Hydraulic Effects of Urban Development to Floodplains in Dhaka, Bangladesh

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Introduction

Urbanization causes land use change and increase impermeable land cover of urban area, which changes the characteristics of hydrology of a city or a town. In undeveloped areas, such as areas of rural characteristics, farmland, forests and grasslands, rain water is collected and stored on vegetation, in between the soil particles or soil column, or in surface depressions. When this storage capacity is filled, runoff flows slowly through soil as subsurface flow. In contrast, urban areas much of its land surface is covered by roads and buildings have less capacity to store rainfall. Construction of roads and buildings often involves removing vegetation, soil, and depressions from the land surface. The permeable soil is replaced by impermeable surfaces, such as buildings, roads, roofs or terrace, parking lots, sidewalks or any other paved areas reduce infiltration of water into the ground and accelerate runoff to the nearby low- lying areas, lakes, canals or rivers. Dense networks of brick and concrete drains and culverts in the cities reduce the distance that runoff must travel overland or through subsurface flow paths to reach streams and rivers. Once water enters a drainage network, it flows faster than either overland or sub-surface flow.

In the last three decades, growth rate of urbanization in Dhaka city was very high. Uncontrolled urbanization has always the possibility of encroachment into floodplain areas or the depressions of the city. In the last two decades, Dhaka city has expanded in the low lands of its surroundings, especially towards the east and the west. Hence, under an environment of weak development control, people recklessly filled up natural drainage channels for their new settlements. During 1990-2000, about 270 sq km of wetlands in and around Dhaka city were filled up. Due to encroachment, earth filling, deposition of city garbage in natural canals and lakes and construction of buildings, roads etc. in an unplanned and uncontrolled way, hydrologic characteristics have been changed vigorously. With less storage capacity for water in urban basins and more rapid runoffs, urban streams rise more quickly during storms and have higher peak discharge rates than do rural streams. In addition, the total volume of water discharged during a heavy rainfall tends to be larger for urban streams. Therefore, changes of hydrological characteristics of Dhaka city increased the propensity of internal flooding in the study area. Few phenomena worked together with the urbanization process of Dhaka City as per as 'urban hydrology' is concerned. These are:

- Increased impermeable surfaces with the faster pace of urbanization
- Shrank of pathway of rivers and canals
- Disappeared lot of canals and their small branches
- Changed hydrological characteristics of urban hydrograph; increased storm water runoffs, peak discharge etc
- Lost water detaining areas due to land filling for expanding new urban areas.
- Taking the leverage of weak development control of the concerned authority, urbanization has taken place in the surrounding depressed areas of the city or illegally occupying the khash land of natural canals and rivers.

In addition, building construction with no/ inadequate provision of drainage, blocking of main natural drainage systems of the urban area by unauthorized constructions, insufficient storm-water sewer system in the extensions to the urban area, lack of maintenance to the system and lack of co-ordination among the different organizations engaged in urban area further worsens the situation. Development along the water channels[1] and floodplains can alter the capacity of a channel to convey water and can increase the height of the water surface. Besides, sediment and debris carried by floodwaters can further constrict a channel and increase flooding. Small stream channels can be filled with sediment or become clogged with debris, because of undersized culverts, for example. This creates a closed basin with no outlet for runoff.

Planners in Bangladesh always demand for recover of canals, stress on planned urbanization by ensuring proper zoning of flood plains, urgent implementation of retention ponds, restoration of abundant channels, dredging of rivers and streams, building of efficient storm sewer systems, establishment of buffer zones along rivers etc. By ensuring a proper water management plan for cities can prolong their sustainability.

The major objectives of this paper are to identify the aspects of hydraulic changes of urbanization and changes of land use on the floodplains of urban areas of Bangladesh, and discuss the impacts of hydraulic changes due to urban development. This paper deals with the relationship between urbanization and hydrologic changes in the process of land use changes by urbanization process.

Explaining the Concepts and Definitions

Few concepts are extremely necessary to discuss before entering into the main discussion of this paper. The components of urban hydrology, wetland, floodplain, flood flow zone etc. carry operational and theoretical significance in the planning practice.

Urban Hydrology and Its Components

Process of urbanization changes the hydrology of a drainage basin in urban area. Hard and artificial surfaces cut down infiltration and storage while storm sewers speed up the flow of water into the drainage channels and subsequently rivers. It is suggested that urbanization increases the risk of flooding as rivers respond much more violently to a storm event. Generally, there are five categories of components that involved with the urban hydrology. Here components are explained considering the example of Dhaka City's hydrology.

- Internal canals; those created naturally or artificially and linked with the wetland or depression areas or rivers of the surrounding. Most of the time, the canals are connected with the rivers, depression areas around the city or the lakes. For instance, Kollayanpur khal, Ramchandrapur khal, Begunbari khal and other canals etc in Dhaka city (Figure 1).
- Rivers or open channels; those are linked with the bigger water channels. These fluvial water bodies include the surrounding rivers (Turag, Buriganga, Balu River and Tongi Khal) of the city.
- Pond, ditches and lakes
- Depression areas or wetland; those are naturally low land areas around the study area connected by drains and contains the rain water in the wet season. These water bodies comprise marshy and peaty inundated (during significant part of the year) low-lying areas of the Turag-Buriganga and the Balu floodplains.
- Artificial Drainage Network; has also a significant role connecting the natural water bodies, wetland and rivers.

[1] Water Channel is the bed of a stream or river. It is the deeper part of a river or canal or stream especially a deep navigable passage. Water channel may be natural and artificial, or both.

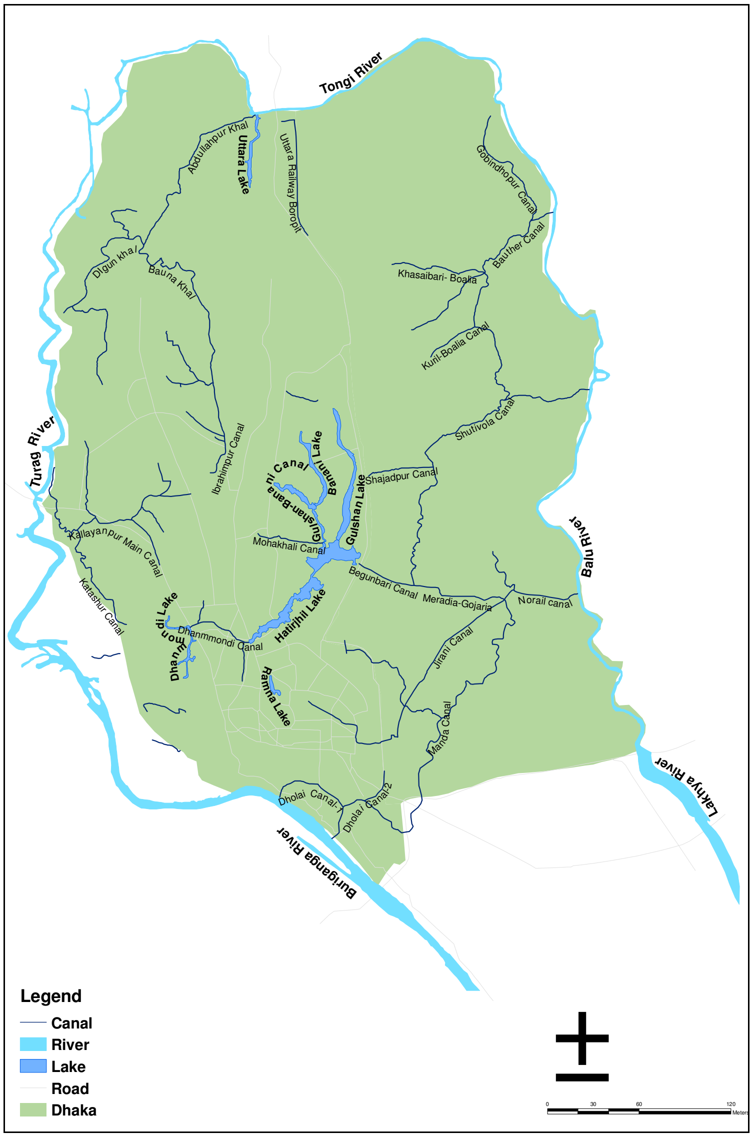

Fig 1: Map of the major water bodies in and around Dhaka City

Wetland: In the Ramser convention Rivers and canals are defined as wetland. As the signatory of this convention Bangladesh has the obligatory to conserve the wetland of the country[2]. The RAMSER convention has defined "*wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or*

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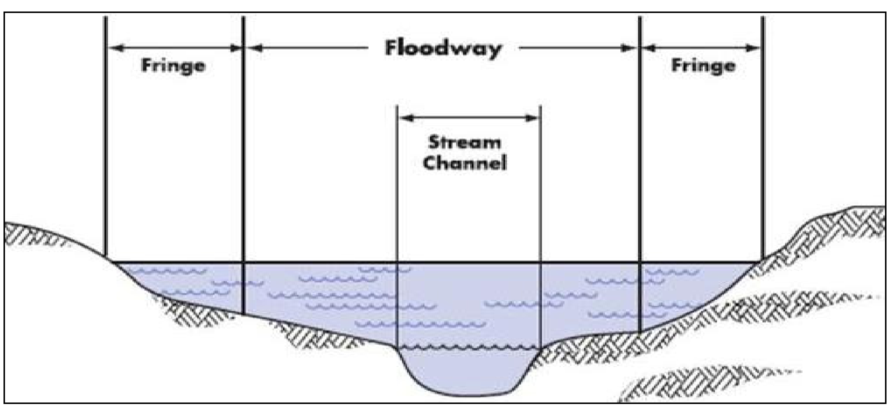
2 The Convention on Wetlands, held in Ramsar of Iran in 1971, known as *Ramsar Convention* which is an inter-governmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the "wise use", or sustainable use, of all of the wetlands in their territories. Unlike the other global environmental conventions, Ramsar is not affiliated with the United Nations system of Multilateral Environmental Agreements, but it works very closely with the other MEAs and is a full partner of the "biodiversity-related cluster" of treaties and agreements.

flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." According to Khan et al (1994) wetland holds water for a significant duration sufficient to support organism adapted to life in inundated or saturated soil condition and consists of wide variety of types ranging from lakes, rivers and coastal forest to deepwater paddy fields and ponds.

Floodplain: An internet based website (http://www.wordiq.com/definition/Floodplain) defined floodplain as "*an area of relatively level land that is inundated from time to time. A floodplain may be border a stream, lake or river, or may be a watercourse in its own right. It is often defined as contained the floodway, which normally is inundated during annual flooding (or less often, say, ten-year flooding), and the floodway fringe (which may be inundated during a "100-year flood", "500-year flood" or even "1250-year flood)".* So floodplain areas consist of a floodway and a flood fringe that adjacent to a stream or river that experiences occasional or periodic flooding. And 'floodway' must be reserved in order to pass the base flood (100-year flood) flow without increasing flood depths. Flood fringe, portion of the floodplain that is outside the floodway, is generally associated with standing, rather than flowing water (Figure 2).

Concept of flood plain is more or less same all over the world. Local authorities have maintained their own regulation to control the floodplain area and shore line. Floodplains are generally not well suited for urban development, because of the flood hazard, the presence of high water tables, and soils poorly suited to urban uses. Many policies and regulations regarding floodplains are based on the 100-year flood. The 100-year flood has a 1% chance of occurring in a given year. The 100-year flood does not refer to a flood that happens once every 100 years. The 100-year flood is also known as the base flood.

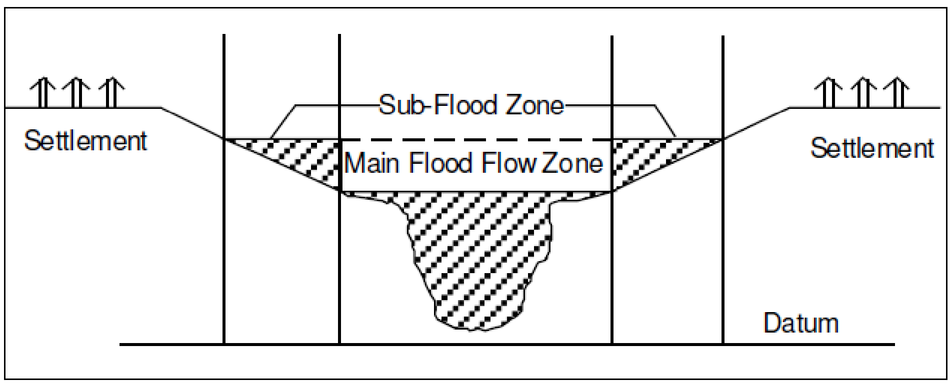
Benefits of natural floodplains are critical for the sustainability of a city. Floodplains offer flood water the opportunity to spread out over a large area which is undeveloped. Thus it reduces flood velocities and provides flood storage to reduce peak flows downstream. Natural floodplains reduce wind and wave impacts and their vegetation stabilizes soils during flooding. Besides, Water quality is improved in areas where natural cover acts as a filter for runoff and overbank flows; sediment loads, and impurities are also minimized. Natural floodplains moderate water temperature, reducing the possibility of adverse impacts on aquatic plants and animals. Floodplains also act as recharge areas for groundwater and reduce the frequency and duration of shallow flooding. Floodplains are particularly important for aquatic habitat.



Source: http://www.a2gov.org.

Fig 2: Definition of floodplain line.

Flood Flow Zone: In Dhaka City, Structure plan and Detailed Area Plan has defined the flood flow zone and restricted the development or land filling. 'Flood Flow Zone's are identified and imposed regulatory measures for preservation of those areas. Only for DMDP areas of RAJUK, these areas are earmarked as a zone. JICA in its report 'Flood Action Plan for Dhaka (FAP-8A and FAP-8B)' in 1990 identified main and sub-flood flow zones (Figure 3). The DMDP Structure Plan adopted the policies stated in JICA reports. Policy says, *"Land development, within the designated flood plain areas of the DMDP Structure Plan, will be controlled in order to avoid obstructions to flood flow, which might otherwise result in adverse hydraulic effects, such as, the rise of flood water levels and change in flow direction"*. A river in its flow regime maintains a width in which the flood flows occur during flooding time. The rivers and flood plains play an important role in both the ecology and economy of the region. Land developments within the designated flood plain areas require control to avoid obstruction to flood flow; which might otherwise result in adverse hydraulic effects like rise of flood water levels, and changes in flow direction. Main flood flow zone is the cross sectional area of a river that carries the dominant flood flow.



Source: DMDP, 1995.

Fig 3: Explanation of flood flow and sub-flood flow zones.

Urbanization and Hydrologic Changes

With the urbanization process, a significant change is visible in the urban hydrology. Change of land use, transformation of non-built up area into built up area, characteristics of land cover, impermeable materials in built up area and other human activities influence the characteristics of runoff water. It results the peak discharge of rain water by modifying how rainfall are stored on natural drainage of a city. Frequency and extent of inundation, internal flooding and water logging increase with this urbanization.

Following discussion will help planners to forecast the future changes in hydrologic factors of urbanization and take necessary action of mitigation accordingly in the planning process. Of all land use changes affecting the hydrology of an area, among them urbanization is the most forceful and significant. There are 3 major interrelated but separable effects of land use changes on the hydrology of an urban area. They are as follows;

- changes in the peak discharge flow characteristics
- changes in the total runoff
- changes in the water retaining capacity

Changes in the Peak Discharge Flow Characteristics

Runoff, which spans the entire regimen of flow, can be measured by number and by characteristics of rise in water flow. Urbanization can make a significant impact on flooding situation in a watershed. Prior to urbanization, there exists a greater lag time between intense rainfall and peak stream flow. After urbanization, the lag time is shortened, peak flow is greatly increased, and the total run-off is compressed into a shorter time interval, creating favorable conditions for intense flooding (Figure 4). For example, in a city that is totally served by storm drains and where 60% of the land surface is covered by roads and buildings (like Dhaka City), floods are almost six times more numerous than before urbanization (Khalequzzaman, 2001). Following urbanization, it is necessary to adjust drainage capacity in the watershed to take into account the "basin development factor (BDF)" in order to accommodate the extra runoff that results due to urbanization. The amount of adjustment in the carrying capacity of natural streams following urbanization depends on the degree of BDF. Table 1 shows the simplified Table of Rational Method Runoff Coefficients. For an increase, the amount of impervious surface by 10% in a watershed, a 23% increase in the drainage capacity by dredging or deepening of streams is suggested by Sauer et al. (1983). One of the simplest and common methods to determine the "peak discharge" from drainage basin runoff is:

Equation: $Q=ciA$

Where,

Q = Peak discharge, cfs

c = Rational method runoff coefficient

i = Rainfall intensity, inch/hour

A = Drainage area, acre

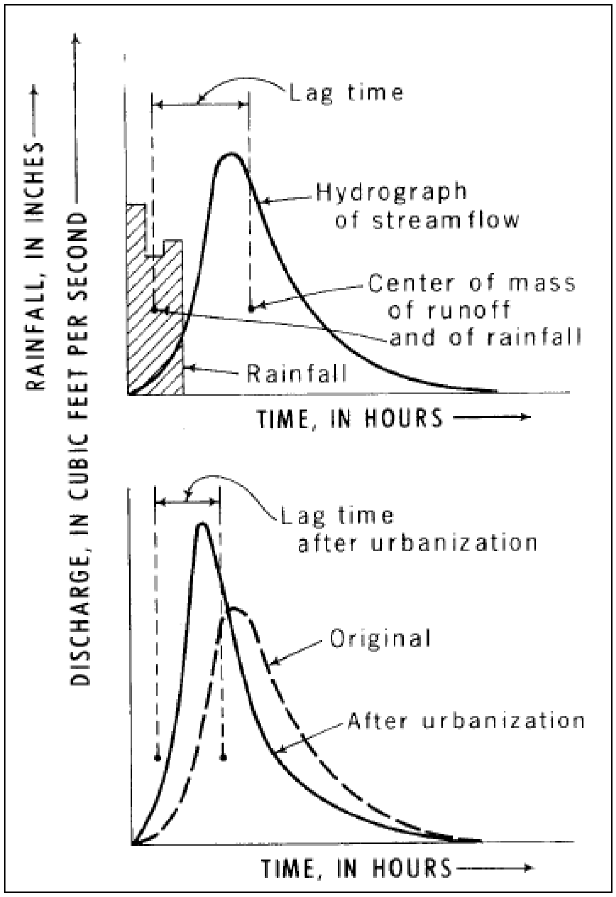
Other units may be applicable in calculating the same. Runoff coefficient (c) is a function of the soil type and drainage basin slope. Units of rainfall intensity (i) and drainage area (A) may be different in different cases. Peak discharge depends on the runoff coefficient (c), where this value is the highest in the built up areas of city.

In a location of a city, peak discharge can be calculated from the above formula. Before development, it is necessary to design in accordance to the peak discharge. For example, in a specific location, peak discharge is 200 cfs (ft3/s), and it is estimated that after development, peak discharge will be 300 cfs at the same location. For the city's development, regulatory authority must ensure that this project has incorporated enough water retention areas that can store water and reduce the peak discharge of the original 200 cfs.

Table 1: Simplified Table of Rational Method Runoff Coefficients.

Ground Cover	Runoff Coefficient, c	Ground Cover	Runoff Coefficient, c
Residential areas	0.3 - 0.75	Lawns	0.05 - 0.35
Business areas	0.5 - 0.95	Forest	0.05 - 0.25
Industrial areas	0.5 - 0.9	Cultivated land	0.08-0.41
Asphalt streets	0.7 - 0.95	Meadow	0.1 - 0.5
Brick streets	0.7 - 0.85	Parks, cemeteries	0.1 - 0.25
Roofs	0.75 - 0.95	Unimproved areas	0.1 - 0.3
Concrete streets	0.7 - 0.95	Pasture	0.12 - 0.62

Source: http://www.lmnoeng.com/Hydrology/rational.htm, retrieved on 15December 2011.



Source: Leopold, L.B.1968.

Fig 4: Changes in peak flow characteristics for urbanization.

Changes in the Total Runoff

Urbanization of the land usually results in the highly accelerated removal of storm water with corresponding increases in the volume and peak rate of runoff (Figure 5). The principal effects of land use change have been discussed by Leopold (1968) in his Hydrology for-Urban Land Planning - A Guidebook on the Hydrologic Effects of Urban Land Use.

Bari, M.F and Hasan, M. (2008) have shown in their research article that water falling on a catchment due to rainfall is split into different hydrological components: evapo-transpiration, overland flow, interflow, base flow and infiltration through a set of numerical parameters. Ultimately, it is seen that the ratio of accumulated runoff and accumulated rainfall increases progressively with an increase in impervious area[3].

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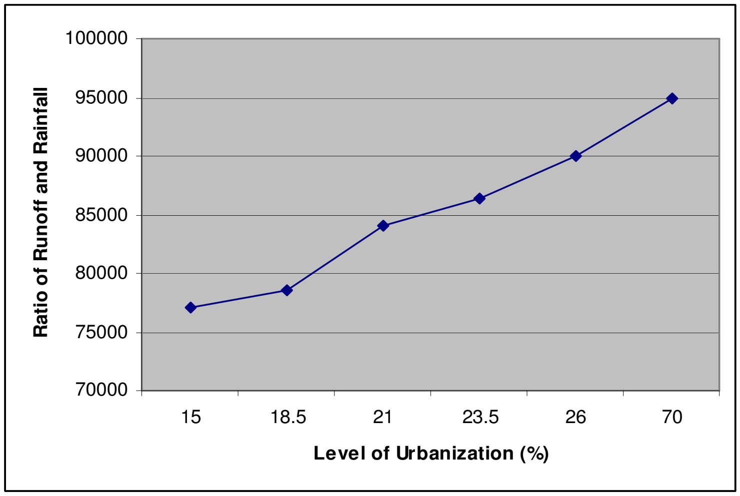
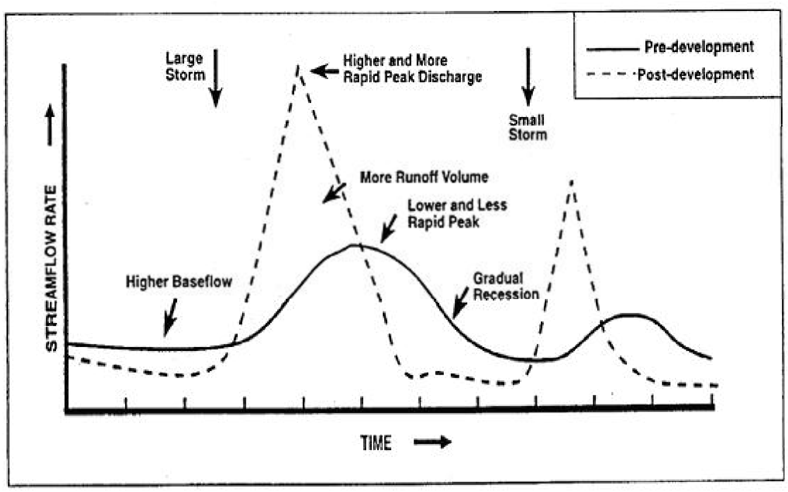
[3] Impervious areas are defined as “the land surface having an infiltration capacity equal to zero” (Lazaro, 1991). Impervious area was defined in the study area as any man-made object of impermeable nature that considerably diminishes the water storage capacity. Normally when it rains, the rain water is usually soaked up by the ground, that is to stay unpaved land, and the rest of the



Source: Constructed from data of Bari, M.F and Hasan, M. , 2008.

Fig 5: Relationship with runoff and rainfall.

During the last more than three decades, tremendous urbanization has taken place in Dhaka city. Therefore, it has increased the paved areas for development of residential, commercial and other activities. It resulted substantial increase in impervious area, created obstruction to natural drainage pattern, and reduced detention basins, which in turn, led to shortening of the runoff concentration time and an increase of the peak flow. Bari and Hasan (2008) has shown that the ratio of accumulated runoff to accumulated rainfall against percent impervious area for 1986 to 1995 and 2010 of Dhaka city has increased progressively with an increase in impervious area.



Source: Donaldson, 2010

Fig 6: Pre and post development effects on water flow.

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water builds up in small to large scale water bodies such as ponds, lakes and even rivers (Khan, N.I., 1997).

Therefore, with the urbanization, it brought two things for Dhaka city:

- rainfall in the city quickly fill up the drains and canals and run towards the outer lowland quite faster than before. Within a lesser time, it travels to the floodplain areas in the surrounding areas of Dhaka city (Figure 6).
- Because of unplanned urbanization, whenever runoff water does not gets its retaining areas, it accumulates in the city areas and get water logged.

Changes in the Water Retaining Capacity

Uncontrolled urbanization in the developing countries, like Bangladesh, where monitoring and implication of development laws are weak is found to take place giving the priority of individual profit. Benefits of the general people, city as well as the society are merely acknowledged by the beneficiaries. Garrett Hardin (1968) describes this situation as *tragedy of commons*[4].

Table 2: Wetlands (in Hectre) of DMDP areas in the years, 1989, 1999 and 2005.

Item	1989		1999		2005	
	Area (hectre)	(%)	Area (hectre)	(%)	Area (hectre)	(%)
Permanent water Bodies	5,608	3.9	5,608	3.9	5,608	3.9
Temporary Wetland	40,765	28.5	35,740	25.0	24,208	16.9
Others	96,770	67.6	101,795	71.1	111,327	79.2

Source: Ishrat I., 2008.

Historically, Dhaka city due to its socio-economic and political importance possessed a great pull power to bring the people to the city. Thus a great pace of urbanization has been taken place here. People have not paid due care on its soil formation, contour, wetland, depression areas, natural drains or rivers. Ishrat, I. (2008) described in a research that yearly loss of wetland during 1999-2005 period was 1922 hectre/year, whereas during 1989-1999 period, yearly loss was 503.5 hectre/year. The land filling activities of the developers become irresistible during the later half of 19 90s (Figure 7). Table 2 provides information on area coverage of wetlands of Dhaka (DMDP area) city during the year 1989, 1999 and 2005.

Loss of wetland in Dhaka city reduces the runoff storage capacity of the city. As a result, during monsoon, city faces the inundation, water logging problems due to backwash effects.

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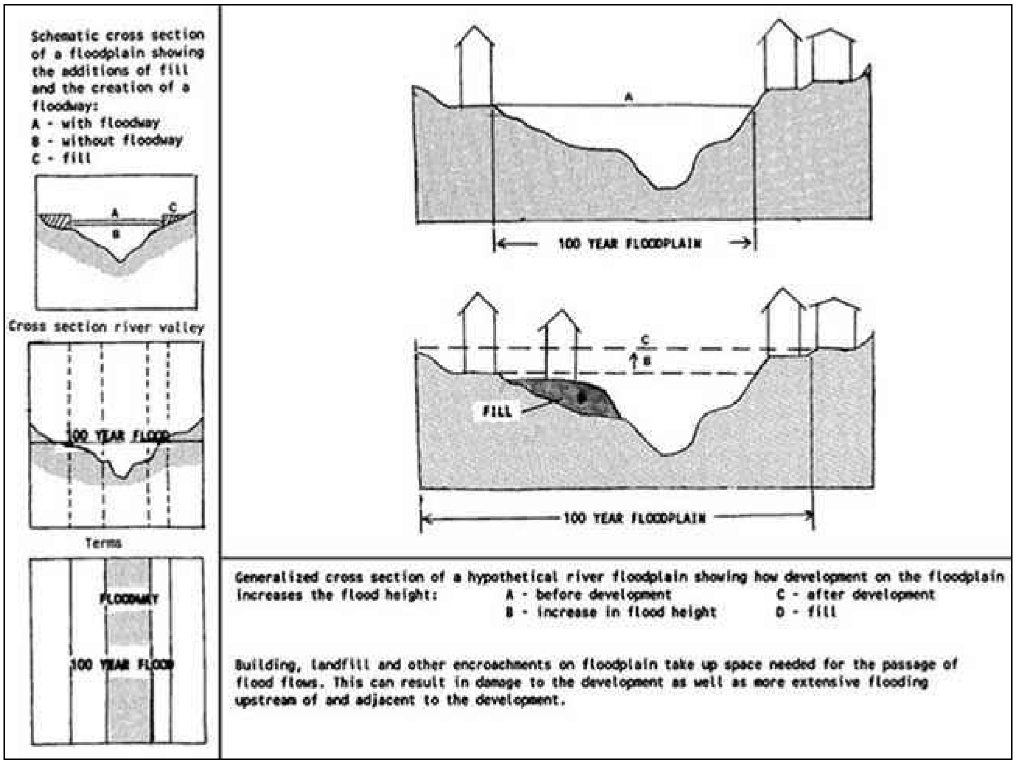
[4] The tragedy of the commons refers to a dilemma described in an influential article by that name written by Garrett Hardin and first published in the journal *Science* in 1968. The article describes a situation in which multiple individuals acting independently, and solely and rationally consulting their own self-interest, will ultimately deplete a shared limited resource even when it is clear that it is not in any one's long-term interest for this to happen. Hardin's Commons Theory is frequently cited to support the notion of sustainable development, meshing economic growth and environmental protection, and has had an effect on numerous current issues, including the debate over global warming.



Source: Adapted from Strahler, A.N., and Strahler, A.H. Environmental Geoscience: Interaction Between Natural Systems and Man (Santa Barbara, California, U.S.A.: Hamilton Publishing Co., 1973); and Riggs, H.C. Streamflow Characteristics (New York, U.S.A.: Elsevier, 1985).

Fig 7: Effect of land filling on the floodplain areas.

A Tale of Two Cities: Protection of Floodplains

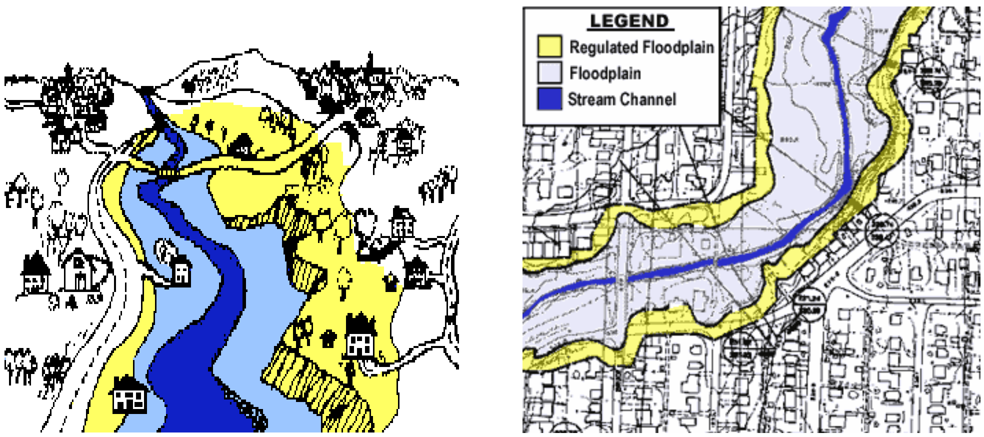
Regulated Floodplain Areas of Ontario, Canada

Lakehead Region Conservation Authority (LRCA) of Ontario, Canada created in 1946 by an Act of the Provincial Legislature, are mandated to ensure the conservation, restoration and responsible management of Ontario's water, land and natural habitats through programs that balance human, environmental and economic needs. This authority's jurisdiction boundary comprising of eight municipalities, encompassing an area of 2600 sq. km and extends along 200 km of Lake Superior shoreline. Main objectives are to ensure that Ontario's rivers, lakes and streams are properly safeguarded, managed and restored and to protect, manage and restore Ontario's woodlands, wetlands and natural habitats.

There may be a difference between the floodplain of a watercourse and the regulated floodplain area. The floodplain is the nearly level land adjacent to the watercourse that is subject to overflow flooding. The regulated floodplain area is defined as the area adjacent to a watercourse which would be flooded during a regional storm or as the highest observed flood level in some cases.

In Figure 8, dark linear feature is the water channel (river) and the light shaded areas are flood plain areas and regulated flood plain. This floodplain area demarcated on the basis of the highest flood level of base year (100 years).

The cross-section *(at left)* demonstrates how the floodplain *(shown in light blue)* is usually thought of as the low land near a watercourse. However, the Lakehead Region Conservation Authority (LRCA) of Ontario uses the regional storm to define the regulated area *(shown as yellow)*. A much broader area is considered to be at risk in the event of such a large storm. Unrestricted development within a floodplain can result in flood damage to buildings and threaten public safety. Development can also affect neighboring properties both upstream and downstream by changing the physical characteristics of the floodplain and the watercourse (LRCA, 2011)



Source: http://www.lakeheadca.com/fillreg.htm
Fig 8: Floodplain line declaration by rules.

Legal Basis of Protecting Wetland in Dhaka City

Detailed Area Plan (DAP) allocates 5737 acres of land for retention ponds at the end of major outfall of runoff/storm water of the city. It earmarked 81024 acres of land as flood flow zone for free movement of monsoon flood and protection of the wetland-habitat. For reducing the water logging and protection of people from flood, there is no alternative than full implementation of DAP. Table 3 presents the components of urban hydrographs in DAP.

Table 3: Components of urban hydrographs in DAP.

Sl No	Land Use Category	Acre	Hectare	Percentage of Total DMDP Area
1	Flood Flow Zone	81024.21	32790.05	24.71
2	Water Retention Area	5737.88	2322.09	1.75
3	Water Body	18782.14	7601.03	5.73

Source: Calculated from Detailed Area Plan Composite Map, 2010.

DAP is now a legal document for implementation and ‘Open space and Wetland Conservation Act 2000’ provides further legal basis for protection of components of urban hydrology for the city's sustainability. Open Space, and Wetland Conservation Act 2000 (Law number 36 of 2000; published in 18/09/2000 in Bangladesh Gazette) provides a clear mandate for protecting the components of urban hydrology. In addition to several definitions depicted in the Act, section 5 of this Act also prohibits change of the land use, nature, leasing out or transfer of any land that has been earmarked as a natural reservoir[5]. This includes river, khal, ponds, flood flow zones, or any other water bodies as identified in the Master Plan. Again, section 8 of the Act says that any person who acts in contravention of this Act is liable to imprisonment not exceeding 5 years or a fine not exceeding Taka 50,000 or both. Section 8(2) further provides that if any land or part of it is changed by violating the provision of section 5, the concerned authority might make impediment for the owner of the land or the violator in changing class of the mentioned land by notice. Thus any unapproved construction can be knocked down or dismantled immediately. Whatever the other Acts say, there will not be any compensation for that destruction.

Conclusion

Urbanization and its hydrologic effects in Dhaka City are taken place in two ways; one is changes in characteristics of runoff water and another is alteration of natural drainage by land filling and encroachment. Therefore, impact is quite high. Uncontrolled urbanization covered the floodplain areas around the city. Future city dwellers will be facing massive environmental problems including threats of flood and shortage of fresh drinking water, if the present situation is not handled carefully and immediately. Dhaka city faces the effects and consequences of unplanned urbanization on natural canals, wetland, depressions and water channels every year both in the dry season as well as in the rainy season. During the rainy season after a heavy shower, city faces drainage congestion and water logging and in the dry season, serious crisis of drinking water. Due to reduction of water recharging zones and pollution of surface water sources, city faces dual problems, like water table lowering and water crisis. Instead of having some legal instruments, government failed to protect the water bodies and natural drainage system from disappearance and pollution.

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[5] Natural water body means proposed river, canal, swamp, tank, fountain or any reservoir in Master Plan or declared by Government, local Government or other organization, Gazette notified area, which is declared as flood flow region and it will also include any area containing fresh and rain water (GoB, 2000).

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