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1. Hydrology and Water Resources Engineering

Hydrology is the science which deals with the waters of the Earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the physical and biological environment, including their responses to human activity. Hydrology is a field which covers the entire history of the cycle of water on the Earth (UNESCO International Hydrological Decade, 1964). Water is the source of all lives on the Earth and is a resource that is indispensable for our social and economic activities. The water cycle and its time and space distribution depend on the solar radiation, topography and various conditions of the Earth surface. Hydrology is a discipline that provides the understanding of the physical processes of the water movement and the foundations for proper use and protection of water resources.

Keywords : hydrology, hydrologic cycle, waters budget, water resources

1.1 The Science of Water Cycle: Hydrology

Water constantly circulates on the Earth due to solar energy and gravitational energy, and changes its phases (ice, liquid, and vapor). **Hydrology** is the science that clarifies the movement of water and the distribution of water in time and space on and beneath the surface of the Earth, involving transports of sediment, dissolved nutrients, and contaminants. Hydrology provides the basics for applied fields such as engineering and agricultural sciences, which aim for proper development, protection and management of water resources, mitigation of water-related disasters such as floods and droughts, and agricultural production by drainage and irrigation.

Fig. 1.1 illustrates the major components of the **water cycle**. **Precipitation** falls on the Earth surface. Part of the precipitation is intercepted by trees and vegetation, which does not reach the ground surface and is evaporated into the atmosphere. Precipi-

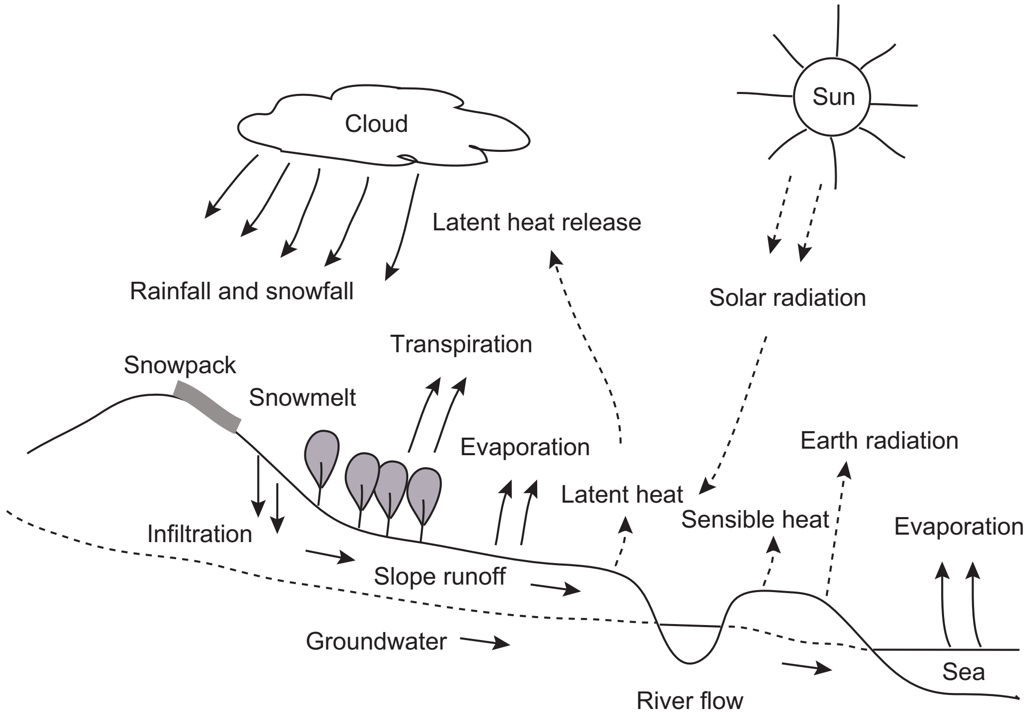

Fig. 1.1: Hydrologic processes and water and energy movement with change of water phase.

tation which reaches on the land surface infiltrates into the soil layers and forms **subsurface flow** and **groundwater flow**. Rainfall which exceeds the **infiltration capacity** forms **surface runoff**. Precipitation falling on the ground as snow is accumulated as snow cover, which melts and flows through similar routes to rainfall-runoff. The water in the surface layer evaporates and returns to the atmosphere. Trees and vegetation absorb the soil moisture from the roots and release the vapor through the stomata. This process is called **transpiration**. Combining **evaporation** with **transpiration**, it is collectively called **evapotranspiration**.

The water cycle is inextricably associated with the **energy cycle**. When the soil moisture on the ground surface evaporates and changes the phase from water to vapor, the **latent heat** moves from the Earth surface to the atmosphere. When the vapor changes to raindrops, the latent heat is released to the atmosphere as **condensation heat**. In other words, the solar energy provided to the Earth surface is transferred to the atmosphere through evaporation and precipitation. The solar energy given to the Earth surface is spatially and timely distributed, which determines the climate of the Earth. The water cycle and the energy cycle are closely related to the climate of the Earth and the spatiotemporal distribution of water.

To understand the water cycle and energy cycle, it is necessary to understand the physical mechanism of water and energy movements by solar radiation as well as the mechanism of water movement governed by the conservation of water mass (continuity equation) and the moment (momentum conservation). Water movement causes the movement of soils and chemical substances dissolved in water. These movements are closely associated with our lives and the environment. Therefore, the scope of hydrology includes the cycles of water, energy and physical, chemical, and biological processes associated with the cycles of water and energy.

1.1.1 Hydrologic cycley and water resources engineering

Hydrological science has both pure and applied aspects. The first aspect relates to questions about how the Earth works, and specifically about the role of water in natural processes. The second relates to the use of scientific knowledge to provide a sound basis for proper use and protection of water resources (Hornberger *et al.*, 1998). The second aspects is the main themes of water resources engineering. The research topics include:

- flood and drought
- flood risk management
- water resources management
- climate change and water resources

【Example 1.1】Topics of hydrologic cycle and water resources

Describe any topics related to the hydrologic cycle and water resources in your countries. For example, flood, drought, water quality, water resources development, climate change and so on.

1.2 Water Budget and Hydrologic Cycle

1.2.1 Water on the Earth

The radius of the Earth is 6,371km and the surface area is 5.1×10^8 km^2. 71% of the surface is ocean, and 29% is land. The total volume of water exiting on the Earth surface is estimated about 14.6×10^{20} kg (14.6×10^8 km^3). Approximately 97% of such water is seawater, and the remaining 3% is inland water, such as snow, ice, groundwater, lakes, and rivers. Vapor and cloud water in the atmosphere account for 0.001%.

【Example 1.2】 The volume of water on the Earth

Using the numerical values provided above, calculate the average thickness of seawater, inland water, and atmospheric moisture supposing each of them is spread out evenly on the ocean, the land, and the surface of the Earth, respectively.

(Solution)

The average thickness of water in the ocean is given by dividing the volume of seawater by the area of the ocean:

$$\frac{14.6 \times 10^8 \text{ km}^3 \times 0.97}{5.1 \times 10^8 \text{ km}^2 \times 0.71} = 3,911 \text{ m}$$

The average thickness of water on the land is given by dividing the volume of inland water by the area of the land:

$$\frac{14.6 \times 10^8 \text{ km}^3 \times 0.03}{5.1 \times 10^8 \text{ km}^2 \times 0.29} = 296 \text{ m}$$

The average thickness of atmospheric water is given by dividing the volume of moisture in the atmosphere by the surface area of the Earth:

$$\frac{14.6 \times 10^8 \text{ km}^3 \times 0.00001}{5.1 \times 10^8 \text{ km}^2} = 28.6 \text{ mm}$$

1.2.2 Water balance equation

To discuss the spatiotemporal distribution of water, suppose a closed compartment (referred to as a control volume) shown in **Fig. 1.2**. M_{in} is the rate of mass flowing into the control volume [M T^{-1}]; M_{out} is the one flowing out of the control volume [M T^{-1}]; and M is the mass stored in the control volume [M]. The equation of **conservation of mass** is given by

$$\Delta M = (M_{\text{in}} - M_{\text{out}})\Delta t \tag{1.1}$$

where ΔM is the change of the water mass in the control volume over time Δt. Using the **density** of water ρ, $M = \rho S$, $M_{\text{in}} = \rho I$, and $M_{\text{out}} = \rho O$, where S is the volume of

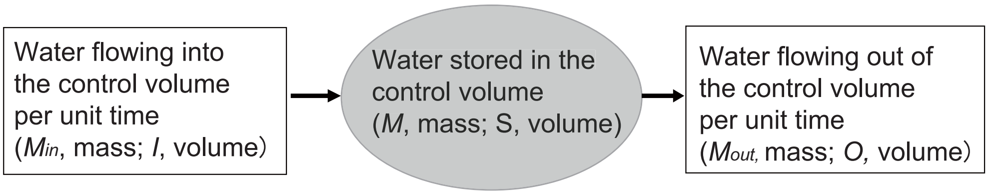

Fig. 1.2: Water budget and continuity relation.

the water stored in the control volume [L^3]; I is the volume inflow rate [L^{3}T^{-1}]; and O is the volume outflow rate [L^{3}T^{-1}]. Canceling the the density from both sides of Eq.(1.1)

$$\Delta S = (I - O)\Delta t \tag{1.2}$$

By dividing both sides by Δt and taking the limit of Δt, the equation of volume conservation (continuity equation) is given as:

$$\frac{dS}{dt} = I - O \tag{1.3}$$

Generally the density of water is regarded as constant and that the continuity equation is expressed with volume, not with mass. The continuity equation is often referred as a **water balance equation** or a **water budget equation**.

1.2.3 Global water budget

We can develop a global water budget equation using Eq.(1.3). For the land, S is the volume of water stored on and in the land, I is precipitation P [L^{3}T^{-1}], and O consists of evapotranspiration E [L^{3}T^{-1}] and runoff Q [L^{3}T^{-1}]. Integrating Eq.(1.3) over a time period τ, the continuity equation becomes

$$\int_\tau dS = \int_\tau I dt - \int_\tau O dt = \int_\tau P dt - \int_\tau (E + Q) dt \tag{1.4}$$

The integration of dS/dt over a year could be negligibly small. In the case, the continuity equation becomes

$$\int_\tau P dt = \int_\tau (E + Q) dt \tag{1.5}$$

and evapotranspiration is estimated from observed precipitation and discharge.

【Example 1.3】 Annual precipitation

The motion of water is described in terms of reservoirs that store water and the movements between them. **Fig. 1.3** indicates the volume of water stored in the atmosphere, oceans and lands on the Earth and its annual movement volume. Using the values shown in **Fig. 1.3**, calculate the annual precipitation per unit area on the ocean, the land, and the surface of the Earth.

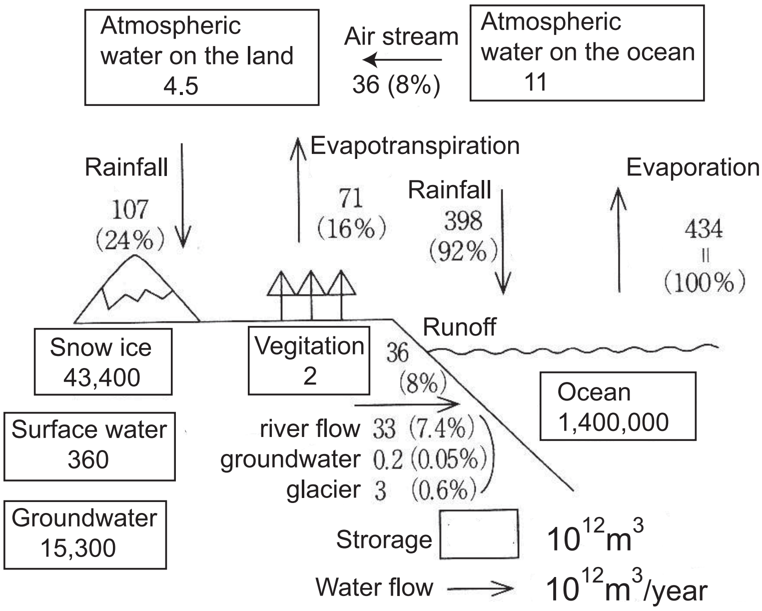

Fig. 1.3: The water stored on the Earth and the annual movement. The percentage represents the ratio when the annual evaporation from the ocean is 100%. (Takeda, T. *et al.*, Meteorology in water environment, University of Tokyo Press, 1992)

(Solution)

The annual precipitation per unit area on the ocean is given by dividing the total volume of the annual precipitation on the ocean by the sea surface area:

$$\frac{398 \times 10^{12}\ \mathrm{m^3 yr^{-1}}}{5.1 \times 10^8 \times 0.71\ \mathrm{km^2}} = 1,099\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual precipitation per unit area on the land is given by dividing the total volume of the annual precipitation on the land by the land surface area:

$$\frac{107 \times 10^{12}\ \mathrm{m^3 yr^{-1}}}{5.1 \times 10^8 \times 0.29\ \mathrm{km^2}} = 723\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual precipitation per unit area on the Earth surface is given by dividing the total volume of the annual precipitation on the Earth surface by its area:

$$\frac{(398+107)\times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1\times 10^8\ \mathrm{km^2}} = 990\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual precipitation amount in Japan is approximately 1,700 mm·yr^{-1} on average, which is substantially greater than the average annual precipitation on the land. **Fig. 1.3** indicates that approximately 66%(=71/107) of precipitation on the land originates from evapotranspiration from the land. Most of precipitation in Japan is brought in the rainy season and typhoons and the rainwater originates from the evaporation on the ocean.

【Example 1.4】 Annual evapotranspiration

Using the values shown in **Fig. 1.3**, calculate the annual evapotranspiration per unit area on the ocean, the land, and the surface of the Earth.

(Solution)

The annual evaporation per unit area from the ocean is given by dividing the annual total volume of evaporation from the ocean by the sea surface area:

$$\frac{434\times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1\times 10^8\times 0.71\ \mathrm{km^2}} = 1,199\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual evapotranspiration per unit area from the land is given by dividing the annual total volume of evapotranspiration from the land by the land surface area:

$$\frac{71\times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1\times 10^8\times 0.29\ \mathrm{km^2}} = 480\ \mathrm{mm{\cdot}yr^{-1}}$$

The annual evapotranspiration per unit area from the Earth surface is given by dividing the total volume of the annual evapotranspiration from the Earth surface by its area:

$$\frac{(434+71)\times 10^{12}\ \mathrm{m^3yr^{-1}}}{5.1\times 10^8\ \mathrm{km^2}} = 990\ \mathrm{mm{\cdot}yr^{-1}}$$

【Example 1.5】 Annual runoff and runoff ratio

Calculate the annual runoff per unit area and runoff ratio on the land using the values in **Fig. 1.3**.

(Solution)

The annual runoff per unit area from the land is given by dividing the total volume of the annual runoff by the land surface area:

$$\frac{36 \times 10^{12}\ \mathrm{m^3 yr^{-1}}}{5.1 \times 10^8 \times 0.29\ \mathrm{km^2}} \times 10^3 = 243\ \mathrm{mm \cdot yr^{-1}}$$

or annual precipitation minus annual evapotranspiration ($723 - 480 = 243\ \mathrm{mm \cdot yr^{-1}}$).

The runoff ratio is given by dividing the annual runoff by the annual precipitation:

$$\frac{243\ \mathrm{mm \cdot yr^{-1}}}{723\ \mathrm{mm \cdot yr^{-1}}} = 0.34$$

1.2.4 Catchment water budget and water resources

A **catchment**, as shown in **Fig. 1.4**, is an area in which rain water drains into a **channel network** (river network) and finally flows into the river mouth. A catchment is separated by a topographically defined watershed boundary. Consider A is the area of a catchment basin [$\mathrm{L^2}$]; r is the precipitation rate [$\mathrm{LT^{-1}}$] (volume of precipitation falling on the catchment basin per unit time per unit area); e is the evapotranspiration rate [$\mathrm{LT^{-1}}$] (the volume of water evaporating per unit time per unit area); and Q is the runoff rate flowing out of the catchment [$\mathrm{L^3T^{-1}}$]. The inflow rate into the catchment I in Eq.(1.3) is

$$I = Ar$$

and the outflow rate is

$$O = Ae + Q$$

Substituting these into Eq.(1.3), the continuity equation in the catchment is defined as

$$\frac{dS}{dt} = A(r - e) - Q \tag{1.6}$$

Integrating Eq.(1.6) from time t_s to t_e, the continuity equation becomes

$$\int_{t_s}^{t_e} dS = S(t_e) - S(t_s) = A\left(\int_{t_s}^{t_e} r dt - \int_{t_s}^{t_e} e dt\right) - \int_{t_s}^{t_e} Q dt$$

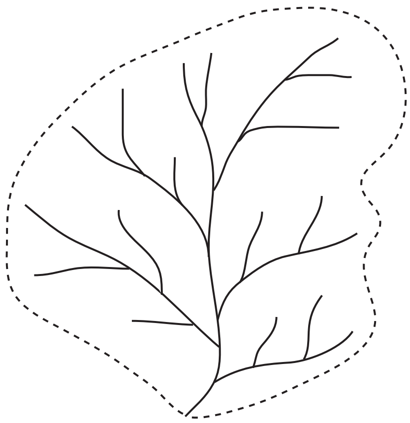

Fig. 1.4: Watershed divide and catchment basin.

If we take the start time t_s and the end time t_e as $S(t_s) = S(t_e)$, the continuity equation becomes

$$A\left(\int_{t_s}^{t_e} r dt - \int_{t_s}^{t_e} e dt\right) - \int_{t_s}^{t_e} Q dt \tag{1.7}$$

For the time period, the total volume of water flowing into the catchment basin is equal to that flowing out of the basin. If we take t_s in the dry season and t_e after one year, the time-integrated value of dS/dt is negligible, and the evapotranspiration value for the time period can be estimated using the observed precipitation and discharge data.

【Example 1.6】 Hydrologic characteristics in Asian regions

Table 1.1 shows the annual precipitation, evapotranspiration, and runoff at the Chao Phraya River basin (CPRB) in Thailand (157,925 km^2) and the Katsura River basin in Kyoto, Japan (887 km^2). Calculate the values in (1) and (2) in **Table 1.1** and discuss the difference of the catchment hydrologic variables from the view point of water resources.

Table 1.1: Annual catchment hydrologic variables.

Region	Precipitation	Evapotranspiration	Runoff
Chao Phraya River (Thailand)	1,144	962	(1)
Katsura River (Kyoto, Japan)	1,796	708	(2)
World (mean)	723	480	243

*unit is mm/year.

(Solution)

(1) 1,144-962=182 mm/yr. (2) 1,796-708=1,088 mm/yr.

【Example 1.7】 Annual surface water resources in Thailand and Japan

Table 1.2 shows the estimated mean annual runoff in Thailand, Japan and the world. Calculate the per capita maximum water resources for one year for each area and discuss the difference of the water resources.

Table 1.2: Annual water resources in Thailand and Japan.

Region	Runoff (mm/yr)	Area (km^2)	Population (person)
Chao Phraya River (Thailand)	182	513×10^3	69.5×10^6
Katsura River (Japan)	1,088	378×10^3	126.5×10^6
World (mean)	243	147.9×10^6	6,968×10^6

(Solution)

The maximum water resources per capita in the Chao Phraya River basin in Thailand is obtained by dividing the total annual runoff volume by the population, which is

$$\frac{182\text{mm/yr} \times 513 \times 10^3\text{km}^2}{69.5 \times 10^6\text{person}} = \frac{93,366 \times 10^6\text{m}^3\text{/yr}}{69.5 \times 10^6\text{person}} = 1,343\text{m}^3\text{/person/yr}$$

The maximum water resources per capita in the katsura River basin in Japan and the mean value of the world are

$$\frac{1,088\text{mm/yr} \times 378 \times 10^3\text{km}^2}{126.5 \times 10^6\text{person}} = \frac{411,264 \times 10^6\text{m}^3\text{/yr}}{126.5 \times 10^6\text{person}} = 3,251\text{m}^3\text{/person/yr}$$

$$\frac{243\text{mm/yr} \times 147.9 \times 10^6\text{km}^2}{6,968 \times 10^6\text{person}} = \frac{35,940 \times 10^9\text{m}^3\text{/yr}}{6,968 \times 10^6\text{person}} = 5,158\text{m}^3\text{/person/yr}$$

【Example 1.8】 Surface water resources under a changing climate in Thailand and Japan

Global warming could induce the change of the hydrologic cycle. If evapotranspiration increases in 5%, estimate the decrease percentage of river discharge, namely the maximum surface water resources for the Chao Phraya River basin in Thailand the Katsura River basin in Kyoto, Japan using the values in **Table 1.1**.

(Solution)

In the Chao Phraya River basin, annual runoff is $1,144 - 962 \times 1.05 = 134$ mm/yr. The decrease ratio is

$$\frac{182 - 134}{182} \times 100 = 26\%$$

In the Katsura River basin, annual runoff is $1,796 - 708 \times 1.05 = 1053$ mm/yr. The decrease ratio is

$$\frac{1088 - 1053}{1088} \times 100 = 3.3\%$$

Increase of evapotranspiration has high influence on surface water in Thailand.

【Example 1.9】Change of annual surface water resources in Thailand

Assuming the surface runoff obtained in the above example and the population in Thailand with increase in 5%, estimate the decrease percentage of water resources per capita. Discuss using the values in **Table 1.2**.

(Answer)

The maximum water resources per capita in Thailand is

$$\frac{134\text{mm/yr} \times 513 \times 10^3\text{km}^2}{69.5 \times 10^6 \times 1.05 \text{ person}} = \frac{68,742 \times 10^6\text{m}^3/\text{yr}}{73.0 \times 10^6\text{person}} = 942\text{m}^3/\text{person/yr}$$

The decrease ratio is

$$\frac{1,343 - 942}{1,343} \times 100 = 30\%$$

1.3 Mean Residence Time

The mean residence time refers to the times that are required for the water in the drainage basin to be completely replaced with new water flowing into the drainage basin. The mean residence time provides a time scale of the movement of water and substances that travel with water in the basin. Assuming the **steady state** condition ($dS/dt = 0$), the mean residence time is easily calculated by dividing the volume of water stored in a control volume by the volume of water that flows into the region per unit time, or by the volume of water that flows out of the region per unit time.

【Example 1.10】Mean residence time in global water budget

Calculate the mean residence time of water that exists on the land and in the atmosphere, using the values provided in **Fig. 1.3**.

(Solution)

The annual mean precipitation on the lands (sum of annual evapotranspiration and runoff from the land) is 107×10^{12} m^{3}yr^{-1}. The total volume of water stored on and beneath the land is $(43,400 + 360 + 15,300 + 2) \times 10^{12}$m^3. Therefore, the mean residence time of water on the land is:

$$\frac{(43,400 + 15,300 + 360 + 2) \times 10^{12}\ \mathrm{m}^3}{107 \times 10^{12}\ \mathrm{m}^3\mathrm{yr}^{-1}} = 552 \text{ year}$$

The annual precipitation on the lands and oceans is $(107 + 398) \times 10^{12}$m^{3}yr^{-1}. The total volume of water stored in the atmosphere is $(4.5 + 11) \times 10^{12}$m^3. Therefore, the mean residence time of water in the atmosphere is:

$$\frac{(4.5 + 11) \times 10^{12}\ \mathrm{m}^3}{(107 + 398) \times 10^{12}\ \mathrm{m}^3\mathrm{yr}^{-1}} = 11.2 \text{ day}$$

The mean residence time of water in the atmosphere is very short, indicating that water is frequently exchanged with heat energy.

The volume of water in snow ice and groundwater accounts for more than 99% of the water on and beneath the land, and runoff from snow ice and groundwater accounts for less than 10%. Assuming only surface water and water in vegetation move, the mean residence time of the water on the land is

$$\frac{(360 + 2) \times 10^{12}\ \mathrm{m}^3}{107 \times 10^{12}\ \mathrm{m}^3\cdot\mathrm{yr}^{-1}} = 3.4 \text{ year}$$

Most of surface water is stored in lakes and soil layers. Movement such water is slower than that of water in rivers. Therefore, the mean residence time of water in rivers is estimated as several ten days.

【Example 1.11】Mean residence time in dam reservoirs

Table 1.3 shows the characteristics of the largest dams in Thailand and Japan. How many years it take to completely replace the water in the full storage capacity at the Bhumibol Dam, the Tokuyama Dam, and the Hiyoshi Dam? Use the annual hydrologic variables in **Table 1.1**.

Table 1.3: Characteristics of the dams in Thailand and Japan.

Dam	Storage capacity($\times 10^6$m^3)	Catchment area (km^2)
Bhumibol Dam	13,420	26,400
Tokuyama Dam	660	254.5
Hiyoshi Dam	66	290

(Solution)

The annual inflow to the Bhumibol Dam is 182 mm/yr $\times$ 26,400 km^2. The mean residence time of the dam reservoir is given by dividing the storage capacity by the annual inflow:

$$\frac{13,420 \times 10^6 \text{ m}^3}{26,400 \text{ km}^2 \times 182 \text{ mm/yr}} = 2.8 \text{ year}$$

Similarly for the Tokuyama Dam

$$\frac{660 \times 10^6 \text{ m}^3}{254.5 \text{ km}^2 \times 1088 \text{ mm/yr}} = 2.4 \text{ year}$$

and for the Hiyoshi Dam

$$\frac{66 \times 10^6 \text{ m}^3}{290 \text{ km}^2 \times 1088 \text{ mm/yr}} = 0.21 \text{ year}$$

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2. Water Resources Projection under a Changing Climate

2.1 Climate Change Scenario and GCM data

General circulation models (GCMs) provide future atmospheric and hydrologic variables under various climate change scenarios. The output hydrologic variables are used to various applications of future hydrologic projections to evaluate future water resources under a changing climate. One of the latest GCMs is MRI-AGCM3.2S developed by the Meteorological Research Institute, the Japan Meteorological Agency. The products of MRI-AGCM3.2S consist of various atmospheric and hydrologic variables for the present climate experiment (1979-2008), the near future climate experiment (2015-2044), and the future climate experiment (2075-2104), which were simulated under the SRES A1B scenario. **Fig. 2.1** shows the GCM outputs related to the hydrologic cycle.

Recent GCMs adopt new scenarios, the RCP (representative concentration passway)

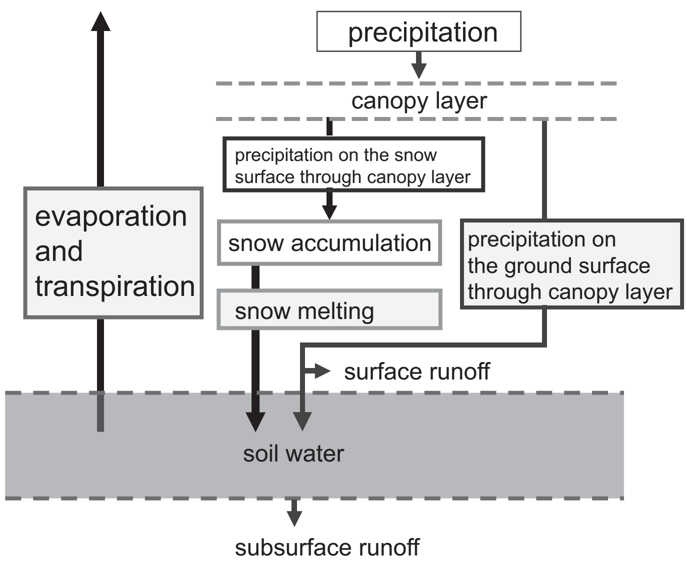


Fig. 2.1: GCM outputs related to the hydrologic cycle in the MRI-AGCM.

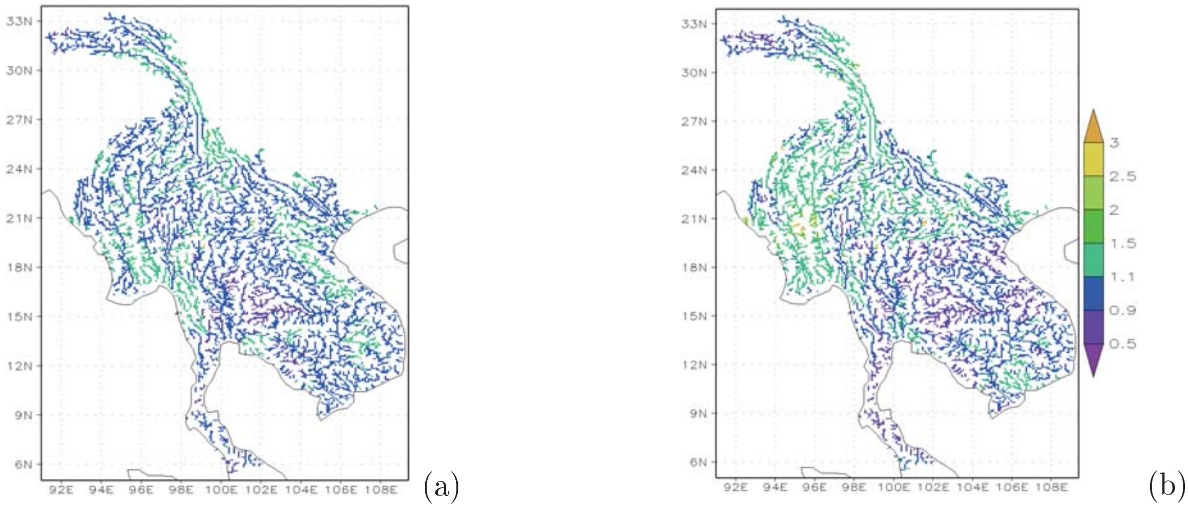


Fig. 2.2: Ratio of annual mean discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

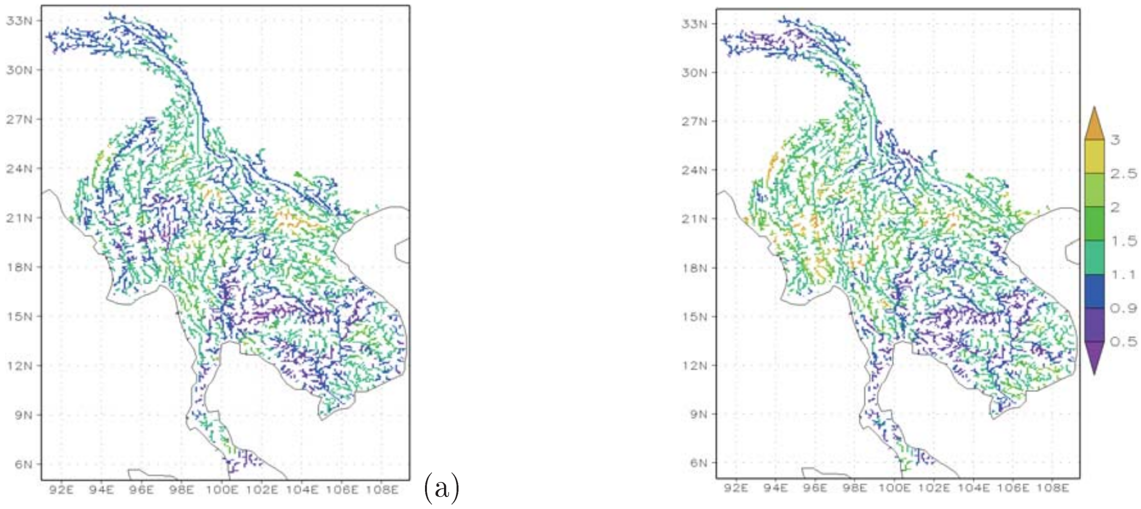
instead of the SRES scenarios. The RCP scenario assumes a greenhouse gas concentration trajectory for the future. The RCPs have four scenarios, RCP2.6, RCP4.5, RCP6 and RCP8.5. The RCP8.5 is the severest among the four scenarios.

2.2 River Flow Simulation in Indochina Peninsula

River discharge projection in Indochina Peninsula region was carried out using MRI-AGCM3.2S. Daily mean discharge, maximum hourly discharge in a day is stored in 5-minute spatial resolution. The simulated river discharge was analyzed to locate possible hotspot basins with significant changes of floods, droughts and water resources.

2.2.1 Change of water resources

Annual mean simulated river discharge for three climate experiments was calculated and used to analyze changes in water resources in Indochina Peninsula region. **Fig. 2.2** shows the change ratio of annual mean discharge for the near future climate and the future climate to the present climate experiment. From **Fig. 2.2**(a), it can be seen that there are not so much changes in annual mean discharge in the near future. Slightly increases in annual mean discharge with the ratio smaller than 1.5 can be detected at the most upper parts of Salween and Mekong River basin, the lower part of Irrawaddy River basin, and western part of Vietnam. Only eastern part of Chao Phraya River basin shows a trend of



(a) (b)

Fig. 2.3: Ratio of annual maximum discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

decreasing in annual mean river flow with the ratio is between 0.5 and 0.9. **Fig. 2.2**(b) shows a similar trend with higher intensity in the future climate experiment. We can see that the area with changes in annual mean discharge and ratio range become larger, especially at the middle and lower part of Irrawaddy River basin, and eastern part of Chao Phraya River basin. However, the annual mean flow in the future climate tended to decrease in the central part of Vietnam. The change ratio is lower than 0.9.

2.2.2 Change of flood risk

Annual maximum discharge data for three climate experiments were compiled and were analyzed. The change ratio of mean of annual maximum discharge for the near future climate and the future climate with respect to the present climate experiment are shown in **Fig. 2.3**. For the near future climate experiment, the mean of annual maximum discharge has significant changes at the upper and lower part of Salween River basin, north-western part of Vietnam, and eastern part of Chao Phraya River basin. The changes, which were detected in the near future climate experiment, become more visible in the future climate experiment. Irrawaddy River basin and Red River basin showed a noticeable increasing of mean of annual maximum discharge in the future climate experiment. The ratio at some areas are larger than 2.5. It means that the risk of flooding at those areas will increase.

The ratio of the standard deviation of the annual maximum discharge for the near future climate and the future climate to the present climate experiment were also calcu-

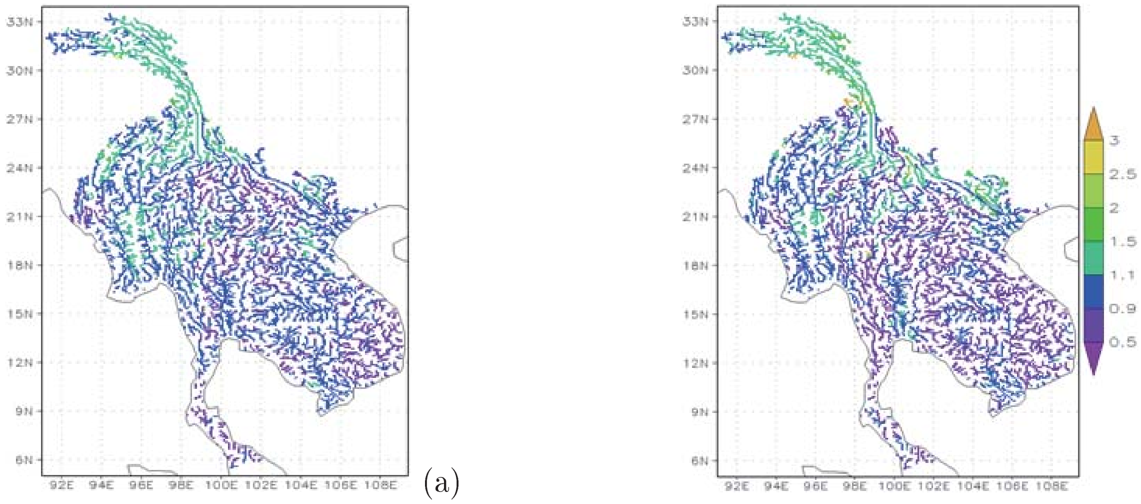


Fig. 2.4: Ratio of mean of annual minimum discharge for the near future climate to the present climate (a), and the future climate to the present climate (b).

lated and analyzed. The standard deviation also showed a similar trend to the changes of mean of annual maximum discharge. The increases of standard deviation of annual maximum discharge can be found in Irrawaddy River basin, Salween River basin.

2.2.3 Change of drought risk

The change of drought risk in Indochina Peninsula region was also analyzed by comparing the mean of annual minimum discharge in the near future climate and the future climate experiment with those values in the present climate experiment. From **Fig. 2.4**, it can be seen that there is a decrease trend at the middle part of Mekong River basin in the territory of Lao PDR, western part of Chao Phraya River basin, and the south-eastern part of Indochina Peninsula, especially the southern part of Vietnam. This trend becomes clearer in the future climate experiment.

References

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