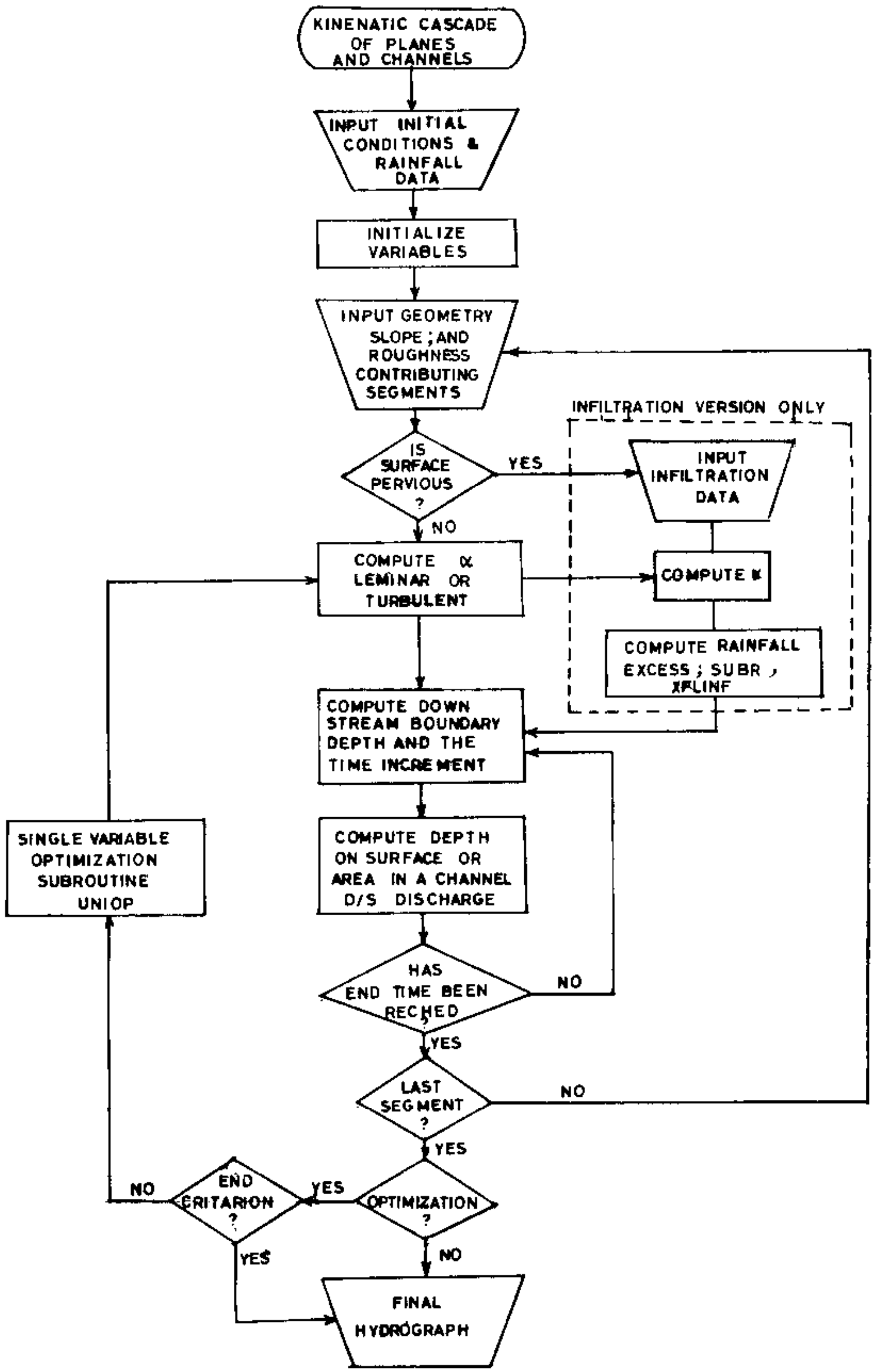

FIG.1E.FLOW CHART OF PROGRAM KINGEN

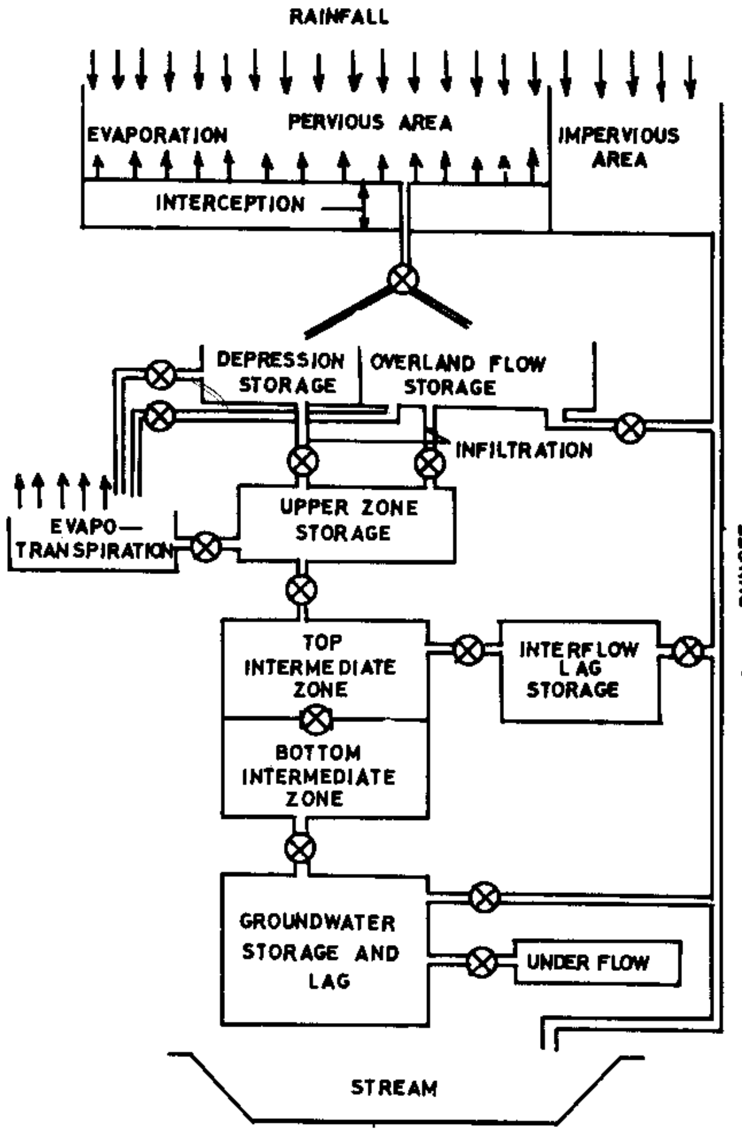

FIG.12 SCHEMATIC DIAGRAM OF WATERSHED SIMULATION PROGRAM
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2955	Hall, M.J.	Urban Hydrology
618	UNESCO	Socio-Economic Aspects of Urban Hydrology
2576	Watkins L.H.	Highway and Urban Hydrology in the Tropics
4996	Yen, B.C.ed.	Topics in Urban Drainage Hydraulics Hydrology
7627	K.Singh & F.Steinberg	Urban India in Crisis

Appendix–A2

List of some available Computer Programmes & Reports

i) R663, COMP. PROG.-85 : (Completion report, project number B-034-SDAC). Urbanisation effects and the control of the surface runoff process in small watersheds., NIH Library.

ii) 556.166 (1-201) N76 1463, COMP.PROG.153: Optimization model for the design of urban flood -control systems., NIH Library

iii) 556.51:556.16 N76 1476, COMP.PROG.159: Evaluation of urban runoff by watershed simulation., NIH Library.

iv) 626.86 (1-201) N74 140, COMP.PROG.19 : The illionis urban drainage area simulator, illudes., NIH Library.

v) 556.18(1-201)N78-1539, Centre for research in water resources (A technical report) : Methodology for analysing effects of urbanisation on water resources systems., NIH Library.

vi) R849, COMP.PROG.139: (Department of water affairs.) The analysis of areal rainfall using multiquadratic surfaces., NIH Library.

vii). 556.58 .072 N75 150, COMP.PROG.16: Optimal capacity expansion model for surface water resources system., NIH Library.

viii). 556.53:51 N73 2775: Prepared by officer of water research and technology Washington, D.C.: The mathematical description of BOD reaction in stream water., NIH Library.

ix). REPORT CS/AR 135: Design of surface drainage system for Bulandshar area. , NIH Library.,(1993)

x). REPORT CS/AR 140: urban watershed modelling, a comparative study (a case study of Nazargarn drainage basin). NIH Library.,(1993)

xi) REPORT TR 144: Inter comparison of urban watershed models., NIH Library.,(1992)

xii). REPORT TN 92: Effect of Urbanisation on runoff, NIH Library.,(1991).

xiii). REPORT SR 15: Status report on Urban Hydrology., NIH Library., (1992)

xiv). REPORT TR(BR) 124: Effect of Urbanisation on Runoff Hydrograph., NIH Library., (1994)

xv) REPORT TN-49: Storm drainage estimation in Urban areas, NIH Library, 1988.

xvi). REPORT TR/BR 113: Excess rainfall and direct surface runoff modelling using geo-morphological characteristics., NIH Library.

xvii). M.E.Dissertation, Evaluation of sewerage system at Hardwar., Central Library,U.O.R., Roorkee

xviii). HV-91/ARY. M.E.Dissertation, Trends of urbanisation in Roorkee and its environmental impact.,Central Library, U.O.R., Roorkee

xix). HV-89/RAJ. M.E.Dissertation, Rainfall- runoff relations of a natural watershed., Central Library, U.O.R., Roorkee

xx). HV-79/DAT. M.E.Dessertation, Overland flow due to time variant rainfall excess., Central Library,U.O.R., Roorkee

Major Problems of Urban Hydrology

- Supply of clean pure drinking water
- Provision of adequate flows for the disposal of water- born wastes.
- Magnitude of the per capita domestic consumption of water.
- Requirement of water for Industrial processes, recreation and amenity purposes.
- Flood & Pollution control problems.
- Internal and External drainage problems.
- Surface Runoff
- Heat production in Urban Area.
- Sewerage System
- Water Quality
- Recycling of Used Water.
- Sources of Urban pollutants
- Housing and Shelter
- Sanitation
- Basic services for the urban poor
- Finance for urban development, infrastructure and housing
- Urban land development
- Urban management

Appendix – A4

List of Some Recent Publications on Urban Hydrology

1. **Journal of Hydrology, 186(1-4): 129-151, 1996.**

Bruce, B. W. and McMahon, P. B.

Shallow ground-water quality beneath a major urban center: Denver, Colorado, USA.

About: A survey of the chemical quality of ground water in the unconsolidated alluvial aquifer beneath a major urban centre (Denver, Colorado, USA) with the objective of characterising the quality of shallow ground-water in the urban area and relating the water quality to land use; sampling of alluvial wells; dissolved constituents; residential, commercial, and industrial land use; sulphate and bicarbonate concentrations in samples; redox conditions; US national drinking-water standards; nitrate contamination of shallow ground water; total pesticide concentration; atrazine; volatile organic compounds in sampled wells; anthropogenic ground-water impact of urban environment.

2. **Journal of Hydrology, 179(1-4): 305-319., 1996**

Arnbjerg-Nielsen, K. and Harremoes

The importance of inherent uncertainties in state-of-the-art urban storm drainage modelling for ungauged small catchments.

About: Method to assess the relative importance to the overall uncertainty, by performing Monte Carlo simulations; detrimental effects from urban storm drainage; continuous and discrete variables; rainfall; surface runoff; discharges of chemical oxygen demand; combined sewer overflows; hydraulic resistance.

3. **Journal of Hydrology, 140(1-4): 297-312, 1992.**

Ford, M., Tellam, J. H., and Hughes, M.

Pollution-related acidification in the urban aquifer, Birmingham, UK.

About: Identification of the potential causes of acidification of the groundwater below the city of Birmingham (UK); rise of water level into the carbonate-poor upper levels of the sandstone aquifer; oxidation of the Quaternary deposits overlying the aquifer; inorganic acid spills; acidic recharge; oxidation of inorganic pollutants; degradation of industrial organic pollutants; solubility of toxic metals; groundwater quality survey.

4. **Journal of Hydrology, 109(3-4): 221-236, 1989.**

Driver, N. E. and Troutman, B. M.

Regression models for estimating urban storm-runoff quality and quantity in the United States.

About: Development of linear regression models for the estimation of storm-runoff loads and volumes from physical, land-use, and climatic characteristics of urban watersheds throughout the United States; delineation of statistically different regions, based on mean annual rainfall; models for dissolved solids, total nitrogen, and total ammonia plus organic nitrogen; models for suspended solids; gaged and ungaged urban watersheds.

5. **Journal of American Water Works Association, 85(7): 89-94,1993.**

Chadderton, R. A., Christensen, G. L., and Henry-Unruth, P.

Planning a distribution system flushing program.

About: Flushing distribution systems for improving water quality and services; evaluation of the effectiveness of flushing programs; method to assist with program organisation and analysis; review of a flushing program conducted by the Philadelphia Suburban Water Company; water distribution systems.

6. **Journal of American Water Work Association, 84(7):62-67,1992**

Cannistra, J. R., Leadbeater, R., and Humphries, R.

Washington suburban sanitary commission implements GIS.

About: Construction of a co-operative pilot project; development of a complete 59-layer geographic information system (GIS) data base for a portion of its service area; digitisation of water and sewer facility maps; planimetric and parcel data; geographic information systems; water supply.

7. **Journal of American Water Works Association,83(8):46-49,1991**

Harberg, R. J. and Macy, P. P.

Reliability analysis for master planning of a water system.

About: Application of a reliability analysis to a water delivery system; description of how th City of Boulder, Colo., used this analysis to determine the need for and priority of water systei improvements; urban water systems; environmental impact; water supply.

8. **Journal of American Water Works Association,83(3):46-51,1991**

Bakken, J. D. and Bruns, T. M.

Assessing the reliability of urban reservoir supplies.

About: The Indianapolis Water Company conducted a thorough study of its reservc supplies to assess the reliability of its water supply; evaluation of the safety of dams; reservc storage capacity; surface water supply; sedimentations.

9. **Journal of American Water Work Association,80(6): 34-42,1988**

Perry, J. A.

Networking urban water supplies in West Africa.

About: Characterization of the diversity among four West African water supply system problems faced by managers of these kinds of utilities; discussion of the solutions to commı problems and the role of water utility professionals from the developed countries; wat management; sub-Saharian nations; waterborne diseases.

10. **Journal of Hydraulic Research, 34(6): 815-826,1996.**

Harremoes, P. and Rauch, W.

Integrated design and analysis of drainage systems, including sewers, treatment plant aı receiving waters.

About: Outline on the basic approaches in integrated design of urban drainage syster which aims on the abatement of water pollution in the receiving water; formulation a assessment of appropriate water quality criteria; analysis of a hypothetical system by means o deterministic model of the total system; discharges of the sewer system and the treatment plɛ into the receiving water.

11. **Journal of Hydraulic Research, 34(6): 771-784,1996.**

Ellis, J. B. and Hvitved-Jacobsen, T.

Urban drainage impacts on receiving waters.

About: The causes and consequences of urban storm drainage impacts on receiving waters; discussion of available methods and tools for implementation of structural and non-structural measures to improve surface water quality from the deleterious effects of such intermittent urban discharges; effect of changes within the catchment or surface water system with a specific quality and ecological improvement of the receiving waters; urban water and wastewater systems; water quality and biotic criteria; modelling systems; pollution.

12. Journal of Hydraulic Research, 33(4): 535-554,1995.

Kutija, V.

A generalized method for the solution of flows in networks.

About: A method for computing flows in combined dendritic and looped networks of channels; urban-drainage and irrigation networks; computer-algebraic procedures.

13. Hydrological Sciences Journal, 41(3): 345-362,1996.

Desa, M. M. N. and Niemczynowicz, J.

Spatial variability of rainfall in Kuala Lumpur, Malaysia: Long and short term characteristics.

About: Study of spatial variability of both long and short term rainfall in an urban environment in Malaysia; monthly and yearly rainfall data; humid tropics region; time and space resolution; spatial structures; geographical orientation; monsoon seasonality effects; sea influence; depth-area relationship; thunderstorms; urban runoff calculations.

14. Hydrological Sciences Journal, 35(3): 285-302,1990.

Buttle, J. M.

Effects of suburbanization upon snowmelt runoff.

About: Examination of the influence of suburbanisation upon runoff response to snowmelt and rain-on-snow inputs for a small drainage basin in south-central Ontario; modification of the basin area leading to a six-fold increase in the spring quickflow response ratio and in the number of snowmelt events that generate appreciable quickflow; distinction between hydrograph properties associated with snowmelt and rain-on-snow events; reduction in hydrograph recession coefficients; variable time of rise value; peak discharge; peak flows.

15. ASCE Journal of Water Resources Planning and Management, 121(4): 318-325,1995.

Greene, R. G. and Cruise, J. F.

Urban watershed modeling using geographic information system.

About: Construction of a geographic information system (GIS) for an urban watershed in Baton Rouge, Louisiana; hydrologic modelling of urban watersheds; hydrologic response units; curve number method; standard kinematic wave model.

16. ASCE Journal of Water Resources Planning and Management, 121(1): 41-48,1995.

Lund, J. R. and Israel, M.

Optimization of transfers in urban water supply planning.

About: Applications of two-stage and multistage linear programming for preliminary estimation of the least-cost integration of several water marketing opportunities with water conservation and traditional water supplies; water supply agencies; water transfers.

17. ASCE Journal of Water Resources Planning and Management, 120(4): 523-530, 1994.

Ferguson, B. K. and Deak, T.

Role of urban storm-flow volume in local drainage problems.

About: Storm water management policy to prevent overflows at drainage obstructions computer model for a culvert entrances; storm hydrographs with different flow volumes and peak rates; storm water infiltration; stage-discharge relationships; stage-storage relationships.

18. ASCE Journal of Water Resources Planning and Management, 118(6): 603-619,1992.

Miloradov, M.

Planning and management of water-resource systems in developing countries.

About: Yugoslav experience in planning the development of water-resources systems methods and procedures for optimal analysis of water-resources solutions; criteria for evaluation of optimal solutions; multipurpose systems; multiphase optimisation procedures; urbanisation areas.

19. ASCE Journal of Water Resources Planning and Management, 118(4): 351-355.1992.

Muyibi, S. A.

Planning water supply and sanitation projects in developing countries.

About: Water supply and sanitation systems in rural and preurban areas; case histories of project failures in rural areas due to many factors including choice of inappropriate technology, lack of effective backup support, non-involvement of user community in the planning and implementation process, and implementation of projects for political gains; sequential procedure for total involvement of the user community in the planning construction, operation, and maintenance.

20. ASCE Journal of Water Resources Planning and Management, 116(6): 742-763,1990.

Wigmosta, M. S. and Burges, S. J.

Proposed model for evaluating urban hydrologic change.

About: A model for simulating flux rates and spatial distributions of evapotranspiration, Horton and saturated overland flow, subsurface storm flow, and dry-weather base flow; application of the model to a 39-ha ungauged catchment in King County, Washington; use of the model to explore the relative temporal and spatial effects of land use change on storm hydrographs, flow duration, and long-term mass balance.

21. ASCE Journal of Water Resources Planning and Management, 115(4): 523-540,1989.

Tucci,C.E.M., Braga,B. P. F., and Amaral,M.F.

Hydrodynamic analysis of floods in urban system.

About: A hydrologic-hydrodynamic model to simulate a river network system with hydraulic structures in an urban watershed; application of the model to simulate floods in the metropolitan region of Sao Paulo; finite difference method; urban hydrology.

22. ASCE Journal of Water Resources Planning and Management, 114(4): 399-413,1988.

Garcia, A., Jr. and James, W. P.

Urban runoff simulation model.

About: A study conducted to determine the sensitivity of the unit hydrograph to the effects of the urbanisation process; formulation of a hydrologic model for an urban catchment located at Houston, Texas, using the kinematic wave model developed by the Hydrologic Engineering Centre (HEC); regression equations to quantify the impact of urbanisation on the unit hydrograph; incorporation of these equations into the A & M Watershed Model.

23. ASCE Journal of Water Resources Planning and Management, 114(4): 365-382,1988.

Kuczera, G. and Diment, G.

General water supply system simulation model: WASP.

About: A mass-balance quasi-simulation computer package (WASP) to facilitate analysi of the performance of the headworks and transfer components of a water supply system unde different operating policies and changes to system configuration; principles used to formulate th network linear program; case study involving a complex urban water supply system t demonstrate the generality of WASP.

24. ASCE Journal of Water Resources Planning and Management, 112(4): 419-438, 1986

Dziegielewski, B. and Crews, J. E.

Minimizing the cost of coping with droughts: Springfield, Illinois.

About: A framework that allows planners of water supply systems and utility managers t formulate least-cost drought emergency plans, and to systematically examine the trade-o between the expected value of the long-term cost of coping with water supply deficits and the co: of the long-term water supply/conservation projects; application of the framework to the wate supply system of Springfield, Illinois; urban water supply.

Remarks: Discussion and reply: 114(2): 244-245 (Ben-Zvi, A.).

25. ASCE Journal of Water Resources Planning and Management, 112(1): 36-47,1986.

Heaney, J. P.

Research needs in urban storm-water pollution.

About: The results of an analysis of research needs in urban storm-water pollution contrc evaluation of the state-of-the-art in four areas: urban runoff characterization, water quality effect: control effectiveness, and decision-making models; automated monitoring systems; water qualit standards.

26. ASCE Journal of Hydraulic Engineering, 116(6): 754-764, 1990

Frick, D. M., Bode, D., and Salas, J. D.

Effect of drought on urban water supplies. II: Water-supply analysis.

About: Use of a water-resource-system model to simulate the water-supply system of th City of Fort Collins, Colorado, for selected drought periods; determination of the yield of the city existing water supplies and for other potential water-supply sources; use of a water-rights model (MODSIM) to simulate allocations of water supplies based on existing and future water-rights ownership scenarios for the city; determination of safe demand levels.

27. ASCE Journal of Hydraulic Engineering,116(6): 733-753., 1990

Frick, D. M., Bode, D., and Salas, J. D.

Effect of drought on urban water supplies. I: Drought analysis.

About: Summary of studies conducted for the City of Fort Collins, Colorado, to determine the effects of prolonged droughts on the city's water supplies; development of various water-supply strategies to be used by the city for handling the problems associated with extreme droughts; development of a stochastic model for the five river basins that account for the city's water supplies; verification of the stochastic model with 400 years of tree-ring data obtained for the area.

28. Water Resources Bulletin, 32(4): 855-864,1996.

Hoos, A. B.

Improving regional-model estimates of urban-runoff quality using local data.

About: Statistical methods, termed model-adjustment procedures, which use a combination of local data and published regional models to improve estimates of urban-runoff quality; importance of load estimates of storm-runoff pollutants for design of effective remedial programs to urban water-quality managers; estimation of storm-runoff quality at unmonitored sites and storms in the locality; single-factor regression against the regional model prediction; least-squares regression against P(u); nonpoint source pollution; stormwater management.

29. Water Resources Bulletin, 32(3): 511-520., 1996

Barbe, D. E., Cruise, J. F., and Mo, X.

Modeling the buildup and washoff of pollutants on urban watersheds.

About: Development of a model for urban stormwater quality; linear function of the antecedent dry time; power function of the storm runoff volume; net accumulation; model calibration; urban basins; Baton Rouge, Louisiana; phosphorus concentrations; nonpoint source pollution; water quality; management; urban hydrology wet climate.

30. **Water Resources Bulletin, 31(3): 491-504,1995.**

Kaufman, M. M.

Community response to stormwater pollution in an urbanized watershed.

About: Development and testing of a model to identify the factors influencing variation i community response to stormwater pollution; applicability of hazard theory to stormwate response; response index; community environmental response.

31. **Water Resources Bulletin, 23(1): 147-152,1994.**

Ferguson, B. K.

Water conservation methods in urban landscape irrigation: An exploratory overview.

About: Review of a broad range of methods of water conservation in urban irrigatior minimisation of the consumption of irrigation water; design of irrigation hardware for efficier delivery of the required volume of water to the specified landscape; irrigation water demand; urba development.

32. **Water Resources Bulletin, 27(2): 283-291,1991.**

Marsalek, J.

Pollutant loads in urban stormwater: Review of methods for planning-level estimates.

About: A review of methods for planning-level estimates of pollutant loads in urba stormwater; transfer of characteristic runoff quality data to unmonitored sites; prediction c pollution load changes resulting from runoff controls, or other changes of the urban systerr calibration of simulation models for evaluation of control alternatives; water quality.

33. **Water Resources Bulletin, 26(4): 563-575,1990.**

Zaghloul, N. A. and Al-Shurbaji, A.-R. M.

A storm water management model for urban areas in Kuwait.

About: Results of a comprehensive study conducted to implement the Storm Wate Management Model (SWMM) for urban areas in Kuwait; urban runoff simulation in arid area: design of drainage systems; rational method; fine and coarse discretization approaches; storr sewers; water harvesting.

34. **Water Resources Bulletin, 25(3): 517-525,1989.**

Kuo, C. Y. and Zhu, J.-L., 1989.

Design of a diversion system to manage the first flush.

About: Design of a diversion box and detention basin system for a new storm sewer system or for retrofitting an existing system to manage the first flush of storm runoff in urbanized areas; development of a software package to facilitate the analysis and design of the system; generation of hydrographs and pollutographs at the inlet and outlet of the diversion box and the detention basin; urban stormwater quantity and quality management; nonpoint source pollution.

35. **Water Resources Bulletin, 25(1): 101-109,1989.**

Dziegielewski, B. and Boland, J. J.

Forecasting urban water use: The IWR-MAIN model.

About: Description of a forecasting approach that disaggregates urban water use into a large number of categories and takes account of factors that determine both the need for water as well as the intensity of water use within each category; econometric model; gross per capita water use; IWR-MAIN Water Use Forecasting Model; municipal and industrial water use.

Remarks: Discussion and reply: 26(3): 527-533 (Wilson, L. and Luke, R.); 26(4): 699-707.

36. **Water Resources Bulletin, 24(5): 1091-1101,1988.**

Tasker, G. D. and Driver, N. E.

Nationwide regression models for predicting urban runoff water quality at unmonitored sites.

About: Development of regression models to estimate mean loads for chemical oxygen demand, suspended solids, dissolved solids, total nitrogen, total ammonia plus nitrogen, total phosphorous, dissolved phosphorous, total copper, total lead, and total zinc at unmonitored sites in urban areas; use of several explanatory variables including drainage area, imperviousness of drainage basin to infiltration, mean annual rainfall, a land-use indicator variable, and mean minimum January temperature; estimation of model parameters by a generalized least-squares regression method.

37. **Water Resources Bulletin, 24(1): 169-174,1988.**

Whitlatch, E. E. and Martin, M. J.

Identification of monthly trends in urban water use.

About: Analysis of monthly water use for the period 1960-1984 for the Columbus, Ohic metropolitan area to identify differential monthly trends in growth of water use; determination c the causes of the observed trend in overall water use; leakage and water-main breakage in th water distribution system due to freeze/thaw conditions; regression analysis; water supply.

38. Water Resources Bulletin, 24(1): 125-132,1988.

Kuo, C. Y., Cave, K. A., and Loganathan, G. V.

Planning of urban best management practices.

About: Development of a 'user-friendly' computer program for application in persona computers for preliminary design, evaluation, and cost effectiveness analysis of various bes management practice (BMP) measures to control stormwater quantity and quality; use of the SCS TR-55 method for calculating runoff hydrographs for a single storm event; use of a first orde pollutant washoff equation to generate pollutographs; comparative evaluation of three types o BMP measures, namely detention ponds (dry, wet, and extended wet ponds), infiltration trenches and porous pavements; cost analysis; nonpoint source pollution; stormwater management;

39. Water Resources Bulletin, 24(1): 113-124., 1988

Bhaskar, N. R.

Projection of urbanization effects on runoff using Clark instantaneous unit hydrograph parameters.

About: Review of a major flood study undertaken by the U.S. Army Corps of Engineers to alleviate serious flooding problems brought upon by rapid urbanization in the Beargrass Creel watershed, located in Loisville, Kentucky; prediction of flood conditions in 1990 for the Beargrass Creek watershed by utilizing trends in the Clark Instantaneous Unit Hydrograph (Clark IUH parameters; maximum annual historical flood data; regression models; rainfall-runoff modeling.

40. Water Resources Bulletin, 23(6): 1101-1107, 1987

Arnold, J. G., Bircket, M. D., Williams, J. R., Smith, W. F., and McGill, H. N.

Modeling the effects of urbanization on basin water yield and reservoir sedimentation.

About: Application of a model called SWRRB (Simulator for Water Resources in Rura Basins) to determine the effect of urbanization on water and sediment entering the White Rocl

Lake located in Dallas, Texas; sediment delivery ratio; land use; reservoir capacity; hydrologic modeling.

41. Water Resources Bulletin, 22(5): 753-757,1986.

Foster, K. E. and DeCook, K. J.

Impacts of residential water reuse in the Tucson area.

About: Study of the impact of urban water reuse on water supply in the Tucson Active Management Area, Arizona; groundwater pumping; imported water; water conservation; treated municipal effluent.

Remarks: Discussion and reply: 23(5): 961-965 (Martin, W. E. and Bush, D. B.).

42. Water Resources Research, 29(10): 3363-3369,1993.

Howe, C. W. and Smith, M. G.

Incorporating public preferences in planning urban water supply reliability.

About: A study undertaken: (1) to compare the attitudes of the water-using public, water officials, and elected officials toward the risk of water supply shortage, and (2) to develop a methodology for incorporating water users' valuation of reliability in system design.

43. Water Resources Research, 29(7): 1975-1981, 1993.

Fass, S. M.

Water and poverty: Implications for water planning.

About: Planning of urban water supply systems in developing countries; discussion of the relationship between water, nutrition, housing and health; water supply.

44. Water Resources Research, 28(3): 609-615,1992.

Nieswiadomy, M. L.

Estimating urban residential water demand: Effects of price structure, conservation, and education.

About: A study undertaken: (1) to estimate urban water demand in the United States using the most current American Water Works Association (1984) survey of 430 (of 600 largest) U. S. utilities, and (2) to test if consumers respond to average prices or marginal prices using Shin's (1985) model; water demand equations; public educations.

45. **Water Resources Research, 27(7): 1739-1755,1991.**

Grimmond, C. S. B. and Oke, T. R.

An evapotranspiration-interception model for urban areas.

About: A model to calculate evapotranspiration from urban areas over a wide range meteorological conditions; comparison with field observations; surface water state; latent heat flu British Columbia; rainfall; irrigation.

46. **Water Resources Research, 23(7): 1139-1144,1987.**

Moreau, D. H. and Snyder, T. P.

Financial burdens and economic costs in expanding urban water systems.

About: Identification and investigation of the important variables for evaluating the equity (inequity) between established residents and new-development residents when urban water ar sewer facilities are expanded with public financing; comparison of per capita payment with p capita economic costs of providing water and sewer systems; rates of growth of demand; lengtl of financing periods; real interest rates.

47. **Water Resources Research, 23(3): 393-398,1987.**

Moncur, J. E. T.

Urban water pricing and drought management.

About: Analysis of pooled cross-sectional and time series observations on single-fam residential customers of the Honolulu Board of Water Supply; estimation of the demand for wat as a function of price, income, household size, rainfall, and a dummy variable denoting a wat restrictions program; short-run elasticity; marginal price of water.

48. **Water Resources Research, 22(13): 1735-1741,1986.**

Martin, W. E. and Thomas, J. F.

Policy relevance in studies of urban residential water demand.

About: Feasibility of using cross-sectional comparisons of prices and quantities in simi areas for pricing policies related to urban residential water demand; comparison of well-defin price and quantity data from five cities with similar arid environments; long- and short-run pri elasticities.

49. **Water Resources Research, 22(10): 1397-1403., 1986**

Grimmond, C. S. B., Oke, T. R., and Steyn, D. G.

Urban water balance. 1. A model for daily totals.

About: Development of a simple model for evaluating the components of the urban water balance based on standard climate data and easily obtained parameters; evapotranspiration submodel; sensitivity analyses; pervious irrigated suburban area.

50. **Water Research, 28(2): 437-443,1994.**

Ferchichi, M., Ghrabi, A., and Grasmick, A.

Urban wastewater treatment by trickling filter and rotating biological reactor.

About: A comparison between the secondary treatment performances of two semi-industrial biofilm reactors: trickling filter and a rotating biological contactor; pollution removal; hydraulic residence time; biological sewage treatment; urban wastewater.

51. **Water Research, 26(9): 1255-1259,1992.**

Ermolin, Y. A.

Automated control of urban sewage disposal systems.

About: An algorithm for the automated control of an urban head-and-gravity flow sewage disposal system; sewage pumping plants; control criterion; linear programming; mathematical models.

52. **Water Research, 25(5): 557-565, 1991.**

Bomboi, M. T. and Hernandez, A.

Hydrocarbons in urban runoff: Their contribution to the wastewater.

About: Application of a hydrocarbon characterization analysis to extractable organic matter from Madrid runoff; aliphatic and aromatic hydrocarbons; gas chromatography.

53. **Water Research, 22(8): 1017-1026.1988.**

Harremoes, P.

Stochastic models for estimation of extreme pollution from urban runoff.

About: Investigation of the transport of pollutant by urban runoff to the environment; rair statistics; water pollution.

54. Water Research, 22(4): 491-496,1988.

Hvitved-Jacobsen, T. and Yousef, Y. A.

Analysis of rainfall series in the design of urban drainage control systems.

About: A discussion of the concept of inter-event dry periods for evaluation of desigr storms derived from a rainfall record; analysis of the rainfall record for the city of Odense Denmark; illustration of the basic statistics as well as the importance of the concept; water qualit control; return period.

55. Water Research, 22(2): 133-137, 1988.

Dange, V., Jothikumar, N., and Khanna, P.

One hour portable test for drinking waters.

About: A procedure for enumeration of coliforms in drinking waters; correlation o phosphorus uptake under stipulated experimental conditions and bacterial population bacteriological examination of drinking waters in rural and semi-urban communities; radiotrace technique.

56. Water Research, 20(5): 651-659,1986.

Zanoni, A. E.

Characteristics and treatability of urban runoff residuals.

About: Characterization and treatability studies conducted on stormwater residual obtained from a field-assembled sedimentation basin in Racine, from swirl and helical ben separators in Boston, and from an in-line upsized storm conduit in Lansing; analyses of residual for the traditional parameters, namely solids, BOD5, COD, TOC, nutrients, as well as 9 metals, pesticides and PCB; stormwater runoff; sludge dewatering.

57. Advances in Water Resources, 10(4): 205-211,1987.

Rao, A. R. and Han, J.

Analysis of objective functions used in urban runoff models.

About: Comparison of the objective functions used in parameter estimation in urban runo models by using a method proposed by Diskin and Simon and the urban runoff model ILLUDAS.

58. Advances in Water Resources, 10(2): 78-86,1987.

Selvalingam, S., Liong, S. Y., and Manoharan, P. C.

Use of RORB and SWMM models to an urban catchment in Singapore.

About: Evaluation of the Runoff Routing Model (RORB) and the Storm Water Management Model (SWMM); discussion of parameter estimation, floods, hydrology, and urban development.

59. Ground Water, 31(3): 417-424,1993.

Nazari,M.M., Burston,M.W., Bishop,P.K.,and Lerner,D.N.

Urban ground-water pollution: A case study from Coventry, United Kingdom.

About: Discussion of the results of a regional ground water quality survey of an industrialized city; ground water pollution; chlorinated hydrocarbon solvents; inorganic and trace element concentrations; ferric hydroxide precipitation; heavy metal precipitation; inorganic contamination; degradation in ground water quality.

60. Ground Water, 31(1): 4-11,1993.

Somasundaram, M. V., Ravindran, G., and Tellam, J. H.

Ground-water pollution of the Madras Urban Aquifer, India.

About: A study of the quality of the Madras ground waters; determination of the variations in major ion and nitrate concentrations; a local survey of pollution adjacent to one of the city's rivers performed to determine heavy metal and bacterial pollution.

Remarks: Discussion and reply: 31(6): 1029-1030 (Clement, T. P.).

Director : S M SETH

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