CHAPTER 3

WATER BALANCE THROUGH

HYDROLOGIC CYCLE
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3.1. Introduction

There is a need to gain a better understanding of the response of the regional hydrological systems in global changes. In the coming decades water availability will become a major international concern. Already, lack of water is a major constraint on industrial development and aggravates the water pollution problems which are responsible for non-availability of good drinking water and spread of disease in many parts of the world. Climate changes arising from the build up of greenhouse gases could have significant effects on regional water resources. Changes of local land use caused intervention by human are responsible for global warming and in turn it will affect the hydrologic cycle. The role of the natural factors namely physiography, geomorphology, climate and vegetation with their spatial and temporal variations affects the occurrence, distribution, movement, storage and availability of water and is therefore, very important in the study of water balance of a country or a region.

In this context it would be worthwhile to make an attempt to analyze the various types of hydrologic conditions prevailing in Haora river basin with a view to understand, at least conceptually, their effects on the rainfall and the availability of water.
3.2. Nature of the Hydrologic Cycle

3.2.1. Hydrologic Cycle

The hydrologic cycle is summarized by the relationship

\[ R = P - E + S \]

where \( R \) is runoff, \( P \) is precipitation, \( E \) is evaporation or evapotranspiration, and \( S \) is water released from storage (Fig. 3.1).

Hydrology is the science that treats the waters of the Earth, their occurrence, circulation, movement and distribution, their chemical and biological properties and their reaction with their environment, including their relation to living things. The domain of hydrology embraces the full life history of water on the earth.

Fig. 3.1. Hydrological Cycle
Nature is a great recycler, and water is a prime. The water that flows in streams comes from the ocean and is returned again in a constant cycle called the hydrologic cycle. In most areas the P and E terms are relatively large on an annual basis. The runoff (R) tends to be smaller and is sometimes considered a residual term. In some regions the storage (S) term is very complex. It includes storage of water in lakes, snowpacks, glaciers, and shallow and deep aquifer systems and storage in the soil in both liquid and ice forms. The natural storage “reservoirs” operate on a range of time and space scales; consequently, they affect the transient responses of the hydrologic cycle to global change on regional and basin scales.

Each parameter in the hydrologic balance will be affected by global change. In particular, most precipitation scenarios produced by global climate models (GCMs) indicate that P will increase. Also increase in temperature may result an increase in potential evapotranspiration. The storage term cannot be easily assessed using GCM scenarios alone. However, one could project that the winter snowpack will not last as long and that glaciers may diminish in size with global warming. Assuming that changes in the storage term will average out to zero for long enough periods of time, it is reasonable expect that the net long-term effect of global change on annual runoff will be governed by the changes in precipitation and evaporation (Fig.3.2).

3.2.2. Spatial Variability
A number of factors influence spatial scales in the hydrologic cycle. In order to analyze and predict river flows, hydrologists use the concept of a river basin as a geographic unit. River basins vary in size from few square kilometers to tens of thousands of square kilometers. Because river basins are land based, their size and shape are determined by the geomorphologic characteristics of the region. The spatial dimensions of river basins are to a large extent a function of topography, with larger watersheds tending to occur on flatter terrain, often with mountains on one boundary.

**Fig. 3.2. Water Cycle**

In addition, the topographic features within a watershed control the spatial dimensions of the storage terms. Although the spatial scales of precipitation are controlled primarily by atmospheric processes, they are also influenced by the scale of variations in the topography.
The spatial scale of evapotranspiration is less variable than that of precipitation and is strongly influenced by the distribution of the vegetation cover and water bodies. Lakes and wetlands vary in size and tend to cover larger areas where the climate is humid, soils are only moderately permeable, and the terrain is relatively flat. The water-holding capacities of soils and underground aquifers also depend on terrain features such as the slope, depth, and type of soil.

### 3.2.3. Temporal Variability

Temporal variability in the hydrologic cycle ranges from millennia on one extreme to minutes on the other. Most geomorphologic processes operate on longer time scales, and meteorologic processes operate on much shorter time scales. The annual cycle is the dominant periodicity in precipitation and evaporation processes, particularly at more northerly latitudes. However, the timing of the annual maximum precipitation is dependent on geographic location and the atmospheric processes producing precipitation (e.g., synoptic processes or localized convection).

Potential evaporation has a strong annual variation, with the highest rates occurring in the summer. Longer-term variability has also been observed in many of these hydrologic parameters. This longer-term variability leads to difficulties in separating long-term hydrologic variations from possible changes forced by global warming and other factors such as land use change. In addition, phenomena such as the El Nino, which occurs every 4 to 8 years, lead to variations in hydrology worldwide. Runoff also had shown
strong seasonal variations, with peak flows tending to occur in the spring in many areas of Canada and the northern United States. In coastal areas, peak flows may occur in different seasons and extreme events may be initiated suddenly. Farther south, in Mexico, precipitation and runoff maxima occur in the summer months. Nearer the equator in Central America, two precipitation maxima occur each year.

Some storage terms such as snowpack have strong annual cycles, whereas others tend to vary on longer time scales (e.g., ground water and lake levels). Different water reservoirs reach their maximum storage values at different times of the year. Storage terms with an ice phase, such as glaciers and snowpacks, reach their maxima in the early spring and their minima in the autumn. At higher latitudes the maxima occur later in the spring and the minima occur earlier in the autumn. Mountain snowmelt makes its maximum contribution to runoff during the late spring and early summer, and glaciers contribute throughout the summer. In summary, the temporal variability of the regional hydrologic cycle cannot be understood without knowledge of the spatial and temporal characteristics of the regional temperature and precipitation patterns and the local and regional geomorphology.

3.3. Water Balance

The total quantity of water in the world is estimated to be about 1386 million cubic kilometers (M km$^3$). About 96.5% of this water is contained in the oceans as saline water. Some of the water on the land amounting to about 1% of the total water is also saline.
Thus only about 35.0 M km$^3$ of fresh water is available. Out of this about 10.6 M km$^3$ is both liquid and fresh and the remaining 24.4 M km$^3$ is contained in frozen state as ice in the polar regions and on mountain tops and glaciers. The water resources of the Ganga Basin in India whose area is 862769 km$^2$. on an average, this basin receives 1200 mm of precipitation and runoff is of the order of 525 km$^3$. the utilizable water resources of a basin depend on factors such as topography and land use and for basin. The average annual rainfall in the Tripura is 2543 mm out of that the total rainy days being 99.6 days whereas the maximum and minimum temperatures are 37 $^0$C and 5$^0$C respectively

3.3.1. The Haora River

The region has large surface and groundwater resources mainly because of its location in high rainfall area and the extensive river system. But all the water resources cannot be utilized because these are inaccessible or non-reversible. The exploitable water balance is mostly concentrated in Tripura. Water application on slopes for irrigating planting crops poses serious problem of soil erosion.

Annual water balance studies of the basin area for the period of 1997 to 2004 indicate interesting facts. The water balance of the Haora river is shown in Table 3.1 and Figs.3.3 to 3.8. It is interesting to see from this table that in the year 2000, 55% (as rounded) of the precipitation going as runoff, where the rainfall is 64.48 mm as observed in the year 2004. The results reveal that the percentage of runoff is sometimes increased or decreased due to temperature fluctuation also the changes of land use pattern.
Table 3.1: Water Balance of Haora River Basin in a Year wise

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (km²)</th>
<th>Precipitation (mm)</th>
<th>Total runoff (mm)</th>
<th>Runoff as % of ppt.</th>
<th>Evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>414</td>
<td>78.20</td>
<td>32.32</td>
<td>41.33</td>
<td>35.18</td>
</tr>
<tr>
<td>1998</td>
<td>414</td>
<td>73.15</td>
<td>33.75</td>
<td>46.14</td>
<td>37.13</td>
</tr>
<tr>
<td>1999</td>
<td>414</td>
<td>62.29</td>
<td>25.52</td>
<td>41.00</td>
<td>41.62</td>
</tr>
<tr>
<td>2000</td>
<td>414</td>
<td>64.48</td>
<td>35.79</td>
<td>55.50</td>
<td>35.75</td>
</tr>
<tr>
<td>2001</td>
<td>414</td>
<td>77.10</td>
<td>32.83</td>
<td>42.58</td>
<td>36.58</td>
</tr>
<tr>
<td>2002</td>
<td>414</td>
<td>78.09</td>
<td>38.66</td>
<td>49.51</td>
<td>39.43</td>
</tr>
<tr>
<td>2003</td>
<td>414</td>
<td>72.62</td>
<td>33.33</td>
<td>45.90</td>
<td>39.29</td>
</tr>
<tr>
<td>2004</td>
<td>414</td>
<td>84.08</td>
<td>46.81</td>
<td>55.67</td>
<td>37.27</td>
</tr>
</tbody>
</table>

3.4. Ground Water System

If ice caps and glaciers are excluded, ground water accounts for 97% of the earth’s total ‘fresh water’ (Van der Leeden et al., 1990). Many watersheds have large, deep aquifers underneath. The great age of the water in some of these aquifers suggests that significant amount of water do not readily move between the surface and these aquifers. The boundaries of these deeper aquifers may differ markedly from the boundaries of the surface watersheds. In undulating terrain, hills tend to recharge areas and valley frequently constitutes discharge areas. In these discharge areas, water in the soil is released into a wetland or a river channel. The precise locations of ground water recharge zones are often not fully known and depend on climatic extremes. Deeper aquifers may
undergo episodic recharging when an unusually heavy precipitation or snowmelt event leads to a large floods and a sudden recharge event (Benson and Klieforth, 1988). After such a major recharge event, the ground water may be slowly released to the surface water system over a long period of time. Falkenmark (1989b) has shown how dating studies of water lens can be used as a means of obtaining information about the wet period leading to the formations of lens.

On the other hand, ground water is another major component of the total available water resources. In the coming years, the ground water utilization is likely to be increased manifold for expansion of irrigated agriculture and to achieve national targets of food production. Although groundwater is an annually replenishable resource, its availability is non-uniform in space and time. At the same time, it should also be kept in mind that over withdrawl of groundwater exceeding the recharging value is detrimental for the watershed.

The estimation of groundwater potential in an area has to take into account the various natural, physical and hydraulic properties of the material through which groundwater is transmitted from place to other. The evaluation of groundwater potential in the respective basins in India would, therefore, be based on hydrologic properties. The water table for Haora river basin has been found from 1 m to 4.5 m.

The Haora river basin lies in one of the most flood prone areas of the country. With an average annual renewable water availability of Haora river of 341 MCM, the total
replenishable ground water resource is 334 MCM per year of the basin (Table 3.2). The details of ground water have been delineated in the Chapter 4.

Table 3.2: Groundwater Potential for various Basin

<table>
<thead>
<tr>
<th>Name of Basin</th>
<th>Total Replenishable Groundwater Resource (MCM/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haora River</td>
<td>334</td>
</tr>
</tbody>
</table>

3.5. Soil Condition and Land use

3.5.1. For Haora River Basin

The basin has divided into two layers of soils. The soil consists of reddish brown clayey silt with a cover of alluvial deposit somewhere up to depth of 6 m. The average soil and texture properties are (i) Field Moisture content (18-20%) (ii) Liquid Limit (28.5-31.5%) (iii) Plastic Limit (16.3-18.5%) (iv) Bulk density (1.82-1.85 t/m$^3$) (v) Specific gravity (2.68-2.69) (vi) Void Ratio (0.48-0.54) and the percentage of silt (48-51%) is maximum by analyzing the grain size distribution followed by clay (30-43%) and sand (10-20%).

This layer continues up to termination depth of 15 m. It consists of brownish sandy silt with presence of mica. The average properties are i) Field Moisture content (20-23%) (ii) Liquid Limit (21-22%) (iii) Plastic Limit (11.2%) (iv) Bulk density (1.9-1.92 t/m$^3$) (v) Specific gravity (2.59-2.61) (vi) Void Ratio (0.5-0.61) and the percentage of sand (92-97%) is maximum by analyzing the grain size distribution followed by silt (3-8%).
In the river bed, between 95-97% of sand is dark brownish and grayish fine to medium sand followed by silt content vary from 3-5% with field moisture content i.e. 24% up to depth 9.0 m. As the depth increases up to 11.5 m, the composition of soil texture has been found maximum in blackish silty clay (58%) followed by silt (25%) and sand (17%) having field moisture content 49%. The yellowish brown sand medium to coarse has been found maximum (99%) from depth 11.5 m to 20.0 m.

The land use pattern in the Haora river basin is primary activities dominate the occupational structure. Almost 35% of the total land area is either used for cultivation or grazing or cultivable waste or kept as fallow. The forest cover in this part of the basin is also high, which is 30-35% approximately. This indicates the magnitude of the land degradation in the Haora basin.

The chief occupation of the population in the state is agriculture. The principal crops are paddy, wheat, jute, sugar cane, potato, turmeric, coconut and oil seeds. Handloom weaving is the single largest industry in Tripura. Bamboo Handicrafts also make a major contribution to the state economy. Some quality timber like Sal, Garjan, Teak, Gamar are found abundantly in the forests of the State. The service sector comprises only real estate, insurance and tourism industry.

3.6. Climate Change and Hydrologic effects
The implications of changes in temperature and precipitation for hydrology at the regional level are likely to be quite significant. Different approaches have been used to assess the hydrologic impacts of climatic change. **Gleick (1987)** and **Cohen et al. (1988)** have used water balance models to assess the significance of temperature and precipitation scenarios for runoff. However, decreased water use by plants arising from an enriched CO$_2$ atmosphere may compensate for the effects of changing precipitation and temperatures on runoff.

**Fig3.3.: Water Balance curve for the period of 1997**
Fig. 3.4: Water Balance curve for the period of 1998

Fig. 3.5: Water Balance curve for the period of 1999
Fig. 3.6: Water Balance curve for the period of 2000

Fig. 3.7: Water Balance curve for the period of 2001
3.7. Summary

In view of the foregoing discussion, the following summary can be stated:

- Water balance depends on processes such as evaporation, precipitation, and infiltration on time and space scales. The relative importance of these processes depends on the large-scale temperature and precipitation patterns and the characteristics of the underlying topography. This is particularly evident in the hydrologic patterns of Haora river basin at Agartala, Tripura.
The water balance of important Haora river basin will be affected under changed climate scenario in a number of ways. Both precipitation and evaporation regimes are likely to be changed. Also land use pattern and soil cover must be better understood to a greater detail to anticipate how local changes may affect on hydrologic cycle.

Assessment of the hydrologic response to climate change require better understanding of

- The implication of increased temperature in evaporation.
- The variability of precipitation and temperature and the occurrence of extreme values computed at regional scales.
- The linkages between meteorologic inputs and runoff at regional scales.
- The sensitivity of the spatial and temporal characteristics of the storage components in the hydrologic cycle due to the climate change.