Chapter 2: Global Water Budget

Introduction

Water is one of Earth's most essential resources, driving life, ecosystems, weather patterns, and human development. Understanding the **global water budget** is fundamental to the field of hydrology and water resources engineering. It quantifies how much water exists on the planet, how it is distributed among different reservoirs (like oceans, glaciers, and the atmosphere), and how it moves through various components of the hydrologic cycle.

This chapter explores the global distribution of water, the mechanisms governing its movement and storage, and the quantitative understanding of inputs and outputs within the hydrological system. Engineers use this understanding to manage water sustainably, model hydrological systems, and address challenges such as droughts, floods, and climate change impacts.

2.1 The Hydrologic Cycle: A Recap

The hydrologic cycle is a continuous movement of water on, above, and below the surface of the Earth. Major components include:

- **Evaporation**: Transformation of water from liquid to vapor from oceans, lakes, and soil.
- **Transpiration**: Evaporation from plant surfaces.
- **Condensation**: Formation of clouds by cooling water vapor.
- **Precipitation**: Rainfall, snowfall, sleet, and hail.
- **Infiltration**: Water seeping into the ground.
- **Percolation**: Downward flow of infiltrated water.
- **Runoff**: Flow of water over the surface into streams and rivers.
- **Groundwater flow**: Subsurface water movement.

In the global context, the water budget reflects the balance between these components across various regions and reservoirs.

2.2 Components of the Global Water Budget

The global water budget consists of the quantification of:

- **Total volume of water on Earth**
- **Distribution in different reservoirs**
- **Annual water fluxes between reservoirs**

2.2.1 Water Reservoirs

Reservoir	Approx. Volume (km^3)	% of Total
Oceans	1,350,000,000	96.5%
Ice caps & glaciers	24,000,000	1.74%
Groundwater	23,400,000	1.70%
Freshwater lakes	91,000	0.007%
Inland seas	104,000	0.008%
Soil moisture	16,500	0.001%
Atmosphere	12,900	0.001%
Rivers	2,120	0.0002%
Biosphere	1,120	~0.0001%

Note: While oceans hold the largest volume, freshwater accessible to humans is very limited—less than 1% of total water.

2.2.2 Water Movements (Annual Fluxes)

Process	Flux (km^3/year)
Precipitation (land)	~119,000
Precipitation (ocean)	~382,000
Evaporation (land)	~74,000
Evaporation (ocean)	~425,000
Runoff (to ocean)	~45,000

This imbalance between precipitation and evaporation over land and ocean drives the runoff from land to sea and governs atmospheric water vapor transport.

2.3 The Global Water Balance Equation

The global water balance can be expressed using the basic water balance equation:

$$P = ET + R + \Delta S$$

Where:

- P = Precipitation
- ET = Evapotranspiration
- R = Runoff (surface and subsurface)
- ΔS = Change in storage (soil moisture, groundwater, surface water)

Over a long-term global average, $\Delta S \approx 0$, leading to:

$$P \approx ET + R$$

The equation varies regionally and seasonally, but over the entire globe, it gives an understanding of inputs and outputs balancing out.

2.4 Role of Oceans in the Water Budget

- **Evaporation**: Oceans contribute ~86% of global evaporation.
- **Precipitation**: Receive ~78% of global precipitation.
- **Storage**: Oceans are the largest reservoir (~96.5% of global water).
- **Ocean-Atmosphere Exchange**: Critical for climate regulation, driving monsoons and ocean currents.

2.5 Terrestrial Water Budget

On land, the water budget is influenced by:

- **Climatic zones**: Arid vs humid
- **Vegetation cover**: Influences evapotranspiration
- **Soil type and porosity**
- **Topography**
- **Human activities**: Dams, irrigation, deforestation

Region-specific water budgets are necessary for water resource planning and management.

2.6 Atmospheric Water Budget

Though only ~0.001% of total water is in the atmosphere, it plays a crucial role in:

- **Weather systems**
- **Water vapor transport**
- **Global precipitation patterns**

Residence time of water vapor is ~9–10 days, meaning atmospheric water is cycled very quickly.

2.7 Groundwater in the Global Budget

Groundwater represents:

- ~30% of global freshwater
- ~0.7% of total water

It's a long-term reservoir with slow recharge and discharge rates. Key aspects include:

- **Aquifer types (confined/unconfined)**
- **Recharge mechanisms**
- **Over-extraction and its impact**

Groundwater depletion contributes to long-term imbalance in local and regional water budgets.

2.8 Cryosphere: Ice and Snow Storage

The cryosphere includes:

- Glaciers
- Ice caps
- Permafrost
- Seasonal snow cover

It holds ~68.7% of global freshwater. Changes due to global warming significantly affect sea level rise and water availability.

2.9 Human Influence on the Global Water Budget

Human activities are significantly altering the global water balance:

2.9.1 Land Use Changes

- Urbanization increases runoff, decreases infiltration.
- Deforestation reduces evapotranspiration.

2.9.2 Water Withdrawals

- Irrigation, industry, and domestic usage affect river flows and aquifer levels.

2.9.3 Reservoir Construction

- Artificial storage changes natural flow regimes and evaporation losses.

2.9.4 Climate Change

- Alters precipitation patterns, intensifies droughts/floods, and disrupts monsoons and snowmelt patterns.

2.10 Residence Time of Water in Different Reservoirs

Reservoir	Average Residence Time
Atmosphere	~10 days
Rivers	~2 weeks
Lakes	~10 years
Groundwater	~100 to 10,000 years
Glaciers	~20 to 100 years
Oceans	~3,000 to 3,200 years

Residence time affects how quickly water responds to changes in inputs, withdrawals, or climate forcing.

2.11 Global Water Budget Estimation Techniques

2.11.1 Satellite Remote Sensing

- Data on precipitation, snow cover, soil moisture (e.g., TRMM, GRACE)

2.11.2 Ground-Based Observations

- Rain gauges, stream gauges, piezometers

2.11.3 Hydrological Modelling

- Large-scale models (e.g., VIC, SWAT, WEAP) for estimating water balance.

2.12 Importance of Global Water Budget in Engineering

Understanding the global water budget is vital for:

- **Hydrologic modeling and simulation**
- **Integrated water resources management**
- **Disaster planning (droughts/floods)**
- **Climate change adaptation strategies**
- **Design of water infrastructure (dams, canals, drainage)**

It also informs international water treaties, sustainable development goals (SDG 6: Clean Water and Sanitation), and environmental conservation efforts.