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Urban Hydrology A state-of-the-art Report

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Preface

The world growth of urbanisation over the years is very high. This rapid process of urbanisation has tremendous effect on hydrology of the region. Internal growth and migration from rural to urban areas has been putting a colossal pressure on the administration and management. With this rapid urbanisation, the basic amenities (such as safe drinking water supply, sanitation, drainage, and solid waste management) requirement increased tremendously.

These problems of urban hydrology have been of world 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. Keeping this facts in mind, Dr. Vivekanand Singh, Scientist B and Dr. B. Soni, Scientist 'F' of the Institute have prepared this report to present the status of urban hydrology and to highlight some of the hydrological problems related to urbanisation in India. Mr. Omprakash, SRA has assisted in the collection of the literatures for preparing the report.

K S RAMASASTRI
Director

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ABSTRACT

Due to rapid urbanisation and industrialisation, urban population of the country is increasing year after year posing a major challenge to the concerned with planning, development and management to cope up with the problem of providing the basic amenities such as safe drinking water, sanitation, drainage, solid waste management, etc. During the last 50 years considerable progress has been made in providing the safe drinking water supply and hygienic sanitation facilities to the urban population, it is still a long way to go in order to achieve 100 percent coverage in all the basic amenities.

Under the circumstances, there is an urgent need to initiate action for effective perspective planning for the next 25-30 years keeping in view the targets to be achieved in respect of water supply, sanitation, solid waste management and drainage facilities. The main objective of this report is to present the status of urban hydrology and to highlight some of the hydrological problems related to urbanisation in India. This report includes the trends of urbanisation in World and in India, and discussion on urban hydrologic cycle, hydrological and related problems of India, impact of urbanisation on streamflow, and urban water management. Some information on available urban hydrological models and the recommendations for the management of urban areas is also included.

1.0 INTRODUCTION

Urban hydrology is defined as the interdisciplinary science of water and its interrelationships with urban man (Jones, 1971). In other words, urban hydrology is a special case of hydrology applied for cities i.e. area with very high level of human interference with natural processes. It is a relatively young science; the bulk of its knowledge has accumulated since the early 1960s. The beginnings of urban hydrology can be traced to the time shortly after the automobile became the major means of transportation in the United States. Roads were paved to facilitate travel, allowing the growth of the suburbs where the commuter escaped the congestion of inner-city life. Growth of urban areas brought significant changes in physical properties of land surface increasing integrated vulnerability of inhabitants, agricultural land and rural ecological life support systems. The result was 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 (Lazaro, 1990).

1.1 Urbanisation

Urbanisation is defined 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 (Davis, 1965; Savani and Kammerer, 1961). Urbanisation of a region includes the transformation of a rural region into an urban region, development of a suburban region to an urban region and rural-urban migration. The urban areas have developed in response to human social and economic needs. The important causes of urbanisation are advances in science and technology, industrialisation, advance in agriculture, better scope of employment, service-oriented business, better education, medical facilities and transportation. Economic development and urbanisation can be correlated. The forces of urbanisation are the product of man's genius, of his continuous quest for efficiency and of his need for the social and cultural milieu that an urban area can provide (Lazaro, 1990). Urbanisation represents a particular form of land use and surface cover. Industrialisation is included in urbanisation because the latter can be regarded as human activities involving change in land occupancy and use resulting from the conversion of rural lands to industrial uses and to urban, suburban and industrial communities. Also, there are instances, where the effects of water pollution from large-scale mining operations are comparable to those from industries. Urban areas affect, and are affected by, some time distant human activities. Among the obvious effects are increased population density and increased concentrations of residential, industrial and commercial buildings and facilities, with resultant increases in areas that are impervious. The micro-climate in an urban neighbourhood is modified by the form of urban structures, by changes in the heat balance, there is increased drawl from surface water and groundwater sources, reduced infiltration, increased peak flow, increased waste water with corresponding effect on water quality etc. Hydrological impacts then include the effects of these changes on the natural drainage, runoff, groundwater, sediment, water quality, water demands, and on measures utilised for the disposal of wastes and surplus waters and for the supply of water. The impact of highway development, and rail lines on soil erosion and water quality is significant. Channel straightening and narrowing, culvert sizing, drainage etc. affect the runoff timing significantly. Receiving waters have often become waste receptacles, subject to increasing flow volumes and effluents harmful to both quality and ecology.

Among the hydrological problems associated with urbanisation are the continually increasing demands for water for various uses, changes in the physical environment that alter the natural water balance, and the disposal of wastes that may contaminate streams and groundwater. Of course, there are wide differences in both the distributions of population density and of natural water occurrences around the world.

1.2 Trends of Urbanisation in the World

The world growth of urbanisation over the years is logarithmic. In 1950 about one-third of the world's population lived in cities. In 35 years since 1950, the number of people living in cities had almost tripled, increasing by 1249 millions (734 to 1983 million). In more developed countries, about 75% of the population is concentrated in urban areas. On a world wide scale, total population growth during this century has been accompanied by a continuous increase in the ratio of urban to rural dwellers (McPherson, 1974). The average populations increase between 1960 and 1990 was 75%, but in Asia where growth is fastest, the population increases by 158% and in Africa by about 135%. Figure 1 presents the urban population in the world from 1965 to 2000 for the developed and less developed countries. It can be seen from Fig. 1 that the urban growth in developed countries is linear, but exponential in less-developed countries. About half of the world's population live in cities today, and projections shows that by the year 2001 the number of city dwellers will be twice as large as the rural population. Figure 2 presents the number of cities in the world with population above five million inhabitants. The number of cities would have increased to 60. In this figure, values for the year 2000 and 2025 are the projected.

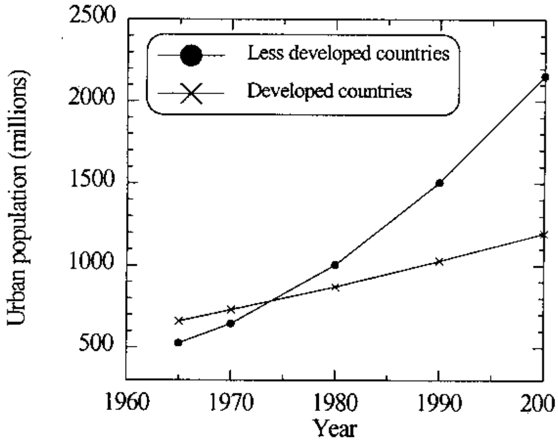

Figure 1: Urban population in world from 1965 to 2000 (Niemczynowicz, 1996)

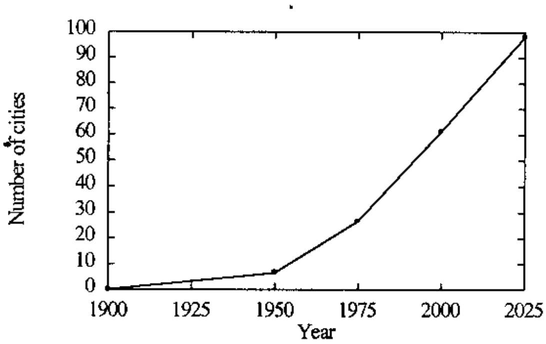

Figure 2: Number of cities greater than five million population in the world (Niemczynowicz, 1996)

1.3 Trends of Urbanisation in India

The rate of urban growth is especially high in developing countries like India. By year 2001, the urban population of India would be nearly 330 million, which is about 33% of the total population. It is expected to be about 405 million (35% of total population) by 2011 and 549 million (41% of total population) by 2021 to live in urban areas. Such increasing trends of urbanisation in India would change the age-old image of India as a rural nation. Urban population growth in India is shown in Figure 3. In this figure, population for the years 2001, 2011 and 2021 are the projected. 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, it can be seen in Figure 4.

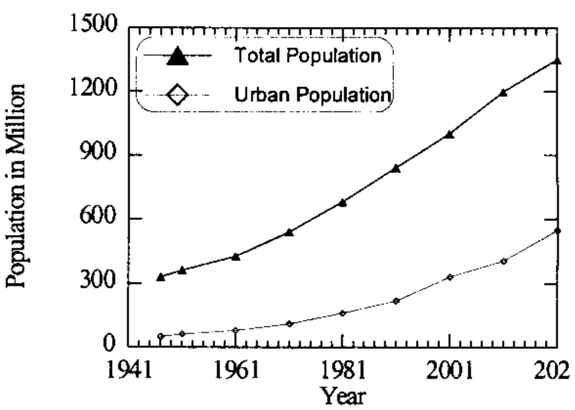

Figure 3: Urban population in India (Suresh, 2000)

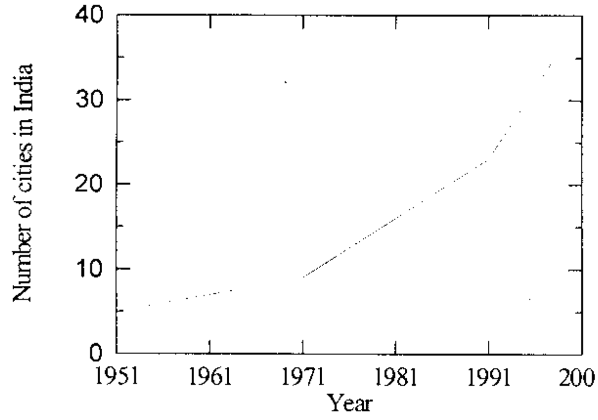

Figure 4: Number of Indian cities with more than 1 million population (Suresh, 2000)

2.0 URBAN HYDROLOGICAL SYSTEM

Figure 5 shows the hydrological system of a typical large sector of land prior to its urbanisation. The hydrological cycle describes different hydrological processes. Various paths by which water precipitated onto the land surface finds its way to the ocean and evaporation gives moisture, thus completing the cycle. Different components of a hydrologic cycle are evaporation, precipitation, infiltration, runoff, streamflow and groundwater. However, due to the effect of the urban environment, the hydrological processes are more complicated. Some of the differences are (Hall 1984),

- Natural drainage systems are altered and supplemented by sewerage systems.
- Effects of flooding are mitigated by different schemes.
- Wastewater disposal scheme exists.
- Water is supplied from remote location.

Figure 5 has been designated as the pre-urban hydrological system in order to visualize the water components for a typical large sector of the land prior to its urbanisation. The complexities imposed on the system of Figure 5 by urbanisation can be appreciated by comparing it with Figure 6, an urban hydrological system. Of considerable hydrological importance is the relative location of an urban centre in the river basin of which it is a part, as well as the degree and character of its hydrological overlap with other urban centres, and their distance from a large lake or an ocean. Because early commerce utilized waterways for transportation, the great majority of metropolises are located on or near major water bodies. Hence, they frequently occupy low-lying ground, and tend to be located near estuaries of major streams or the junction with their tributaries, or along a coast. The advantages of superior water transport, water supply and waste-assimilation capacity through self-purification afforded by many of these locations have since been partly offset by increases in flooding damages and pollution that have accompanied more intensive urbanisation. Further, growth in water-using industries and in mining enterprises has strained capabilities for enlarging community water supplies, and aggravated thermal and chemical pollution. Because total water withdrawals for domestic and industrial uses are expected to climb dramatically over future decades, present problems can be regarded as merely a prologue of what is to come.

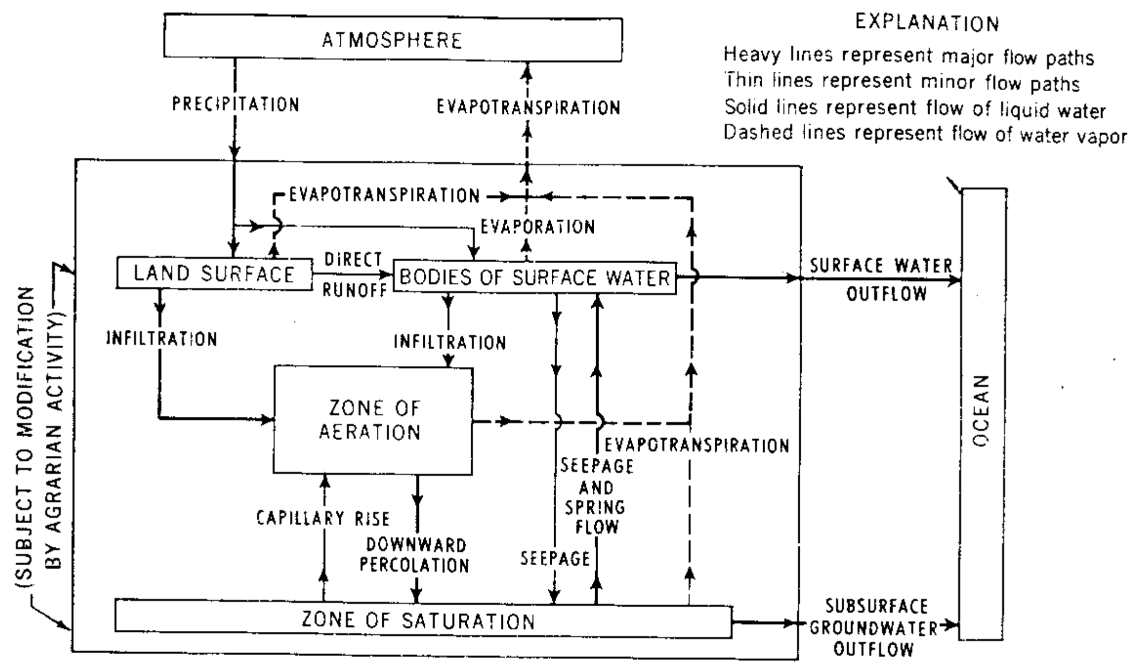

Figure 5 Preurban hydrologic system

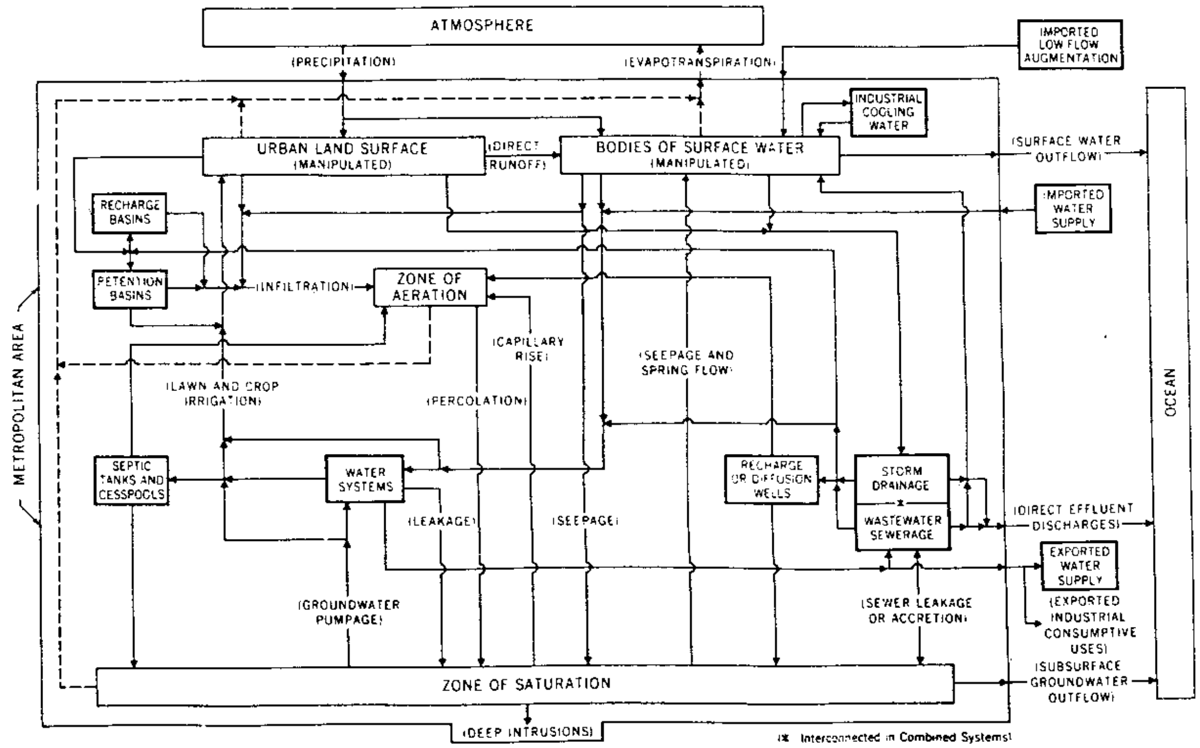

Figure 6 Urban hydrologic system

3.0 HYDROLOGICAL PROBLEMS, CHALLENGES AND ISSUES OF URBAN AREAS

3.1 Hydrological Problems

The following are the major hydrological and related problems of urban areas:

- Supply of clean pure drinking water
- Provision of adequate flows for the disposal of waterborne 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
- Storm water management
- Heat production in urban area
- Sewerage system
- Water quality
- Recycling of waste water
- Sources of urban pollutants
- Lowering of ground water table .

3.2 Hydrological Issues

Various authors have dwelt on major hydrological issues which are as follows:

- Disruption of the natural hydrological cycle due to reduction of infiltration and groundwater recharge, increase in surface runoff and flooding
- Decline in water levels and possible land subsidence due to groundwater mining
- Determination of surface and groundwater quality
- Increase pollutant loads from runoff discharges and sewage outfalls of poor quality
- Leakage to groundwater from old and poorly maintained sewers
- Extensive soil and groundwater contamination from industrial leakage, or spills of hazardous chemicals or poorly planned solid and liquid waste disposal practices
- Increased artificial surface water infiltration and recharge from source control device leading to poor groundwater quality
- Reduction in ecological habitat and species diversity of the receiving water body

- Need for integrated land use and catchment planning.

3.3 Hydrological Challenges

Major hydrological Challenges in urban water management are as follows

- Delivery of drinking water supply for growing cities
- Water for sanitation versus sanitation without water
- Recycling of wastewater nutrients
- Wastewater irrigation
- Storm water management and drainage
- Rain water harvesting
- Artificial recharge of depleted aquifers
- Urban agriculture
- Recovery of resources present in solid and fluid wastes
- Paradigm shift from water disposal and treatment to conservation and recycling of resources
- New programs like dry sanitation
- Major changes in life style and societal structures as well as educational and research programs
- Transfer of knowledge and technology.

The rapid process of urbanisation in India is a challenge for administrators and planners, as well as for technicians and research workers. Since 1970, urban hydrology has played an increasing role as a supporting activity to the design and the implementation of urban water resources systems. Figure 7 shows the physical urban water resources system. In Fig. 7, it should be noted that storm sewers are almost an isolatable part of the urban water resources system. Not shown explicitly in the pictorial representation of Fig. 7 is the interconnection between wastewater collection-treatment and storm sewers, via combined sewers, elaborated upon below. A further enlargement of these activities has to reckon emphatically with the scale and time horizon of the urbanisation process and its water related steps. These scale and time horizons will affect the approach and the particular actions to be taken. Chances to solve these complex problems of urbanised cities depends on economic and social prerequisites of the host country. In developing countries, like India urban populations and accompanying problems grow fastest. A large part of the population lives in slum and squatter areas in bad sanitary conditions, poverty, and misery. In these countries, the priorities for economic development and investment are for food, shelter, clothing, health and education. Urban drainage is generally not taken into consideration except when it affects significantly any of the above factors, particularly as a part of the more general problem of flooding of urban areas. As almost all important cities of India are on the banks of rivers and are subject to flooding. Drainage of urban areas and riverine flood control are generally interlinked. The proposals for urban drainage improvements such as in the Delhi Metropolitan area, Lucknow, Patna etc., can be attributed to such a linkage. Because of financial limitations and because urban drainage problems constitute "negative goods," very little attention has been paid in India to urban drainage.

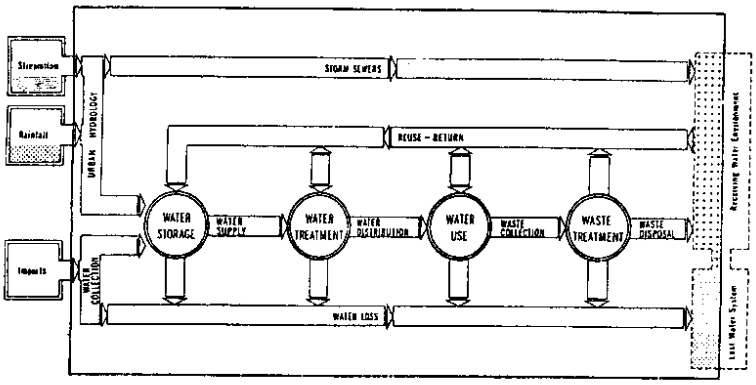

Figure 7: The physical urban water resources system (Zuidema, 1978)

4.0 LITERATURE REVIEW

A state-of-the-art study of the effect of urban development on flood discharges revealed areas of needed research suggested by replies from a national questionnaire and indicated that "too few data have been collected to describe the effect of urban and suburban development on flood runoff. It was recognised that, in general, the volume of flood runoff is increased by the increase in impervious roofs, streets and parking areas, which are a part of urban development. It was agreed that the acceleration and concentration of flood water by runoff from impervious areas, and by the concentration of storm sewers, gutters, catch basins, and channel improvements contributed most to the increased flows experienced in urban. Disclaimers or qualifications to further generalization were stipulated because of the throttling effect of various encroachments, e.g., loss of natural storage from flood-plain development and the wide variety of drainage and flood mitigation development patterns commonly encountered. Examination of available data and of the results of various studies indicates that the most dramatic hydrologic impact of urban development, and the one that has received the most attention, is that on peak flows in streams and storm drains. Comparative studies of urban versus rural drainage basins indicate that as the relative magnitude of flood peaks increases, the ratio of urban peak rate to rural peak rate declines, the effect of urbanization being more pronounced for the more frequent occurrences.

The intensive concentration of large numbers of people in urban areas is characterized by water demands exceeding the sustainable withdrawals that can be obtained exclusively from yields of the portions of catchments occupied by the immediate urban vicinities. The larger an urban complex the greater the hydrologic region that may be impacted in the acquisition of its water supply. Base flows of streams can be raised by wastewater effluents that originated as imported water or can be diminished as a consequence of recharge denied by imperviousness or via surface-water diversions. The increased volume of direct storm runoff resulting from urbanization can reduce low flows because less precipitation is available for soil moisture replenishment and ground-water storage. However, it is evident that the cumulative effects of urbanization on a drainage basin can be either a decrease or an increase in the low flows of streams. Interbasin diversions of water further complicate hydrologic patterns.

Over-exploitation diminishes the overall yield of ground-water supplies as water levels and pressures in ground-water reservoirs progressively decline. Evapotranspiration can be reduced by its denial from impervious surfaces and increase where lawn irrigation is practiced extensively. Yields of portions of aquifers may be increased by leakage of imported water from water distribution systems (Howe, 1971) or they may be decreased by ground-water drainage into wastewater and combined sewers. Part of imported lawn irrigation water and seepage from cesspools and septic tanks can contribute to ground-water recharge. In some communities roof drainage is spread over lawns. Many case histories have been documented that involve a mixture in changes in overall ground-water recharge in the urban environment depending on local situations: 1. It has not been affected; 2. It has increased; or 3. It has decreased.

Water yields can be enhanced by human intervention. Local water yield can be increased inadvertently as a result of greater precipitation in the microclimate or deliberately by means of artificial ground-water recharge, successive multiple reuse, desalination, and weather modification. Stream-regulating structures for amelioration of droughts and protection against floods and seawater intrusion management can have pronounced impact on local urban water yields.

Water quality is surely as important issue as quantity. Major causative sources of water quality degradation in urban areas include: 1. Agricultural storm runoff; 2. Soil erosion; 3. Combined sewer overflows; 4. Industrial process effluents; 5. Heated effluents from electric power plants; 6. Community waste-water treatment plant effluents; 7. Natural drainage from marsh lands; 8. Seepage from septic tanks and cesspools; 9. Urban storm runoff; 10. Oil spills in water and on the land; 11. Contamination from mining activities; and 12. Wastewater discharged due to inadequate or malfunctioning sewer systems. Such degradation inhibits or makes more costly, or both; 1. Use and reuse of urban surface-water and ground-water supplies; 2. Water-oriented recreation; 3. Waterfront use; 4. Esthetic improvements; 5. Commercial fisheries; 6. Shipping and navigation; 7. Wastefowl and sport fish propagation; and 8. A number of other uses and services. The natural dissolved mineral content of water tends to increase in concentration with each successive reuse unless means for its removal are employed prior to a reuse.

Urbanisation and associated human activities have accelerated geological processes of land erosion. Evidence being made available by current research suggests that sediment yields in areas undergoing suburban development can be as much as 5 to 500 times greater than in rural areas" (Task Committee, 1975).

In nearly all great metropolises around the world, every important level of government participates in each major public service category; the proliferation of single purpose agencies dealing with specialized public service has been continuous; and the most common type of metropolitan institution through out the world, by far, is the independent district, corporation, or authority (UNESCO, 1978). Thus, despite the social importance of urban water resources and the substantial investments in associated facilities, we find national, territorial and local governments involved in a tangle of interests. This fragment is one of the reasons why urban water resources research around the world commonly has suffered from inadequate attention and support and from discontinuous and erratic efforts. (UNESCO, 1974). In addition, few local agencies can support hydrological research that will yield results transferable to other metropolitan areas. Noted earlier was that urban drainage has suffered the most research neglect and technical knowledge on it is the most primitive among the various aspects of urban water resources. An important contributing factor is undoubtedly the conventional isolation in the past of the urban drainage subsystem from the total urban water system. New interest in urban drainage performance has arisen at least partly because of a desire to integrate the urban drainage subsystem with other subsystems, such as for water pollution abatement or water re-use. The various countries have prepared a state-of–art-report, which is briefly described.

In USA, It was found that all but a small percentage of urban storm drainage systems were being sized using a completely empirical relation called the "rational method". Limitations of the methods have been discussed at length (UNESCO, 1977). The most analysis and design is still being performed using such empirical methods; however, models are gaining in use, and newly accelerated metropolitan water quality improvement planning activities foretell a possible explosive use of such models in the near future.

For models of the Storm Water Management type and for STORM, average percentage of imperviousness is the most sensitive parameter affecting the estimation of runoff amounts and because of currents indexing of pollutants to street loadings noted below, street gutter density is the most sensitive parameter affecting estimates of pollutant loadings. With the increase interest in metropolitan studies, it is not surprising that generalizations are being sought between these two variables and type of land use (Graham, 1974). Because of the very limited amount of field data available, just about all sewer application model verification has been for total catchment resaponse, at a single flow measurement location. That is, under contemporary conditions a distributed model deteriorates into a lumped system model, for all practical purposes. In USA, calibration and verification are further confused by the fact that much more field data is available for partially sewered catchments. Adding streamflow hydraulics to sewer hydraulics hardly simplifies the lumped system dilemna, yet much of the data used to verify various models has been from such mixed catchments. Relatively few runoff-quality field gauging have been made in USA, and these have been mostly in outfalls. Source quality have been investigated principally as a function of street surface pollutants accumulated between rainfalls. In order to accommodate cause-effect relationships required for modeling, it is current practice to estimate potential street loadings, separately for individual parameters, on the basis of the few documented solids accumulation histories. Arbitrary allowances are then added to account for off-street contaminant accumulations, expressed as multiples of the potential street loadings. Thus, no direct verification of the hypothesized buildup of pollutants and their transport to receiving waters is presently available. It is reasoned that when pollutographs generated by models reasonably approximate field observations for a catchment, that the overall accumulation and transport hypothesis is validated. In order to resolve the lumped system hydrologic dilemna and truly validate the pollutant accumulation and transport hypothesis there is a major research need for simulation measurement of rainfall, runoff and quality at inlets and various collections may yield new process insights in the near future (UNESCO, 1977).

Although Australia is sparsely populated, it is a highly urbanised nation. With two-thirds of the population in 12 urban centres, Australian cities present similar urban hydrological problems to those existing in more highly populated countries overseas. Another notable factor concerning Australian cities is that it has been the practice, almost without exception, to separate the stormwater drainage system from the wastewater sewer system. This situation is of course in direct contrast to that existing in many of the older cities in the United Kingdom, Europe and the USA.

Storm Water Management Model (SWMM), developed by the US Environmental Protection Agency, is a package of models linked together and divided into a number of blocks. It is a comprehensive model covering both quantity and quality aspects. However, it is unwieldy to apply in Indian hydrological conditions. Design of urban drainage system in India is based on rational formula, because of lack of adequate continuous records of precipitation and stream flow (UNESCO, 1978). Ramaseshan (1983) has also reported that the urban hydrologic problems of India differ from those of developed countries in several important points such as lateral rather than vertical development, limited amounts of paved area, initial interaction between urban drainage and flood control, preference for open drains over closed ones, limited availability of continuous records of precipitation, stream flow and water quality, limited number of sewer connections and hence shifting of combined sewer, high cost of construction and modification and limited capacity of financial investment. The urban drainage index adopted in urban storm water runoff modelling of Rohini, Delhi was 3.5 cumec/sq. km with 35 mm/hr rainfall intensity with once in two years recurrence interval. Since the rate of urbanisation in Rohini is expected to increase from 55 % to 84 %, the urban drainage index needs to be modified to 5.5 cumec/sq km (Chakraborti, 1989). Yen (1987) has presented the evolution of urban storm drainage technology by a schematic diagram as shown in Figure 8.

The Runoff Routing Model (RORB) and the Storm Water Management Model (SWMM) were evaluated for the purpose of storm water drainage design and management in an urban catchment in Singapore by Selvalingam et al (1987). It was found that suitable division of the drainage area into sub-area and the storm into bursts were essential for proper simulation of the catchment runoff using RORB. The nonlinear roouting procedure is one of the main features of the model. SWMM is a sophisticated model capable of taking into account a very comprehensive range of parameters. They concluded that the SWMM model is a good replacement for the Rational model used and can be incorporate without much difficulty to simulate urban drainage systems in Singapore. Driver and Troutman, (1989) has developed a regression models for estimating urban storm-runoff quality and quantity in the United States. In this model, the total storm rainfall and total contributing drainage area were the most significant variables. Other significant variables in the models included impervious area, land use, and mean annual climatic characteristics. Models for storm-runoff loads of dissolved solids, total nitrogen, and total ammonia plus organic nitrogen as nitrogen provided the most accurate estimates, whereas models for storm-runoff loads of suspended solids provided the least accurate estimates. The most accurate models were those for the more arid western United States, and the least accurate models were those for the wetter coastal northeastern and southern United States. Information about other explanatory variables, including antecedent dry days, rainfall intensity, other specific land uses, traffic density, street density, and average basin slope, should be considered as it becomes available to improve the accuracy of the models, especially in region III. Authors also suggested that generally the storm-runoff-volume models were more accurate than the storm-runoff-load models. Arnbjerg-Nielsen and Harremoes (1996) has proposed a method to assess the relative importance of the individual contributions to the overall uncertainty based on an analysis of the Monte Carlo simulations. They found that the risk of flooding depends mainly on the uncertainty in the description of the rainfall field. This uncertainty is also of major importance when annual discharges are evaluated, but the uncertainty of the surface runoff was also found to be very important. Uncertainty of the evaluation of extreme loads of COD in receiving waters was dominated by uncertainty of the COD concentration in the urban storm water. If the sewer system is poorly maintained, the uncertainty of the assessment of the hydraulic resistance in the sewer pipes may become very important in the evaluation of the risk of floodind. Barbe et al (1996) has developed an urban stormwater quality model. This model represents a combination of conceptual approaches. It is much easier to apply than the deterministic model. The model allows for the analysis of long term pollutant behavior and the impacts of land use changes on pollutant runoff from an urban area. It had been pointed out that in many cases, the method of rating curves is used to estimate pollutant loads washed off by storms. This model simulates transport capacity of storms. If it was used to predict runoff quality in areas with frequent storms like the two studied watersheds, pollutant loads will be overestimated due to the supply-limited nature of the process in these area.

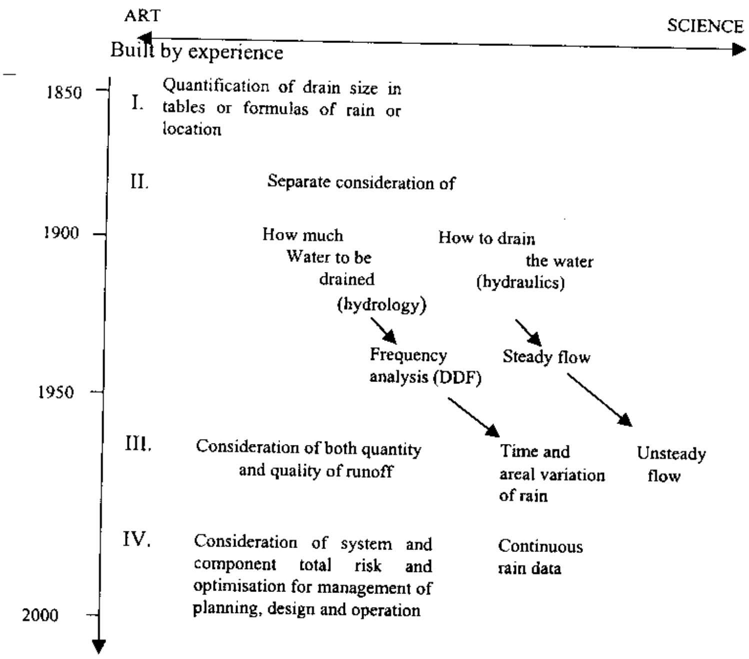

Fig. 8 Evolution of urban storm drainage

5.0 IMPACT OF URBANISATION

5.1 Climate

Rapid population growth and expanding economic activity are already putting enormous pressure on global water resources. The growing cities and towns alter surface of the ground. Therefore the radiation balance of the area is modified and resulting in the change in the aerodynamic roughness affects air motion. Broadly the industries, buildings and water borne pollution influence the urban climate.

Heat is added to the atmosphere by industrial heating processes and by motor vehicle. Thermal power stations and other industries use coal, diesel, wood, kerosine or other fuel as energy source. Air pollution occurs through coal and wood burning for fuel. Due to non-availability of regular electric supply, the residents have to install heavy generator sets run on diesel, kerosene or petrol. These generator sets are also installed in most of the business establishments. With electricity cut being so frequent, the use of generators create pollution by their exhaust emission containing carbon monooxide, sulpher dioxide, led, nitrogen dioxide, ozone and particulate matters. Dust particles in the climate along with sulpher dioxide and other gasses reduce the clarity of the atmosphere, thereby decreasing the amount of incoming radiation and sunshine.

Due to higher thermal conductivity and greater heat capacity of the buildings, compared with those of vegetated areas, the thermal properties of urban areas contrast strongly with those of their rural environment. Heat is also added to the atmosphere by industrial heating processes and by motor vehicle. The buildings induce mechanical turbulence in the air movement. When coupled with the thermal turbulence, which results from urban heat production, the structure of the city may be seen to exert a considerable influence on air movement. According to climate models, rising levels of greenhouse gases are likely to raise the global average surface temperature by 1.5 - 4.5°C over the next 100 years. Changes in temperature and in winds would clearly have profound effects on the water cycle.

5.2 Streamflow

The population density increases as urbanisation progresses. Therefore, the total demand of water increases. Due to the high standard of living, the per capita demand also increases. Thus, the demand of adequate water resources increases. The amount of water borne waste increases in response to the growth in the population. This results in an increased load entering the river systems and oceans downstream of urban areas with a resultant increased stress on the assimilative capacity of these aquatic environments.

Urban water supply scenario in India (Suresh, 2000)

Access to drinking water

- Within their houses : 58 %
- Within a distance of 0.5 km : 40 %

Water available in urban slums : 27 lpcd (litre per capita per day)

National targets

- Urban area where piped water supply and underground sewerage system available : 135 lpcd
- Urban area where piped water supply available but underground sewerage system not available : 70 – 100 lpcd
- Towns with spot sources or stand posts : 40 lpcd

Increasing water scarcity

- National average of water availability is estimated at 2464 cubic meters of water per capita per year.

- From as high as 18417 cubic metres in the Brahmaputra valley, per capita water availability comes down to a low of 411 cubic metres in the east flowing rivers between Pennar and Kanyakumari.

Figure 9 shows the general trend of declining availability of water per capita per year in India. The values for the year 2000 onward are the projected values. It has reduced from 6000 to 1200 per capita for the period of 100 years.

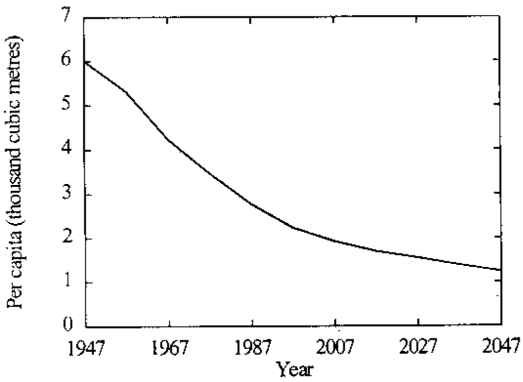

Figure 9: Declining availability of water per capita in India (Engelman and Roy, 1990)

Impervious area

Depending on the percentage of land use, urbanisation may be classified into 4 categories viz. 1. Rural; 2. Early urban; 3. Middle urban and 4. Late urban. The building density increases in the progresses of the urban environment from one category to the next. The surface is modified drastically due to the increased building density as a result of construction of roads and parking lots. Therefore, the extent of impervious area increases resulting in less infiltration and consequently, more runoff. Less infiltration results in less groundwater recharge and more surface runoff. Associated with impervious surfaces is a decrease in surface roughness and presence of constructed drainage systems which results in the runoff flowing with higher velocities compared to the natural condition. Thus, a higher volume of flow takes place within a shorter duration and peak rates of flow inevitably increased. This results in the problem of stream drainage and floods in the urbanised area. Figure 10 shows the change in the response of runoff due to urbanisation in a region.

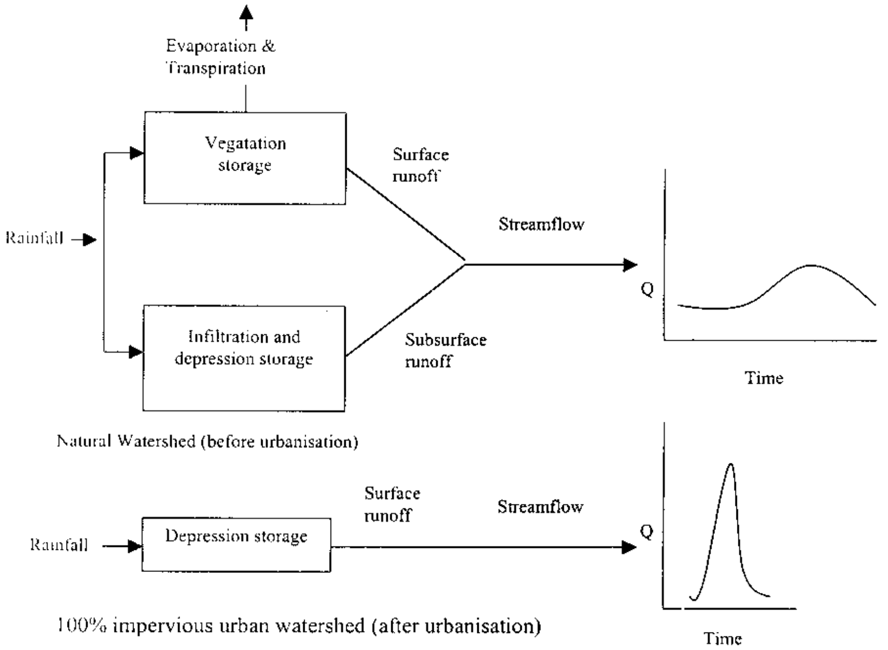

Figure 10: Comparison of stream flow patterns for natural and urban watersheds (Lazaro, 1990)

Water quality

The rise in population density and increase in the extent of impervious areas affect the water quality aspects of the urban hydrological cycle. As the runoff volume is more, and the amount of soil moisture recharge is reduced, less water will percolate and low flow will decrease. In addition, the volume of waterborne wastes increases. Therefore, the quality of storm water runoff deteriorates. The factors, which influence the quality of water within an urban area, are shown in Figure 11. Contaminants are washed away from roofs, streets and roads. Soluble particles go into solution and particulate matters are dislodged. The processes of washing of surface contaminants are:

- Freeing the contaminants from the surface;
- Transporting the particles transversely across the surface to a gutter;
- Transporting the particles parallel to the curb line to the storm sewer;
- Carrying the particles through the storm sewer.

The disposals of solid and waterborne wastes also have an adverse effect on the ground water quality.

The entry of pollutants into a flowing stream sets off a progressive series of physical, chemical and biological events in the downstream waters. The character and quantity of polluting substance govern their nature. After entry into the stream waters, sewage acts as an excellent food source for bacteria, and logarithmically stimulates their growth. As they multiply, they require large amount of dissolved oxygen. They exert a high BOD value thereby decreasing the streams supply of DO with a resultant impact on the ecology of the stream. The resultant ecological impacts are as follows:

- Aquatic ecology upset;
- Earlier organisms die/move;
- Low in DO region is created;
- Septic region occupied by bacteria;
- A predatory relation exists between ciliated protozoa and bacteria;

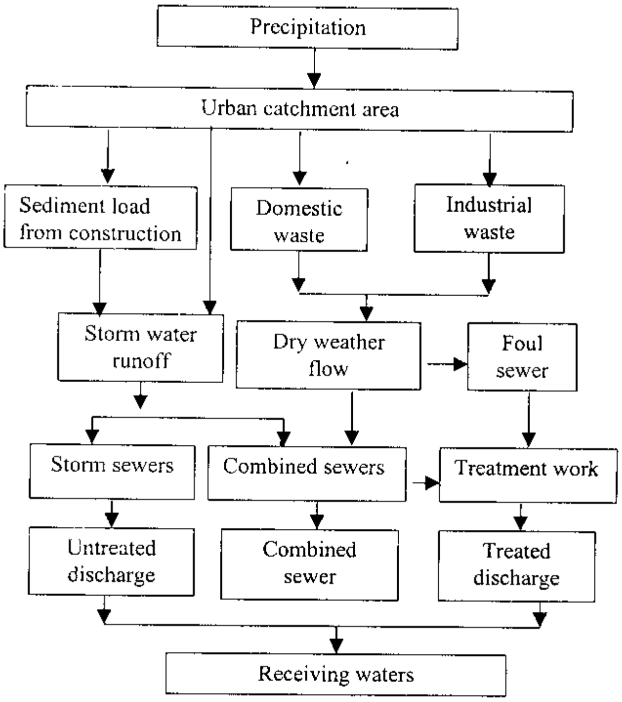

Figure 11: Water quality changes in urban areas (Hall, 1984)

5.3 Mountainous region

Population growth in the Himalayan region has led to an increased demand for food, which has been met by the increased use of fertilisers and the expansion of agricultural land. These changes modify the quality and quantity of river flows downstream from the affected areas and therefore have a regional as well as a local impact. In the Himalayas, nitrate and sulphate concentrations of similar magnitude to those observed in NW Europe have been reported in snow samples. In general, the waters from these catchments have high background concentrations of sulphate, calcium and bicarbonate, all derived from bedrock weathering sources.

6.0 URBAN WATER MANAGEMENT

In the previous section the adverse impacts of the quality and quantity of storm water due to urbanisation have been described. Therefore, urban storm water management (USM) is necessary to tackle these problems. Urban storm water management describes a group of techniques whose common aim is the mitigation of adverse effects to the quantity and quality of urban runoff. The common practices in urban storm water management are presented in Table 1. Hierarchy of the water resources management system is shown in Figure 12.

As previously discussed, the flow quantity is adversely affected by urbanisation with associated increase in the suspended sediment. This increase in suspended sediment may produce changes in the downstream channel network. Owing to the changing flow regime brought about by urbanisation, predevelopment bankful discharge will occur more frequently. Therefore, enlargement of channel will take place. The extent of the enlargement reduces the visual appeal and the recreational value of the stream. The costs for remedial work are also very high. The drainage engineer's response to the changes in the channel network brought about by urbanisation has often been eminently predictable. Attempts have been made to improve the capacity of the channel by adjustments to its alignment, slope and cross-section and to reduce bank erosion and bank instability by lining and the placement of riprap.

Table 1: Stormwater management practices (Hall, 1984)

Type of measure	Quantitative	Qualitative
Structural	-Channelisation -Balancing Ponds -Recharge Basins -Rooftop Storage -Porous Pavements	-Effluent treatment at source -Balancing Ponds -Recharge Basin
Non–structural	-Preservation of local landforms -Flood plain Zoning	-Street sweeping -Gully Cleaning -Anti-litter legislation -Control of de-icing

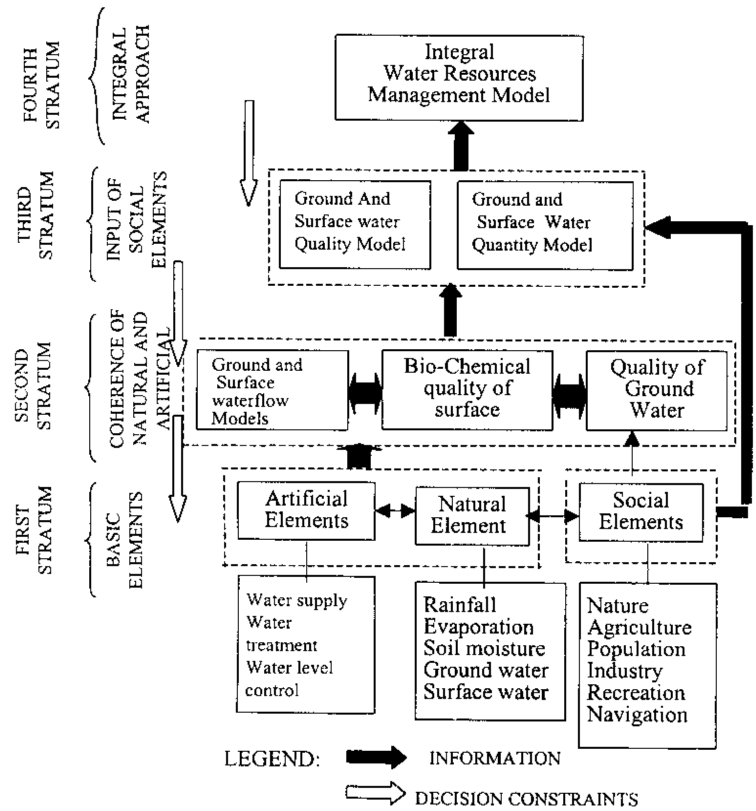

Figure 12: Hierarchy of the water resources management system (Zuidema, 1978)

The most four important consequences of channelisation from the environmental viewpoint are as follows:

- vegetation removal
- channel deepening
- meander removal
- destruction of pools and riffles.

Most of the large cities are already facing acute shortage in water supply. Now a days rainwater harvesting is becoming very popular for this purpose. The rain water harvesting can be done through:

- Individual house
- Percolation pits (individual house)
- Pebble bed (building complexes)
- Ponds
- Ditches and furrow storage
- Recharge wells

The rapid increase in population and consequent increase in activities all round, has led to occupation of the flood plains resulting in increased flood damage. A flood storage pond represents an attempt to replace the natural storage capacity that has been lost through urbanisation. Since the flood storage pond is concentrated at a single site but the natural storage capacity was distributed through out the catchment area, a regional perspective is required in the design of such installations in order to ensure that ponds do not worsen rather than lessen downstream flooding problem.

Unlike channelisation, flood storage ponds may have a beneficial effect on the water quality by the removal of particulate matter by settlement. Unfortunately the bulk of the pollutant loading carried is liable to be carried by the large numbers of small and medium size storms, where as the major flood damages result from the larger, more infrequent events. In contrast to flood storage ponds, whose principal function is to reduce the peak rate of inflow and to redistribute the runoff volume overtime, recharge basins are intended to contain the whole of the storm hydrograph for subsequent recharge to underlying aquifers. Such basins are therefore confined to regions that have reasonable permeable surficial deposits and a water table that is sufficiently deep to remain below the floor level of the urban area. In addition to augmenting local ground water reserves, recharge basins may also effects considerable savings in the cost of outfall sewers. Of the structural methods, the uses of rooftop storage and porous pavement is largely confined to more localised applications.

In general, non-structural storm water management practices involve some element of either prior planning or continual maintenance. In an area with mature drainage network, the streams meander through natural flood plains located between spurs through out from the watershed. The hill slopes located between these ridges and the valley floors are well drained and provide choice sites for development. Encroachment of the flatter flood plains in the valley floors is thereby avoided, and the need to undertake costly flood alleviation works are greatly reduced.

For the management of urban water quality, that of effluent treatment at source is perhaps the most obvious structural method, but also the most inflexible because of its inability to cope with rapid changes as runoff changes. In contrast, balancing ponds and recharge basins can serve to control flood flows as well as provide an opportunity for the settlement of waterborne solids. The non-structural methods for water quality management are predominantly concerned with preventing the entry of dust and dirt into the drainage network. Street sweepers are relatively inefficient at removing the fine solids. Fraction of street dirt, which has been found to account for a significant proportion of the pollution potentials. Road gullies are similarly ineffective in retaining the finer solids for subsequent removal. As can be seen from preceding discussion. There are a wide variety of alternatives for the management of urban storm water. The selection of the best alternatives is achieved generally through the development of a catchment wide Storm Water Masterplan (Hall, 1984). Such a plan considers all impacts of Storm Water runoff and its management.

6.1 Storm Water Masterplan

The steps in the development of a storm water masterplan are as follows:

- Definition of Goals and Objectives

  This steps defines the stockholders in storm water management and their desired goals in the management;
- Definition of Principles

  Defined in this step are the responsibilities of authorities, organisation and people in storm water management;
- Constraints

This step considers constraints on alternative management plans. These constraints may be hydrologic and hydraulic such as in the capacity of the drainage system, financial such as in the cost of the drainage system, legal such as in the legally defined requirements of a drainage system, or social such as the acceptability of the proposal;

- Strategies

  In this steps strategies for implementation of the management plans are outlined. It should be noted that these strategies are not prescriptive but rather are flexible and subject to constant review and change as necessary;

- Assessment Criteria

  This step defines how the success of the strategies can be assessed. Changes to the strategies are based on these criteria.

7.0 URBAN WASTE WATER MANAGEMENT

In most urban areas in India, the water is heavily polluted with domestic sewage, industrial effluents and solid wastes. The principal organic and inorganic contaminants are: acids, alkalis, carbohydrates, dyes, fats, soaps, waxes, gases, suspended matters, oils, toxic metals, and pesticides including radioactive materials and heated effluents that impose thermal loading on receiving waters. Only 209 of India's 3119 towns and cities have even partial sewage systems and treatment facilities (Mukherjee, 1999). Consequently many urban rivers have steadily deteriorated in quality although on a national scale ambitious projects have been started to reverse this trend. The status of urban sanitation at the end of the eighth five year plan is given in the Table 2.

Table 2. Status of urban sanitation (as on 31.03.97, Shukla, 1999)

Percentage population provided with sewerage and sanitation facilities		
Sewer (%)	On-site Sanitation (%)	Total (%)
28.21	21.11	49.32

Wastewater management is a serious problem in major cities of our country. The amount of water, which gets into an urban centre's system finally empties out as sewage and drainage water. These pollute both surface and subsurface water resources in the region.

Figure 13 indicates the status of the wastewater generation and its treatment in 6 mega cities in million litre per day.

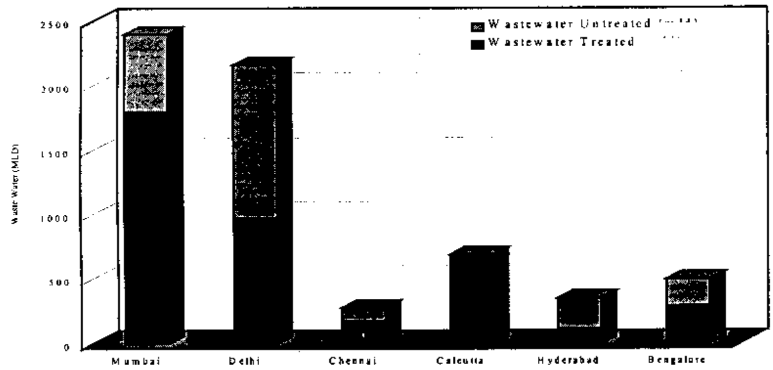

Figure 13: Wastewater management in the mega cities (Shukla, 1999)

A very huge quantity of solid waste is generated by the Indian cities and it is estimated that only sixty percent of it is collected. The uncollected solid waste fills open space, drains and roads and it is a major cause of the insanitary conditions and diseases. The scenario of solid waste management in 6 mega cities (in mt/day) is shown in Figure 14.

8.0 COMMON URBAN HYDROLOGY MODELS

Several researchers have proposed and developed mathematical model for estimation of runoff from non-linear reservoirs in an urban drainage basin. These models are as follows:

RRL: (Road Research Laboratory Method and Illinois Simulator) an urban runoff model that utilise the time –area runoff routing method. It was developed in England and described by Watkins 1962. The technique was developed specifically for the analysis of urban runoff and ignores completely all pervious areas and all impervious areas that are not directly connected to the storm drain system; hence estimates of peak flow rates and runoff volumes are likely to be low.

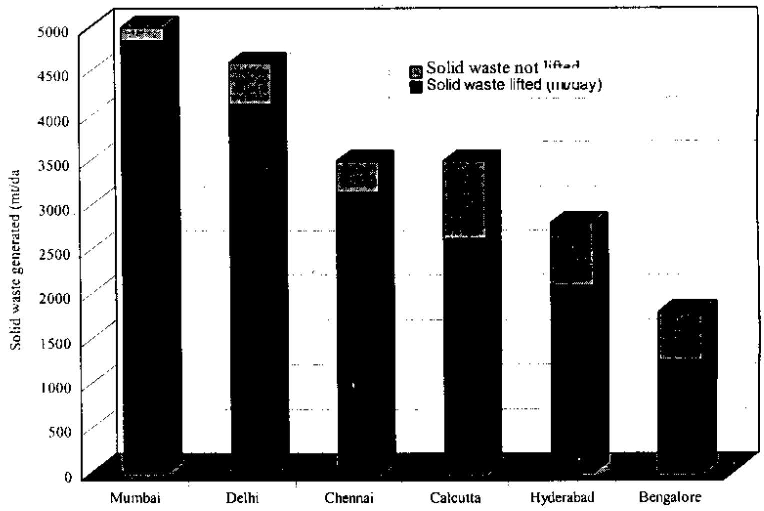

Figure 14: Solid waste management in mega cities (Shukla, 1999)

SWMM: (Storm Water Management Model) A very widely accepted and applied storm runoff simulation model was jointly prepared by Metcalf and Eddy 1971, Inc., the University of Florida, and Water Resources Engineers for use by the U.S. Environmental Protection Agency (EPA). This model was designed to simulate the runoff of a drainage basin for any predescribed rainfall pattern. The total watershed is broken into a finite number of smaller units or subcatchments that can be readily described by their hydraulic properties.

ILLUDAS: (Illinios Urban Drainage Area Simulator) developed by Terstriep and Stall (1974). This model is an improved version of RRL that has a wider range of capabilities. It incorporates the impervious area neglected by RRL and is a demonstrated improvement over RRL.

UCURM: (University of Cincinnati Urban Runoff Model) This model is developed by the Division of Water Resources, the Department of Civil Engineering, of the University of Cincinnati in 1972. It is similar to EPA model and divides the drainage basin into subcatchments whose flows are routed overland into gutters and sewers pipes. Starting at the upstream inlet, the flows are calculated in successive segments of the sewer system, including discharges from inlets, to produce the total outflow.

EDI-QUAL-I: is developed by Willis, Anderson and Dracup (1975) and the modelling procedure consists of breaking up the riversystem into reach and routing the governing over each reach and finally determining initial concentration of conservative and nonconservative constituents for each reach.

HEC-1: (Flood Hydrograph Package) is designed for the simulation of flood events in watersheds and river basins. Similar model has been developed by Kidd, (1978); Falk and Niemczynowicz (1979) to simulate rainfall-runoff, which are applicable on small, impermeable urban catchments.

HYROM: developed by the Institute of Hydrology (1989), is designed to produce hourly estimates of streamflows from hourly catchment rainfall and potential evaporation derived from meteorological data using the Penman formula.

GIUH: Gupta (1983) and Bhatacharya (1995) have developed similar numerical models for simulation of rainfall-runoff processes in urban catchments.

FLAPS: (1995) is developed for rainfall-runoff simulation that considers system both as a lumped or distributed system.

The above mentioned models have been practised by many researchers over the years and they are improving gradually by introducing one or more effective parameters.

9.0 INTEGRATED URBAN WATER MANAGEMENT PROGRAMME OF IHP-5

The International Hydrological Programme of UNESCO in the fifth phase (1996–2001) focussed on Hydrology and Water Resources Development in a vulnerable environment covering 8 themes. In theme 7, integrated urban water management is covered with following aims:

- To improve the management of existing urban drainage system through an integrated approach;
- To disseminate knowledge on integrated urban water management;
- To analyse the effectiveness of non-structural flood control measures such as: flood warning systems, flood plain zoning, flood plain insurance and relocation in reducing damages as an alternative to structural measures (contribution to IDNDR through pilot projects);
- To identify the impact of urbanisation on surface and ground water quality through point and non-point pollution;
- To establish experimental urban catchments and to create a world-wide data base for comparative urban hydrology studies concerning megacities as an extension of the FRIEND approach;
- To create access to available technology for developing countries through the establishment of regional centres of excellence in different climatic zones;
- To study impacts of storm water (wastewater discharges) on ecosystem health of receiving water courses in all parts of the world;
- To assess feasibility of drainage source controls designed to replicate the natural hydrology of area as closely as possible;
- To consider the need of urban inhabitants for reasonable land use.

The proposed plan of the 6th phase (2002-2007) is focussed on water interaction – systems at risk and social challenges. The urban hydrology area is covered under theme 3 and it has the following main aims and activities:

- To address the processes and strengthen research into urban water systems interactions in particular climate regions;
- To develop and apply appropriate modelling tools for analysis of interactions;

- To create conditions for multidisciplinary interactions, appropriate transfer of knowledge and technology and for running training programmes for water managers, urban planners and sanitary specialists, in connection with Theme 5;
- To search for low cost technology for brackish water reclamation.

Activities:

- Efforts for urban water demand management under scarcity conditions;
- Acquisition of remotely sensed data-particular needs of urban areas in arid and semi-arid regions;
- Study of water re-use in human settlements;
- Study on urban groundwater problems;
- Consideration of urban sedimentation management-interaction of water, sediment and solid waste;
- Perspectives of urban runoff harvesting;
- Detailed water balance study in urban areas;
- Study of the aquatic habitats in urban areas of the humid tropics;
- Acquisition and processing of high resolution (terrain and land use) data for urban water needs and urban water data (reliability, robustness, availability);
- Hydrological, biological and chemical processes in urban water environment for sustaibnable cities of the future;
- Development of urban water amenities systems (urban ponds, enclosed water bodies, coastal areas);
- Development of innovative techniques for integrated urban water modelling;
- Hydrological processes (surface, underground and receiving water) in urban areas under wintry conditions;
- Interactions of urban water sub-systems under wintry conditions;
- Performance of source control, urban amenity and urban ecological habitats system under wintry conditions;
- Modelling of urban water interactions in cold climate regions.

10.0 CONCLUSIONS AND GENERAL REMARKS

With the growth of the population and increase in industrial development activities, there is general tendency of shifting of population from rural to urban areas. The planning, development and management processes of urban settlements have to keep pace with this scenerio and take necessary measures for supplying water, sanitation and waste disposal facilities. As the gap between demand for services and availability is quite significant, there is rise in density of slums and squatter settlements, which have neither sewerage, nor adequate storm water drainage and often inadequate water supply. Such, often unplanned growth of urban townships and mega cities poses threats to both the availability and quality of surface water and groundwater resources.

The management and control of water quality within large urban catchments demands an integrated and interdisciplinary approach involving engineers, scientists, ecologists and planners. Forecasting environmental risks and the design of mitigating measures to reduce them is, however, prone to much uncertainty due to factors such as extreme spatial variability of land use, land cover, the heterogeneity of the geologic materials and difficulties associated with the description and parameterisation of the coupled flow, transport and chemical transformation processes involved. An interdisciplinary perspective with proper understanding of fundamental principles and ecological awareness, as well as changes in attitudes to water resource exploitation and pollution are necessary if sustainable urban development is to be achieved.

There is need for increasing development and application of scientific modelling approaches for urban hydrology studies, to consider various present and future scenerios for ensuring proper, sustainable development and management of urban areas.

In India, not much work has been done in the field of hydrological modelling of urban watershed; storm water management and urban water quality. Various models have been used in the past like SWMM, ILLUDAS, RRL, and TR-55 in the western country for simulation of runoff for a urban drainage basin and estimation of peak flow. More emphasis is needed in the area of urban ground water problems, runoff harvesting and integrated urban water modelling. A beginning has been made but still lot of efforts field studies are needed to verify/implement the urban hydrological models.

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