International Hydrological Programme

Hydrology related to Headwater Management

— The Textbook for the 10th IHP Training Course in 2000 —

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Cover: Devastated hilly mountain at 1900 near Nagoya City, Central Japan

Preface

This training course, as one of the activities of the International Hydrological Programme (IHP), has been supported by a large number of university professors, institute researchers and governmental engineers who are devoted to hydrological education for young scientists from the Asian-Pacific region. Substantial efforts have also been made by those who are involved in some committees; Japan National Commission for UNESCO, Sub-committee for IHP, and Working Group for IHP Training Course. In addition, contributions from governmental organizations and institutions have been essential for the training course to be successful. Since 1997, a new trial had been planned for the schedule of the training course. Firstly, we put a clearly defined training target every year for the training students, Snow Hydrology in March 1998, Remote sensing in March 1999, Limnology in June-August 1999 and Hydrology related to Headwater Management in July-August 2000. Secondly, we established an experimental programme to allow the students to better understand the target.

For this purpose we need to edit a textbook. The textbook of this year is titled Hydrology related to Headwater Management and is composed of selected contents from which students can obtain introductory and up-to-date knowledge of Hydrology related Headwater Management in a short period. We express our gratitude to the authors for dedication to prepare this book.

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Chapter 1

History of mountain devastation in the Watarase River Basin
Shigeki Kobatake

1.1 General description

Watarase River is a tributary of Tone River, the largest river in Japan. The drainage area of Watarase River is 2,602km^2 and its watercourse length from the water source to the confluence of Tone River is about 108km. Watarase River basin became famous as the place where environmental pollution struggle first happened in Japan.

In 1610, a copper vein was discovered, in Ashio district, the upstream region of Watarase River. Tokugawa Shogunate Government then started activities of mining and refining. Though these activities were interrupted temporarily and the ownership changed on the way, exploitation continued for over 360 years, until 1973. In this period, environmental pollutions occurred and led to the first environmental pollution struggle in Japan. In the Ashio district, the sulfurous acid gas affected 278km^2 of forest and the mining remnants contaminated the wide paddy field in the downstream of Watarase River. Reforestation and sabo-works were started since 1897 in order to ease these environmental pollutions.

In the present paper, the outline of Watarase River basin, the history of copper mine, environmental pollutions and restoration measures are briefly explained.

1.2 Outline of Watarase River basin

Watarase River is 108 km long and drains an area of 2,602 km^2. Originating from Mt.Sukai (2,144 m), it first flows southward through a narrow valley to the Takatsudo area located in northwest edge of Kanto-Plain. It then continues southeastwards to the confluence with the Tone River. About 66 % of the basin is mountainous area while the remaining 34% is plains.

The catchment's area receives an average annual precipitation of approximately 1,400mm(basin average). The mean annual discharge at Takatsudo(472km^2) during the period 1960 to 1996 was 18.75m^3/s. There are two multi-purpose reservoirs on the main channel and a small one on a tributary. Watarase Daiichi Reservoir, one of the two reservoirs on the main channel, was constructed by excavating about 4.5km^2 area of the Watarase Retarding Basin, located near the confluence. In 1990, the population in the basin was about 1,300,000 people.
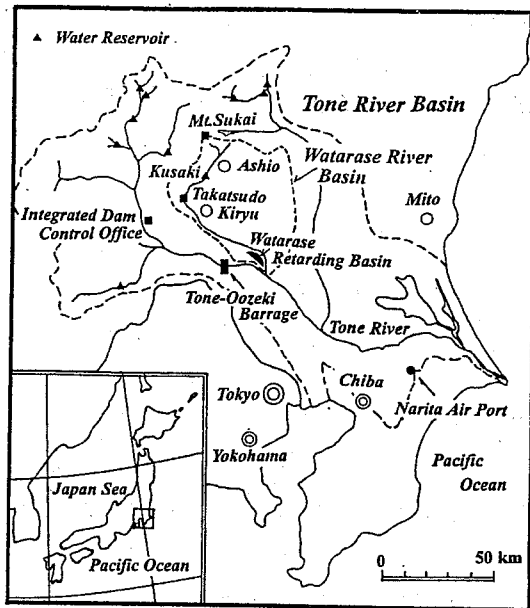
Fig.1 Map of Tone and Watarase River Basin
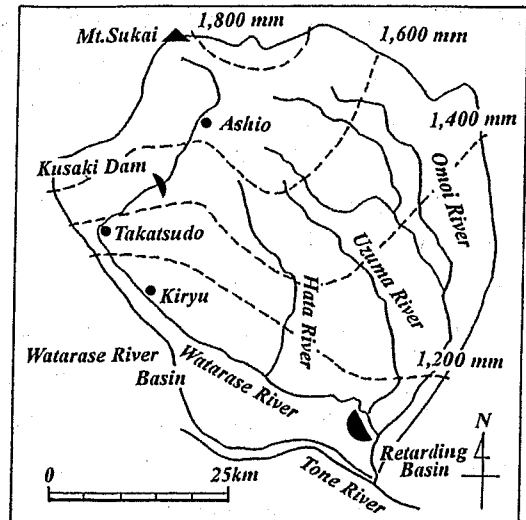
Fig.2 Channel network and annual isohyetal map of Watarase River basin

Fig.1 shows the location of Tone and Watarase River. Fig.2 is a precise map of Watarase River. In addition it shows distribution of annual rainfall in the river basin. Ashio, the headwaters, is located in the northeast of the basin. Ashio is a region with the largest amount of rainfall in Watarase River basin. Moreover, during winter, it receives a small amount of snowfall.

The mountain slopes facing the southeast in this basin experience heavy rainfall by the intrusion of damp southeasterly winds due to typhoon. In 1947, occurred the famous disastrous flood due to Typhoon Catherine. This typhoon caused an exceptionally huge flood, which surpassed all previous record floods. 709 persons were killed or lost in Watarase River basin, mainly in Kiryu and Ashikaga districts, due to breaks of embankments. The rainfall amounts observed at Ashio and Kiryu during this typhoon were 386mm and 370mm respectively. A maximum value of 470mm in the Watarase River basin was observed at Mt. Akagi located 20km northwest from Kiryu.

Based on the 1947 flood, the peak discharge of the Watarase River before regulation is 4,600 m^3/s at the control point of Takatsudo. 1,100 m^3/s of peak discharge is to be regulated by Kusaki Dam and 3,500m^3/s is to be discharged through the river channel. At the confluence with Tone River, the design flood becomes 9,400 m^3/s. Near the confluence, there is the Watarase Retarding Basin that has an area of about 33 km^2 and a capacity of about 200 million m^3. This scale is the largest in Japan as a retarding basin.

The Watarase Retarding Basin regulates the design flood discharge of 9,400 m^3/s (Watarase River 4,500 m^3/s,Omoi River 3,700 m^3/s, Uzuma River 1,200 m^3/s), in order not to increase the peak discharge of Tone River.
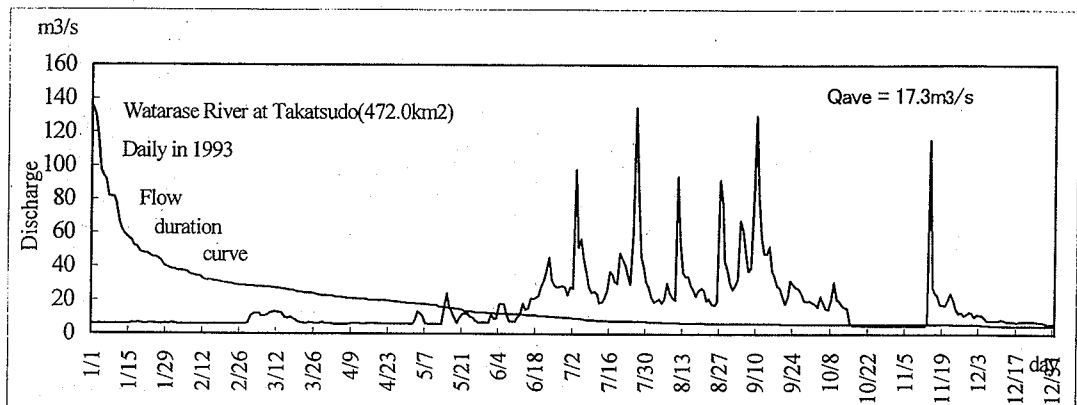
Fig.3 An example of daily discharge and the flow duration curve in 1993

Fig.3 shows an example of daily discharge and the flow duration curve at Takatsudo in 1993. From June to September, we have a huge amount of rainfall caused by front and typhoon.

1.3 History of the Ashio copper mine

Since the discovery of copper vein in 1610, the mine was under the management of Tokugawa Shogunate Government, until Shogunate Government died out in 1867. Mining activities reached the peak between 1660 and 1690; 1500 tons of copper mined per year, overbalancing the needs of Shogunate Government. The mineral reserve, approximately 1/5 of the mined quantity, was sold to merchants of Netherlands and China. As a result of mining activities development, 14 new villages appeared in Ashio district. Ashio, originally a mountainous village, showing its prosperity at that time as called "1000 houses in Ashio". That was the first golden era for Ashio district.

However, in early 1700's the mined output decreased, becoming 10% of previous era. The output continued to decrease until the beginning of 1800, when the production completely stopped. Nevertheless, during this era, environmental pollution was still not so severe.

In 1867, Meiji Government took over the administration by overthrowing the Shogunate Government, and the modernization of Japan began. In 1871, the management of Ashio mine was transferred to private sector and finally Mr. Ichibei Furukawa purchased the mine at 1876. His company discovered a new vein in 1881 and

the mine entered a new era of prosperity.

Fig.4 shows the output of the crude copper at Ashio mine for recent 120 years. The bar graph shows change of the output per year (ton/year) and black points show population of Ashio Town. After the discovery of the new vein at 1881, more veins were successively discovered and the output quantity of crude copper recorded its maximum value of 15,735 ton/year in 1917.
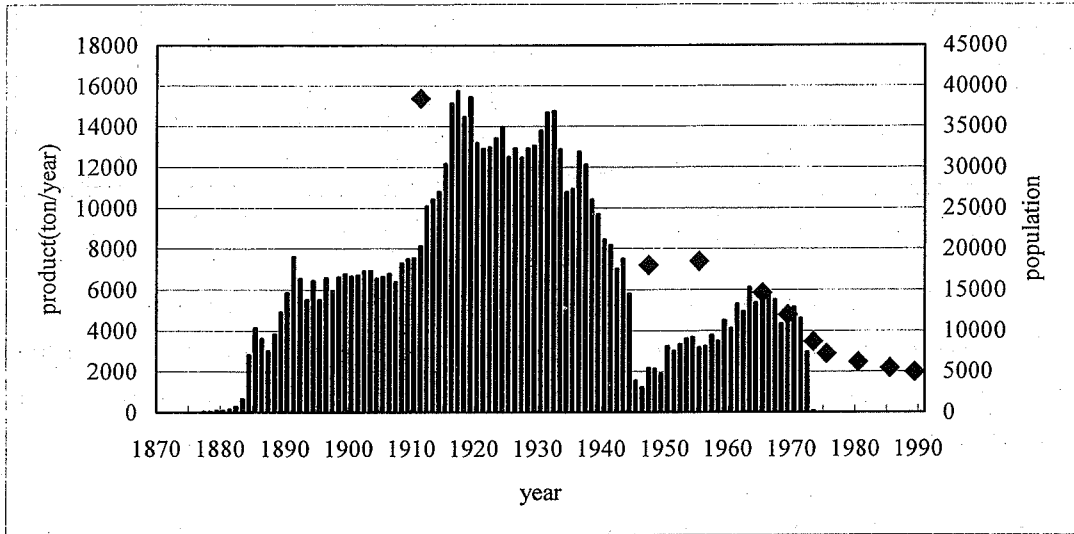
Fig.4 The output of the crude copper at Ashio mine for recent 120 years

After the World War II, the output decreased due both to exhaustion of industry and dissolution of financial combine. Despite a slight increase in output the following years, worldwide recession of the copper price and the revalued of Yen rate at 1970, gave a decisive blow for the domestic copper mining industry. Gradually, mining industry stopped production. Mining activities effectively stopped in Ashio in1973.

Though the population of the Ashio town counted 38,000 people in the second golden era, the population went on decreasing afterwards. Nowadays, the population is less than 5,000 people, as shown in Fig.4.

1.4 History of environmental pollution

During the second period of development, where new veins were successively discovered and exploited, severe environmental pollutions occurred. Deforestation was widely carried out for the production of timber for supporting tunnels and fuel necessary to the refining activities. Moreover, the huge wood fire catastrophe called "Matsuki

conflagration" occurred in 1887. In addition, the introduction of Bessemer refining method in 1893 decisively caused the devastation of the mountainous area. Sulfurous acid gas discharged by the Bessemer refining method, blighted the sprouts after the conflagration. As the geology of Ashio soil is fragile granite and paleozoic strata, once the topsoil was washed away, surface layer flaking and collapse were repeated. Finally, a very wide area of the land was devastated.

In the meantime, contamination of the farmland by copper remnants transported and deposited by flash flood, often occurred at the downstream. Especially, in 1890, a large flood occurred in this area and about 7,000 ha of farmland were contaminated. Farmers petitioned for removal of contaminated soil and Mr. Shozou Tanaka who had been a member of the Diet, presented this problem to the Diet. Arbitration was carried out between farmers and the company. A withdrawal vessel for powdered ore was installed, and the composition was also paid. However, while the runoff of the remnants continued, about 11,700 ha of the farmland were again contaminated by flood in1896. The Ministry of Agriculture and Commerce ordered the installation and operation of a filtration pond by the company. Also the reforestation of the devastated mountainous area was decided to be carried out by the Forest Service. However, farmers continued their struggle requiring the closure of the mine, and finally, Mr. Shozou Tanaka made a direct appeal to the Emperor at 1901.

However, the company was not ordered to close the mine, and the government attempted to solve the struggle by transferring the farmers. At that time, the polluted area was treated and turned to a part of the Watarase Retarding Basin.

Watarase River is called as the cradle of environmental pollution struggle in Japan.

1.5 Measures for environmental pollution

In 1897, Forest Service began the reforestation in the Ashio district. However, afforested tree did not grow, as the discharge of the sulfurous acid gas continued. The company kept on the effort to reduce the discharge of the sulfurous acid gas, but without success, until a new refining method that can produce sulfuric acid from sulfurous acid gas, was introduced in 1956. After the introduction of this new refining method, reforestation began again. It was decided that the three parties, namely Ministry of Agriculture and Forestry, Ministry of Construction and Tochigi Prefecture, would share the reforestation operations. Ministry of Agriculture and Forestry took charge of afforetation for national forest, and Tochigi Prefecture took charge of afforestation for private forest while Ministry of Construction took charge of construction of Sabo-dam

and bank-revetment of the main channel. After the historical flood in 1947 caused by Typhoon Catherine previously mentioned, the largest Sabo-dam in Japan having capacity of 5 million m^3 was constructed in Ashio.

Various kinds of afforestation methods were introduced. One of them was seeding using helicopter. This method is composed of three steps, which are, the fertilizing step, seeding step and covering step using asphalt emulsion. Combining the manpower and the helicopter, they were able to deal with various kinds of landforms and geology. In 1988, treatment of 720 ha was finished within all the 1670 ha of devastated area.

Appendix: Main historical events

1610	Two farmers discovered the copper vein in Ashio
1660-1690	First golden era (output is 1,500 ton/year, 1,000 houses in Ashio Village)
1700	The output decreased to 1/10 of that of the golden era
1800's	The production completely stopped
1871	The management of Ashio mine was transferred to private sector
1876	Mr. Ichibei Furukawa purchased the mine
1881	New ore was discovered
1882	New ore was discovered
1883	New ore was discovered
1886	The first telephone as private use
1887	Masuki conflagration
	The first iron bridge for road use in Japan
	The first hydraulic power plant in Japan
	The first iron cable-way in Japan
1890	7,000 ha of farm land was contaminated by remnants
1891	Mr. Shozou Tanaka took up the petition of farmer at the Diet
1892	Arbitration was carried out between farmers and the company, and a withdrawal vessel for powdered ore was installed; the composition was also paid
1893	The Bessemer refining method was introduced
1890's	The output occupies 40% of whole output of Japan
1896	11,684 ha of farm land was contaminated by remnants
	The Ministry of Agriculture and Commerce ordered the Installation and operation of filtration pond by the company
1897	The Forest Service began afforestation in the devastated area

1900	Kawamata Matter (The demonstrators clashed with the police)
1901	Mr. Shouzou Tanaka made a direct appeal to the Emperor
1904	The government announced the retarding basin plan
1907	The establishment of mine labor union
1908	Remained farmers were compulsorily removed for the purpose of construction of the retarding basin
1911	The population of Ashio Town recorded maximum value of 38,428 persons
1913	Mr. Shozou Tanaka died
1914	New ore was discovered
1915	The output recorded maximum value of 15,735 ton/year
1916	The Cottrell type electric dust collector was installed
1918	The first strike in Japan
1945	The World War II ended
1947	The historical flood caused by Typhoon Catherine
1950	The construction of Ashio Sabo-dam began
1956	The new refining method was introduced instead of the Bessemer
1957	A new effort of afforestation began
1965	Seeding using helicopter
1973	Ashio mine was closed
1988	The population of Ashio Town decreased further to 5,000 persons
	The treatment of 720 ha was finished within all the 1670 ha of devastated area

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Chapter 2

Hydrological Processes in Headwater and the evaluation of reforestation
Yoshihiro Fukushima

2.1 Introduction

Headwater is generally known to be essential area on taking stable water supply of not only irrigation but also drinking for living people in downstream. Recently, we have realized that such area has another worth maintaining diversity of biosphere and human being has begun to get aware of this real meaning.

Developed countries never paid attention to this worth until the end of 18 century and developing countries began to understand this worth nowadays. The increase of human population and the demand of food production, however, have kept its situation difficult. Nevertheless, the environment of source area has to be kept in natural vegetation with long-life in the viewpoint of echo-hydrology.

The author would like to explain quantitatively the importance of headwater area by using hydrological analysis. Basically, rainfall over catchment area turns to both infiltration and surface flow. The infiltration rate is low in bare surface and high in land surface covered by vegetation, generally. The infiltrated water turns to sub-surface flow along A and A_0 layers of the soil. Deeply percolated water is to reach to the bottom of soil, that is the surface of bedrock. Usually, such water flows down to the open channel along the slope as ground water flow. Though some parts of ground water percolates vertically along rock crack, its amount is usually negligible in mountainous catchment area composed of old sedimentary rock such as the Paleozoic except limestone, and plutonic rock such as granite. The whole catchment area is possible to categorize in two parts. One is slope system and the other is open channel system.

Both surface flow and sub-surface flow in the slope system and channel flow are called as direct runoff or quick flow component. The other runoff is called as base-flow or delayed runoff component. Evapo-transpiration are separated to three components, these are evaporation and transpiration in the slope system with vegetation cover, and evaporation in the open channel system.

How could we replace real process to numerical model and how could we get synthetic understanding by the aid of hydrology? In this chapter, each fundamental

process is explained at first, and a numerical model is proposed and applied for the evaluation of reforestation in devastated mountain.

2.2 Evaporation

Though there are various kinds of theoretical and empirical methods concerning estimation of evaporation, we need to inquire how to obtain daily or monthly actual evaporation in hydrological cycle. Therefore, I wish to describe several practical methods with theoretical background in the chapter.

The forcing factors relevant to evaporation are solar radiation, atmospheric radiation, air temperature, humidity and wind velocity. The equation of radiation balance is written as follows.

$$Rn = Rs\downarrow + Rs\uparrow + Rl\downarrow + Rl\uparrow = (1-\alpha)Rs\downarrow + Rl\downarrow + \varepsilon\sigma T^4 \text{-----------------(1)}$$

where, Rn: net radiation

$Rs\downarrow$: incoming short-wave radiation or solar radiation

$Rs\uparrow$: outgoing short-wave radiation

$Rl\downarrow$: incoming long-wave radiation or atmospheric radiation

$Rl\uparrow$: outgoing long-wave-radiation

α :albedo

ε : emission ratio

σ :Stefan-Boltzmann constant

T: surface temperature

The heat balance is written as follows.

$$Rn = H + \lambda E + G \text{----------------------------------(2)}$$

where, H: sensitive heat flux

λE: latent heat flux

λ :latent heat of evaporation

E: evaporation

G: soil heat flux

Effective energy, Re is defined as Equation (3).

$$Re = Rn - G --------------------------------(3)$$

Bowen ratio, β is defined as follows,

$$\beta = \frac{H}{\lambda E} ----------------------------------(4)$$

When land surface is kept in wet condition, β is almost close to zero.

On the other hand, Penman (1948) proposed a practical equation for estimating evaporation in open water, wet bare and glass surface.

$$\lambda E = \frac{\Delta Re}{\Delta + \gamma} + \frac{\gamma \lambda f(u)}{\Delta + \gamma} \{e_s(T_a) - e_a\} ----------------------(5)$$

where   f(u):function of wind velocity

Δ :slope of saturation vapor pressure, namely des/dT

γ :Psychrometric constant

es(Ta):saturation vapor pressure at air temperature (mmHg)

ea: vapor pressure at Ta (mmHg)

The function of wind velocity, f(u) was empirically determined for short grass by Penman(1948).

$$f(u) = 0.35(1 + 0.01u) ------------------------------(6)$$

where, the unit of f(u) is mm day^{-1}. And u is wind velocity at 2m height (miles day^{-1}).

In the case of free open water, the following equation is used

$$f(u) = 0.35(0.5 + 0.01u) ----------------------------(7)$$

Usually, we use the term of relative humidity on explaining dryness in the air.

$$RH = \frac{ea}{es(Ta)} \times 100(\%) \text{-----------------------(8)}$$

The units of mmHg, mb or hPa are used for es and es(Ta). 1mb is just the same as 1hPa and 760mmHg is the same as 1013mb.The following figure shows the relationship between air temperature and saturation vapor pressure.
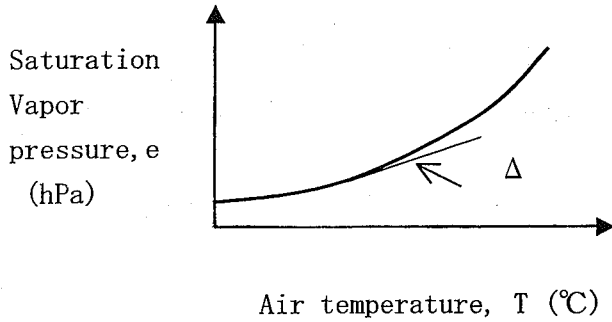
Figure 1 Relationship between air temperature and saturation vapor pressure

In the field of atmospheric science, the specific humidity, q is used for presenting the ratio of the mass of water vapor against the total air mass. The relationship between e and q is converted by the following equation.

$$q = \frac{\varepsilon e}{P-(1-\varepsilon)e} = \frac{0.622e}{P-0.378e} \text{----------------------(9)}$$

where　P: atmospheric pressure (hPa)

　　　　ε :molecular weight of water/molecular weight of dry air

Priestly-Taylor (1972) proposed the following simple equation applicable for wet land surface and ocean on considering large-scale evaporation. Equation (10) is called as potential evaporation.

$$\lambda E = 1.26 \frac{\Delta \text{Re}}{\Delta + \gamma} \text{--------------------------(10)}$$

Equation (5), Penman's equation, is apt to estimate larger amount in dry condition as actual evaporation decreases in dry land surface of wide area. It causes that es(Ta)-ea, namely the saturation deficit, overestimates evaporation amount in dry surface.

Morton (1983) proposed the following complementary relationship in order to resolve the above-mentioned problem in rather wide area. It is written as follows.

$$Ea + Ep = 2Epot \text{ ------------------------------------(11)}$$

where, Ea: actual evaporation rate

Epot: evaporation rate in wet surface

Ep: potential evaporation rate estimated by vapor transfer and energy balance
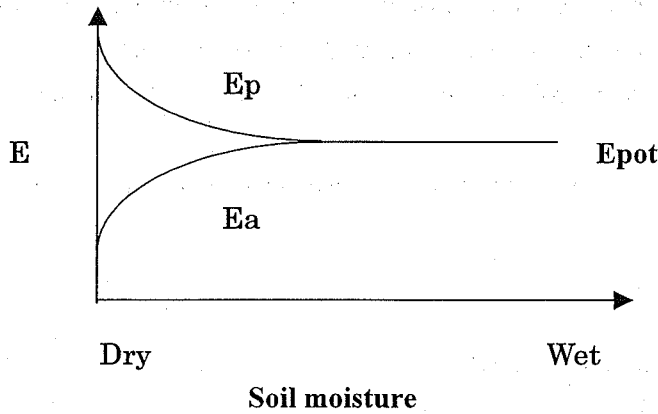
Figure 2 Concept of the complimentary relationship

Practically, Equation (10) and Equation (5) are used for the estimation of Epot and Ep, respectively.

Nevertheless, we don't have any complete equations to estimate actual evaporation in local-scale river basin because the decreased soil water restricts real evaporation. Furthermore, grass and tree species that cover land surface might restrict evaporation rate through controlling its stomata on leaves.

Concerning the role of vegetation on evapo-transpiration process, Monteith (1965) proposed the following equation. As it expands Penman's equation basically, it is called as Penman-Monteith equation.

$$\lambda E = \frac{\Delta Re + \rho Cp\{es(Ta) - ea\}/ra}{\Delta + \gamma(1 + rc/ra)} \text{ ----------------------(12)}$$

$$ra = \frac{[\ln(z - d)/z_0]^2}{\kappa^2 u(z)} \text{ ----------------------------(13)}$$

where, ρ : air density

Cp: specific heat at constant pressure

ra and rc: aerodynamic resistance and canopy resistance, respectively

z_0: roughness length

d: zero plane displacement

κ :Karman's constant

u(z): wind velocity at the height z

Physiological parameter, rc is controlled by light condition, air temperature, humidity and so on. Light condition can be estimated from solar radiation, practically. As a numerical utilization of Penman-Monteith equation, Ma *et.al*(1998) applied it in a cold Siberian region,

The practical equation for the estimation of basin-scale evaporation is proposed by Hamon(1961).

$$Ep = CD^2 Pt ---(14)$$

where,   Ep: daily evaporation (inch day^{-1})

C: constant(=0.55)

D: sunshine duration for 12 hours

Pt: saturated water vapor density (absolute humidity) at the mean daily temperature (g/m^3).

2.3 Soil water

The soil layer is usually very thin, which has almost 0.5 to 2.0 meter in depth on lithosphere in mountain catchment basin except mountain foot. It is composed of three components, these are air, water and solids. Figure 3 shows its components.

In Figure 3, the mass of air, Ma is negligible compared to the mass of solids and water. The volume of pore, Vf is Va+Vw. The following terms are defined for explaining the condition of soil water

● Density of solids (Mean particle density): ρ s

$$\rho s = Ms / Vs --(15)$$

The mean density of the particles is about 2.6-2.7 gm/cm^3.

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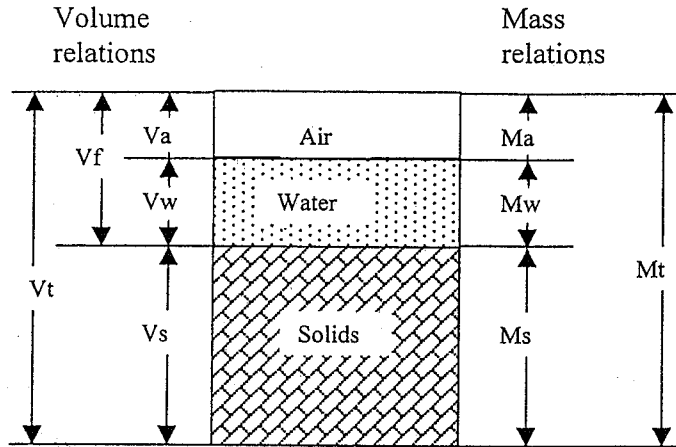
Figure 3 Schematic diagram of the soil structure with three phases

● Dry bulk density: ρ b

$$\rho b = Ms / Vt = Ms /(Vs + Va + Vw) ------------------------(16)$$

If the pores constitute half volume, ρ b is half of ρ s, namely 1.3-1.35 gm/ cm^3.

● Porosity: f

$$f = Vf / Vt = (Va + Vw) /(Vs + Va + Vw) -------------------(17)$$

● Volumetric water content: θ

$$\theta = Vw / Vt = Vw /(Vs + Vf) -----------------------------(18)$$

● Degree of saturation: s

$$s = Vw / Vf = Vw /(Va + Vw) ---------------------------(19)$$

It is well known that the actual evaporation on land surface is affected by soil water condition. Figure 4 shows the relationship between the degree of saturation, s and the ratio of actual evaporation, Ea for the potential evaporation, Ep. It must be paid attention that the degree of saturation equivalent to the dropping point of Ea/Ep changes by soil materials, such as sandy, silt or loam. Though modern hydrology focuses on clarifying the function of restraint by soil water to evaporation process, it is still difficult to estimate actual evaporation because of heterogeneity of land surface and nonlinearly of the process.
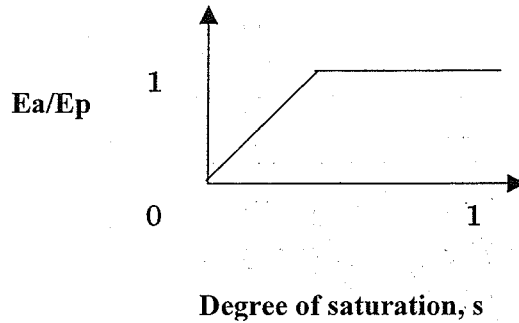
Figure 4 Relationship between degree of saturation and the ratio of actual evaporation, Ea for potential evaporation, Ep

2.4 Water budget

Water budget in a catchment basin is written as follows.

$$P = Q + E + \Delta S \mathrm{-------------------------------------(20)}$$

where, P: precipitation

Q: runoff

E: evaporation

Δ S: difference of water storage

Usually, water budget is taken at annual interval, but seasonal budget is sometimes possible to be taken in the region where seasonal change of radiation or air temperature occurs clearly. The water year is not always the same as calendar year because the starting date has to be taken from the stable condition in river discharge. It means that Δ S, namely $q(t_{end})-q(t_{initial})$, might be negligible small under the same soil moisture.

2.5 Effects of reforestation on hydrological model in a catchment basin

Though there are many models for explaining hydrographs observed in catchment basins, we don't realize how reforestation affects river discharge quantitatively, yet.

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Figure 5 (Suzuki and Fukushima, 1989) shows annual sediment yields observed by different kinds of methods, such as peg, trap and so on, in a weathered granite region, Japan. The sediment yields in bare mountains indicate almost 5,000 to 10,000 $m^3km^{-2}y^{-1}$ in spite of the results by different methods. Compared with bare slope or catchment, the reforested catchment basins show a remarkable decrease in sediment yields.
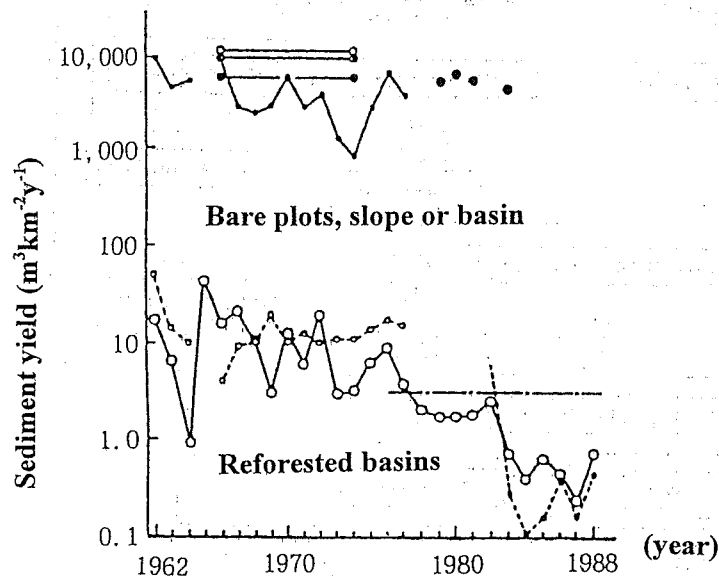
Figure 5 Inter-annual change of sediment yield between bare and reforested area observed by different methods in a granite hilly mountain, Mt.Tanakami, Central part of Japan (Suzuki and Fukushima, 1989).

At the primary stage of reforestation, sediment yields from the basin rapidly decreased to 5 to 50 $m^3km^{-2}y^{-1}$. Furthermore, at the time of 25 years after the reforestation works, sediment yields shows 0.1 to 1.0 $m^3km^{-2}y^{-1}$. It is one of principal effects of reforestation. Why such a big difference has occurred among two kinds of land surface? On the addition of investigations and observations concerning erosion processes (Seno et al., 19821: Takei et al., 1981), it was clarified that movable soil material was produced on bare slope by weathering and it was transported downstream by tractive force on hydraulics , every flood events.

HYCYMODEL (Fukushima, 1988) was proposed for understanding the hydrological effects of reforestation. It is a kind of conceptual runoff models and has a feature that takes only seven parameters with time independence in runoff formation

system. The structure of HYCYMODEL is shown in Figure 6.
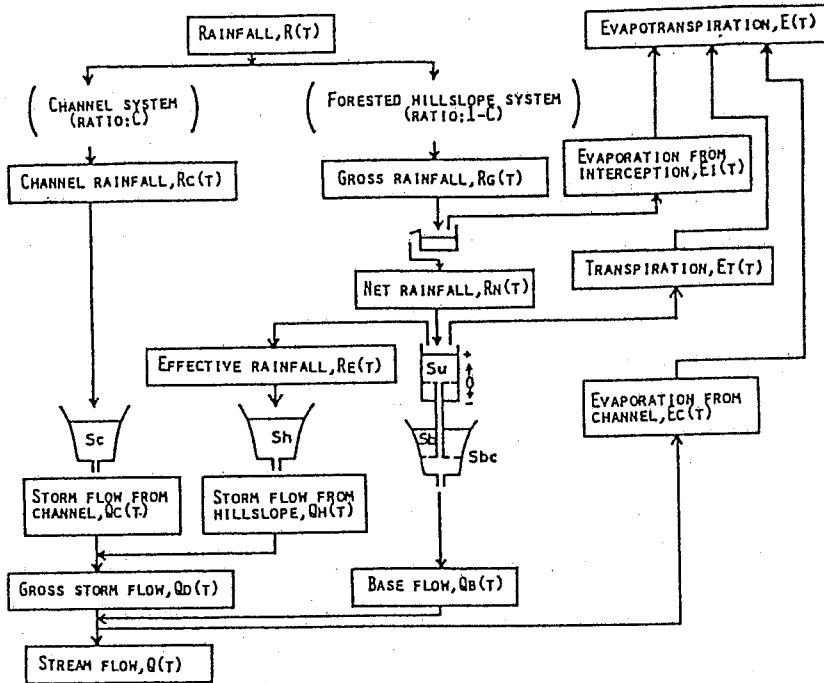
Figure 6 Structure of HYCYMODEL (Fukushima, 1986)

In figure 6, C means the area ratio of impermeable channel. Effective rainfall, Re(t) to the other area except the impermeable channel area is determined by the mean effective soil depth parameter, D_{50}(mm) and its deviation, D_{sig}. Re(t) is calculated by the following procedure in detail.

At first, an apparent storage in the Su Tank of figure 5, Su'(t) is

$$S'u(t) = Su(t-1) + Rn(t) \text{ ----------------------------- (21)}$$

where, Su is storage in the Su-Tank, Rn is net rainfall reached to the ground and t is time step.

The variable for the normal distribution, ξ is

$$\xi = \left\{ \log \left[S'u(t) / D_{50} \right] \right\} / D_{sig} \text{ ------------------------ (22)}$$

The m value which means the contributing area ratio, can be calculated as the excess probability using the normal distribution

$$m = \int_{-\infty}^{\xi} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \text{ -----------------------------------(23)}$$

The effective rainfall forming a direct runoff component, Re(t) is

$$\text{Re}(t) = mRn(t) \text{ ------------------------------------(24)}$$

Otherwise, the relationships between storage S and discharge Q in each Tank on Figure 6 are

$$Sc = KcQc^{0.6}, Sh = KhQh^{0.6} \text{ --------------------------------(25)}$$

$$Su = KuQu \text{ ---(26)}$$

$$Sb = KbQb^{0.1} \text{ --------------------------------------(27)}$$

where, Equation (25) is used for direct runoff component in each channel or hillslope system, Equation (26) is for the change soil water at top soil layer, and Equation (27) is for base flow component. Kc, Kh, Ku and Kb are parameters, respectively.

HYCYMODEL was applied for the forested small mountain catchment. Figure 7 shows the simulated hydrographs for the continuous ten years discharge at daily interval. And Figure 8 shows the hydrograph of one month pulled out from the continuous ten years hourly simulation.

2.6 Evaluation of reforestation using HYCYMODEL

HYCYMODEL parameters were determined by applying to the observed hydrographs chosen from the six mountain small catchment basins which were located at the same granite mountain and had different passing years after the reforestation works have been done.
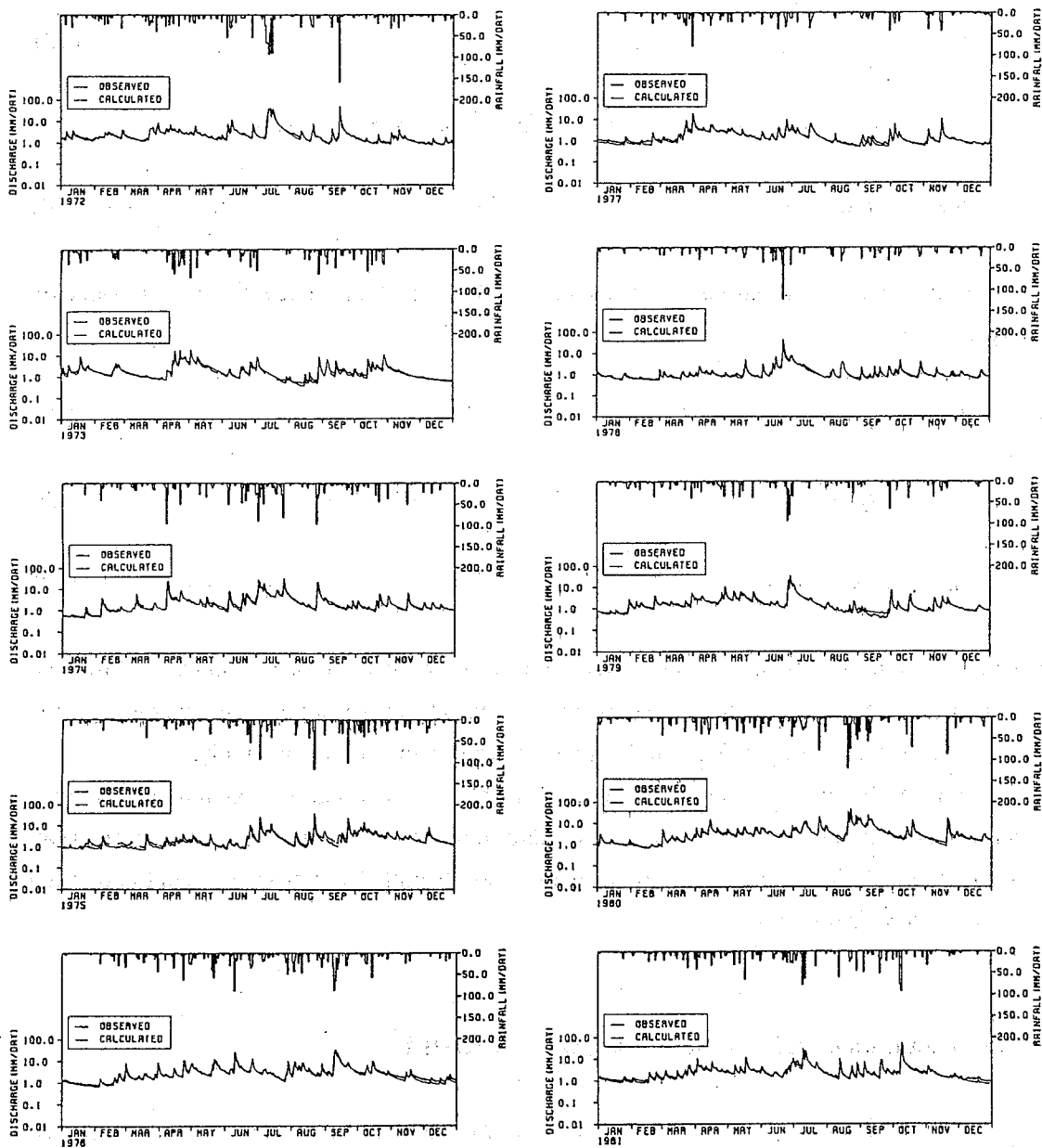
Figure 7 Simulated hydrographs for the continuous ten years
discharge at daily interval.(Fukushima, 1988)

22
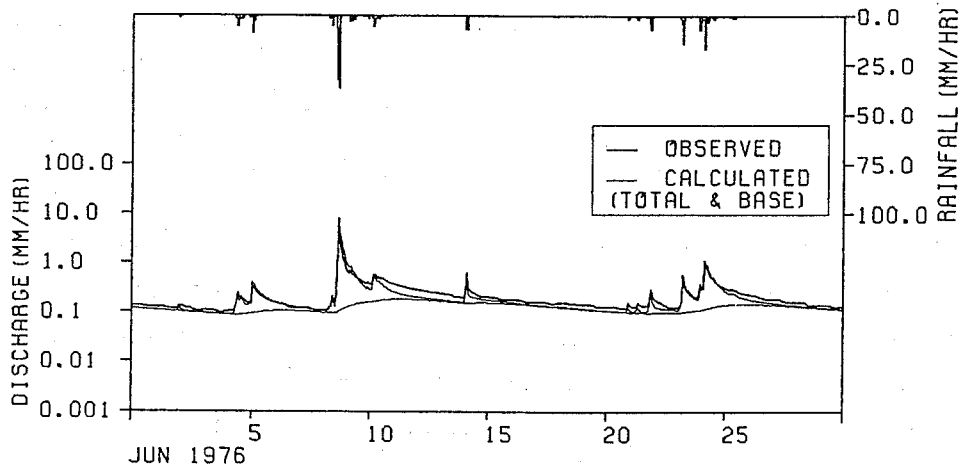
Figure 8 Hydrograph of one month pulled out from the continuous
ten years hourly simulation. (Fukusima, 1988)
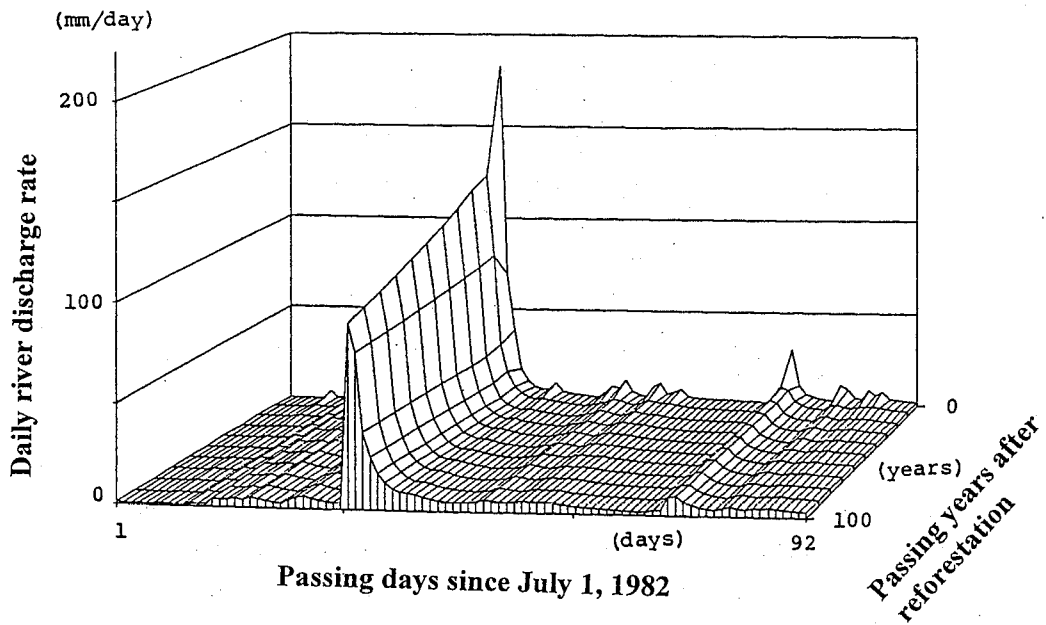
Figure 9 Forecasted hydrpgraphs of ninety-two days using the
same rainfall data at an interval of ten years after
reforestation. (Fukushima and Suzuki, 1987)

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The effects of reforestation could be quantitatively evaluated by the parameters determined by the observed data. At first, Figure 9 shows the hydrpgraphs of ninety-two days using the same rainfall at an interval of ten years after reforestation works were carried out for devastated mountain. The hydrograph passing 100 years after reforestation works seems to be very mild, but the hydrograph at bare basin shows a rapid change and wide fluctuation.

The inter-annual changes of water balance components, such as evaporation, direct runoff and base flow, are calculated at an interval of ten years after reforestation. The result is shown in Figure 10 as the ratio for rainfall amount. It indicates that water balance at a devastated basin without vegetation has much total runoff that is consisted of direct runoff and base flow component and less evaporation than others, and base flow component is less than direct runoff.
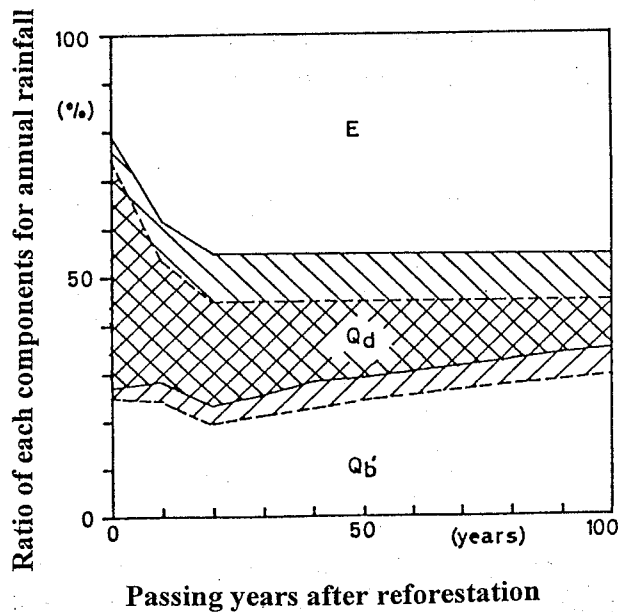
Figure 10 Change of water balance components at different passing years after reforestation. Hatched parts by slant lines are the results of year with much/less annual rainfall than the mean. (E: Evapotarnspiratiom, Qd: Direct runoff, Qb': Base flow) (Fukushima and Suzuki, 1987)

When it passed almost twenty years, the ratio of evaporation reaches at the highest ratio because forest canopy almost completes to cover land surface. The tendency is not

changed in the year with much rainfall, either with less rainfall, as shown by two kinds of slant lines. Generally, river water of base flow component in headwater is clean and is easy to be used for all of demand. How could we increase base flow component is an ultimate objective on considering headwater management. Although it is true that devastated mountain can supply much water downstream than forested area, nowadays all of us recognizes that river water from bare land contains 100 to 1,000 times of sediment yield than that in forested area shown in Figure 5. Figure 10 indicates that the ratio of base flow recovers almost 40 to 60 years later since the reforestation. It just means that the worth of reforestation may be recognized and supported by those who keep sustainable life with long-term perspective.

2.7 Development of hydrological models related to headwater management

Hydrological models related to headwater management are requested both local applicability and universality at the same time as a fundamental function. Regarding local climatic feature in Asian region, we should pay attention that seasonal and diurnal variation of rainfall events in tropical region is different from that in temperate region as shown in Figure 11. Rainfall event in tropical region usually seldom occurs in the morning but occurs in the afternoon. It, however, occurs independently with time series in a temperate region such as Japan. The feature might affect to runoff formation. Hydrological models are requested to keep the applicability and accuracy at hourly analysis.

Evaporation process is comparatively possible to generalize by using SVAT (Soil-Vegetation-Atmosphere Transfer) scheme. The application of a simple SVAT model such as Penman-Montheith equation as shown in Equation (12) and HYCYMODEL has already been done for a headwater with 4.9 km^2 in area, of Japan and Lena River, Siberia with 2,420x10^3 km^2 in area (Ma et al., 1999, 2000). The development of hydrological research relevant to evaporation process may be shown in Figure 12.

In Figure 12, (A) to (D) show additional explanation.

(A) Atmospheric water vapor budget method by assimilated data, such as ECMWF provides the input data to land surface as grid mean value. It just means P-E (precipitation minus evaporation) on hydrology. But this method is too rough in time and space resolution, basically. Moreover, the accuracy of this method depends upon the structure of atmospheric model. Hydrological process is only focused against the delayed

time in river-line. Vorosmarty *et al.*(1989) and many results show that effective velocity of river water is the extent of almost 0.35 to 0.5 m/sec. Thus results are still important on considering continental-scale river-line because the delayed time from source area to river mouth sometime indicate one to two months in the largest river group of the world.
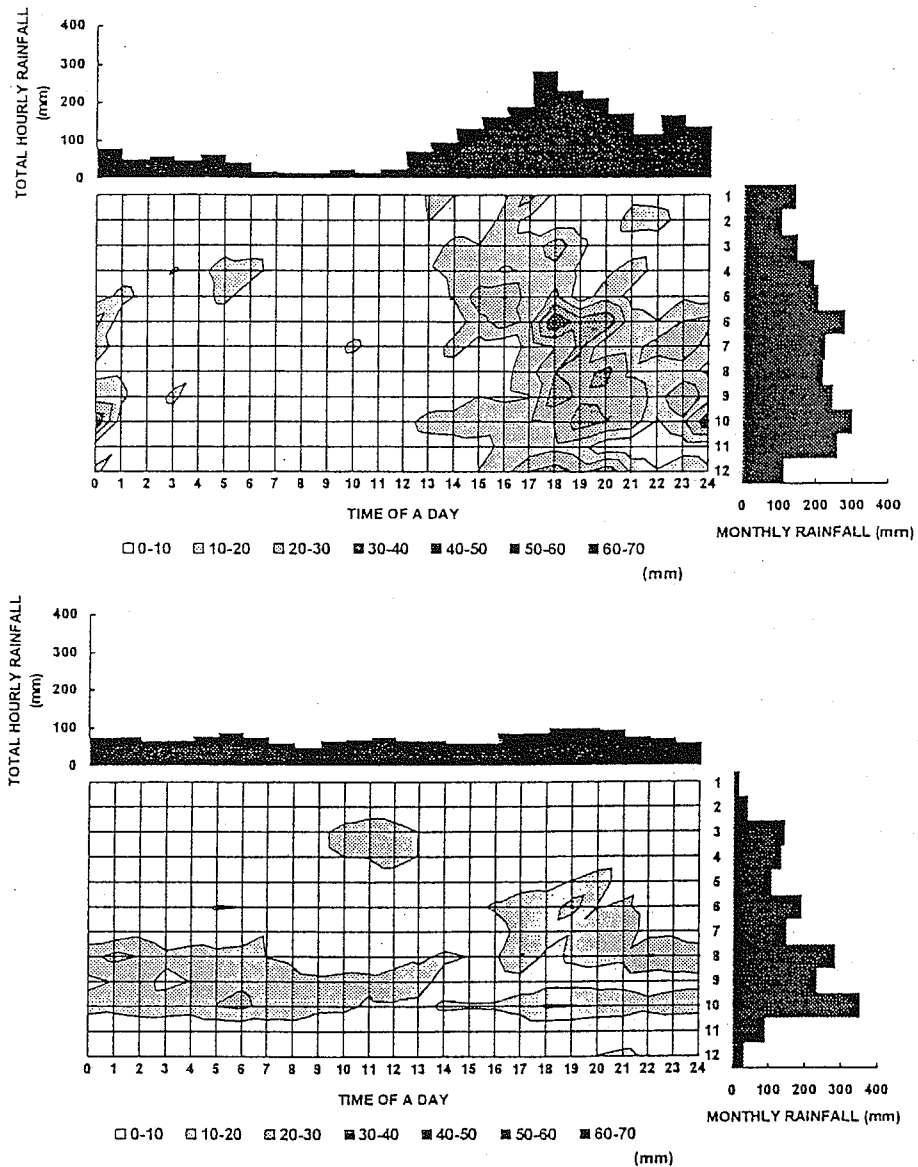
Figure 11 Seasonal and diurnal variations of rainfall events in tropical and temperate regions. Above: Sapulut, Sabah, Malaysia(1986-87, 1991-1992), Below: Yatakesawa, Chiba, Japan(1991-1992). (Kuraji, 1996)

(B) On considering what actual evaporation is, traditional or empirical method needs potential evaporation. We used to take Penman equation as monthly amount of potential evaporation. The mean water storage in the basin as index of soil moisture is thought to control actual evaporation.

(C) Soil-vegetation-atmosphere transfer models are applied to the estimation of actual evaporation. The big-leaf model based upon plant physiology is an example. As a result, water vapor deficit in the air affects transpiration amount occupying considerably major part of total evaporation on canopy of plant.

(D) The relationship between forcing parameters and soil moisture is expected to be analyzed and be built in a physical model nowadays because development of satellite sensor made possible for obtaining of albedo, surface temperature, soil moisture and so on globally.
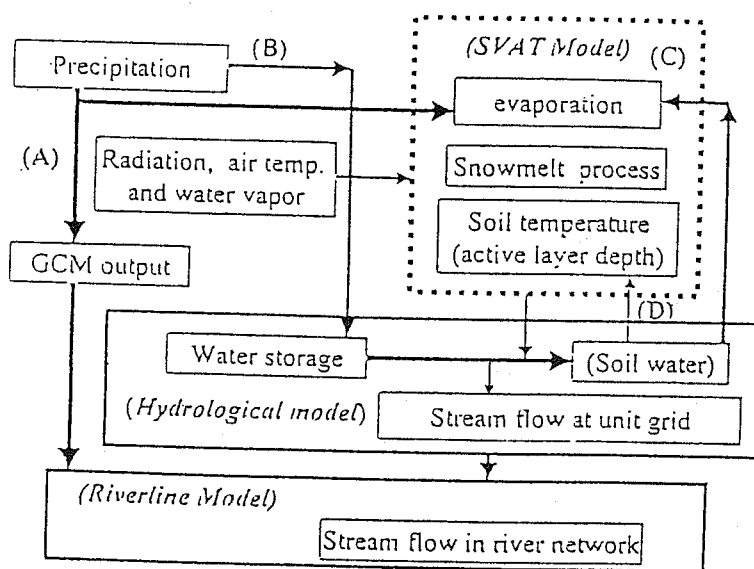
Figure 12 Development of macro-scale hydrological models
(Fukushima and Ma, 2000)

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Chapter 3

Forest conservation projects in headwater areas
Yasuro Kawano

3.1 History of forest disturbances in Japan

Destruction and disturbance of forest began and expanded with the advance of civilization. Once there were widespread bare land tracts in the central part of Japan. In ancient times, timber for court buildings in the Heijo capital (Nara) and the Heian capital (Kyoto) was obtained from neighboring areas. As a result, the mountains near Kyoto and Nara were eroded due to the indiscriminate felling of trees. Since then felling has continued in suburban forests to obtain building and fuel materials or fertilizer for rice fields. Consequently, disasters such as debris slides and debris flows occurred in mountainous areas and severe floods occurred frequently on downstream plains.

The government often prohibited or restricted the felling of trees in order to prevent erosion. For example, in 1682 the feudal government prohibited cutting of headwater forest and encouraged planting in the Yodogawa River basin. (In 1689, check dam construction was initiated.) But the situation continued until the end of the 19th century.

In 1896 and 1897 the government promulgated the River Law, the Forest Law, and the Sabo Law (Sediment Control Law), in order to carry out erosion and sediment control projects throughout the country. These three laws are called the Three Laws for Flood and Sediment Control. From then on, forests in suburban areas began to improve. Today's situation of forested land in Japan is better than in the past.

The Japanese have traditionally realized these functions of the forest based on their experience from historical times and have established the "protects forest system" as a method of erosion prevention.

【Quotation】 Takchiko Ohta : Protection of Japanese Forest and Transfer of the
　　　　　　　Japanese Experience p9～p10/ Asian Productivity Organization

3.2 The system of forest conservation project

a. Protection forest system

In addition to the function of sediment disaster prevention, the forest provides additional public benefits. Since river gradients are steep and rainfall varies greatly throughout the year in Japan, the conditions for the effective use of water resources are not ideal. On the other hand, due to expanded industrial production and improved living standards, the demand for water has grown continuously. Therefore, the function of the forest to ensure a stable water supply is very important. In addition, people have been showing an increasing interest in the natural environment, and forests have become very popular places for recreation. Forests are also used for the conservation of birds and animals.

In order to preserve forest expected to fulfil such public benefit functions or to establish forests in areas that need such functions, the protected forest system has been established based on the Forest Law promulgated in 1897. Forests are registered as protected forests in accordance with the law and are placed under certain limitations in management.

Three restrictions are mainly imposed on the management of protected forest: restriction on felling of standing trees, conversion of topography, and obligation to plant. Felling of standing trees is to be done within the framework of the Forest Management Plan that provides for a felling system (clear cutting, selective cutting, or cutting prohibition) and the annual cutting area, and the conversion of land topography is regulated so as to require the permission of the governor concerned. After felling, the regulation requires planting to commence within two years.

If owners of protected forests are individuals since private property is restricted for use for the public service, the government grants the following special favors: tax exemption and reduction: financing; raising of reafforestation subsidies; execution of planting at the expense of the government in case of natural disasters(without any burden on the individual); and monetary compensation for loss.

The protected forest system has been modified several times since 1897. In 1989, the protected forests were divided into 16 types according to purpose (Table 1). The protected forest system has been effective in preserving forests. It is fortunate that this excellent system was established some 100 years ago.

【Quotation】 Takehiko Ohta : Protection of Japanese Forest and Transfer of the
Japanese Experience   p10〜p11 / Asian Productivity Organization

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Table 1 Classification of protection forest (H11.3.31)

Type	Function	Area(ha)
Headwater conservation forest	Control flood and draught	6,278,014
Soil erosion control forest	Control soil erosion	2,009,310
Hillside failure prevention forest	Protect houses, farms or roads from failure of unstable hillslope	48,282
Sand shift control forest	Control sand shift	16,183
Windbreak forest	Reduce wind speed and protect houses or farms behind	55,380
Flood control forest	Reduce damage by flood	708
Sea salt control forest	Reduce damages on agricultural products from tidal wave or high tide	11,939
Drought prevention forest	Maintain stable water supply	48,079
Snow break forest	Protect railroad or road from snowstorm	15
Fog control forest	Protect farm land from fog drift	58,074
Avalanche prevention forest	Prevent avalanche from occurring and reduce its damage	17,132
Rockfall prevention forest	Prevent rockfall	1,761
Fire prevention forest	Prevent spread of fire	341
Fish breeding forest	Conserve fish habitat and breeding	25,658
Navigation landmark forest	Landmark for navigation	341
Public health forest	Provide recreation place, conserve air quality, and control noise	108,056
Landscape conservation forest	Conserve scenic quality of noted places and historic spots	14,807
Total		8,694,080
Rate of total forest area		34.6%
Rate of total land area		23.0%

b. Forest conservation projects system

Forest conservation projects serve to protect people's lives and property from disasters through management of forests. It is also essential in enhancing conservation of headwaters and for improving the environment for safer and comfortable living conditions.

The forest conservation projects are defined by the Forest Law, Landslide Prevention Law, and Forest and Water Conservation Urgent Countermeasures Law as conservation facility installation projects and Landslide prevention project carried out by either the government (prefectural or national) or prefectural governor.

(1) Conservation facility installation project

Forest conservation or other forest management projects carried out by national or prefectural government aimed at realization of defined objectives of protection forests. (Forest Law)

(2) Landslide prevention project

Landslide prevention works such as facility installation, improvement, or other preventative measures in designated areas. (Landslide Prevention Law)

Such as, forest conservation projects have a long history in Japan, and have been carried out in long-term planning phased beginning with the first term in 1911.

The disaster resulting from the Ise Bay Typhoon in 1959 prompted the enactment of Forest and Water Conservation Urgent Countermeasures Law and forest conservation project has been carried out on the five-year plan based on this law.

The fundamental objectives of the current ninth plan are as follows:

① Promotion of disaster-free national lands development

② Upgrading of function as headwater conservation in water resource areas

③ Promotion of a greener environment development

National and prefectural governments are responsible for project operations. Projects taking place in privately-owned forests that are large in scale, require refined technology, and/or involve interests of more than one prefecture are to be carried out by the national government in addition to projects within the nationally-owned forest lands. Local prefectural governments are in charge of projects taking place within other privately-owned forests.

3.3 Execution Policy of Forest Conservation Projects

a. Hillside works

(1) Definition of hillside works

Hillside works is the process of executing civil engineering works and of planting and growing vegetation to restore devastated land which has lost forest cover by land collapse or surface erosion or land which is changing to devastation (denuded mountains, collapsed land and landslide) to restore such land into forests. This text does not describe special works executed for landslide.

Covering of the ground surface by vegetation is most dependable to cover wide devastated land and to ensure continuing soil conservation effects. This is also economical. Stand establishment will allow land to have a productivity and will be useful to cultivate water resources.

(2) Execution policy of hillside works

Hillside works execution policies are to prevent: 1) Surface erosion of devastated land and 2) Expansion of land collapse.

1) Prevention of surface erosion of devastated land

The amount of earth from denuded land is very large compared with that from covered land such as forest land. This is because erosion of top soil is caused by impacts of raindrops and by tractive flow of overland flow water, triggered by direct contact of rainwater and flow water with top soil.

① Prevention of raindrop erosion

Raindrop erosion can be prevented by avoiding raindrops from directly contacting soil particles. If the surface is covered by grass or fallen leaves, even very heavy rains does not erode soil.

② Prevention of erosion by overland flow water

Top soil in erosion by overland flow water is eroded if a rain continues after rainwater is first absorbed in soil and after the infiltration capacity of soil is surpassed, stagnating on the surface and flowing downward.

The erosion force of flowing water relates to the water depth and slope inclination and can be weakened by the following methods.

① Make slope inclination easy

A large amount of earth has to be moved to make slope inclination easy. In many cases, cutting of the surface till erosion force is sufficiently weakened is difficult. If

the inclination to some extent.

Example of execution Type

Grading work and soil retaining work:

Easing of inclination

Terracing work, fence work and simple terracing work:

Reduction in force of water

② Rainwater is dispersed and flowed

Concentrated flow of rainwater can be prevented by grading slopes as flat as possible. Making the ground surface coarse by covering it with grass is also effective.

Example of execution type

Slope grading and covering work

③ Ground surface is covered

Covering of the ground surface is most direct and effective method to prevent erosion.

The ultimate purpose is to cover with low cover and with fallen leaves to make forest land. As a process till that stage, various methods are used to cover by herbaceous   plants or by artificial means.

Example of execution type

Sodding work, covering work

④ Gather rainwater to specified watercourses to reduce flow on exposed surface.

Flowing water from upper slopes is intercepted halfway and led to the outside by head races, or collecting channels are built in the area to collect flowing water in the water-channels as much as possible to prevent water from flowing surfaces of devastated areas.

Example of execution type

Water channel work

2)Prevention of Land Collapse Expansion

Landslip is a phenomenon in which weathered soil layers forming hillside slopes collapse after losing a balance. The direct causes of it are infiltration of rainwater, low binding power of soil particles due to a raise of the underground water level, ground vibration and other f actors .

Land stabilizes once unstable portions collapse. Sometimes, unstable earth lumps remain near top parts of collapsed surfaces. Collapsed surfaces are exposed to the outside air and rapidly weather, collapsing after becoming unstable.

Unstable earth lumps cannot be fixed as they are. The effective way is to cut

outside air and rapidly weather, collapsing after becoming unstable.

Unstable earth lumps cannot be fixed as they are. The effective way is to cut dangerous portions and to make inclination easy. Earth lumps are fixed by retaining wall work and infiltrated water is drained by water channel work or culvert closed conduit work.

b. TORRENT WORKS

(1) Significance of Torrent Works

Torrent works is the foundation works executed with torrents to establish and maintain forests. The specific purposes of torrent works are to

① prevent moving of earth on stream beds.

② Ease and correct stream bed gradient.

③ prevent erosion of torrent banks.

④ Stabilize mountain feet.

⑤ Regulate and fix channels.

These purposes are accomplished by installing civil engineering structures and facilities on torrents to prevent erosion of hillsides of torrents and torrent banks in order to establish the forest base.

Torrent works and hillside works are closely related each other. Torrent works is the basis of hillside works. If hillside works alone cannot prevent erosion of a mountain foot, torrent works is provided to fix the mountain foot to prevent hillside landslide.

(2) Execution policy of torrent works

In planning torrent works, the layout of works types in the area must be decided in accordance with the condition of the devastated torrents and with execution purpose. An execution method suiting them must be selected.

Torrent works can be classified as follows in accordance with the types of structures and purposes of the works :

① Torrent gradient is eased and mountain foot is fixed by structure that traverses the torrent :   Erosion control dam works

② Torrent bank is protected by structures along the torrent :Revetment works

③ Water flow is regulated by structures to build a dike in the torrent : Spur dike works

④ Watercourse is regulated by structures along watercourse to protect torrent banks: Channel works

The torrent works purposes and construction methods suiting these purposes can be

summarized as follow:

1) To ease the torrent slope to obtain an equilibrium slope to prevent longitudinal and lateral erosion. The torrent slope can be eased by an erosion control dam. By building a structure that traverses the torrent (transverse works), the torrent slope is eased by the deposited silt in the upstream of the levee body.

The flow velocity lowers and erosion intensity also weakens if the torrent slope is eased.

The scales and the number of erosion-control dams will be decided by the range and design-accumulating gradient for the stream bed intended to be stabilized. If the range is wide, a decision will be made whether to build one dam with a tall height or more than one dam in a step form.

If the range to be stabilized is very long, high erosion-control dams and low dams will be combined. In this case, the erosion-control dam and high dam in the farthest downstream should preferably be built on an underlying rock. If an underlying rock cannot be found, a counter dam or other facility shall be built to prevent scouring.

2) To fix the mountain foot and to prevent torrent bank and hillside landslide.

The stream bed is raised by an erosion-control dam and the mountain foot is fixed if lateral erosion caused by longitudinal erosion of the stream bed is the problem.

If lateral erosion is caused by curving of the watercourse, the watercourse is made straight to prevent lateral erosion by curving. A straight watercourse increases the flow velocity and longitudinal erosion will be caused. Thus, the torrent slope must be eased by building erosion-control dam/s.

The mountain foot is fixed by revetment and spur dike work. In this case also, a low erosion control dam is built on the downstream side to prevent scouring of the stream bed.

3) To prevent turbulent flow of debris area to fix the watercourse.

Groundsel work is built in a step form. Generally, debris areas have a wide river breadth and an easy gradient and groundsel work is executed mainly to fix the watercourse.

Turbulent flow is prevented by revetment, spur dike and channel work.

4) To maintain present stream bed

This work is planned if sediment flow from the upstream is reduced by the completion of torrent works in the upstream zone and the stream bed in the downstream rapidly lowers.

5) Purposes for preventing runoff sediment

If collapsed land exists in the upstream and sediment continuously runs off from there, an erosion-control dam is planned immediately below the collapsed land to fix the sediment there.

If a suitable execution site cannot be found immediately below the collapsed land, a dam is built under stream to ease the stream bed slope and to check sediment runoff. A location which has a large sedimentary area in the upstream of the dam is recommended.

Runoff sediment by a mud flow has very large flow energy and it cannot be stopped directly inside the mud flow zone. The mud flow is flowed to the sedimentary area where the gradient becomes easy and is accumulated by groundsel work with a long length.

3.4 Main works in forest conservation project

a. Types of works

■ Stream works
○ Check dam works
○ Revetment works
○ Channel works
○ Spur dike works

Purpose of check dam

1 Fix of the devastation stream
    (1) Fix of the stream bed
    (2) Checking of soil and sand
2 Prevention of vertical and side erosion
    (1) Prevention of vertical erosion
    (2) Side erosion
3 Reduction of the stream bed
4 Foundation of hillside foot

■ Hillside works

○ Hillside foundation works
    / Grading works
    / Bench cut works
    / Wall works
    / Channel works
    / Underground works
    / Grating crib works

○ Hillside vegetation works
    / Wicker works
    / Step works
    / Sodding works
    / Covering works
    / Direct seeding works
    / Spray works
    / Plantation works

■ Landslide prevention works

○ Control works
    / Surface drain works
    / Groundwater drain works
      (Closed conduit, Drilled conduit,
      Drainage well, Tunnel conduit)
    / Earth cut works
    / Torrent works
    / Retain wall works
    / Earth retain works

○ Restrain works
    / Pile driving works
    / Shaft works
    / Anchor works

b. Kinds of each main type of works

■ Checking method

    / Soil retaining
    / Piling
    / Anchor work

■ Check dam
    / Concrete dam
    / Dry masonry dam
    / Wet masonry dam
    / Masonry concrete da
    / Concrete block darn
    / Steel screen dam
    / Steel crib darn
    / Gabion dam
    / Log (wood) darn
    / Concrete crib dam
    / Steel slit dam
    / Steel segment dam
    / Vegetation sack work

■ Covering work
    / Straw covering work
    / Net covering work
    / Straw mat covering work

■ Wall work
    / Concrete wall
    / Dry masonry wall
    / Wet masonry wall
    / Masonry concrete wall
    / Concrete block wall
    /Steel crib wall
    / Gabion wall
    / Log (wood) wall
    / Concrete crib wall

■ Channel work

    / Concrete channel work
    / Stone channel work
    / Log (wood) channel work
    / Vegetation sack channel work

■ Grating crib work
    / Concrete grating crib work
    / Log (wood) grating crib work
    / Tire grating crib work

■ Step work
    / Fascine step work
    / Sod step work
    / Stone step work
    /Kaya (Miscanthus sinensis ande.)
     step work

■ Spray work
    / Seed spray work
    / Mud spray work

■ Wicker work
    / Fascine wicker work
    / Bamboo wicker work
    / Log (wood) wicker work
    / Net wicker work
    / Steel wicker work

Chapter 4

Erosion control in Japan
Masato Nishi

4.1 Natural and social conditions in Japan

Japan is rich in the natural landscape. The fact, however, can be said to mean that Japan is surrounded by severe natural conditions. The Japanese Islands, where rivers mostly floe rapidly and grounds are weak geologically, are in the circumstances which favor the occurrence of sediment-related disasters by weather conditions such as typhoons, localized torrential downpours, etc.

Rapid rivers take a higher proportion in Japan than in other countries in the world.
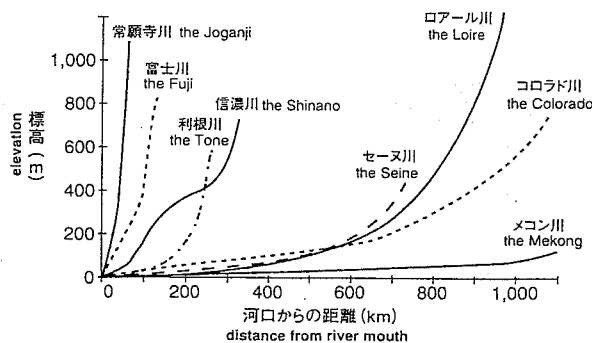
The comparison of rainfalls in major world cities of a similar latitude
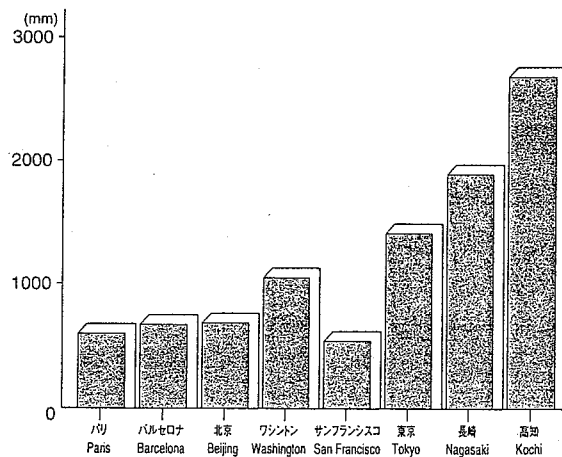
In the Japanese Islands, which are located on the circum-Pacific volcanic belt, there are active volcanoes as many as 86, about 10% of those in the world, distributed around the country. In addition, this place is on the world-famous mobile belt where four plates

meet: Pacific plate, Eurasian plate, Philippine Sea plate, and North American plate; thus there are frequent earthquakes and volcanic eruptions in these islands. In urban areas more and more places have been put at risk of the sediment-related disaster to increase through the development of piedmonts and hill zones for residence. On the other hand, in mountain areas there is a tendency for the risk of the sediment-related disaster to increase through insufficient forestry and mountain deterioration caused by the local depopulation, etc. Besides a growing number of people have been becoming vulnerable to a disaster, as the aging society has progressed: they have difficulty escaping quickly at the time of an emergency.

■The proportion of disaster-vulnerable people, such as the highly aged, etc., to the total, in the dead and missing in the sediment-related disasters in 1998

■ The populational constitution in Japan (estimation as of March, 1999 by the Management and Coordination Agency)

38% 62%

79% 21%

■ 災害弱者　the disaster-vulnerable
□ それ以外　the others

■ 高齢者及び幼児　the highly aged and infant
□ それ以外　the others

4.2 Occurrence of sediment-related disasters

The sediment-related disaster caused by the localized torrential downpour, earthquake, volcanic eruption, etc. occurs frequently every year, and the sediment-related disaster accounts for about a half of the dead and missing by the natural disaster (excluding those by the Southern Hyogo Earthquake, January 1995).

Localized torrential downpour

Localized torrential downpour (Total amount of rainfall: 1,267 mm; maximum rainfall per hour: 90 mm) caused sediment-related disasters in many places in Fukushima and Tochigi prefecture in late August 1998. In Nishigo-mura, Fukushima prefecture soil flowing into a social welfare facility caused tragic damage in which five person were killed.

In June 1999, in various places in the coastal aria of Hiroshima Prefecture, such as places in Hiroshima City, Kure City, and Akitsu town, debris flows and slope failures

were caused by heavy rain the Bai-u front brought. At 5 chome, Matoba, Kure City, a slope failure gave the damage of: one person killed, one house completely destroyed, three houses partly broken, and two houses a little broken.

A sediment-related disaster caused by a localized torrential downpour (Nishigo-mura, Fukushima prefecture)

A slope failure disaster caused by a localized torrential downpour (Kure City, Hiroshima Prefecture)

Earthquake

A landslide occurred on the hillside of the left bank of a sabo dam at the time of the Southern Hyogo Prefecture Earthquake (January 1995). There was a residential area closely below the place where 1,500 m³ of sediment came to deposit and hence a fear of damage by sediment outflow.

Volcanic disaster

In June 1991 serious damage was caused by a pyroclastic flow, a debris flow, etc., including the loss of the valuable lives of 43 persons as the dead and missing.

Snowmelt

On May 10, 1997 a soil flow caused by a landslide went into a river and turned into a debris flow. The occurrence of casualties was avoided because of the appropriate evacuation and the sabo dam checking the debris flow.

4.3 Progress of Sabo Works

Disasters caused by sediment have occurred frequently in this country since the ancient age; this is due to the characteristics of nature there. To prevent these disasters, a law, for example, was enacted to limit deforestation as early as the Nara period (around 700 A. D.). After that, however, disasters due to sediment continued as exemplified by

frequent ship transportation hindrances and flood accompanying national land development. Thus in the Edo period (1603-1868) the way of thinking of the mountain and river control appeared and each han (daimyo administration) came to do sabo works in its domain. In the Meiji period sabo technologies were introduced from Europe and three laws for river control (the River Law, the Sabo Law, and the Forestry Law) were also enacted. This triggered the beginning of sabo works throughout the country by the central government and local administrative authorities.

In the Showa period large-scale sabo dams were built using concrete technologies, and the sabo technology made a big leap in its level. Also in the legislative aspect, not only laws for sabo but those for the prevention of landslide and slope failure were prepared and enacted. Thus now our sabo system has reached so high a level that it enables us to provide technological cooperation for various countries in the world.

The sabo works conducted by Fukuyama han

Let us introduce one remarkable achievement in the Edo period. Fukuyama han (Hiroshima prefecture) built a lot of sunadome (sabo dams) by stone masonry although technologies using both wood and stone were overwhelmingly prevailing at the time. Those sunadome still work effectively even at present when 150 years have passed since their construction.

The sabo works at Mt. Tanakami

Once Mt. Tanakami was bare because people had cut down a lot of trees in the forest there for use for building temples, etc. since the Nara period. In the Meiji period sabo works were applied there, which was the first sabo works in the country done directly by the central government. After that, hillside works, etc. were actively applied there, and as a result, the mountain has been restoring green trees in recent years.

The achievement of de Rijke

After the Meiji Restoration, in addition to reviewing technologies han had developed, foreign engineers, mainly Dutch engineers, were invited. Especially, Johannis de Rijke, who came to Japan in 1873, devised 17 kinds of construction methods, explored the drainage basins of the Yodo and various rivers, and guided people in sabo works in this country for a period as long as 30 years.

The progress to the modern sabo

The sabo technology of Japan, which had progressed on its own based on the introduced European technologies, was further developed by Masao Akagi, an engineer of the Ministry of Home Affairs. Of the constructions designed by him, Shirakawa sabo dam (63 meters high and highest in Japan) at the Joganji River is known very well.

4.4 For the Prevention of Sediment-related Disasters

A sediment-related disaster can occur in a very wide range from the headwater area to the cities downstream, in a variety of forms. Preventive measures to be taken against such a disaster are classified into two types: a hardware means of installing structures with which people's lives and properties will be protected, and a software means of setting up and improving a system of warning and evacuation. Particularly in recent years, disasters by debris flows and slope failures have been occurring frequently, and thus it is desirable to take action to improve the situation as soon as possible.

The three Laws for Preventing Sediment Disasters

In order to conserve the national land and allow people to live comfortably, following three laws regulate harmful acts that will cause sediment-related disasters, and also give a basis for the implementation of sabo-related works.
The Sabo Law: From the necessity of doing sabo works for river control, the Sabo Law was enacted in 1897, which was intended to regulate harmful acts in sabo-designated areas and also promote to set up sabo facilities.
The landslide prevention Law: the Landslide Prevention Law was enacted in 1958, which was intended to prevent damage by landslides and contribute to the conservation of the land and the stabilization of people's life.
The Law Concerning the Prevention of Disasters Due to Collapse of Steep Slope (The Steep Slope Law): In order to protect people's lives from slope failures, the Law concerning the Prevention of Disasters Due to Collapse of Steep Slope (the Steep Slope Law) was enacted in 1969.

River System Sabo
Rivers which have devastated mountains as their headwater areas can have their streambeds raised with sediment flowing out of those mountains and cause floods leading to disasters covering their whole basins. In those rivers it is necessary to control sediment flows with the whole river system so that their streambeds will not vary

extremely in the downstream areas. Sabo works done in those kinds of drainage basins are called river system sabo. The river system sabo is now being done in 33 blighted basins throughout the country directly by the central government.

An example: sabo in Mt. Tateyama protecting Toyama plain: Sabo works are being done in the upstream area in the Joganji river for the purpose of decreasing the sediment flow out of Tateyama caldera, a famous devastated area in this country, and its surrounding area and thus protecting Toyama plain from floods that would be caused by the riverbed aggradation in the downstream.

図1 常願寺川は河口から10km地点では富山市内を見下ろす高さであり、天井川になっている。
Fig. 1 The Joganji river is so high in elevation that the city of Toyama is looked down from the river at 10 km upstream from the river mouth; i.e., it is a raised bed river.
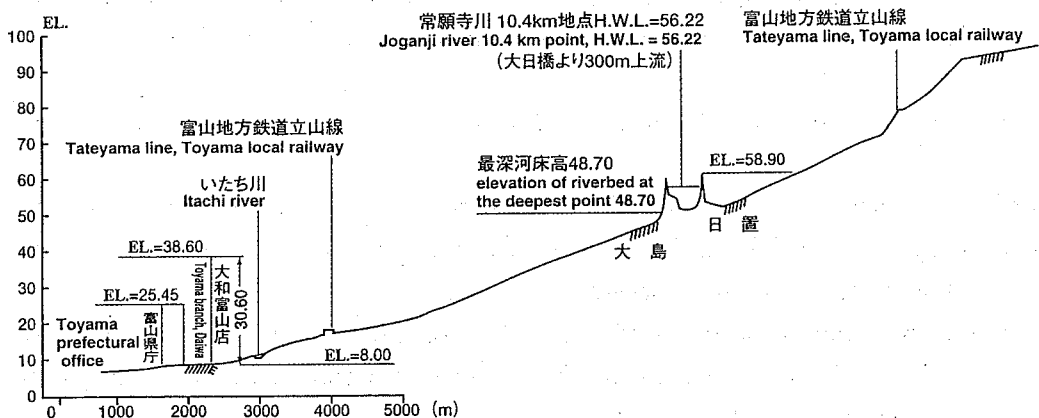
Fig.1) The Joganji river is a raised bed river. The river is so high in elevation at the point about 10km upstream from the river mouth in the alluvial fan of Toyama plain that it commands the city of Toyama. A raised bed river is one which has its riverbed raised higher than the surrounding ground because of aggradation within the bank. The Joganji river has become a raised bed river after a large amount of sediment came from the upstream area for a long time. Thus the river has potential for causing a great disaster once it floods.

図2

① 土砂が貯まることによって、川底が削られるのを防ぎます。また勾配がゆるくなることで水の流れが遅くなります。

The accumulation of sediment will prevent the erosion of the riverbed and also make the riverbed slope less steep to make the water flow slower.

設置前
before dam construction

川の勾配をゆるやかにすると流れのスピードが落ち、大きな石から堆積します。

The less steep riverbed slope will make the water flow slower, resulting in larger stones being deposited faster.

設置後
after dam construction

② 土砂が貯まり、川底が上がることで山くずれを防止します。また川幅が広がることで水の流れが遅くなります。

The riverbed raised by the accumulation of sediment will prevent hillside landslide and also make the river width larger resulting in slower water flow.

土砂が埋まって上がった河床
riverbed raised with sediment accumulation

山腹が崩壊しなくなり、固定されます。
hillside fixed without landslide

川幅が広がることで流れが遅くなります。
broadened river width resulting in slower flow

③ 一度に大量の土砂が出るのを防ぎます。
Flowing-out of a large amount of sediment at a time will be prevented.

洪水前
before flood

砂防ダム上流が満砂になるまで土砂を貯めます。
Sediment will be accumulated until the space in the upstream side of the sabo dam is filled up with sediment.

大洪水直前
immediately after great flood

土砂が一気に出たとき、これだけの土砂を止めます。
This amount of sediment will be made to stay here when a large amount of sediment flows in at a time.

大洪水直後の中小洪水
medium and small floods after great flood

上流からの土砂が減ってくると、貯まった土砂が中小洪水によって流れて、次の大洪水のときに土砂を止める空間になります。
When flowing-in of sediment from the upstream gets decreased, some of the accumulated sediment will be carried away by medium and small floods to make space which will receive sediment at the time of the next great flood.

Fig. 2) Sabo dams will prevent riverbed erosion and hillside landslide by accumulating sediment there, and at the same time will prevent a large amount of sediment from flowing out at a time.

Preventive measures against debris flows

When stones and soil on a hillside and a riverbed are carried downstream in a rush by a long-continuing or localized torrential rainfall, the flow is called a debris flow. The flow speed is in the range of 20-40 km per hour depending upon the flow scale, high enough to destroy houses and field in an instant.

Sabo dam: Sabo dams built in the upstream areas of mountain streams will accumulate sediment and suppress production and flow of sediment. Further, those built at the exits of valleys will work as a direct barrier to a debris flow that has occurred.

For example, the sabo dam in the middle reaches of the Aratani River prevented the damage by a debris flow and woody debris at the time of the localized torrential rain that attacked the coastal area of Hiroshima Prefecture in June 1999.

Preventive measures against landslides

When the part or whole of a slope moves down slowly by gravity and by the influence of ground water, the phenomenon is called a landslide. Generally the amount of soil that moves is large, so a landslide will cause very serious damage. Once it begins to move, a landslide is very difficult to stop completely. In Japan the ground is weak geologically and, in addition, there are torrential rainfalls in a rainy and typhonic seasons. Thus landslides occur around the country every year.

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A landslide is caused by a combination of various factors (topography, geological structure, rainfall, artificial factors, etc.). Accordingly, measures to be taken for landslide prevention come in a variety of types. Broadly they are classified into two types: control works and restraint works; control works removes or mitigates factors which will lead to the occurrence of a landslide; restraint works aim at the stabilization of a slope by checking the landslide with structures.

· The Yamato river corrects rainfall in the whole Nara basin. The Kamenose valley is the exit through which the Yamato river goes into Osaka plain. This place have had landslides frequently since the ancient time, and it is expected that the Nara basin might be inundated and that a wide area in Osaka plain and its vicinities might be damaged by rushing-out of the accumulated water. The landslide prevention works done in Kamenose are of the largest scale in Japan: caisson pile works reaching as deep as 100m and piling works using a lot of steel pipes have checked the landslide pressure; soil removal works also have been done; further, water channel works, water catchment well works, and tunnel drainage works have been done using a variety of technologies. Those preventive measures, taken doubly or triply, are so sure that their failure couldn't be imagined.

Preventive measures against slope failures

When a slope is collapsed abruptly by the influence of a rainfall or an earthquake with the earth's self-retainability weakened by water penetration, the phenomenon is called a slope failure. Because of the high speed of collapse, people are likely to fail to escape and the death rate is often high when a slope failure occurs in a place near living houses.

In this country where 130 million people live in a small territory, it is unavoidable for a lot of people to have to live in places adjoining dangerous steep slopes. There are dangerous slopes not only in hilly areas but also in urbanized hill-foot areas and coastal areas.

Grating crib works: concrete frames are laid down on a slope, which frames have plants grown inside to protect the slope from weathering and erosion.

Retaining wall works: Concrete retaining walls are built on the lower part of a slope to directly suppress the collapse of that part and also check coming-down collapse soil and stop it before living houses there.

Sabo works as comprehensive measures against volcanic eruptions

Reportedly, in this country there are more than 200 volcanoes formed in the Quaternary Period (about two million years ago), 86 of which are active volcanoes. These active volcanoes are being monitored and observed by the Meteorological Agency, universities, the Geographical Survey Institute, and other research

organization.

With only one eruption, volcanoes can cause a large-scale disaster, damage a wide area, and destroy a lot of people's lives and properties, and so comprehensive measures against volcanic eruptions have to be taken including not only hardware measures such as sabo dams, etc. but also software measures such as warning and evacuation system, etc.

In hardware measures, various volcanic sabo facilities are installed in preparation for volcanic mudflow, pyroclastic flow, lava flow, etc. to be generated by eruption, and also debris flow to be caused by rainfall. By doing so, the damage will be minimized. Works to be done include: "check dams" for checking the flow of volcanic products, "training dike" for leading mudflow and lava flow to safe zones, "slit dams" for preventing large rocks from flowing down, "sand pockets" for accumulating mudflow, etc., and "channel works" for making flow-out materials flow down safely.

In software measures, warning and evacuation systems are prepared and established in line with the hardware measures, to mitigate or prevent sediment-related disasters accompanying volcanic activities. Maps predicting volcanic disaster areas are drawn based on the simulation of volcanic disasters, and roads and places to be used for refuge are improved to better conditions in preparation for disaster occurrence. Systems for collecting quickly information on volcanic activities and informing local citizens of it are set up by installing monitor cameras and various of sensors.

Works for avalanche prevention measures

Almost 20% of the whole population of Japan live in areas with heavy snowfall, and there are many dangerous places threatening villages with an avalanche, as many as 15,242 in the whole country. In these dangerous areas, measures are being taken to prevent avalanches.

Preventive fence works: The works will prevent the occurrence of total layer and surface layer avalanches on slopes where the snow depth is about 5-6m or less.

Energy dissipator works: The works, which are done on paths where predicted large-scale avalanches will run, will mitigate their powers.

Protection works: The works will weaken further the power of flowing avalanches and stop them to accumulate there

4.5 Establishment of Warning and Evacuation Systems

In order to protect people's lives from sediment-related disasters, the establishment of warning and evacuation system is very important as well as hardware measures such as the installation of sabo facilities. Thus, following comprehensive measures have been

taken to minimize damage: regulating land utilization by guiding, making known to everyone the importance of early evacuation, making dangerous spots known to everyone by direct mails, slope charts, dangerous spot maps for sediment-related disasters, etc., promoting works for urgent set-up of information bases, and utilizing sabo Volunteers.

Hazard map on sediment-related disaster

"A hazard map on sediment-related disaster" indicated the relationship between the locations of dangerous spots for sediment-related disasters (mountain streams at risk of a debris flow, steep slopes at risk of collapse, and spots at risk of a landslide), the locations of refuges, and the routes to reach them. This map is distributed among local citizens, calling their attention to the sediment-related disaster.

Notifications by direct mail to the people living in the threatened area

If a sediment disaster occurs, a notification is made by direct mail to the people living in the area that may be damaged by it. The safety measures such as the warning and evacuation system are promoted in case of a heavy rain by the direct mail in addition to the "hazard map on Sediment Disaster" and the "Regional Plan for Disaster Prevention".

Set up the window to contact about the sediment disaster information

The window to contact about the sediment disaster information is set up at 1,200 municipalities all over the country in order not only to collect the information of a sigh of the sediment disaster and the disaster occurrence, but also establish the emergency communication system.

Works for urgent installation of information system

For district which damaged by a sediment-related disaster in the past or which are very likely to be damaged by that and yet have a lot of objects to be conserved, equipment for collecting information on rainfall, etc. and processing the information will be installed; promote the advanced disaster monitoring system intended to support the warning and evacuation activities against the sediment disaster in combination with the information from the comprehensive river information system.

Inspection of spots in danger of causing a sediment-related disaster

A system for sabo volunteer activities on sediment-related disasters, such as education of people in the local community to improve their understanding, inspection of dangerous spots, assistance for warning and evacuation, etc., will be established.

Chapter 5

Forest Restoration Monitoring and
Erosion Control Work Planning
Kiyoshi Honda

Abstract

This paper describes the qualitative evaluation of forest destruction and erosion control work at Asio copper mine.

The vegetation restoration process is grasped using remote sensing and GIS. This data is used to develop the vegetation restoration model. The vegetation restoration process is expressed by a growth curve that is applied to the vegetation index. The sediment and flood discharge models are also developed which can use the result of the vegetation restoration model.

Under some scenarios about executing erosion control work, vegetation restoration process, sediment and flood discharge are simulated from 200 years. As a result, the serious influence of forest destruction and the remarkable effect of erosion control work can be seen.

5.1 Introduction

Forest destruction causes sediment and flood disasters. On the other hand, Erosion control work plans trees on bare land, helps the forest to be restored quickly, and prevents flood and sediment disasters. This is evident when we see many past examples of forest destruction and erosion control work. But it is a qualitative evaluation.

Quantitative evaluation of forest destruction and erosion control work is needed, such as how much faster erosion control work can restore the vegetation compared with natural restoration, or how much it deters floods and sediment yield. In order to make more suitable and reliable plans, or to get the agreement of people about executing erosion control work, quantitative simulation models are needed. To make quantitative evaluation, the forest restoration model, sediment discharge model, and flood discharge model have to be developed.

We selected Asio copper mine as a study area. Asio copper mine is very famous for severe forest destruction (Fig.1,2). A vast area of forest was severely damaged mainly by sulfurous acid gas that had been exhausted from the smeltery. It continued for more than 60 years until 1956. The damaged forest area extended to 149km^2. Especially within 32 km^2, all of the trees were lost and the soil was entirely washed away. Within another 38 km^2, only plants that were resistant to sulfurous acid gas such as bamboo grass remained [Maebashi Forestry bureau 1990]. With the loss of forest, flood and sediment disasters happened very frequently. Since 1957 when just after the discharge of sulfurous acid gas stopped, full-scale erosion control work has been executed continuously at a huge expense. At the work area, the forest is now restoring and disasters happen less frequently than before. At Asio, the vegetation restoration model has been developed [K.Honda 1993].

5.2 Vegetation restoration model
5.2.1 Growth curve
To describe the vegetation restoration process, Mitscherlich's growth curve that is very popular in growth prediction of tree height or diameter [Minowa 1990] is applied to the vegetation index.

$$V.I. = V.I.min + M(1- Le^{-kt}) \qquad (1)$$

Where V.I.min demotes the minimum of the V.I. (134.5), M demotes the range of V.I. fluctuation (102.5), t demotes time, L is the fall ratio of V.I. when t is zero. k is a constant. k is directly related to time t; k is called as a restoration speed.

5.2.2 Grasping restoration process
Overlaying the vegetation index image and the erosion control map, the restoration process was grasped.

Fig.3 shows the vegetation restoration process in the work area. The vegetation Index is NDVI, which is scaled from its range of −1.0, 1.0 to 0-255. Elapsed time after erosion control work is obtained from the map of erosion control work. It is clear that vegetation has been restored steadily, and that the Mitscherlich's growth curve is applicable to the vegetation restoration process.

Fig.4 shows the vegetation restoration process in non work area. The vegetation index of 1957 when the vegetation restoring started was calculated from the 1957 photo interpretation image using the relationship between interpreted damage class and vegetation index. The vegetation index change is not smooth or natural, so, the growth curves are decided using 1957's and 1992's data. Restoration speeds are all nearly 0.01 (1/yr). When each starting point is located on the growth curve of k=0.01 (1/yr), it shows good fitness as a whole. It indicates that the restoration process at non work area also can be expressed by the growth curve and the restoration speed is nearly 0.01 (1/yr) in whole process.

In the work area, V.I. at elapsed year=1 and the value of the growth curve at t=0 are both higher than the V.I. range of bare land. The restoration speed k in the work area is twice as much as that of the bare land. Therefore, in the work area, right after the execution of erosion control work, vegetation is introduced firmly. After that, vegetation restores twice as fast as in non work area.

5.2.3 Vegetation restoration prediction model
To make it possible to predict vegetation restoration considering various conditions of each mesh, restoration speed k is decided as a function of conditions using multi regression analysis at each class and at each slope direction.

$$k = f(\text{altitude, slope inclination, area of watershed, point of geology [National Land Agency 1986], PRV)}$$

5.2.4 PRV index
PRV is an index of Proximity to Remaining Vegetation.

$$PRV = \sum \frac{1}{R^2} \qquad (2)$$

Where R is distance from an object mesh to the remaining vegetation. The remaining vegetation means the forest in 1957. The relationship between PRV value and remaining vegetation is shown in Fig.5.

PRV has a highly positive correlation with vegetation restoration speed of non work bare land. It is concluded that vegetation restoration is more difficult in a large block of forest loss than spatially dispersed blocks even if the extent of forest loss area may be the same.

5.3 Developing water and sediment discharge model
5.3.1 Water discharge model
Fig. 6 shows the element of water movement in the model.
Parameters of crown interception, evaporation, evapo-transpiration area estimated using V.I. (fig.7).
Soil layer depth is estimated form land cover at 1957 (Fig.8). Parameter D_{30} is decided from adapting calculation to the observed discharge. Soil layer is assumed to grow at 2.5mm/year, after V.I. becomes greater than the range of grass land.

Motion equation of under ground flow is as following.

$$Q1 = Ks \, S^{\beta} \sin \omega \, D \, L \qquad \text{[Kubota 1987]} \qquad (3)$$

- Q1 : Flow in soil layer
- Ks : saturation transmission coefficient 0.2cm/sec
- S : mean of saturation ratio
- β : parameter that indicates fall of transmission coefficient in non saturated area
- ω : gradient
- D : soil layer depth
- L : mesh interval 50m

Motion equation of surface flow is as following.

$$Q2 = V2A$$
$$V2 = \frac{1}{n} R^{2/3} I^{1/2} \qquad (4)$$

- Q2 : flow of surface
- V2 : velocity
- A : cross-sectional area
- A = H2L
- H2 : water depth
- n : roughness of manning
- R : hydraulic mean depth
- I : gradient of slope

Where

$$R = 0.255F^{-0.171}A^{2/3} \qquad \text{[Ishihara 1977]} \qquad (5)$$

- R : hydraulic mean depth (m)
- F : watershed area (km^2)
- A : cross-sectional area (m^2)

5.3.2 Sediment discharge model
Sediment discharge is calculated as average annual sediment yield at slope surface.

$$E = E_{30} \, (S/S_{30})^{0.9} \tag{6}$$

E : surface erosion of a year

E_{30} : surface erosion of a year when gradient is 30 (deg)

Land cover	Vegetation index	E_{30} (mm/yr)
bare land	- 145	20
grass land	146 - 175	1
forest	176 -	0.1

S : gradient of object mesh (%)

S_{30} : tan 30(deg) = 0.57735

5.4 Simulation and evaluation
5.4.1 Scenarios
To evaluate the effect of erosion control work, the following cases were assumed.

Case I   Do nothing from the starting point of vegetation restoration (1957)

Case II   Stop erosion control work in 1992

Case III   Continue erosion control work until the bare land has disappeared (until 2007)

In addition, calculation at natural state was done assuming that there was not a copper mine and the watershed was covered by a good forest.

5.4.2 Vegetation restoration
Fig. 9 shows the result of vegetation restoration simulation for 200 years.

Comparing Case I and II at the west area, where erosion control work has been executed at high priority, the effect of erosion control works is remarkable in all the predicted period.

Comparing Case II and Case III at the center area, where terrain is very steep and erosion control works is not executed yet, if erosion control works were stopped now, there would remind bare land. But by continuing erosion control works, vegetation restoration is expected.

5.4.3 Sediment yield
Fig.10 shows the simulated sediment yield from the result of vegetation simulation.

At 1957, sediment yield was very large compared to the natural state.

Past erosion control work and future erosion control work have a remarkable effect to lower sediment yield. Past erosion control work prevent will 4.2 million m^3 in 200 years. Future erosion control work will prevent adding 4.7 million m^3.

5.4.4 Flood discharge
Fig. 11 shows the peak flow of simulated flood hydrograph at 100 years probable rain. At 1975, the peak flow increased 46%. Even if erosion control work has a significant effect on sediment discharge, there is a not big effect to lower the peak flow. It is clear that erosion control work helps forest restoration and the restoration of soil layer, but the speed of soil creation is very slow, so the effect of erosion control work on peak flow is very small. It indicates that forest destruction that causes soil loss increases the flood peak flow for a long term.

5.5 Conclusions

A method to make quantitative evaluation of forest destruction and erosion control work was totally developed. Forest restoration process, sediment yield, and flood peak in each scenario is calculated and evaluated. Followings are the result of evaluation.

(1) Erosion control work has make forest restoration twice as faster as natural restoration. If we continue work, fully forest restoration is expected.

(2) Erosion control has a remarkable effect on preventing sediment yield. Past and Future erosion control work would present 8.9 million m^3 sediment yield in 200 years.

(3) Forest destruction that causes soil loss, increases peak flow seriously for a long term. We have to avoid such a forest destruction.

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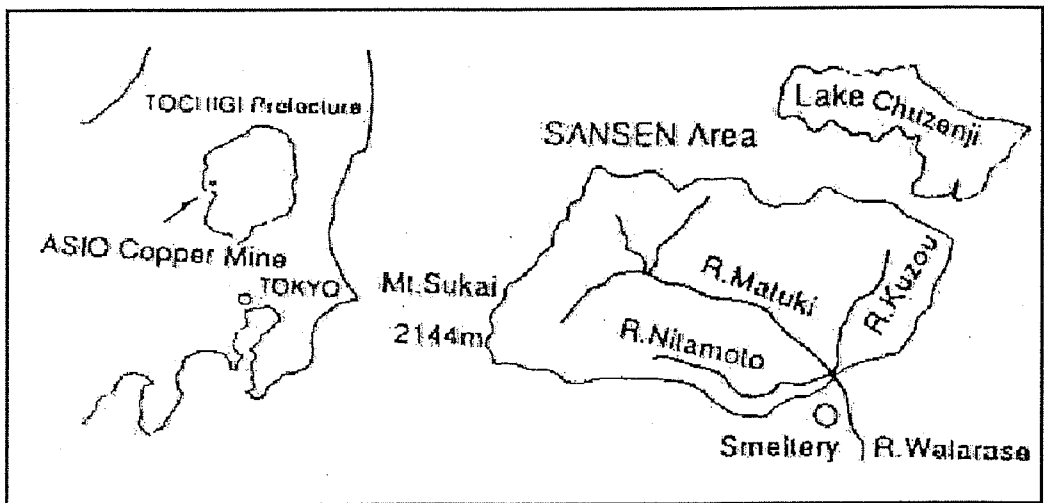
Fig1.Map of Asio Copper Mine

Fig2. Photo of Study Area
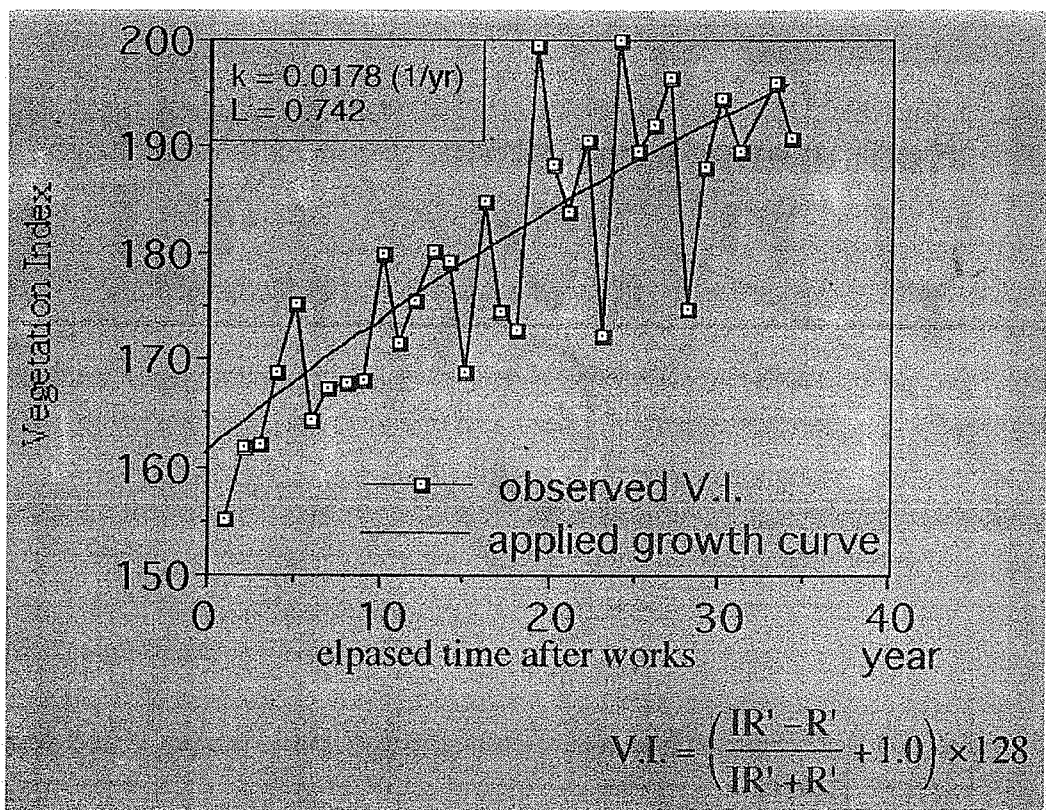
Fig.3 Vegetation Restoration Process in Work Area
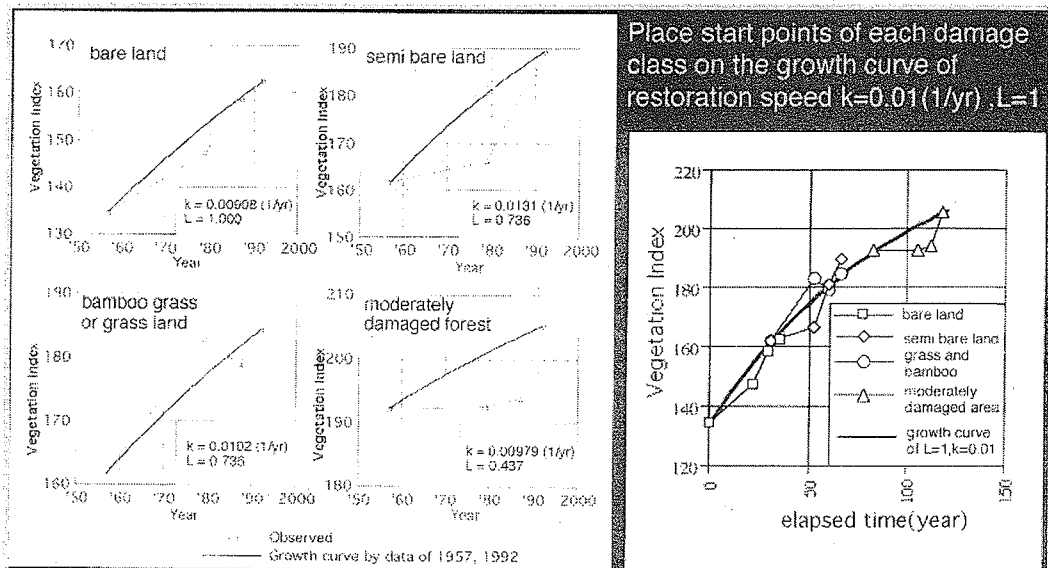
Fig.4 Vegetation Restoration Process in New Work Area
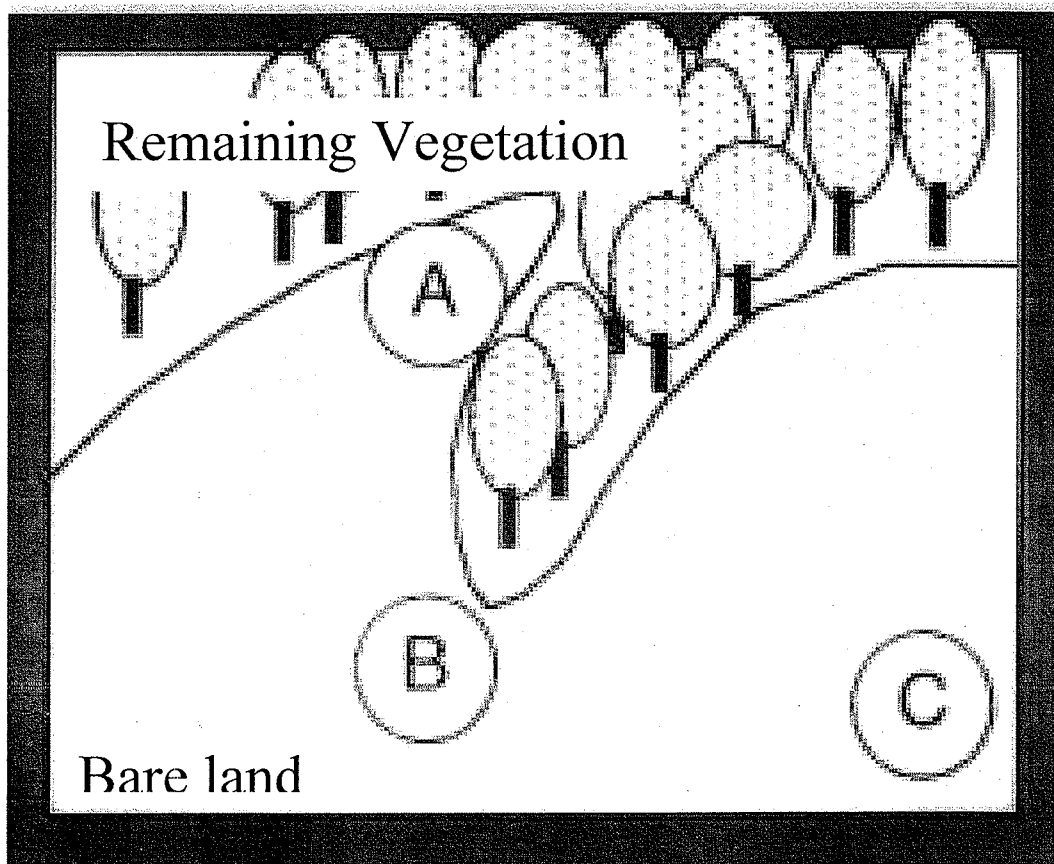
Fig.5 PRV Proximity to Remaining Vegetation INDEX
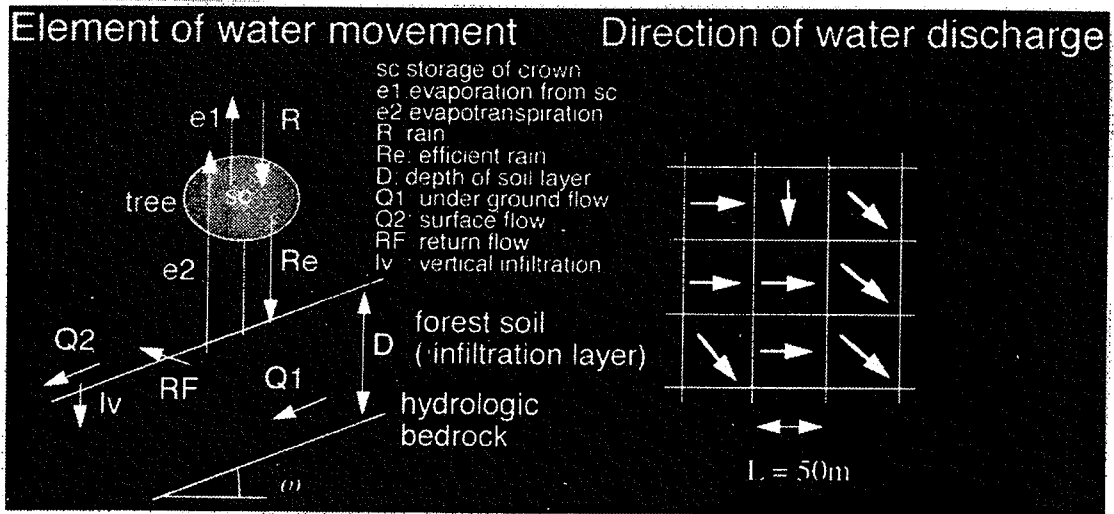
Fig.6 Structure Water Discharge Model
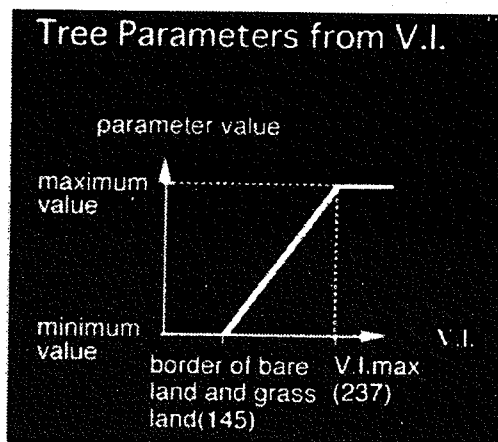
parameter			min.	max.
crown interception	sc	(mm)	0	2.5
evaporation	e1	(mm/hr)	0	0.4
evapo-transpiration	e2	(mm/day)	1.7	5.0

FIG.7 Estimation of Crown Interception, Crown Evaporation, Evapo-transpiration from Vegetation Index
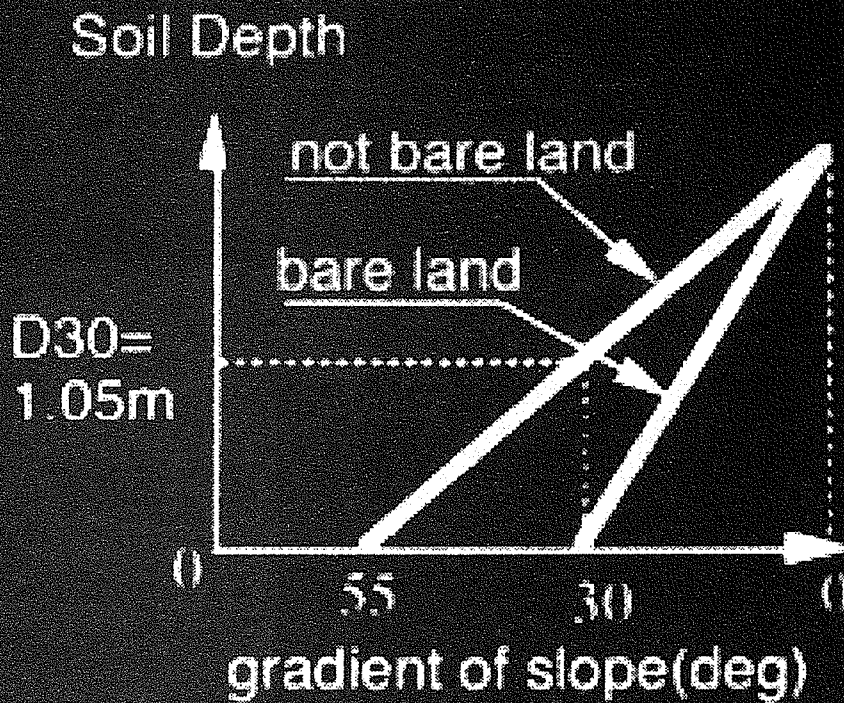
FIG.8 Estimation of Soil Depth
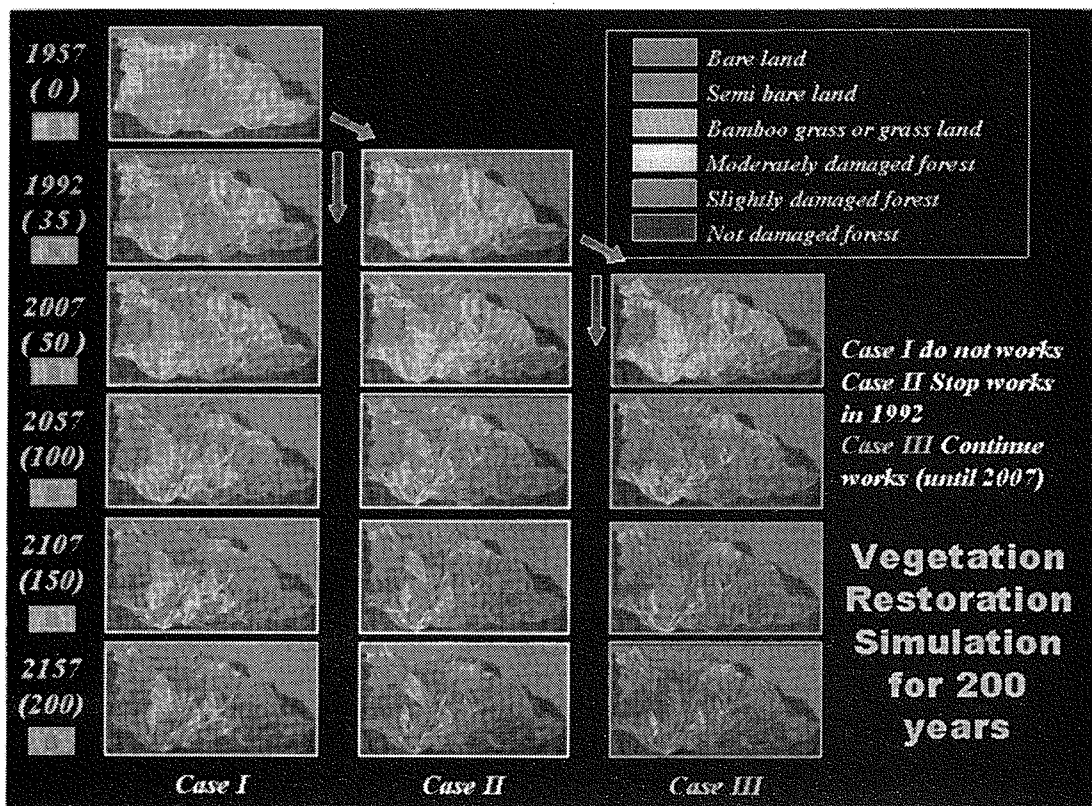
Fig.9 Vegetation Restoration Simulation for 200 years
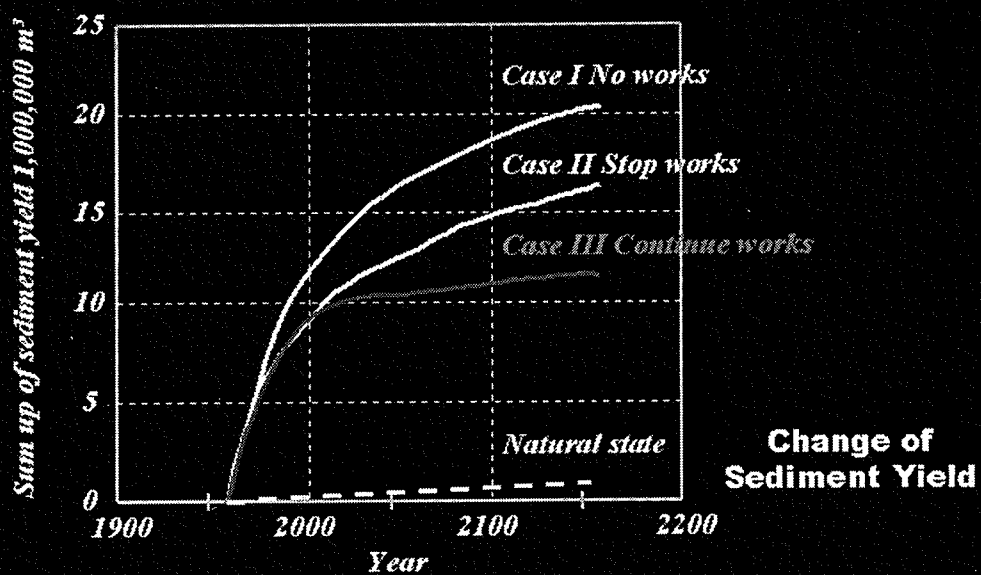
Fig.10 Accumulated sediment yield

Fig.11 Food Peak Discharge
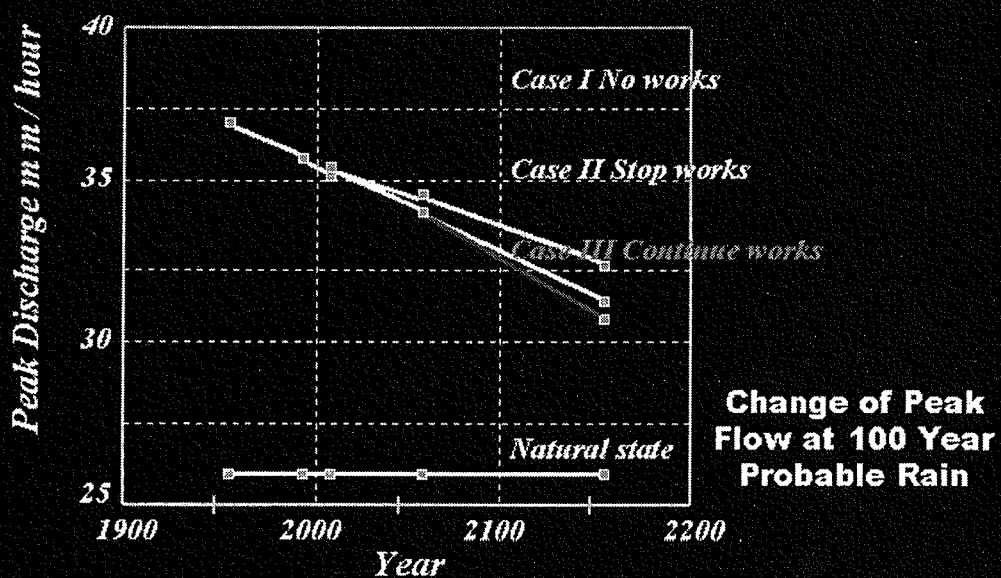
Chapter 6

Runoff Analysis of Head Water
Shigeki Kobatake

6.1 Introduction

In the previous chapter, the elementary hydrological processes were presented. This chapter will deal with the practical runoff analysis techniques.

The runoff analysis model can be classified into long-term and short-term, distributed and lumped or conceptual and physical. The difference between the long-term runoff and the short-term runoff model is the length of the objective period. Similarly, the difference between the distributed model and the lumped model is based on number of partitions of the objective basin. With the conceptual and the physical models, the main difference lies in the extent to which the elementary hydrological processes of runoff are taken into account.

Regardless of what model is selected, the most important thing in run-off analysis is how to estimate the effective rainfall. The notion that, calculation of the effective rainfall controls the fate of the accuracy of the runoff calculation is not an exaggeration. Generally, the important factor that controls the effective rainfall varies from one model to the other. For example, the evapotranspiration is the dominant factor for the effective rainfall in long-term runoff analysis and, the infiltration is considered as the dominant factor in the storm runoff models.

The following sections of this chapter discuss the general concept of effective rainfall for storm runoff, some basic runoff models and recently developed runoff models for large river basins.

6.2 The concept of effective rainfall in storm runoff

The composition of storm runoff component is shown in Fig.1.
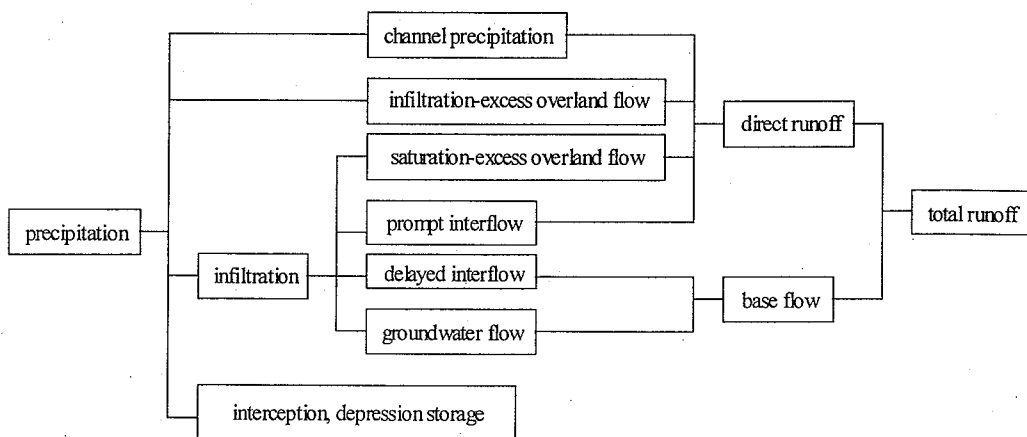
Fig.1 The composition of storm runoff component

The effective rainfall for storm runoff is usually defined as causing direct runoff. The estimation of the effective rainfall for a past flood is usually carried out using the base flow separation of the hydrograph. There are three common methods recommended for separating the base flow from the total hydrograph.

1) Straight line method
2) Variable slope method (I)
3) Variable slope method (II)

The above methods are demonstrated in Fig.2.
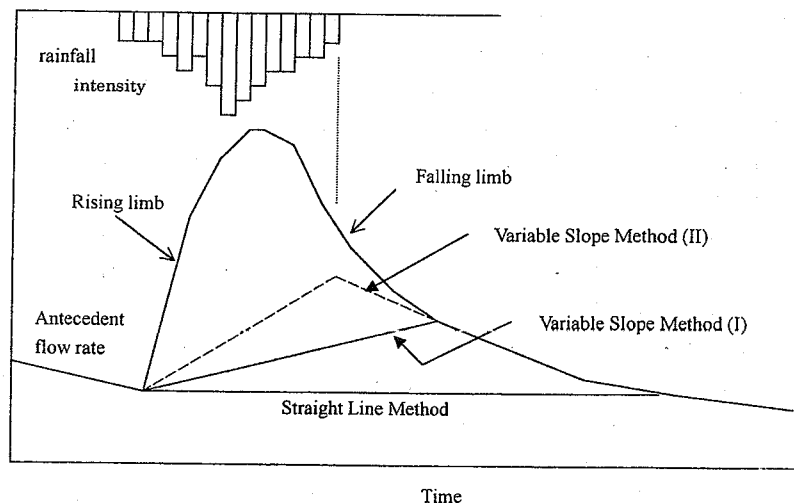
Fig.2 Methods of base flow separation

The straight line method simply connects the beginning point of rising limb with the end point on falling limb by straight line as shown in Fig.2. This method is the easiest to apply.

The variable slope method (I) approaches more precisely the phenomena that occurs in the recession stage of a flood flow. If the groundwater runoff can be approximately expressed by the runoff from a tank, the recession curve of the hydrograph should be the straight line on a semi-logarithm paper. Therefore, on the semi-logarithm paper, the recession curve should change to the straight line from the point at which the interflow disappears.

The variable slope method (II) is based on another understanding of the phenomena, that is, the groundwater flow should take maximum value at the end of water supply from surface layer, if the lag time is not taken into account. Therefore, the straight line on semi-log paper is extended to the time when rainfall ceases, and this point is connected with the beginning point.

Though all these three methods are widely used, the variable slope method (I) is especially well used because of its physical meaning and its simplicity.

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If we analyze many past hydrographs and related rainfall records, we can use the results to estimate the effective rainfall of current rainfall event in the following way.

Step 1: Analyze past hydrographs and calculate the difference between total rainfall amount and direct runoff amount. This quantity is defined as "loss" in the meaning of loss for direct runoff. (Though the word of loss is not suitable because this quantity appears as base flow in future, it is usually called loss.)

Step 2: The calculated results are plotted on a graph by taking the loss in the ordinate and the rainfall amount in the abscissa.

Step 3: By taking previous non-rainfall days into consideration, some representative loss curves are drawn as shown in Fig.3.
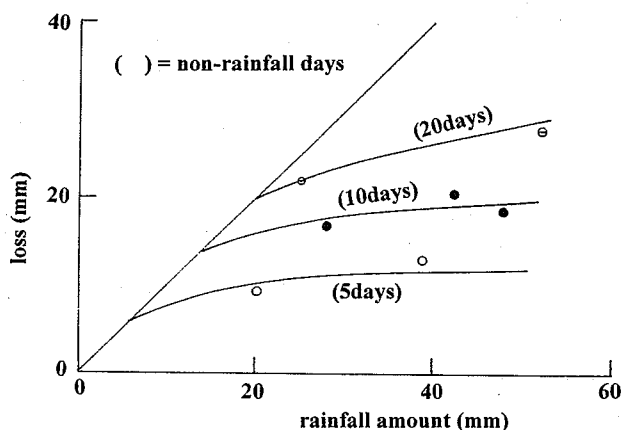
Fig.3 Definition of the loss curve

Step 4: Using Fig.3, we can estimate the current effective rainfall as shown in Table 1, considering in this case, 5 non-rainfall days. (In the case that the non-rainfall period is not presented in Fig.3, the interpolated loss curve can be used)

Table 1 Example of estimation of effective rainfall using loss curve

Time	a	b	c	d	e
(hr)	rainfall r (mm/hr)	accumulated R (mm)	loss curve (mm)	= b - c (mm)	effective r (mm/hr)
0 - 1	2	2	2	0	0
2	3	5	5	0	0
3	5	10	7.5	2.5	2.5
4	8	18	10	8	5.5
5	15	33	11.5	21.5	13.5
6	10	43	11.7	31.3	9.8
7	4	47	11.8	35.2	3.9
8	2	49	11.9	37.1	1.9

6.3 Rational Formula

The most simple flood equation is the Rational Formula. This equation was first used in 1890's and is still used in the field of design floods on relatively small basins.

The Rational formula can be only applied to areas where heavy rainfall is almost uniform. For this reason the use of this equation is limited to basins of 40-50km^2 drainage area or less. However it can still be used, if the characteristics of runoff field and rainfall of the basin are considered as nearly uniform.

The Rational Formula is:

$$Q_p = \frac{1}{3.6} fRA \tag{1}$$

Where Q_p is the peak discharge in m^3/sec,

f is the runoff coefficient,

R is the average rainfall intensity during the time of concentration in mm/hr,

A is the drainage area in km^2.

The values of f, commonly used in Japan, are shown in Table 2. If this equation is used for design of small-scale sewerage system, the standard values of each element are as shown in Table 3.

Table 2 The standard value of runoff coefficient used in Japan[1]

The steep mountain	$0.75 \sim 0.90$
The tertiary mountain	$0.70 \sim 0.80$
The land with undulation and wood	$0.50 \sim 0.75$
The flat cultivated land	$0.45 \sim 0.60$
The paddy field under irrigation	$0.70 \sim 0.80$
The mountain stream	$0.75 \sim 0.85$
The small stream of flatland	$0.45 \sim 0.75$

Table 3 The standard value of runoff coefficient for urban area[1]

The roof	0.90
The road	0.85
The other non-permeable plane	0.80
The water surface	1.0
The soil surface between the building	0.20
The park with grass and many trees	0.21
The mountain with small gradient	0.30
The mountain with steep gradient	0.50

The American Society of Civil Engineering also presented standard values of runoff coefficients[2]

R is defined as the average rainfall intensity during the time of concentration T_c that is the propagation time of rainwater from the farthest point of the basin to the basin outlet.

$$T_c = L/V \tag{2}$$

where L is the distance from the farthest point of the basin to the basin outlet,

V is the propagation speed of flood wave.

Until 20 years ago, equations using constant propagation speed, such as Kraven or Rziha equation, were widely used. However recently, more efficient methods for estimating T_c have been introduced. One of these equations is [3]:

$$T_c = CA^{0.22}r_e^{-0.35} \tag{3}$$

where T_c is the concentration time in minutes,

C is the constant which differs by the land use condition,

A is the drainage area in km^2,

r_e is the effective rainfall intensity in mm/hr.

This equation is derived from both the quantitative analysis of river basin geomorphology and the kinematic wave theory. The typical values of C are given in Table 4.

Table 4 the typical value of C

The natural mountain	$250 \sim 350$	$\cong 290$
The pasture land	$190 \sim 210$	$\cong 200$
The golf course	$130 \sim 150$	$\cong 140$
The developed residential area	$90 \sim 120$	$\cong 100$
The urban district	$60 \sim 90$	$\cong 70$

6.4 Unit Hydrograph Method

The unit graph is defined as u_j in the following calculation of a flood hydrograph $Q(t)$.

$$Q(t) = \sum_{j=1}^{n} u_j r_{e,t-(j-1)\Delta t} \tag{4}$$

where $Q(t)$ is the discharge at the time t,

u_j is the j-th component of the unit graph,

$r_{e,t-(j-1)\Delta t}$ is the effective rainfall intensity at the time from $t - j\Delta t$ to

$t - (j-1)\Delta t$,

Δt is the time step of calculation and n is the term number of the unit graph.

For instance, if the term number is 4, the equation (4) can be written down as follow.

$$Q(t) = u_1 r_{e,t} + u_2 r_{e,t-\Delta t} + u_3 r_{e,t-2\Delta t} + u_4 r_{e,t-3\Delta t} \tag{5}$$

If we consider the first 4 time steps from the beginning of the rainfall, the discharge $Q(1), Q(2), Q(3), Q(4)$ can be expressed as follow.

$$\left.\begin{aligned}
Q(1) &= u_1 r_{e,1} \\
Q(2) &= u_1 r_{e,2} + u_2 r_{e,1} \\
Q(3) &= u_1 r_{e,3} + u_2 r_{e,2} + u_3 r_{e,1} \\
Q(4) &= u_1 r_{e,4} + u_2 r_{e,3} + u_3 r_{e,2} + u_4 r_{e,1}
\end{aligned}\right\} \tag{6}$$

From equation (6), we can estimate u_j successively using observed values of $Q(t)$ and r_e.

Nevertheless, the solution usually becomes very unstable due to inaccuracy of these observed values. A variety of methods were developed in order to overcome this problem. For example, the Collins's Runoff Distribution Graph Method[4]. Its mathematical expression is not difficult and it is a simple method. This method is explained below.

Collins proposed the method for correcting the assumed distribution graph successively, using the largest effective rainfall. In the present paper, the method is explained using the example shown in the text book of Kadoya[5].

Table 5 shows the effective rainfall and the observed direct runoff discharge from a mountainous basin of 2.88 km^2. The effective rainfall r_e is calculated using the loss curve method introduced in Chapter 2. The direct runoff discharge Q_D is calculated using the base flow separation method introduced also in Chapter 2. The forth column Q_V is the average discharge during 1 hour, for example, 0.55 at $t=3$ is obtained by the calculation of $(0.2+0.9)/2$. The peak discharge appeared at 6:30, so, the value at 7 was obtained by the calculation of $(4.5+5.5*2+4.9)/4$. The accumulated value of 36.00 of

Table 5　Observed direct runoff and effective rainfall

t	r_e (mm/hr)	Q_D (m3/s)	Q_V (m3/s)	t	r_e (mm/hr)	Q_D (m3/s)	Q_V (m3/s)
0 - 1		0.0		13		1.3	1.5
2	2.5	0.2	0.1	14		1.1	1.2
3	2.5	0.9	0.55	15		0.9	1.0
4	6.0	1.3	1.1	16		0.7	0.8
5	10.0	3.3	2.3	17		0.6	0.65
6	12.0	4.5	3.9	18		0.4	0.5
[6:30]		[5.5]		19		0.3	0.35
7	6.0	4.9	5.1	20		0.16	0.23
8	4.0	4.7	4.8	21		0.10	0.13
9	2.0	3.5	4.1	23		0.02	0.06
10		3.1	3.3	24		0.02	0.02
11		1.9	2.5	1		0.00	0.01
12		1.7	1.8	total	45.0	35.60	36.00

Q_V coincides with the accumulated r_e of 45mm through the conversion of *45*2.88/3.6*. The accumulated Q_D does not exactly coincide with this value because the peak value was not considered in the calculation.

Based on Table 5, the solution is obtained by Collins's distributed hydrograph method as follows.

In Table 6, column 2 is the effective rainfall r_e and column 3 is averaged discharge Q_V shown in Table 5. Column 4 is the first assumption of the distributed graph in % unit values. The first assumption can be roughly obtained as follow: plotting the recession stage of Q_V on semi-log paper and getting the inclination, we can determine the distribution of recession stage using the slightly steeper inclination obtained. Then we determine the distribution of the rising stage, as the total summation becomes 100 %.

Column 5 shows the calculation of runoff caused by effective rainfall for every time step in column 2. For example, the first value of 0.24 for effective rainfall 6.0 is obtained by

$$r_e \times p_{(1)}(1) \times 2.88/3.6 = 6.0 \times 0.05 \times 2.88/3.6 = 0.24,$$
and the second value of 1.15 is obtained by

$$r_e \times p_{(1)}(2) \times 2.88/3.6 = 6.0 \times 0.24 \times 2.88/3.6 = 1.15.$$
The column of the largest effective rainfall 12.0 is not treated and is left as blank. The column 6 of Q_c is summation of runoff component at that time from each effective rainfall except for the largest effective rainfall of 12.0. The column 7 represents the value $(Q_v - Q_c)$, which theoretically corresponds to the runoff component from the largest effective rainfall of 12.0. The value of $(Q_v - Q_c)$ in the column 7 is converted to distributed graph by the inverse operation of the column 5. For example, the first value

5.6% is obtained by *0.54 ×3.6/(12.0 ×2.88) = 0.056*. These values are shown in the column 8.

If the first assumption of the distributed graph $p_{(1)}$ is correct, the values in column 8 approximately coincide with the values of $p_{(1)}$ in column 4. However, the values of column 8 usually do not coincide with the values of column 4. In this case, a second assumption is considered: column 4 is substituted by column 9 and the process is repeated until column 8 coincides with column 4.

Table 6 Collins's method for estimating the distributed graph successively

column 1	column 2	column 3	column 4	column 5								column 6	column 7	column 8	column 9
t	re	Qv	p(1)	runoff from each effective rainfall								Qc	Qv-Qc	pc	p(2)
	(mm/hr)	(m3/s)	(%)	2.5	2.5	6.0	10.0	12.0	6.0	4.0	2.0	(m3/s)	(m3/s)	(%)	(%)
2	2.5	0.1	5	0.10								0.10			
3	2.5	0.55	24	0.48	0.10							0.58			
4	6.0	1.1	20	0.40	0.48	0.24						1.12			
5	10.0	2.3	14	0.28	0.40	1.15	0.40					2.23			
6	12.0	3.9	10	0.20	0.28	0.96	1.92	~				3.36	0.54	5.6	5.3
7	6.0	5.1	7	0.14	0.20	0.67	1.60	~	0.24			2.85	2.25	23.4	24.0
8	4.0	4.8	5	0.10	0.14	0.48	1.12	~	1.15	0.16		3.15	1.65	17.2	18.6
9	2.0	4.1	4	0.08	0.10	0.34	0.80	~	0.96	0.77	0.08	3.12	0.98	10.2	12.0
10		3.3	3	0.06	0.08	0.24	0.56	~	0.67	0.64	0.38	2.64	0.66	6.9	8.5
11		2.5	2.4	0.05	0.06	0.19	0.40	~	0.48	0.45	0.32	1.95	0.55	5.7	6.0
12		1.8	1.9	0.04	0.05	0.14	0.32	~	0.34	0.32	0.22	1.43	0.37	3.8	5.0
13		1.5	1.4	0.03	0.04	0.12	0.24	~	0.24	0.22	0.16	1.05	0.45	4.7	4.3
14		1.2	1.0	0.02	0.03	0.09	0.19	~	0.19	0.16	0.11	0.80	0.40	4.2	3.6
15		1.0	0.6	0.01	0.02	0.07	0.15	~	0.14	0.13	0.08	0.60	0.40	4.2	3.3
16		0.8	0.4	0.01	0.01	0.05	0.11	~	0.12	0.10	0.06	0.46	0.34	3.6	2.7
17		0.65	0.3	0.01	0.01	0.03	0.08	~	0.09	0.08	0.05	0.34	0.31	3.2	2.3
18		0.5			0.01	0.02	0.05	~	0.07	0.06	0.04	0.24	0.26	2.7	1.9
19		0.35				0.01	0.03	~	0.05	0.04	0.03	0.17	0.18	1.9	1.3
20		0.23					0.02	~	0.03	0.03	0.02	0.11	0.12	1.3	0.7
21		0.13						~	0.02	0.02	0.02	0.05	0.08	0.8	0.5
22		0.06							0.01	0.01	0.01	0.04			
23		0.02								0.01	0.01	0.02			
24		0.01									0.00	0.00			
total	45.0	36.00	100	2.01	2.00	4.80	8.00		4.80	3.19	1.59		9.54	99.4	100

The obtained distributed graph can be used directly in runoff calculation for another rainfall event through the same manner as column 5. However, the obtained hydrograph is expressed by histogram because the distributed graph was obtained using averaged discharged. Therefore, the obtained histogram must be converted to a smooth curve by the inverse concept of getting *Qv* in Table 5.

6.5 Kinematic Wave Method

The flow on a steep slope such as mountain slope or channel may not be affected by the boundary condition at downstream, whereas the flow on a mild slope such as alluvial channel is affected by the both boundary conditions of upstream and downstream. The former flow is usually called as kinematic wave and the latter is called dynamic wave.

In this section, the kinematic wave method that is applicable to runoff calculation of head water is presented after the text book by Kadoya[6].

6.5.1 Basic Equation

for flow on slope
$$h = kq^p \tag{7}$$

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r \tag{8}$$

for channel flow
$$W = KQ^P \tag{9}$$

$$\frac{\partial W}{\partial t} + \frac{\partial Q}{\partial x} = I \tag{10}$$

Where:
- t : time
- x : distance
- h : depth of flow on slope
- q : discharge per unit width of slope
- r : effective rainfall intensity
- W : cross sectional area of channel flow
- Q : discharge in channel
- I : lateral inflow intensity per unit length of channel
- k, p, K, P : numerical constants

Equations (7), (9) are the continuity equations and Equations (8), (10) are the equations of motion based on the assumption of uniform flow. The numerical constants k, p in Equation (7) can be expressed by the following equations for several types of flow.

Laminar flow   : $k = (3v / gs)^p$, $p = 1/3$ (11)

Manning   : $k = (N / \sqrt{s})^p$, $p = 3/5$ (12)

Chezy : $k = (C\sqrt{s})^{-p}$, $p = 2/3$ (13)

Darcy : $k = (k_I s / \lambda)^{-p}$, $p = 1$ (14)

Where: ν : kinetic viscosity

g : gravity acceleration

s : inclination of slope

N : Manning's roughness coefficient

C : Chezy's coefficient

k_I : permeability coefficient

λ : effective porosity of soil

Equations (11), (12), (13) are used for overland flow and Equation (14) is used for interflow. For overland flow, Equation (12) is usually used.

6.5.2 Equivalent Form of Basic Equation

Equation (7),(8) can be transformed to the next form.

$$p \times k \times q^{p-1} \frac{dq}{dt} + \frac{dq}{dx} = r \qquad (15)$$

Generally, the partial differential equation (16) is equivalent to simultaneous ordinary differential equations by the theory of Characteristic curve.

Partial differential equation : $A\frac{\partial q}{\partial x} + B\frac{\partial q}{\partial t} = C$ (16)

Simultaneous ordinary equations : $\dfrac{dx}{A} = \dfrac{dt}{B} = \dfrac{dq}{C}$ (17)

Using the upper relation, Equations (15) is rewritten in the next simultaneous ordinary equations.

$$\frac{dx}{1} = \frac{dt}{dh/dq}(\equiv \frac{dt}{pkq^{p-1}}) = \frac{dq}{r} \qquad (18)$$

If $r \neq 0$, Equation (18) is equivalent to the next equations.

$$\frac{dx}{dt} = \frac{q^{1-p}}{p^k} \qquad (19)$$

$$rdt = pkq^{p-1}dq \qquad (20)$$

$$rdx = dq \qquad (21)$$

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If $r = 0$ and q is constant then only equation (19) exists.

For channel flow, the following equations are also obtained.

$$\frac{dx}{dt} = \frac{Q^{1-P}}{PK} \tag{22}$$

$$Idt = PKQ^{P-1}dQ \tag{23}$$

$$Idx = dQ \tag{24}$$

6.5.3 Practical Application
6.5.3.1 Basin Model

In the application of the method, the basin must be expressed as rectangular blocks as show in Fig.4.
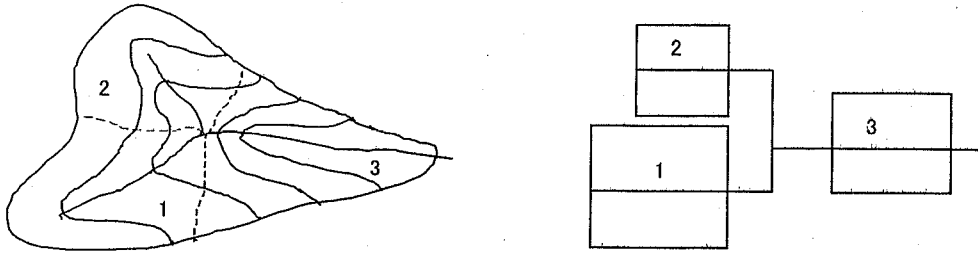
Fig.4   Basin model

6.5.3.2   Flow on Slope

If the effective rainfall intensity r_j is $r_j \neq 0$, we get the next equations by the integration of Equations (20), (21), under the assumption that r_j is constant during the j-th step of time.

$$r_j \Delta t = k(q_j{}^P - q_{j-1}{}^P) \equiv h_j - h_{j-1} \tag{25}$$

$$r_j x_j = q_j - q_{j-1} \tag{26}$$

or,

$$q_j = (q_{j-1}{}^P + \frac{r_j \Delta t}{k})^{1/p} \equiv (\frac{h_j}{k})^{1/p} \tag{27}$$

$$h_j = h_{j-1} + r_j \Delta t \tag{28}$$

$$x_j = \frac{q_j - q_{j-1}}{r_j} \quad , \qquad X_j = X_{j-1} + x_j \tag{29}$$

Where, Δt is time increment, $q_j, h_j, q_{j-1}, h_{j-1}$ and $x_j, X_j, x_{j-1}, X_{j-1}$ are defined as shown in Fig.5. x is the propagation distance during Δt and X is the total distance from the top of slope.
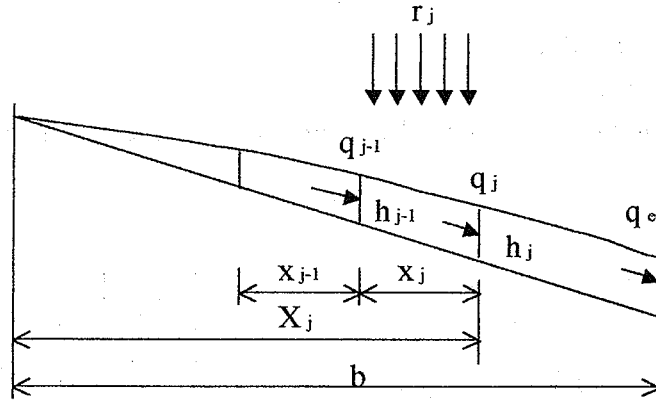
Fig.5 Routine of calculation on slope

If the effective rainfall $r = 0$, q is maintained constant, therefore, we get equations(30) and (31) from Equation (19).

$$q_j = q_{j-1} \tag{30}$$

$$x_j = \frac{q_j^{1-p}}{pk} \Delta t \quad , \qquad X_j = X_{j-1} + x_j \tag{31}$$

The flow which started from the top of slope in time T_0, soon reaches the downstream in time T_j after j steps of time. However, the total distance X_j at time T_j usually does not coincide with the slope length b, because the calculation is done in finite time increment Δt. Therefore, the following case usually arises.

$$X_{j-1} < b \quad \text{and} \quad X_j > b$$

Then, we set x_e as

$$x_e = b - X_{j-1} \tag{32}$$

and we obtain the following equations.

If $r_j \neq 0$, from Equations (25) and (26) we obtain.

$$q_e = q_{j-1} + r_j x_e \qquad (33)$$

$$\Delta t_e = \frac{k}{r_j}(q_e{}^p - q_{j-1}{}^p) \qquad (34)$$

If $r_j = 0$, from Equations (30) and (31) we obtain.

$$q_e = q_{j-1} \qquad (35)$$

$$\Delta t_e = \frac{pk}{q_e{}^{1-p}} x_e \qquad (36)$$

where, q_e is the discharge at the end of slope.

Moreover we can obtain the time T_e when the characteristics curve started at T_0 arrives at the end of slope, from equation (37).

$$T_e = T_0 + (j-1)\Delta t + \Delta t_e \qquad (37)$$

6.5.3.3 Discharge During Initial Period
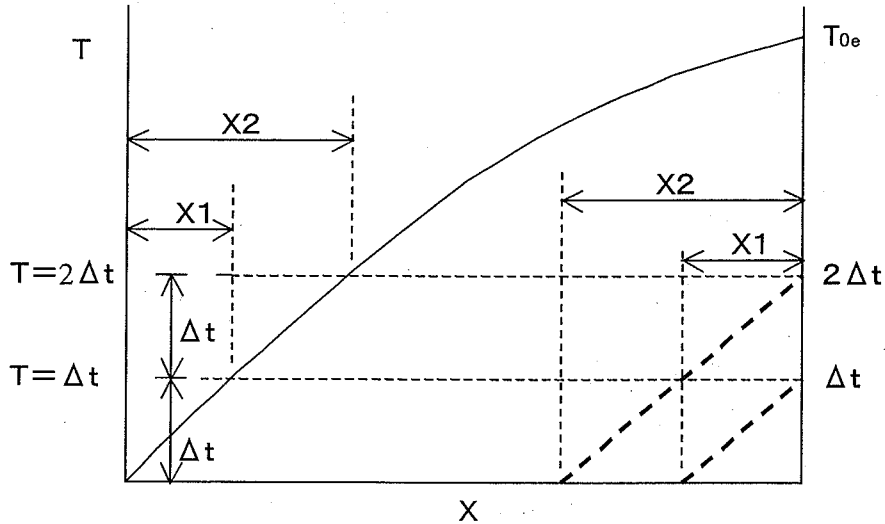
Fig.6   Discharge during initial period

If we start the calculation from $T=0$, that is the begging of effective rainfall, the first characteristics curve from the top of slope will reach the end of slope at time T_{0e}. This means that we can get the first value of discharge from a slope at T_{0e} and we get no value for the period between $T=0$ and T_{0e}. The values during this initial period are

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obtained in the same way described above, if we assume that the slope is shorter. Nevertheless, there is a more simple method by using the results of the first characteristics curve.

Let's consider the X-T plane (X is distance from the top of slope and T is time) as shown in Fig.6. The first characteristics curve may be drawn as continuous line as shown in Fig.6. We can get the discharges at the end of slope at the time $T = \Delta t$ and $T = 2\Delta t$ using the values of the first characteristics curve at $T = \Delta t$ and $T = 2\Delta t$.

6.5.3.4 Discharge After Rainfall

Setting the time when rainfall stops as Ts, the characteristics curve which starts at time Ts-Δt becomes the final characteristics curve. Let Te be the time when the curve reaches at the end of slope, usually, we set $q = 0$ at time $T = Te + \Delta t$.

6.5.3.5 Channel Flow

The procedure of the calculation for the channel flow is same as for the flow on slope. Only the symbols used should be changed as follows.

$$k \rightarrow K, \quad p \rightarrow P, \quad r \rightarrow I, \quad q \rightarrow Q, \quad h \rightarrow W$$

However, two additional cautions have to be taken under consideration.

Rearrangement of lateral inflow
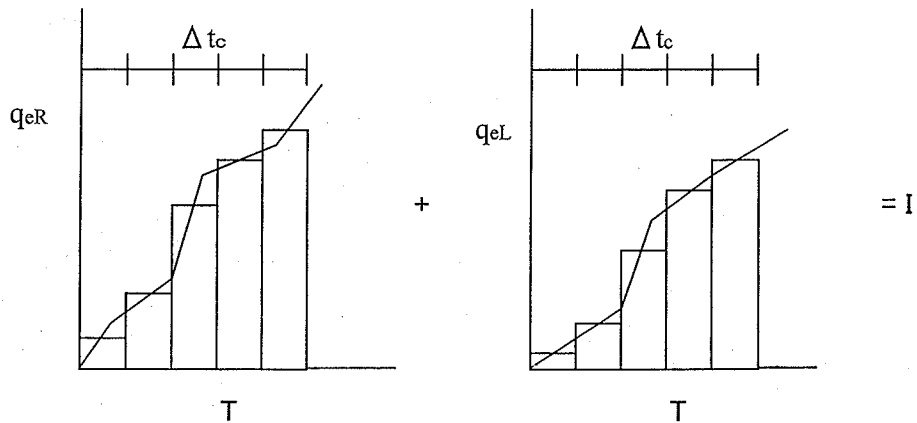
Fig.7   Rearrangement of q_{eR}, q_{eL}

The discharge at the end of right slope is set as q_{eR} and at the end of the left slope as q_{eL}. Therefore, the lateral inflow to channel I is expressed as $I= q_{eR} + q_{eL}$. However, the times when the characteristics curve of right slope and left slope reach the end of the slope, generally do not coincide each other because of difference of slope length. Moreover, the arrival time usually does not coincide with the interval time Δt.

Therefore, the discharge from slope, q_{eR} and q_{eL} must be rearranged using histogram as shown in Fig.7. In Fig.7, Δt_c means the time step of calculation for channel flow. Usually Δt_c is shorter than Δt for slope flow, because the propagation time of flow in channel is usually shorter compared to slope flow.

Crossing of characteristics curve

In a channel that has inflow from upper channel, the crossing of characteristics curve might occur by abrupt increase of inflow, as shown in Fig.8. Mathematically this means breaking wave, therefore there should be no meaning to continue the calculation. However, in the runoff analysis, we usually delete the fore characteristics curve and continue the calculation using the hind characteristics curve.
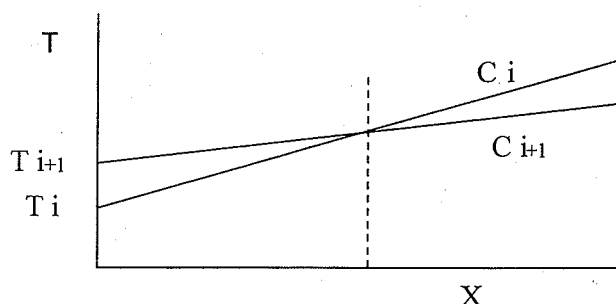
Fig.8   Crossing of characteristics curve

6.5.4   Model Constants

For slope, we use $p = 3/5$, which corresponds to the flow of Manning Type. According to the basin, k varies $k = (N/\sqrt{s})^p$. The standard values of N are listed in Table 7.

Table 7

Land category	$N(\text{sec/m}^{1/3})$
mountain slope	1.0 ~ 2.0
hill slope	0.6 ~ 1.2
grass pasture, golf course, farm	0.3 ~ 0.5
urban district	0.01 ~ 0.04
paddy field	2 ~ 3

For channel, if we know the shape of channel cross section, inclination and the Manning's roughness coefficient of the channel, we can draw the W-Q curve (W : cross sectional area, Q : discharge) on log-log paper. From this figure, we can estimate P, the inclination of the W-Q curve.

$$P = \frac{\log(W_2/W_1)}{\log(Q_2/Q_1)}$$

Using the value of P, calculated from the above equation, we can also obtain the value of K.

6.5.5 Example

Basin   The objective basin is shown in Fig.4. The area of sub-basin, length and inclination of slope, length and inclination of channel are given in Table 8.

Model constants

For slope   : p=3/5,   N=1.0 (sec/m$^{1/3}$)

For channel   : P=0.7,   N=0.1 (for block 1), 0.06(for block 2), 0.035(for block 3)

k, K are calculated based on Equation (12) and also shown in Table 8.

Table 8   The basin characteristics

block	left or right	area (km2)	slope			channel			
			length(m)	inclination	k	length(m)	inclination	K	P
1	left	0.200	400	0.20	1.6207	500	0.0200	1.44	0.7
	right	0.325	650	0.20	1.6207				
2	left	0.120	400	0.20	1.6207	300	0.0125	1.20	0.7
	right	0.075	250	0.20	1.6207				
3	left	0.135	180	0.10	1.9953	750	0.0050	0.85	0.7
	right	0.225	300	0.16	1.7330				

Effective rainfall

Table 9   Effective rainfall

T	r(mm/hr)	T	r(mm/hr)	T	r(mm/hr)
0-1	1.6	4-5	18.7	8-9	15.5
2	5.2	6	17.9	10	7.4
3	0.0	7	31.0	11	1.0

Calculation of slope

We set Δt=3600sec.

[block 2, right slope]

T=0-1 : j=1

$$q_{j-1} = 0, \quad q_j = (r_j \Delta t / k)^{1/p} = \left(\frac{1.6 \times (1/3.6) \times 10^{-6} \times 3600}{1.6207} \right)^{5/3} = 0.9788 \times 10^{-5} \quad (m^2/sec)$$

$$x_{j-1} = 0, \quad x_j = (q_j / r_j) = \left(\frac{0.9788 \times 10^{-5}}{1.6 \times (1/3.6) \times 10^{-6}} \right) = 22.02 \ (m) = X_1$$

T=1-2 : j=2

$$q_j = \left(\frac{(1.6+5.2)\times 10^{-3}}{1.6207}\right)^{5/3} = 10.915\times 10^{-5} \quad (m^2/sec)$$

$$x_j = \frac{(10.915-0.9788)\times 10^{-5}}{5.2\times(1/3.6)\times 10^{-6}} = 68.79 \quad (m)$$

$$X_2 = 22.02+68.79 = 90.81 \quad (m)$$

$T=2\text{-}3: \quad j=3$

In this duration $r_j=0$, so, we use Equations (30),(31).

$$q_j = q_{j-1} = 10.915\times 10^{-5} \quad (m^2/sec)$$

$$x_j = (q_j/pk)^{1-p}\Delta t = \{10.915\times 10^{-5}/(0.6\times 1.6207)\}^{0.4}\times 3600 = 96.31 \quad (m)$$

$$X_3 = X_2+x_j = 90.81+96.31 = 187.12 \quad (m)$$

$T=3\text{-}4: \quad j=4$

$$q_j = (q_{j-1}{}^p + \frac{r_j\Delta t}{k})^{1/p} = \{(10.915\times 10^{-5})^{0.6}+\frac{8.8\times 10^{-3}}{1.6207}\}^{5/3} = 43.555\times 10^{-5} \quad (m^2/sec)$$

$$x_4 = (43.555-10.915)\times 10^{-5}/\{8.8\times(1/3.6)\times 10^{-6}\} = 133.53 \quad (m)$$

$$X_4 = X_3+x_4 = 187.12+133.53 = 320.65 \quad (m)$$

The total distance from the top of the slope becomes $X_4 > 250\ m$, then, we set,

$$x_e = b-X_3 = 250-187.12 = 62.88 \quad (m)$$

and use Equations (33),(34).

$$q_e = q_{j-1}+r_j x_e = 10.915\times 10^{-5}+8.8\times(1/3.6)\times 10^{-6}\times 62.88 = 26.286\times 10^{-5} \quad (m^2/sec)$$

$$\Delta t_e = \frac{k}{r_j}(q_e{}^p - q_{j-1}{}^p) = \frac{1.6207\times(26.286^{0.6}-10.915^{0.6})\times 10^{-3}}{8.8\times(1/3.6)\times 10^{-6}} = 1932 \quad (sec)$$

This means that the first characteristics curve reaches the end of the slope at time $3^{hr}32^{min}12^{sec}$, and the discharge is q_{eR}=26.3 $\times 10^{-5}$ (m^2/sec).

For the period from $T=0$ to the time when the first characteristics curve reaches the end of slope, we get the discharge using the results of the first characteristics curve as

explained before.

$$T=1 \quad : \quad q=0.979 \times 10^{-5} \quad (m^2/sec)$$
$$T=2 \quad : \quad q=10.91 \times 10^{-5}$$
$$T=3 \quad : \quad q=10.91 \times 10^{-5}$$

Calculation of channel

We set $\Delta t_c = 15min$.

[channel of block 3]

We rearrange q_{eR}, q_{eL} and inflow from upper channel Q_{in}. The new values are shown in Table 10.

Table 10 Calculation of channel (block 3)

time	discharge from slope			inflow	Discharge at downstream Q	
	qeR (10^{-5}m^2/s)	qeL (10^{-5}m^2/s)	total I (10^{-5}m^2/s)	Qin (10^{-3}m^3/s)	time	Q (m^3/s)
0:00-0:15	0.043	0.034	0.078	0.029	1:02:49	0.007
-0:30	0.181	0.143	0.324	0.334	1:03:28	0.008
-0:45	0.409	0.323	0.732	1.647	1:07:19	0.013
-1:00	0.709	0.560	1.269	5.213	1:14:09	0.021
-1:15	1.617	1.270	2.896	14.34	1:22:27	0.045
-1:30	3.366	2.661	6.027	35.68	1:32:36	0.086
-1:45	5.614	4.438	10.052	71.37	1:44:34	0.147
-2:00	6.569	8.309	14.878	117.0	1:57:41	0.229

$T=0:00 - 0:15 \quad : \quad j=1$

$$Q_{j-1} = 0.029 \times 10^{-3}, \qquad Q_{j-1}^{P} = (0.029 \times 10^{-3})^{0.7} = 0.666 \times 10^{-3}$$

$$Q_j = \left(Q_{j-1}^{P} + \frac{I \Delta t_c}{K} \right)^{1/P} = (0.666 \times 10^{-3} + \frac{0.078 \times 900}{0.85} \times 10^{-5})^{1/0.7} = 0.0917 \times 10^{-3} \quad (m^3/s)$$

$$x_j = \frac{Q_j - Q_{j-1}}{I} = \frac{0.0917 - 0.029}{0.078 \times 10^{-5}} \times 10^{-3} = 80.4 \, (m) = X_1$$

$T=0:15 - 0:30 \quad : \quad j=2$

$$Q_j = \{(0.0917 \times 10^{-3})^{0.7} + (0.324 \times 900) \times 10^{-5} / 0.85\}^{1.4286} = 0.5047 \times 10^{-3} \quad (m^3/sec)$$

$$x_j = \{(0.5047 - 0.0917) \times 10^{-3} / 0.324 \times 10^{-5}\} = 127.5 \quad (m)$$

$$X_2 = X_1 + x_j = 80.4 + 127.5 = 207.9 \quad (m)$$

at $T=0:45 - 1:00$, $Q_4 = 5.473 \times 10^{-3}$ (m^3/sec) and $X_4 = 687.8$ (m),

so, for duration $T=1:00 - 1:15$, we use Equations (32),(33) and (34).

$$x_e = L - X_4 = 750 - 687.8 = 62.2 \, (m)$$

$$Q_c = Q_{j-1} + Ix_e = 5.473 \times 10^{-3} + 2.896 \times 62.2 \times 10^{-5} = 7.274 \times 10^{-3} \quad \text{(m}^3\text{/sec)}$$

$$\Delta t_c = \frac{K}{I}(Q_e^{\ P} - Q_{j-1}^{\ P}) = \frac{0.85}{2.896 \times 10^{-5}}\{(7.273 \times 10^{-3})^{0.7} - (5.473 \times 10^{-3})^{0.7}\} = 169 \quad \text{(sec)}$$

This means that, at $T=1^{hr}2^{min}49^{sec}$, the discharge at the outlet of the basin is $Q=7.3 \times 10^{-3}$ (m³/sec). These results are also shown in Table 10.

Comment on practical application

The method that was introduced suits for calculation of overland flow that is usually observed in urban area. However, for mountainous basin, this method should be combined with the interflow. In the combined model, the interflow is calculated at first using Equation (14), and then we calculate the depth of interflow. If the depth of interflow becomes larger than the thickness of sub-surface stratum, then overland flow appears at that point. From that point, the same process explained above is applied, and discharge from a slope is obtained as the sum of interflow and overland flow.

6.6 Storage Function Method

6.6.1 Basic Equation

Usually, the relation between the outflow Q and the storage S in a basin at the same time T shows a two-valued function as shown in Fig.9. However, if we introduce lag time l between outflow and storage, then storage-outflow relation approaches an one-valued function as shown in Fig.10. Therefore, in the storage function method, the outflow Q at time T is defined in the next form using the storage S_l at time T_l. T_l means l hours before time T, namely, $T_l = T - l$.[7]
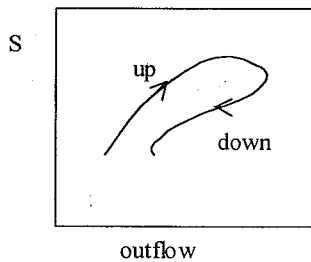
Fig.9 Two-valued function   Fig.10 One-valued function
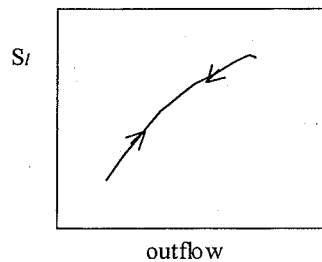
$$S_l = KQ^P \tag{38}$$

$$\frac{dS_l}{dt} = I - Q, \qquad S_l = \int_0^{T-T_l} I\, dt \quad - \quad \int_0^T Q\, dt \tag{39}$$

In Equations (38), (39), K and P are numerical constants and I is inflow intensity.

When the storage S_l and the discharge Q are calculated in the unit of *mm* or *mm/hr*, we can use effective rainfall intensity r_e *(mm/hr)* directly as inflow I. However, if S_l is in m^3 and Q is in m^3/sec, then we have to use the expression below as inflow I.

$$I = \frac{1}{3.6} r_e A \qquad\qquad (40)$$

where, A is basin area in km^2.

The physical meaning of T_l is simply explained as shown in Fig.11.
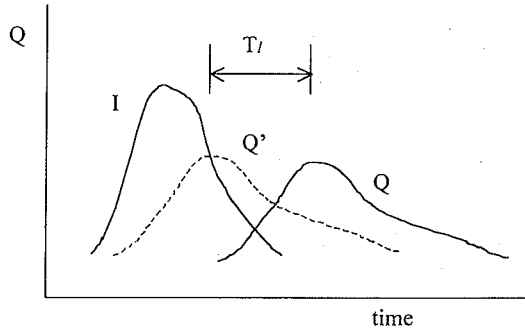
Fig.11　Meaning of the T_l

Using the condition of peak discharge, $dQ/dt=0$, we can get $I(T-T_l)=Q\ (T)$ from Equation (39). We can use this relation for estimating T_l.

6.6.2 Calculations of the Basic Equation

We can get the solution of the Equations (38), (39) by numerical analysis. Substituting Equation (38) into differential form of Equation (39), we get equation (41).

$$\frac{dQ}{dt} = \frac{1}{KP}(I - Q)Q^{1-P} \qquad\qquad (41)$$

For differential equations like Equation (41), we usually use Runge-Kutta method to obtain the solution. By the Runge-Kutta method, we obtain the $Q(T+\Delta t)$ knowing the $Q(T)$ as follows.

i) $\theta_0 = Q(T)$　　　　　　　　vi) $y_2 = \frac{1}{KP}(I - \theta_2)\theta_2^{1-P}$

ii) $y_0 = \frac{1}{KP}(I - \theta_0)\theta_0^{1-P}$　　　vii) $\theta_3 = \theta_0 + y_2 \Delta t$

iii) $\theta_1 = \theta_0 + y_0(\Delta t / 2)$　　　viii) $y_3 = \frac{1}{KP}(I - \theta_3)\theta_3^{1-P}$

iv) $y_1 = \frac{1}{KP}(I - \theta_1)\theta_1^{1-P}$　　ix) $\theta_4 = \theta_0 + \frac{\Delta t}{6}\{y_0 + 2(y_1 + y_2) + y_3\}$

v) $\theta_2 = \theta_0 + y_1(\Delta t / 2)$　　　x) $Q(T + \Delta t) = \theta_4$

6.6.3 Practical Application

In case of large basin, the basin must be divided into sub-basins, of size between 100-300km². After the division, each sub-basin is connected by a channel block for which the same type storage equation mentioned before are applied.

The synthesized parameters for mountainous regions of Japan are given as follows.

For basin block : $T_l=0$ $(L \leqq 11.9km)$

$T_l=0.047L-0.56$ $(L>11.9km)$

where, L is channel length of sub-basin, and T_l is time in *hrs*.

$K=40.3$, $P=0.3$ *(mm-hr unit)*

For channel block : $T_l=(7.36 \times 10^{-4})LI^{0.5}$

where, L(km) is channel length, I is inclination and T_l is time in hrs.

K, P are estimated by the storage-discharge relation based on the assumption of uniform flow using Manning's N.

These synthesized values of parameters should be used as the first assumption.

6.7 Tank Model[8]

6.7.1   Basic Equation

Using the notations in Fig.12, the outflow, the storage and the infiltration of a basin are calculated as follows.

$$q_n = \begin{cases} 0 & (X_n \leq h_1) \\ \alpha_1(X_n - h_1) & (h_1 \leq X_n \leq h_2) \\ \alpha_2(X_n - h_2) + \alpha_1(X_n - h_1) & (h_2 \leq X_n) \end{cases} \quad (42)$$

$$i_n = \beta X_n$$

$$X_n' = X_n - q_n - i_n$$

$$X_{n+1} = X_n' + x_{n+1}$$

Where: q_n : runoff rate from side hole at time n

i_n : infiltration rate at time n

X_n : height of storage water at the beginning of time n

X_n' : the height of storage water at the end of time n

X_{n+1} : the height of storage water at the beginning of time $n+1$

h_1, h_2 the height of the side holes

x_{n+1} : observed rainfall intensity at time $n+1$

$\alpha_1, \alpha_2, \beta$: numerical constants

The main advantage of the tank model is that it does not require the calculation of the effective rainfall. We can use observed rainfall intensity directly as input to this

model. Another advantage is that this model can be used in both flood and long term runoff calculation.

Usually, the model composed of two or three tanks is used for flood runoff calculation and for long term runoff calculation, three or four tanks are used.
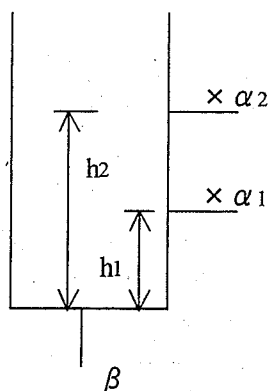
Fig.12 Definition of symbol   Fig.13 Example for calculation
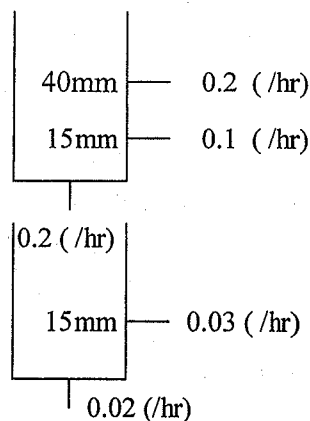
6.7.2 Example of Calculation[8)]

Using the model shown in Fig.13, the runoff calculation is carried out as shown in Table 11.

Table 11   Example of calculation

First Tank					Second Tank				
rainfall	balance	height	outflow	infiltration	balance	height	outflow	infitration	total runoff
r	X_{n-1}'	X_n	q_1	I	X_{n-1}'	X_n	q_2	I	$q = q_1+q_2$
mm/hr	mm	mm	mm/hr	mm/hr	mm	mm	mm/hr	mm/hr	mm/hr
8.0	0.0	8.0	0.0	1.6	0.00	1.6	0.00	0.03	0.00
3.5	6.4	9.9	0.0	2.0	1.57	3.6	0.00	0.07	0.00
0.1	8.0	8.1	0.0	1.6	3.53	5.1	0.00	0.10	0.00
21.7	6.4	28.1	1.3	5.6	5.00	10.6	0.00	0.21	1.30
27.8	21.1	48.9	5.2	9.8	10.39	20.2	0.16	0.40	5.36
15.6	34.0	49.6	5.5	10.0	19.64	29.6	0.44	0.59	5.94
43.2	34.5	77.7	13.9	15.6	28.57	44.2	0.88	0.88	14.78
5.2	48.5	53.7	6.7	10.8	42.44	53.2	1.15	1.06	7.85
0.1	36.5	36.6	2.2	7.4	50.99	58.4	1.30	1.17	3.50
0.0	27.4	27.4	1.2	5.4	55.93	61.3	1.39	1.23	2.59
0.0	20.4	20.4	0.5	4.0	58.69	62.7	1.43	1.25	1.93
0.0	15.5	15.5	0.1	3.2	60.02	63.2	1.45	1.26	1.55
0.0	12.7	12.7	0.0	2.6	60.49	63.1	1.44	1.26	1.44
0.0	10.4	10.4	0.0	2.0	60.40	62.4	1.42	1.25	1.42
0.0	8.0	8.0	0.0	1.6	59.73	61.3	1.39	1.23	1.39

6.7.3 Example of Tank Model[8)]
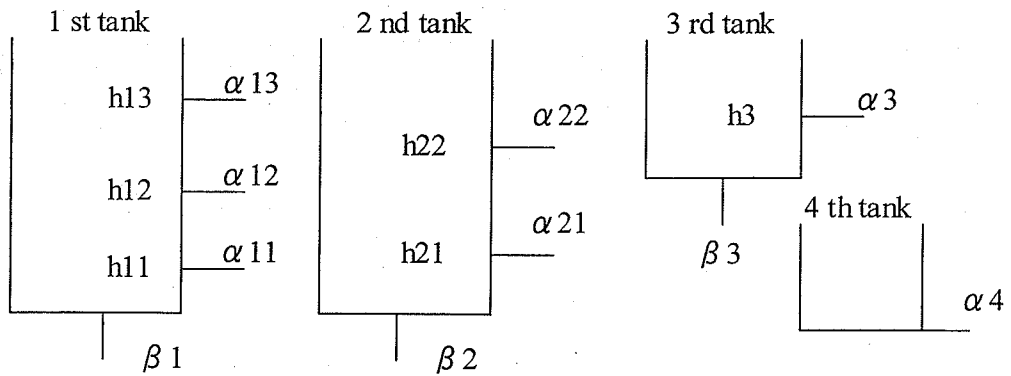
Fig.14　Definition of the symbols in the Table 12, 13

Table 12 Examples of Tank Model for flood calculation

basin	R.Ishikari	R.Arakawa	R.Agano	R.tenryu	R.Yodo	R.Kumano	R.Kumano	R.Niyodo	R.Kuma
site	Ino	Iwafune	Okutadami	Sakuma	nabari	Kazaya	Ikehara	Ino	Setoishi
area(km^2)	3,140	766	134	3,827	462	660	353	1,456	1,629
h13(mm)	30	50	65	90			130		95
h12(mm)	20	20	15	50		50	70	80	55
h11(mm)	0	5	5	15	0	15	10	20	15
$\alpha 13(hr^{-1})$	0.03	0.08	0.06	0.08			0.5		0.1
$\alpha 12(hr^{-1})$	0.03	0.04	0.02	0.04		0.15	0.06	0.15	0.04
$\alpha 11(hr^{-1})$	0.01	0.04	0.02	0.04	$0.0023X^2$	0.15	0.06	0.1	0.02
$\beta 1(hr^{-1})$	0.03	0.05	0.08	0.07	0.12	0.15	0.12	0.15	0.04
h22(mm)								35	
h21(mm)	15	5	15	15	15	15	15	15	20
$\alpha 22(hr^{-1})$								0.02	
$\alpha 21(hr^{-1})$	0.01	0.02	0.01	0.01	0.04	0.06	0.06	0.03	0.05
$\beta 2(hr^{-1})$	0.005	0.015	0.005	0.02	0.06	0.04	0.04	0.05	0.03
h3(mm)		15	15	15	10	10	10	10	10
$\alpha 3(hr^{-1})$		0.004	0.002	0.002	0.01	0.018	0.012	0.015	0.01
$\beta 3(hr^{-1})$		0.004	0.002	0.002	0.02	0.012	0.008	0.015	0.01

Table 13 Examples of Tank Model for long-term runoff calculation

basin	R.Ishikari	R.Ishikari	R.Kitakami	R.Youro	R.Sakawa	R.Mogami	R.Nagara	R.Kurobe	R.Oota
site	ishikari	Ino	Ishibuchi	Yasu	Tanoiri	Kamigou	Ueda	Keyakidaira	R.Yoshiwa
area(km^2)	294	3,379	154	213	157	1,690	713	313	76
h13(mm)			60		100	45			
h12(mm)	30	30	20	25	50	15	35	30	30
h11(mm)	5	5	0	5	15	0	5	5	10
α13(day^{-1})			0.4		0.3	0.25			
α12(day^{-1})	0.1	0.2	0.2	0.3	0.18	0.1	0.3	0.2	0.2
α11(day^{-1})	0.03	0.05	0.1	0.1	0.12	0.05	0.1	0.1	0.2
β1(day^{-1})	0.12	0.3	0.2	0.35	0.3	0.12	0.2	0.35	0.2
h22(mm)					70				
h21(mm)	10	10	10	5	30	5	10	20	10
α22(day^{-1})					0.06				
α21(day^{-1})	0.04	0.05	0.05	0.02	0.03	0.05	0.04	0.08	0.04
β2(day^{-1})	0.1	0.1	0.08	0.08	0.04	0.1	0.1	0.08	0.04
h3(mm)	30	10	0	50	30	20	30	150	10
α3(day^{-1})	0.02	0.015	0.02	0.004	0.015	0.01	0.02	0.01	0.01
β3(day^{-1})	0.02	0.015	0.03	0.016	0.012	0.01	0.04	0.01	0.01
α4(day^{-1})	0.002	0.002	0.0015	0.0003	0.002	0.001	0.0012	0.003	0.001

6.8 TOPMODEL

The TOPMODEL (a TOPography based hydrological MODEL) is a physically based variable contributing area model of basin hydrology. The following section is quoted from the paper of Beven[9].

[One of the features of recent progress in hydrological modeling has been the more widespread availability of digital terrain models and the integration of hydrological modeling with geographical information systems. TOPMODEL provides one of the few easy to use model structures that can make use of digital terrain(DTM) data. As such, it has been used in a wide variety of applications. TOPMODEL is not a single model structure that will be of general applicability, but more a set of conceptual tools that can be used to simulate hydrological processes in a relatively simple way, particularly the dynamics of surface or subsurface contributing areas.

The simplicity of the model comes from the use of the topographical index, $k=a/tan$ β, first introduced by Kirkby and Weyman, where a is the area draining through a point from upslope and $tan\,\beta$ is the local slope angle. This index, or the later soil-topographical index $a/T_0 tan\,\beta$ introduced by Beven, is used as an index of hydrological similarity. All points with the same value of the index are assumed to respond in a hydrologically similar way. Thus it is not necessary to make calculation for all the points in a catchment area, only for different values of the index, spanning the distribution function for a catchment. High index values will tend to saturate first and will therefore indicate potential subsurface or surface contributing area. The expansion

and contraction of such areas as the catchment wets and dries is then indicated by the pattern of the index. (omission in the middle point)

The TOPMODEL has two major advantages : simplicity and the possibility of visualizing the prediction of the model in a spatial context. Both are important. The simplicity of the model code allows the model structure to be changed to reflect the modeller's perceptions of the hydrological response of a particular system. (omission in the middle point) Rapid visualization of the spatial predictions is also important since obvious deficiencies of the model may become apparent, even though discharge may be simulated to an acceptable level of accuracy. Although it may be difficult to assess the accuracy of the spatial predictions in a quantitative way, it may be possible to reject some competing model formulations.]

Many modified TOPMODEL are proposed because of its simplicity. Here, block type TOPMODEL[10] is simply explained.
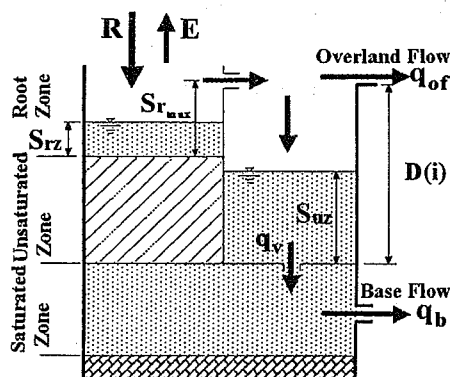
Fig.15 Structure of TOPMODEL[10]

At first, the landform of the objective basin is analyzed in grid size of 1km mesh using the GLOBE(Global Land One-km Base Elevation Data) data set. Next, the basin is divided in some blocks in order to consider the heterogeneity of the large basin. In the following, each block is shown in k and each grid-cell in a block is shown in i.

(a) the averaged saturation deficit $S(k,t)$ over the block k

$$S(k,t)=S(k,t-1)+Q_b(k,t-1)-Q_v(k,t-1)$$

Where, t is time step, $Q_v(k,t)$ is the replenishment to the groundwater and $Q_b(k,t)$ is the total outflow of groundwater.

(b) the saturation deficit $D(i,t)$ in a grid-cell

$$D(i,t) = \{S(k,t) + m(k)(\gamma(k) - \gamma(k,i))\}^+ \tag{43}$$

γ is called *soil-topographical index* defined as Equation (44) and $\gamma(k)$ is averaged value over k block and $\gamma(k,i)$ is the value of i-th grid-cell in the k block.

$$\gamma(i) = ln(a_i/(T_0 tan \beta_i)) \tag{44}$$

where, T_0 (m^2/h) is the saturated transmissivity of soil, m (m) is the decay factor of

T_0, a (m) is area per unit contour line and $\tan \beta$ is inclination of grid-cell. The symbol of $\{ \}^+$ in Equation (43) means that if the value inside the parenthesis becomes negative, then it is set to 0.

(c) evapo-transpiration

$$E(i,t) = min \ [E_p(i,t), \ S_{rz}(i,t-1) + R(i,t) + S_{uz}(i,t-1)] \qquad (45)$$

where, E_p is potential evapo-transpiration, $S_{rz}(i,t)$ is the storage in the root zone and $S_{uz}(i,t)$ is the storage in the unsaturated zone.

(d) the storage $S_{rz}(i,t)$ in the root zone of i-th grid-cell

$$S_{rz}(i,t) = \{ S_{rz}(i,t-1) + R(i,t) - E(i,t) \}^+ \qquad (46)$$

(e) the storage $S_{uz}(i,t)$ in the unsaturated zone of i-th grid-cell

$$S_{uz}(i,t) = \{ S_{uz}(i,t-1) + \{ S_{rz}(i,t) - S_{rmax}(k,t) \}^+ - q_v(i,t) \}^+ \qquad (47)$$

hereupon, $\quad S_{uz}(i,t-1) = \{ S_{uz}(i,t-1) - \{ E_p(i,t) - S_{rz}(i,t-1) - R(i,t) \}^+ \}^+$

where, $q_v(i,t)$ is the replenishment to the groundwater given by the next equation.

$$q_v(i,t) = min \ [K_0(k)exp(-D(i,t)/m(k))tan \beta,$$
$$S_{uz}(i,t-1) + \{ S_{rz}(i,t) - S_{rmax}(k,t) \}^+] \qquad (48)$$

where, K_0 (m/h) is the saturated infiltration coefficient and S_{rmax} (m) is the maximum capacity of root zone storage.

(f) the surface runoff $q_{of}(i,t)$ from a grid-cell

$$q_{of}(i,t) = \{ S_{uz}(i,t) - D(i,t) \}^+ \qquad (49)$$

(g) the groundwater runoff $q_b(i,t)$ from a grid-cell

$$q_b(i,t) = T_0 \ exp(-D(i,t)/m(k)) \ tan \beta_i \qquad (50)$$

(h) flood routing in a channel

Muskingum-Cunge (M-C) method is used. The shape of the pseudo river channel is assumed to be rectangular and the cross section width is given as a function of the area of the grid cell. Also Manning's roughness coefficient is given as a function of the river channel gradient and n_0 that is Manning's roughness coefficient at the outlet of the basin.

In this BTOPMC model, only five parameters need to be calibrated, i.e., T_0 (=K_0), m, S_{rmax}, n_0 and $S_b(0)$ that is the initial saturation deficit of soil.

6.9 Xinanjiang Model

The Xinanjiang Model is a rainfall-runoff, distributed, basin model for use in humid and semi-humid regions. The following explanations are quoted from the paper of Zhao[11].

[The evapotranspiration component is represented by a model of three soil layers. Runoff production occurs on repletion of storage to capacity values which are assumed to be distributed throughout the basin. Prior to 1980, runoff was separated into surface and groundwater components using Horton's concept of infiltration. Subsequently, the

concept of hillslope hydrology was introduced with an additional component, interflow, being identified. Runoff concentration to the outflow of each sub-basin is represented by a unit hydrograph or by a lag and route technique. The damping or routing effects of the channel system connecting the sub-basin are represented by Muskingum routing. There are fifteen parameters in all, of which the model is particularly sensitive to six.
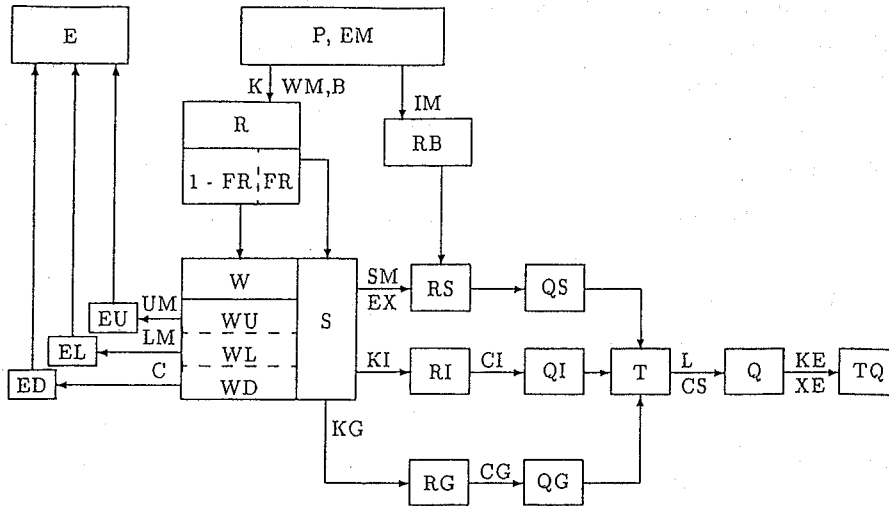
Fig.16　Flow chart for the Xinanjiang model[11)]

The flow chart is shown in Fig.16. The inputs to the model are P, the measured areal mean rainfall depth on the sub-basin and EM, the measured pan evaporation in the same units. The symbols for inputs, outputs and state variables appear inside the blocks of Fig.16 ; those for parameters (constants on each sub-basin) appear outside the corresponding blocks.

The outputs are the discharge, Q, from each sub-basin, TQ, the outlet discharge from the whole basin, E, the actual evapotranspiration from the whole basin, which is the sum of the evapotranspirations from the upper soil layer EU, the lower soil layer EL, and the deepest layer ED.

The state variables are : W' tension water stored at a point in the basin; $W'M$ the corresponding capacity value at a point, varies throughout the sub-basin from zero to a maximum value MM (a parameter); W areal mean tension water storage having components WU, WL, and WD in upper, lower and deepest layer; the capacity value of W is WM (a parameter), equal to the sum of UM, LM and DM, the capacities of the three layers; S' free water storage at a point, having a capacity value of $S'M$, S areal mean free water storage; AU the ordinate of the point x in Fig.17, representing the tension water storage state in the sub-basin; BU the ordinate of the point x in Fig.18, representing the free water storage state; R runoff from the previous area having

components *RS*, *RI* and *RG*, surface, interflow and groundwater runoff, respectively; *RB* runoff from the impervious area *IM*; *Q* the discharge from a sub-basin having components *QS*, *QI*, *QG*, surface runoff, interflow and groundwater, respectively; *FR* the (variable) runoff producing area; *T* the total sub-basin inflow to the channel network, having components *TS*, *TI* and *TG*.

The parameters are: *K* the ratio of potential evapotranspiration to pan evaporation; *MM* the maximum value within the sub-basin of the tension water capacity *W'M* (related through *B* to *WM*); *WM* the areal mean tension water capacity having components *UM,LM* and *DM* the capacities of the three soil layers; *C* a factor, less than unity, by which any remaining potential evaporation is multiplied in application to the deepest soil layer; *B* a parameter in the distribution of tension water capacity; *IM* the impervious area of the sub-basin; *SM* areal mean free water storage capacity; *MS* maximum free water storage capacity (related through *Ex* to *SM*); *Ex* a parameter in the distribution of free water storage capacity; *KI* a coefficient relating *RI*, a contribution to interflow storage; *KG* a coefficient relating *RG*, a contribution to groundwater storage; *CI* the interflow reservoir constant of the sub-basin; *CG* the groundwater reservoir constant of the sub-basin; *L* the "lag" parameter of the flow concentration within the sub-basin; *CS* the "route" parameter of the flow concentration within the sub-basin.

Evapotranspiration

Until the storage *WU* of the uppermost layer is exhausted, evaporation occurs at the potential rate, equal to *K* times the pan evaporation rate.

$$EU = K \times EM \tag{51}$$

On exhaustion of the upper layer (capacity *UM*) any remaining potential evapotranspiration is applied to the lower layer, but the efficiency is modified by multiplication by the ratio of the actual storage *WL* to the capacity storage *LM* of that layer.

$$EL = (K \times EM - EU) \times WL / LM \tag{52}$$

When the lower layer storage *WL* is reduced to a proportion *C* (a parameter) of *LM*, evapotranspiration is assumed to continue, but at a further reduced rate *ED* given by

$$ED = C \times (K \times EM - EU) - EL \tag{53}$$

Runoff production

Runoff production at a point, occurs only on repletion of tension water storage at that point. To provide for a non-uniform distribution of tension water capacity throughout the sub-basin, a tension water capacity curve (Fig.17) is introduced.

In Fig.17, *f/F* represents the proportion of the pervious area of the basin whose tension water capacity is less than or equal to the value of the ordinate W'M. The tension water capacity at a point, (W'M) varies from zero to a maximum MM (a parameter) according to the relationship
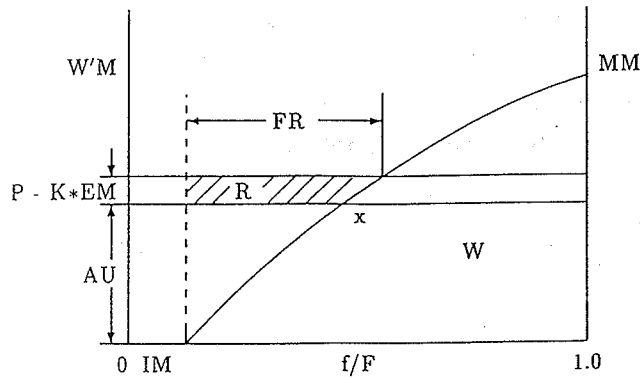
Fig. 17 The distribution of tension water capacity in the sub-basin

$$(1-f/F) = (1-W'M/MM)^B \qquad (54)$$

where, B is a parameter.

The areal mean tension water capacity, WM, constitutes an alternative parameter to the maximum value MM. These are related through the parameter B. From eqn.(54), by integration, it is easy to show that

$$MM = WM(1+B)/(1-IM) \qquad (55)$$

The state of the catchment, at any time, is assumed to be represented by a point x on the curved line of Fig.17. The area to the right and below the point x is proportional to the areal mean tension water storage W (not capacity). This assumption implies that each point in the sub-basin is either at capacity tension (points to the left of x) or at a constant tension (points to the right of x).

Runoff generation on pervious areas

When rainfall exceeds evaporation, the ordinate of Fig.17 is increased by the excess, x moves upwards along the curve and runoff is generated proportional to the area shown shaded to the left and above the point x in Fig.17.

If $P - K \times EM + AU$ is less than MM, then

$$R = P - K \times EM - WM + W + WM \times [1-(P-K+AU)/MM]^{1+B} \qquad (56)$$

Otherwise

$$R = P - K \times EM - WM + W \qquad (57)$$

On the other hand, when evaporation exceeds rainfall, the three tension moisture storage are reduced as explained in the previous section and the point x moves downwards along the curve of Fig.17 to a level at which the areal mean tension water storage W (the area to the right and below the point x) assumes its appropriate value.

Separation of runoff components

The total runoff R, generated in a wet period in accordance with Fig.17, must be separated into its three components, RS surface runoff, RG the groundwater contribution,

and RI a contribution to interflow. To effect this, the concepts of free water storage S' and free water storage capacity $S'M$ are used. The latter is assumed to be distributed between zero and a point maximum MS in a parabolic manner, over FR, that portion of the sub-basin which is currently producing runoff (Fig.18).
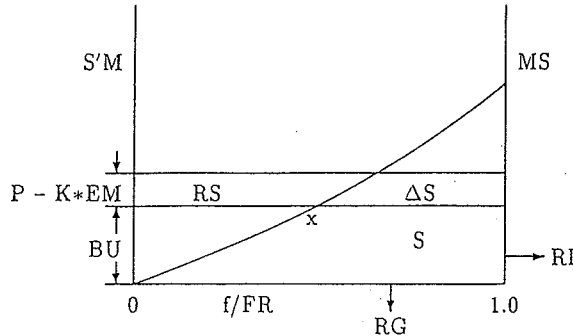
Fig. 18 The separation of runoff components

$$(1 - f / FR) = (1 - S'M / MS)^{Ex} \qquad (58)$$

where f is that portion of the sub-basin area for which the free water storage capacity is less than or equal to $S'M$ and Ex is a parameter.

It is also assumed that the current state of free water storage in the sub-basin can be represented by a point (ordinate BU on the parabola of Fig.18) implying that the portion of the sub-basin to the left of that point is at capacity storage and to the right the storage is constant, below capacity level.

The areal mean free water storage capacity SM may be used instead of MS as a parameter

$$MS = SM (1 + Ex) \qquad (59)$$

By integration of $S'M$ in eqn.(58) and substitution of SM for MS from eqn.(59), the equivalent free water storage S over the runoff producing area FR, can be found to be

$$1 - S / SM = (1 - BU / MS)^{1 + Ex} \qquad (60)$$

The total runoff R, generated in accordance with Fig.17, and expressed as the depth $P - K \times EM$ over the runoff producing area of the sub-basin, is applied by adding $P - K \times EM$ to BU in Fig.18, yielding a contribution RS to surface runoff.

Algebraically, if $BU + P - K \times EM < MS$ then

$$RS = (P - K \times EM - SM + S + SM \times$$
$$[1 - (P - K \times EM + BU) / MS]^{1 + Ex}) \times FR \qquad (61)$$

Otherwise,

$$RS = (P - K \times EM + S - SM) \times FR \qquad (62)$$

The remainder of R becomes an addition, ΔS, to the free water storage S, which in turn contributes RI laterally to inflow and RG vertically to groundwater, according to

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the relations

$$RI = S \times KI \times FR \qquad\qquad (63)$$

$$RG = S \times KG \times FR \qquad\qquad (64)$$

Where KI and KG are parameters.

The surface runoff RS passes unmodified to the channel system as TS. The interflow RI and groundwater RG are routed through linear reservoirs representing interflow and groundwater storage respectively. Outflows TI and TG from these reservoirs, are determined by

$$TI(t) = TI(t\text{-}1) \times CI + RI(t) \times (1\text{-}CI) \qquad\qquad (65)$$

$$TG(t) = TG(t\text{-}1) \times CG + RG(t) \times (1\text{-}CI) \qquad\qquad (66)$$

TI and TG are added to TS to become the total sub-basin inflow T to the channel network.

Flow concentration

Within each sub-basin, this is represented by the convolution of T with an empirical unit hydrograph or by "lag and route" with parameter L and CS, to produce Q, the sub-basin outflow. Flood routing from the sub-basin outlets to the total basin outlet is achieved by applying the Muskingum method to successive sub-reaches (parameters KE and XE of Fig.16).

The parameters

The 15 parameters may be grouped as follows :

(1) Evapotranspiration parameters $\underline{K}$, UM, LM, C

(2) Runoff production parameters WM, B, IM

(3) Parameters of runoff separation $\underline{SM}$, EX, $\underline{KG}$, $\underline{KI}$

(4) Runoff concentration parameters $\underline{CG}$, $\underline{CS}$, CI, $\underline{L}$

Generally, the output is more sensitive to the underlined parameters. K is the ratio of potential evaporation to pan evaporation. SM may be approximately $10\ mm$, increasing to $50\ mm$ for thick and porous surface soils. As the recession duration of upper interflow storage ordinarily lies between 2 and 3 days, we may take $KG+KI=0.7-0.8$. CG usually takes a value between 0.99 and 0.998. CS, the recession constant in the "lag and route" method for routing through the channel system within each sub-basin, is purely empirical. L is the corresponding "lag", also of empirical values.]

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Sediment Transport and River Management
Tetsuro Tsujimoto

7.1 Introduction

Civilization has been supported by urbanization, but human activity with high density brings various type of environmental problem. And we recently have reached the concept of "sustainability", and harmonization between reclamation for human-activities with safety against disasters and conservation of nature has been recognized as an aim of land management. In such land management, the concept of watershed is most important. In the statement for environment management, "think globally, act locally", the watershed is the most adequate spatial scale for "local". Watershed management is most efficient for environment management. The word "river-basin" is often used instead of "watershed". In hydrology, or in the concept of run-off process, the word "watershed" is employed, while when the word, "river-basin" is used, we consider a river systems as a backbone of river-basin and human-activity on the basin area is considered as well as run-off process.

Not only water but also sediment are collected into a river from the watershed, and transported in a river system to sea. Other chemical and organic materials are also transported from the watershed to sea along the river. Water is a medium to transport various materials. The flow is non-uniform and unsteady. Thus, the flux of materials is spatially and temporally variable, and various situations appear along the river.

Sediment is usually produced in mountain area (sediment yield), and it is transported in a river system. Within a river, river bed and bank are sometimes eroded, and sediment is also supplied there. According to non-uniform transport of sediment due to spatially and temporally varied water flow, river morphology changes through fluvial processes. Previously, large amount of sediment yield in mountain area promotes active sediment transport in a river system and often brings about aggradation of a river bed. From a viewpoint of long time scale, it grew alluvial fans and deltas those provide a base of human activity. Fluvial morphology is unstable in general, and we constructed flood levee along the river to obtain a stable base with progressing human activity. River bed aggradation threatens the safe human-life inside the flood levees, and thus sabo-works (erosion control works) have been continued in mountain areas to reduce the sediment supply to a river system as well as to prevent disasters due to land slides and debris flows.

Along a river, many and various structures are constructed for various purposes to support human activities, and they disturb sediment flow. For example, dam stocks sediment in a reservoir, and it reduces capacity of the reservoir for water resources and/or flood-control. In addition, the decrease of sediment supply to the downstream reach of a dam causes river-bed degradation and/or armoring. In Japan, gravel mining and dredging for river improvement are also major causes of river-bed degradation, and it often causes beach erosion in coastal areas. Furthermore, riverine landscape degradation including eco-system degradation in rivers with bed-degradation has recently been focused.

According to the above-mentioned recognition, integrated sediment control along river system or in a river basin is intensively desired. In this text, necessary fundamentals for integrated sediment control are explained.

7.2 Sediment Yield
7.2.1 Sediment yield

Sediment yield is caused by rainfall and flows, winds, earthquakes, volcano action and so on, in the manners of collapse, land slide, and various types of erosion. And sediment is provided into streams and rivers to be transported. The type of transportation is classified into debris flow, bed load and suspended.

According to the data of reservoir sedimentation (Ashida & Okumura, 1974), the annual mean specific sediment production ($m^3/km^2/year$), q_{sp}, is expressed as

$$q_{sp} = KA^{-0.7} \qquad (7.2.1)$$

where A=area of watershed (km^2), K=constant depending on the areas of watersheds. For example, K is around 10^6 in the Chubu area with the highest sediment-productivity (e.g. the Kurobe river, the Tenryu river); and around 10^3 in the Chugoku area with poor sediment production in Japan.

Considering that sediment yield is caused by collapse, amount of sediment production by heavy rainfall is expressed as a product of the spatial ratio of collapsed area, the area of the watershed, and the mean thickness of collapsed layer. The spatial ratio of collapse increases with the total rainfall. On the other hand, the collapse criteria might be given in a diagram composed of the rainfall intensity and the accumulated rainfall.

7.2.2 Debris flow

Collapsed materials and bed materials in a valley may be fluidized as debris flow. Debris flow is characterized as sediment motion dispersed along the depth to the free surface. Takahashi (1980) obtained the minimum bed slope over which materials can move dispersed even to the free surface, θ_{c1}, and the maximum bed slope over which clear water layer cannot appear above the debris layer, θ_{c2}, as follows:

$$\tan\theta_{c1} = \frac{(\sigma/\rho - 1)c_*}{(\sigma/\rho - 1)c_* + 2.4}\tan\phi_r$$
$$\tan\theta_{c2} = \frac{(\sigma/\rho - 1)c_*}{(\sigma/\rho - 1)c_* + 1}\tan\phi_r \qquad (7.2.2)$$

where ρ=mass density of fluid (g/cm^3); σ=mass density of sand (g/cm^3); ϕ_r=friction angle of debris materials; and c_*=volumetric concentration of stationary debris layer. The bed slope θ is within $\theta_{c1}\sim\theta_{c2}$, a debris flow appears.

The thickness of debris flow, H_{df}, is approximately given by the equation of force balance.

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$$\frac{H_{df}}{h} = \frac{\tan\theta}{ac_*(\sigma/\rho-1)(b\tan\phi_r-\tan\theta)} \qquad (7.2.3)$$

where h=flow depth; and ac_*=sediment concentration averaged inside the debris layer. a=0.4 and b=1.0 (Takahashi, 1980); or a=0.5 and b=0.8 (Egashira et al., 1989).

The depth-averaged sediment concentration of debris flow under equilibrium, C_e, is given by Takahashi (1980) as follows:

$$C_e = \frac{\tan\theta}{(\sigma/\rho-1)(\tan\phi_r-\tan\theta)} \qquad (7.2.4)$$

When the debris transport rate is written in a form

$$q_{sd} = C_{df}U \qquad (7.2.5)$$

the debris concentration, C_{df}, and the depth-averaged flow velocity, U, are given as follows (Takahashi, 1980):

$$C_{df} = 6.7C_e^2$$
$$\frac{U}{\sqrt{gh\sin\theta}} = \frac{0.4h}{d} \qquad (7.2.6)$$

Usually, debris flow transports sediment from several valleys into a main stream (a river). On the other words, it is sediment supply for a river. Besides debris flow, erosion and collapse of side bank or hill-tail contribute sediment supply to the river, when the sediment system along a river is focused on.

Debris flow sometimes attacks villages directly. From the viewpoint of disasters, the following characteristics of debris flow should be recognized (see Fig.7.2.1):

(1) At a leading head, coarse materials are aggregated to cause an intensive impact.
(2) Coarser materials concentrate at the surface of a debris flow particularly in the leading head.
(3) A part of debris flow with low concentration and composed of relatively fine materials pursues the leading head.
(4) Several heads intermittently appear.
(5) The leading head has a convex cross section, while, while the continuing part has a concave one.
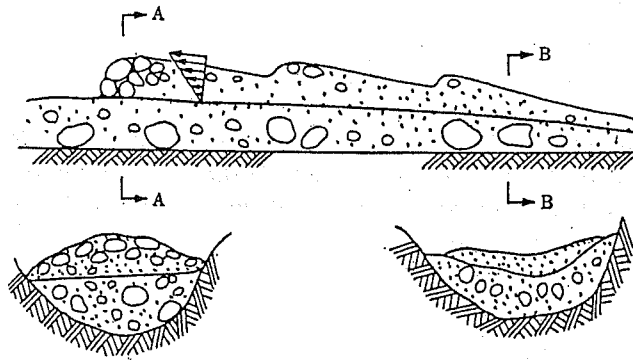
Fig.7.2.1   Geometrical characteristics of debris flow

7.3 Mechanics of Sediment Transport
7.3.1 Classification of sediment transport

Sediment transport is classified into (i) bed-material load; and (ii) wash load.   The former is defined as sediment transport with exchange between moving particles and bed materials, and the flux can be estimated by mechanics of flow and particles. While, wash load component is transported from upstream region and away without exchange with bed material.   Fine material that is never included in the bed is transported without deposition, and in general such fine material becomes wash load. Some amount of wash load deposits in a reservoir but the other passes through dams. Recently, deposition of wash load on a floodplain and near riparian vegetation is focused, because it contains organic materials and promotes growth of riparian vegetation.   It also deposits and aggravates eco-system of gravel-bed rivers during extremely low discharge for example during a period of filling a reservoir.

The bed material load contributes bed deformation, while the wash load is more than the bed-material load as amount.   The flux of bed-material load can be estimated by mechanics of sediment transport, while the flux of wash load depends on hydrological condition of the upstream area.   In general, the amount of wash load is empirically related to water discharge, but the relation has a hysteresis (see **7.3.6**).

On the other hand, the sediment transport is classified into (i) bed-load; and (ii) suspended load, from the type of motion.   The bed-load is transported along the bed with incessant contacts with the bed, while the suspended load is carried without incessant contacts with bed and distributed along the water depth.   The trajectory of bed-load motion is subjected to the time-averaged turbulent flow, while the suspended load is influenced by instantaneous turbulence.   The latter is described by convection-diffusion equation with respect to the sediment concentration.   The total bed-material load transport rate is expressed as a sum of bed-load transport rate and suspended sediment transport rate estimated separately.

7.3.2 Parameters to govern sediment transport

In order to understand the fundamental mechanics of sediment transport, equilibrium sediment transport under uniform flow is considered.   Noncohesive sediment (sand) is assumed.   Then, the factors to govern the phenomenon are as follows:

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g=gravitational acceleration (cm/s^2);
ρ=mass density of fluid (g/cm^3);
ν=kinematic viscosity of fluid (cm^2/s);
d=diameter of sand (cm);
σ=mass density of sand (g/cm^3);
h=water depth (cm); and
u_*=friction velocity (cm/s).

The friction velocity, u_*, is defined as

$$u_* \equiv \sqrt{\frac{\tau_b}{\rho}} \qquad (7.3.1)$$

where τ_b=bed shear stress.   From the above 7 factors, the following 4 dimensionless parameters are deduced (grain-size Reynolds number, Shields parameter (dimensionless bed shear stress), relative depth, and relative density).

$$X \equiv Re_* \equiv \frac{u_* d}{\nu}$$

$$Y \equiv \tau_* \equiv \frac{u_*^2}{(\sigma/\rho - 1)gd}$$

$$Z \equiv \frac{h}{d} \qquad (7.3.2)$$

$$W \equiv \frac{\sigma}{\rho}$$

Among the above 4 parameters, the Shields parameter τ_* is most important, and the grain-size Reynolds number Re_* is secondly important.   Dimensionless forms of various parameters describing fluvial process can be expressed as functions of the above dimensionless parameters.   The similitude in model tests is assured by setting the above dimensionless parameters equal between model and prototype.

7.3.3 Fundamental properties of vertical 2D flow in open channels

Vertical 2D flow in open channels is described as follows: The flow is driven by the gravity, and it produces the following distribution of shear stress.

$$\tau(y) = \rho u_*^2 \left(1 - \frac{y}{h}\right) \qquad (7.5.3)$$

where y=vertical distance from the bed.
When the flow is laminar, the shear stress is subjected to viscosity, τ_L, and the

Newton's law is written as

$$\tau_L = \rho v \frac{du}{dy} \tag{7.3.4}$$

where u=velocity. Then the velocity distribution is deduced as follows:

$$\frac{u}{u_*} = \frac{u_* h}{v} \frac{y}{h}\left(1 - \frac{y}{2h}\right) \tag{7.3.5}$$

where the no-slip condition is imposed at the bed (u=0 at y=0). This flow is called "Hagen-Poiseuille flow."

On the other hand, the shear stress is subjected to the Reynolds stress in the turbulent flow except the region very near the bed (viscous sublayer). In the turbulent flow, the turbulence components (u', v') are correlated each other, and the Reynolds stress, τ_T, is defined as the cross correlation of turbulence as follows:

$$\tau_T = -\rho \overline{u'v'} \tag{7.3.6}$$

What relates the Reynolds stress to the time-averaged velocity gradient, du/dy, is a turbulent model, and two classic models are introduced here. In Boussinesq approximation, the kinematic eddy viscosity v_T is introduced with an analogy to the laminar, and the Reynolds stress is written as

$$\tau_T = \rho v_T \frac{du}{dy} \tag{7.3.7}$$

And, the velocity distribution is deduced as follows where u_B is slip velocity (velocity just above the bed).

$$\frac{u}{u_*} = \frac{u_* h}{v_T} \frac{y}{h}\left(1 - \frac{y}{2h}\right) + \frac{u_B}{u_*} \tag{7.3.8}$$

According to the mixing length theory by Prandtl and Kármán, the Reynolds stress is expressed by introducing the mixing length l as follows:

$$\tau_T = \rho l^2 \left|\frac{du}{dy}\right|\frac{du}{dy} \tag{7.3.9}$$

The mixing length l increases in proportion to the distance from the wall in the boundary layer, but it decreases by approaching the free surface in case of open-channel flow. The vertical variation of the mixing length in open-channel flow is approximated as follows:

$$l = \kappa y \sqrt{1 - \frac{y}{h}} \qquad (7.3.10)$$

where κ=Kármán's constant (=0.4). The velocity distribution is deduced as follows:

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{y}{y_0} + \frac{u_0}{u_*} \qquad (7.3.11)$$

where is imposed the boundary condition that $u=u_0$ at $y=y_0$ near the bed above the viscous sublayer. It is termed a "logarithmic law." When the bed is smooth covered by the viscous sublayer, the scale is measured by the viscous sublayer thickness δ_L, which is proportional to ν/u_*. Thus, y_0 is chosen proportionally to δ_L, and then u_0/u_* must be constant. On the other hand, the bed is completely rough, or the roughness elements protrude to the turbulent flow, roughness height becomes a measure to scale the vertical distance. Thus, y_0 is chosen proportionally to roughness height, and then u_0/u_* must be constant. According to Nikradse's experiment where pipe flows with sand roughness were investigated, the log-law is written as follows:

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{y}{k_s} + B_s(Re_*) \qquad (7.3.12)$$

where k_s=sand roughness ($k_s=d$ for a flat sand bed); and B_s is a function of Re_* as shown in Fig.7.3.1. When Re_* is smaller than 5 approximately, the flow is termed "hydrodynamically smooth turbulent," where the log-law is written as follows:

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{y u_*}{\nu} + 5.5 = \frac{1}{\kappa} \ln \frac{9.0 y u_*}{\nu} \qquad (7.3.13)$$
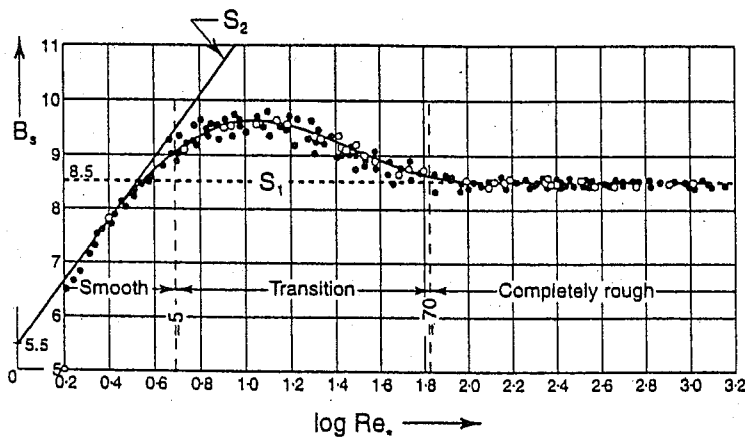
Fig.7.3.1 Relation between Bs and Re* according to Nikuradse's experiments

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Within the viscous sublayer, the viscous effect is dominant and Eq.7.3.5 is employed.

$$\frac{u}{u_*} = \lim_{y/h \to 0} \left\{ \frac{u_* h}{\nu} \frac{y}{h} \left(1 - \frac{y}{2h}\right) \right\} = \frac{u_* y}{\nu} \qquad (7.3.14)$$

As an intersection of curves expressed by Eqs.7.3.13 and 7.3.14, the thickness of the viscous sublayer is known as follows:

$$\frac{\delta_L u_*}{\nu} = 11.6 \qquad (7.3.15)$$

On the other hand, when Re_* is larger than 70 approximately, the flow is termed "completely rough turbulent," where the log-law is written as follows:

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{y}{k_s} + 8.5 = \frac{1}{\kappa} \ln \frac{30.1y}{k_s} \qquad (7.3.16)$$

The log-law is also written as follows in the defect-law expression.

$$\frac{u_s - u}{u_*} = -\frac{1}{\kappa} \ln \frac{y}{h} \qquad (7.3.17)$$

where u_s=maximum velocity=surface velocity.

When the log-law is available, the eddy kinematic viscosity varies vertically in parabolic manner as expressed by

$$\frac{\nu_T}{u_* h} = \kappa \frac{y}{h} \left(1 - \frac{y}{h}\right) \qquad (7.3.18)$$

The depth-averaged value is obtained as follows, and it is often employed in the Boussinesq approximation.

$$\frac{\nu_T}{u_* h} = \frac{\kappa}{6} \qquad (7.3.19)$$

The ratio of the kinematic eddy viscosity to the kinematic viscosity becomes a kind of Reynolds number as shown in the following equation.

$$\frac{\nu_T}{\nu} = \frac{\kappa}{6} \frac{u_* h}{\nu} \qquad (7.3.20)$$

The depth-averaged velocity, U, is obtained by integrating the velocity distribution from the height near the bed to the free surface.

$$\frac{U}{u_*} = \frac{1}{h}\int_{\approx 0}^{h}\frac{u(y)}{u_*}dy \qquad\qquad (7.3.21)$$

U/u_* is a kind of resistance factors, and it can be converted to other parameters, as follows:

$$\frac{U}{u_*} = \frac{C}{\sqrt{g}} = \frac{h^{1/6}}{n\sqrt{g}} = \sqrt{\frac{8}{f}} \qquad\qquad (7.3.22)$$

where C=Chezy's coefficient; n=Manning's coefficient; and f=Darcy-Weisbach's friction coefficient. When the log-law is employed, U/u_* is written as follows:

$$\frac{U}{u_*} = \frac{1}{\kappa}\ln\frac{h}{k_s} + B_s(Re_*) - \frac{1}{\kappa} \qquad\qquad (7.3.23)$$

This is called "Keulegan's equation" for rough turbulent flow, and it is quite similar to Manning-Strickler's equation written below in the range $10<h/d<1000$.

$$\frac{U}{u_*} = 7.66\left(\frac{h}{d}\right)^{1/6} \qquad\qquad (7.3.24)$$

7.3.4 Critical tractive force

The critical condition for sediment motion is the most important parameter for mechanics of sediment transport and fluvial hydraulics. Shields (1936) showed the critical condition for incipient sediment motion is expressed on a diagram composed of the Shields parameter and the grain-size Reynolds number (see Fig.7.3.2). In the following, the subscript c shows the critical condition for incipient motion. Many hydraulic researchers tried to obtain such a relation reasonably. Iwagaki's formula is most available among them (1956).

$$
\begin{aligned}
\tau_{*c} &= 0.05 & (671 \le R_*)\\
\tau_{*c} &= 0.00849\,R_*^{3/11} & (163 \le R_* \le 671)\\
\tau_{*c} &= 0.034 & (54.2 \le R_* \le 163)\\
\tau_{*c} &= 0.195\,R_*^{-7/16} & (2.14 \le R_* \le 54.2)\\
\tau_{*c} &= 0.14 & (R_* \le 2.14)
\end{aligned}
\qquad (7.3.25)
$$

where $R^*=[(\sigma/\rho-1)gd^3]^{1/2}/\nu$. These are available for uniform flow over a flat bed composed of uniform-size sand.
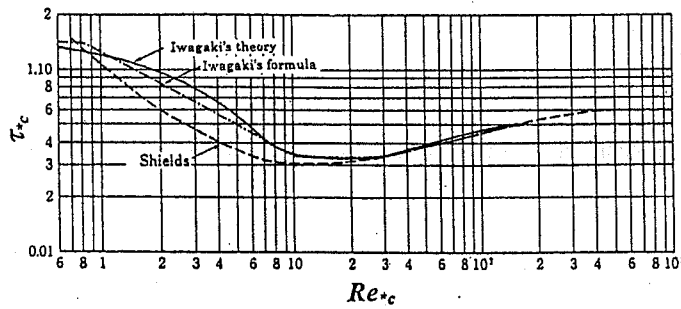
Fig.7.3.2 Shields diagram and Iwagaki's formula for critical tractive force

When the bed is composed of graded materials, the concept of critical tractive force for each grain size is most effective on considering selective sediment transport and sorting process. Ashida-Michiue (1971) modified Egiazaroff's formula (1965) as follows, and it is most available.

$$\frac{\tau_{*ci}}{\tau_{*cm}} = \begin{cases} \left[\dfrac{\ln 19}{\ln(19 d_i / d_m)}\right]^2 & (d_i / d_m \geq 0.4) \\[4mm] 0.85\left(\dfrac{d_m}{d_i}\right) & (d_i / d_m \leq 0.4) \end{cases} \tag{7.3.26}$$

where the subscripts i, m implies the quantities concerned with the i-th fraction and the fraction with mean diameter in the graded materials. τ_{*cm} is often identified with the critical shear stress of uniform-size sand.

The effect of side slope is considered by applying Lane's work (1955):

$$\tau_{*c\theta} = \tau_{*c} \cos\theta_z \sqrt{1 - \frac{\tan^2\theta_z}{\tan^2\phi_r}} \tag{7.3.27}$$

where θ_z=transverse slope of bed; and ϕ_r=angle of repose of sand.

The other effects on the critical tractive force such as cohesion of materials, small submergence, steep slope and so on were additionally investigated.

7.3.5 Bed-load transport

Though a lot of formulae to predict bed-load transport rate were proposed to date, only a few types of models are explained here from the viewpoint of mechanics of bed-load motion. Sediment transport rate is a flux expressed by substantial volume per unit width per unit time.

Kalinske's model and its development

Kalinske (1947) proposed a bed-load transport formula based on a concept that transport rate is given as a product of number density and average speed of moving particles. A lot of works were done to estimate the components and the resultant transport rate. Among them, Ashida-Michiue's formula (1971) is recommended

because it can estimate transport rate with good accuracy as well as the number density and average speed of bed-load particles. Ashida-Michiue's formula is written by

$$q_{B*} \equiv \frac{q_B}{\sqrt{(\sigma/\rho-1)gd^3}} = 17\tau_*^{3/2}\left(1-\frac{\tau_{*c}}{\tau_*}\right)\left(1-\sqrt{\frac{\tau_{*c}}{\tau_*}}\right) \tag{7.3.28}$$

$$n_g d^2 = \frac{1}{A_3\mu_R}\left(\tau_* - \tau_{*c}\right) \tag{7.3.29}$$

$$\frac{u_g}{u_*} = A_d\left(1-\sqrt{\frac{\tau_{*c}}{\tau_*}}\right) \tag{7.3.30}$$

where q_B=bed-load transport rate; n_g, u_g=number density and average speed of bed-load particles; τ_{*c}=dimensionless critical tractive force; A_3=three-dimensional geometric coefficient of a sand; and μ_R=dynamic frictional coefficient of sand.

Recent researches have focused on dynamics of multiple saltating particles with interactions between particles and fluid and among particles (Gotoh *et al.*, 1995).

Einstein's model and its development

Einstein (1937) postulated a model of bed-load motion as a combination of random rest periods and random step lengths (see Fig.7.3.3). In other words, a particle is picked up from a bed at random, and it moves a random and finite distance (step length) instantaneously. The pick up rate, p_s, was defined as the reciprocal of the mean rest period, and it is the probability density for a particle on a bed to be dislodged from a bed per unit time. If the step length is assumed to be constant (Λ), the transport rate equals to the volume of particles picked up from the interval with the distance of the step length, as follows (Einstein, 1942).

$$q_B \equiv \frac{p_s\Lambda}{A_2d^2}A_3d^3 = \frac{A_3}{A_2}p_s\Lambda d \tag{7.3.31}$$

where A_2 =two-dimensional geometric coefficient of a sand. On the other hand, Einstein (1950) deduced the above equation by equating the volume of depositing particles and eroded particles per unit area per unit volume, as follows:

$$\frac{q_B}{\Lambda} = \frac{p_s}{A_2d^2}A_3d^3 \tag{7.3.32}$$
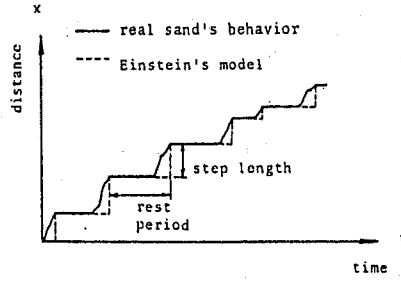
Fig.7.3.3 Einstein's model for bed-load motion

Here, the estimations of the pick up rate and the step length are important to obtain a reasonable transport formula.   Einstein related the pick-up rate to the probability that the instantaneous hydrodynamic force exceeds the critical value for incipient motion; while, the step length was approximated to be 100 times sand diameter (1942). Though Einstein's formula includes an error function and cannot be written in a simple form, the following Swiss formula (Meyer-Peter & Müller, 1949) approximates it well (see Fig.7.3.4).
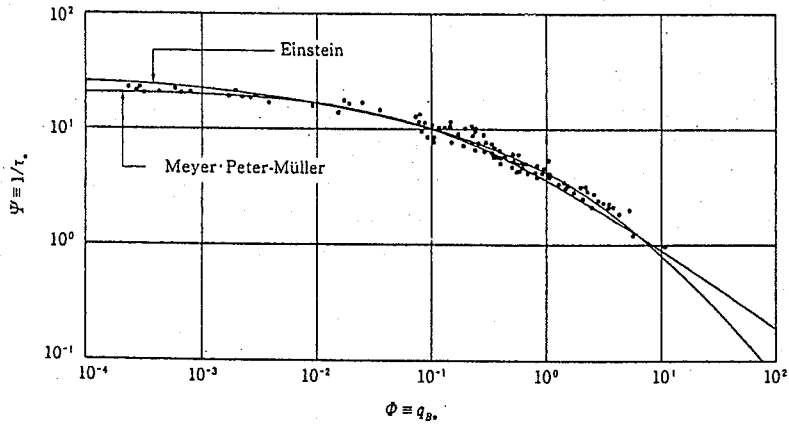
Fig.7.3.4 Einstein's bed-load transport formula and Swiss formula

$$q_{B*} = 8(\tau_* - \tau_{*c})^{3/2} \tag{7.3.33}$$

Nakagawa & Tsujimoto (1980) developed Einstein's idea (1942) to the non-equilibrium condition.   Because the step length is a random variable and p_s varies spatially, local rate of bed-load transport is written as follows in general:

$$q_B(x) = \frac{A_3}{A_2} d \int_0^\infty p_s(x - \xi) \int_\xi^\infty f_X(\varsigma) d\varsigma d\xi \tag{7.3.34}$$

where $f_X(\xi)$=probability density function of step length, the mean of which is Λ.   On a flat bed, step length follows an exponential distribution.   When p_s is constant along x,

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Eq.7.3.34 gives Eq.7.3.31. Eq.7.3.34 can express non-equilibrium property of bed-load motion. Nakagawa & Tsujimoto (1980) proposed the following pick-up rate formula by analyzing the detachment process of a bed particle.

$$p_{s*} \equiv p_s \sqrt{\frac{d}{(\sigma/\rho-1)g}} = 0.03\tau_* \left(1 - \frac{0.7\tau_{*c}}{\tau_*}\right) \qquad (7.3.35)$$

Bagnold's formula

Bagnolds (1965) demonstrated that the bed-load transport must be determined by a balance of work-done of bed-load motion with the power of flow, and proposed the following transport formula.

$$q_B = 4.25\tau_*^{3/2}\left(1 - \frac{\tau_{*c}}{\tau_*}\right) \qquad (7.3.36)$$

The power of τ_*, 3/2, is a typical feature reasonable from the viewpoint of physics.

Empirical formulas

Empirical formulas were proposed, too. If one is working at a specified stream or channel and has sufficient data obtained there, it is a good idea to propose and employ an empirical formula with the following form.

$$q_{B*} = A_B\tau_*^{3/2}\left(1 - \frac{\tau_{*c}}{\tau_*}\right)^m\left(1 - \sqrt{\frac{\tau_{*c}}{\tau_*}}\right)^n \qquad (7.3.37)$$

where A_B, m, n=empirical parameters.

7.3.6 Suspended-load transport

For suspended sediment, the transport rate is expressed as follows.

$$q_S = \int_{\approx 0}^{h} C(y)u(y)dy \qquad (7.3.38)$$

where q_S=suspended sediment transport rate; and $C(y)$=concentration distribution of suspended sediment. Suspended sediment is transported by convection and diffusion. The diffusion coefficient of suspended sediment is simply related with the kinematic eddy viscosity.

$$\varepsilon_s = \beta\nu_T \qquad (7.3.39)$$

where ε_s=turbulent diffusion coefficient of suspended sediment; and β=reciprocal of

turbulent Schmidt number.

Under equilibrium condition for uniform flow, the upward and the downward fluxes of suspended sediment are in balance. The former is caused by the turbulent diffusion, while the latter by settling velocity. Thus,

$$-\varepsilon_s \frac{dC}{dy} = C w_0 \qquad (7.3.40)$$

where w_0=settling velocity of sediment. When the log-law is available for turbulent uniform flow, the kinematic eddy viscosity distributes as expressed by Eq.7.3.18, and then, the following "Rouse distribution" (1937) is deduced:

$$\frac{C}{C_a} = \left(\frac{h-y}{y} \frac{a}{h-a} \right)^{\frac{w_0}{\beta \kappa u_*}} \qquad (7.3.41)$$

where C_a=reference concentration at $y=a$; a=height of reference level from a bed. 5% depth is often employed as a reference level practically. Theoretically, most of researchers consider that a should be the ceiling of the bed-load layer but it is not so definitive. If the depth-averaged value of diffusion coefficient (Eq.7.3.19) is employed, the concentration profile of suspended sediment becomes exponential (Lane & Kalinske, 1941) as follows:

$$\frac{C}{C_a} = \exp\left(-\frac{6w_0}{\beta \kappa u_*} \frac{y-a}{h-a} \right) \qquad (7.3.42)$$

The reference concentration C_a is often identified with bed-load concentration C_B. When the bed-load transport rate q_B, the bed-load layer thickness θ_B (about $2d$) and the speed of the bed-load layer, u_B (about u_g) are known, C_B is given as follows.

$$C_B = \frac{q_B}{u_B \theta_B} \qquad (7.3.43)$$

Tsujimoto (1999) proposed the following empirical formula to evaluate C_a.

$$C_a = 0.002 \left(\frac{u_*}{w_0} \right)^2 \left(1 - \frac{\tau_{*c}}{\tau_*} \right)^{3/2} \qquad (7.3.44)$$

The concentration of suspended sediment changes the turbulent structure and it affects the distributions of velocity and concentration. Hino (1963) proposed the formula to give an apparent change of Kármán constant. Itakura & Kishi (1980) proposed a log-linear distribution instead of the log-law. Tsujimoto et al. (1995) analyzed the change of the wake-strength parameter.

As for the turbulent Schmidt number β, which is often assumed to be constant, Tsujimoto & Nakagawa (1986a) analyzed to deduce the following relation, which is consistent to the empirical regression by Kerssen $et\ al.$ (1979).

$$\beta = 1 + 1.56\left(\frac{w_0}{u_*}\right)^2 \tag{7.3.45}$$

7.3.7 Total-load transport
The total bed-material load transport rate is expressed as a sum of bed-load transport rate and suspended sediment transport rate. Usually bed-load and suspended load are estimated separately, and then they are summed up. Fig.7.3.5 shows the total bed-material-load transport rate and the bed-load transport rate. With the increase of Shields number, suspended load increases and total bed-material-load transport rate increases with 5/2 power of the Shields number, while the bed-load transport rate increases with 3/2 power without suspended sediment.

Total sediment discharge is a sum of bed-material load and wash load. Though wash load transport discharge Q_{ws} (m^3/s) changes with lag to the water discharge Q (m^3/s) during flood, it is roughly related to the discharge as follows (see Fig.7.3.4).

Fig.7.3.5 Total-load transport rate

$$Q_{ws} = A_w Q^{-b} \tag{7.3.46}$$

where A_w=4x10^{-8}~6x10^{-6} and b=2.

7.4 Fluvial Processes
Unbalance of sediment transport causes various fluvial processes. In this section, firstly the generalized framework to describe the processes is explained. Then, several types of fluvial processes are introduced.

7.4.1 Description of fluvial processes
When the fluvial processes are governed by bed-load transport, the governing equation is a continuity equation of sediment.

$$\frac{dy_b}{dt} = -\frac{1}{1-\rho_0}\left(\frac{\partial q_{Bx}}{\partial x} + \frac{\partial q_{Bz}}{\partial z}\right) \tag{7.4.1}$$

where ρ_0=porosity of sand; x, z=longitudinal and lateral coordinates; and q_{Bx}, q_{Bz}=longitudinal and lateral components of bed-load transport rate. When the longitudinal transport is predominant, the lateral components can be neglected (one-dimensional analysis). In general, the bed-load transport rate can be divided into longitudinal and lateral components as follows:

$$q_{Bx} = q_B \cos\phi_B; \quad q_{Bz} = q_B \sin\phi_B \tag{7.4.2}$$

where ϕ_B=deflection angle of direction of sediment motion from x-axis, and it is related to the flow direction γ and the lateral bed slope θ_z as follows (Nakagawa et al., 1986).

$$\tan\phi_B = \tan\gamma - \sqrt{\frac{\tau_{*c}}{\mu_s \mu_R}} \tan\theta_z \tag{7.4.3}$$

where μ_s, μ_R=static and frictional coefficients of sand.

In case of graded materials, bed-load transport rate and direction of bed-load motion should be treated for each fraction, and then, the sorting process can be reasonably analyzed (see **7.4.4**).

When suspended sediment contributes fluvial process, the behavior of suspended sediment is reasonably described by a diffusion-convection equation. If the flow field is analyzed in depth-averaged scheme, the following depth-averaged diffusion-convection equation for suspended sediment is applicable.

$$\frac{\partial}{\partial x}\left(hUC - h\varepsilon_s \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial z}\left(hWC - h\varepsilon_s \frac{\partial C}{\partial z}\right) = S_c \tag{7.4.4}$$

$$S_c = w_0 C_{ae} - \gamma_s w_0 C$$

where W=transverse component of depth-averaged flow; C_{ae}=reference concentration of suspended sediment under equilibrium (for example, it can be evaluated by Eq.7.3.44); and γ_s=ratio of near-bottom concentration to depth-averaged concentration of suspended sediment. γ_s is evaluated as follows if Lane-Kalinske profile (Eq.7.3.42) is assumed.

$$\gamma_s = \frac{6w_0}{\kappa u_*}\left[1 - \exp\left(\frac{6w_0}{\kappa u_*}\right)\right]^{-1} \tag{7.4.5}$$

7.4.2 Micro-scale bedforms

In an alluvial streams, the bed is often covered with micro-scale bedforms (sand waves), and they are contributive to hydraulic resistance and they affect on estimation

of sediment transport rate. The micro-scale bed forms are classified into (i) ripples, (ii) dunes, (iii) antidunes. When the grain-size Reynolds number is smaller than 20, ripples are formed. The average wave length is around 500~1000 times sand diameter, and they have gentle upstream slope. When the Re_* is bigger than 10, dunes or antidunes may be formed. Dunes and/or ripples can be formed under lower regime ($Fr<0.8$), while anti-dunes may be formed under upper regime ($Fr>0.8$), where $Fr=U/(gh)^{1/2}$=Froude number. Bed form and water surface are out-of-phase under lower regime, while in phase under upper regime. The average wavelength of dunes and antidunes is around 5~7 times flow depth. The average wave height reaches 10-20% flow depth. The geometry of a dune is asymmetric and the angle of repose appears in its lee side where the flow separates. On the other hand, an antidune has a symmetric shape without separation.

In Fig.7.4.1, the hydraulic conditions where respective bed forms appear are shown in a plane of q_*I_*~d_* (Nakagawa & Tsujimoto, 1984) In this figure, unit discharge q, bed slope I, gravitational acceleration g, and the properties of water and sand (ρ, ν, d, σ) are considered as known parameters. Then, the following dimensionless parameters are utilized.

$$d_* \equiv \frac{(\sigma/\rho - 1)gd^3}{\nu^2}$$

$$I_* \equiv \frac{I}{(\sigma/\rho - 1)} \qquad (7.4.6)$$

$$q_* \equiv \frac{q}{\sqrt{(\sigma/\rho - 1)gd^3}}$$
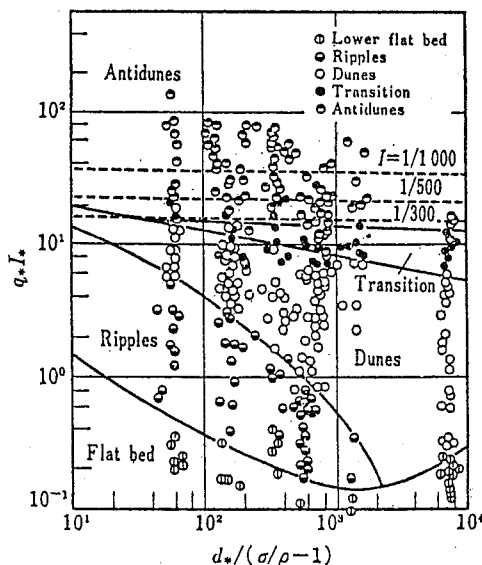
Fig.7.4.1 Conditions for various micro-scale bedforms

In a dune bed, particularly, the flow separation causes appreciable hydraulic

resistance. On the other hand, the shear stress corresponding to the total resistance is never subjective to sediment transport. In other words, the total shear stress τ (=$\rho g h I_e$, I_e=energy slope) is divided into the part concerned with friction (τ_b) and that concerned with form drag (τ_D). The former should be used to estimate bed-load transport rate as the "effective tractive force" τ_e. According to Engelund's method (1967), the following equation is applied in dune regime (see Fig.7.4.2).

$$\tau_{*e} = 0.05 + 0.4\tau_*^2 \qquad\qquad (7.4.7)$$
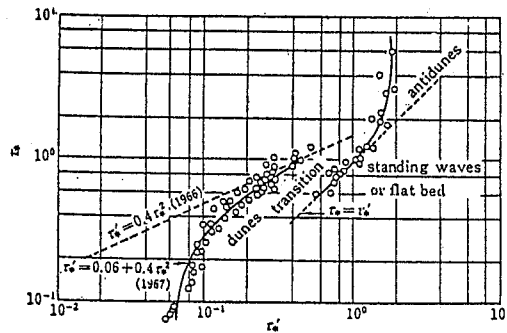
Fig.7.4.2　Effective tractive force (Engelund, 1966)

From a viewpoint of resistance, for example, Chezy's coefficient changes drastically by dunes as shown in Fig.7.4.3 (Nakagawa & Tsujimoto, 1984).

As for the formation mechanism of dunes and antidunes, Kennedy (1963) employed a linear instability analysis, where the lag between bed-load transport and bed geometry is a cause of instability. The lag is composed of a phase shift of bed shear stress to bed geometry, and the lag of bed-load transport to the bed shear stress. Nakagawa & Tsujimoto (1980) quantitatively clarified the lag due to bed-load motion by using non-equilibrium bed-load formula (Eq.7.3.34).
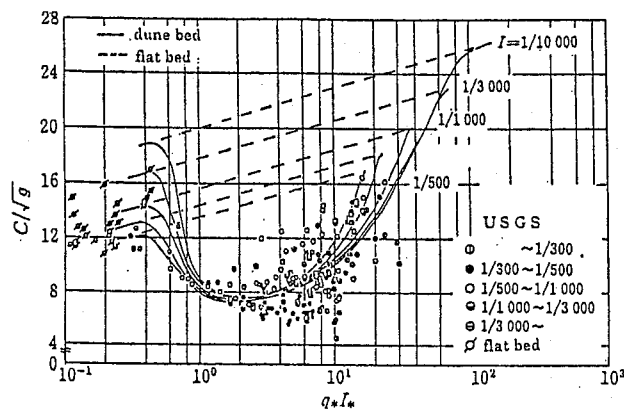
Fig.7.4.3　Change in Chezy coefficient with $q_* I_*$

Bedforms responds to the change of discharge with a lag during flood, thus the size (particularly height) of bed forms and subsequently the water stage draw hysteresis

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curves for the discharge (Allen, 1974, Fredsøe 1979, Nakagawa & Tsujimoto, 1984).

7.4.3 Meso-scale bedforms

Most rivers in Japan are constrained by flood levees and various river-morphology is observed inside the flood levees. These are formed mainly during floods as bedforms. Representative meso-scale bedforms in straight channels are migrating bars. They are classified into (i) alternate bars; and (ii) double-rows bars. A channel with multiple-rows bars are often terms a "braided channel". During low-stage water, riverine areas have combinations of land and water area.

Such meso-scale bedforms are important in riverine management. For example, arrangement of bars determines flow attacking points, migration of bars influences the maintenance of navigation route and intake facilities, and bar area sometimes provide habitat for various organisms.

If the flow has no constrains, meso-scale bed forms cause flow-meandering, and it governs plane patterns of a stream with bank erosion. Most of rivers in Japan has a double-stage cross-section, and the behavior of bars developed in a main channel often causes of erosion of floodplain inside the flood levees.

The conditions for bars formation are shown in Fig.7.4.4, which was obtained by Kuroki & Kishi (1984). In the figure, B=width of channel, which is most important parameters with flow depth. Ikeda (1983) obtained the following empirical mean dimensions of equilibrium bars.

$$L_M = 9B; \quad \frac{H_B}{h} = 0.0442\left(\frac{B}{h}\right)^{1.45}\left(\frac{h}{d}\right)^{-0.45} \tag{7.4.8}$$

where L_M=mean meandering length=twice of bar length; and H_B=mean bar height.
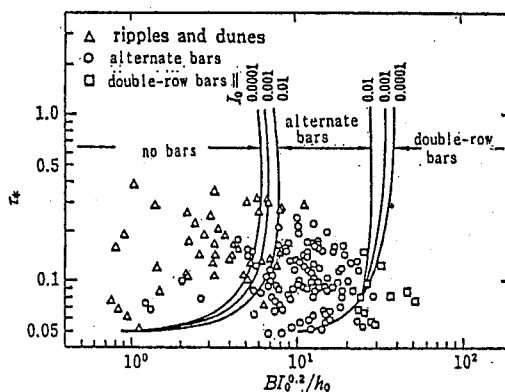
Fig.7.4.4   Conditions for meso-scale bedforms development

The behavior of meso-scale bed forms can be comparatively well described by depth-averaged analysis of flow and bed-deformation. In bed deformation analysis, one has to devise to treat collapse process when the bed slope becomes larger than angle of repose. Particularly it is a key to analyze side-bank erosion. Furthermore, if the flow meandering is appreciable, the streamline is distorted vertically due to three-

dimensional flow behavior. Then, one has to devise to modify the bottom flow direction from the depth-averaged flow behavior by using the knowledge of flow at a river bend.

At a river bend, a secondary flow dominates. According to Ikeda'a analysis (1974), the secondary flow components are evaluated as follows:

$$\frac{u_\theta}{u_*} = f_\theta \left[\frac{U_0}{u_*} + \frac{1}{\kappa}(\ln \eta + 1) \right]$$

$$\frac{u_r}{U_0} = f_\theta^2 \frac{h}{r} \frac{1}{\kappa} \left[F_A(\eta) - \frac{1}{\kappa} \frac{u_*}{U_0} F_B(\eta) \right]$$

$$F_A(\eta) \equiv -15 \left(\eta^2 \ln \eta - \frac{1}{2}\eta^2 + \frac{5}{18} \right)$$

$$F_B(\eta) \equiv \frac{15}{2} \left(\eta^2 \ln^2 \eta - \eta^2 \ln \eta + \frac{1}{2}\eta^2 - \frac{19}{54} \right)$$

(7.4.9)

where u_θ, u_r=tangential and normal components of flow velocity; $\eta=y/h$; U_0=cross-sectionally averaged velocity; $f_\theta=r/r_0$ for rotational flow (completely developed bend flow); $f_\theta=r_0/r$ for irrotational flow (near the entrance of bend); r=radius of bend; and r_0=radius of bend at U_0 appears for depth-averaged velocity.

The above gives the flow direction at the bottom ($\eta=0$). According to Eq.7.4.3, the direction of bed-load motion is a linear combination of flow direction and lateral bed slope (dy_b/dz). For the equilibrium cross-section ($y_b(z)$), bed-load motion has no lateral component. Thus, equilibrium cross section at river bend can be theoretically deduced (Ikeda, 1974).

7.4.4 Sorting

When a bed is composed of graded materials, bed deformation accompanies sorting process. Then, the sediment transport (particularly bed-load transport process) should be treated for each fraction. Fractional bed-load transport rate formula is given by replacing τ_* and τ_{*c} in the transport formula for uniform-size sand into τ_{*i} and τ_{*ci}, respectively, where the subscript i indicates a fraction of sediment with the diameter d_i. τ_{*ci} is estimated by Eq.7.3.26. Then, the bed deformation and the sorting process are described by the following equations (Tsujimoto, 1999a):

$$\frac{\partial y_b}{\partial t} = \frac{1}{\Delta x \Delta z \Delta t} \sum_{i=1}^{N} \Delta q_i$$

(7.4.10)

$$p_i(t+\Delta t) = \frac{p_i(t) \bullet \left\{\theta_e \Delta x \Delta z - \sum_{k=1}^{N} \Delta q_k(t)\right\} + \Delta q_i(t)}{\theta_e \Delta x \Delta z} \quad \left(\frac{\partial y_b}{\partial t} > 0\right)$$

(7.4.11)

$$p_i(t+\Delta t) = \frac{p_i(t) \bullet \theta_e \Delta x \Delta z - p_{i0} \bullet \sum_{k=1}^{N} \Delta q_k(t) + \Delta q_i(t)}{\theta_e \Delta x \Delta z} \quad \left(\frac{\partial y_b}{\partial t} < 0\right)$$

$$\Delta q_i = -\frac{1}{1-\rho_0}\left(\frac{\partial q_{Bix}}{\partial x} + \frac{\partial q_{Biz}}{\partial z}\right)\Delta x \Delta z \Delta t \qquad (7.4.12)$$

where p_i=volumetric ratio of the i-th fraction in the surface layer, p_{i0} =initial value of p_i and equal to that of the substratum; and θ_e=exchange layer. The concept of the exchange layer was introduced by Hirano (1971).

In a river reach downstream of a dam, the sediment supply is appreciably decreased. Then, if a river bed is composed of uniform-size material, a stream changes the bed slope ("rotational degradation", defined by Gessler, 1970) to respond the decrease of sediment supply. On the other hand, the bed is composed of graded materials, the output discharge of sediment is reduced toward new equilibrium by adjusting the surface roughness so that the coarser materials dominate in the surface layer without changing bed slope ("parallel degradation" defined by Gessler, 1970). If the supplied sediment is zero, no sediment transport occurs under new equilibrium, and the bed covered by coarse materials is termed "armor coat". The process is termed "armoring". If the sediment input is still finite and they can be transported, new equilibrium bed is termed "paved bed" or "pavement".

Tsujimoto (1999a) introduced various type of sorting with successful descriptions in the above-mentioned framework besides downstream propagation of armoring and pavement: Diffuse gravel sheet (transverse stripes of sorting), longitudinal stripes of sorting (laterally alternate sorting), and sorting around vegetation. Fig.7.4.5 shows a comparison between flume experiments (Ashida & Michiue, 1971) and calculation (Tsujimoto, 1999a).
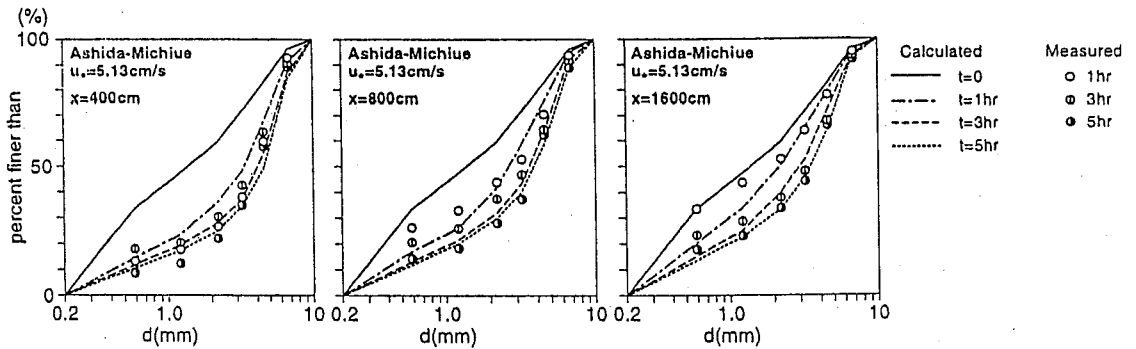
Fig.7.4.5 **Armor-coat formation and propagation**

7.4.5 Local scour

Around a structure in a river, local scour appears and it threatens the function and the safety of the structure. In general, the flow around a structure is three-dimensional and intensively fluctuating, and thus the sediment motion there is too complicated to be expressed by neither usual bed-load nor suspended load.

Roughly speaking, the development of scour hole is expressed as follows:

$$\frac{dV}{dt} = Q_{sout} - Q_{sin} \qquad (7.4.13)$$

where V=volume of scour hole; Q_{sout}, Q_{sin}=sediment transport out from and into scour hole. Local scour occurs when $Q_{sout} > Q_{sin}$. Local scour is classified into (i) clear water scour (C.W.S.) when Q_{sin} is zero; and (ii) scour with continuous sediment motion (S.W.C.S.M.) when Q_{sin} is not zero. As shown in Fig.7.4.6 for scour around a bridge pier (Carstens, 1966), scour depth normalized by pier size, z_s/D, increases with approaching flow velocity in case of clear water scour, but it approaches to constant (around 1.5) with fluctuation in case of scour with continuous sediment motion.

The fluctuation of scour depth is caused by dune migration (Tsujimoto & Nakagawa, 1986b).
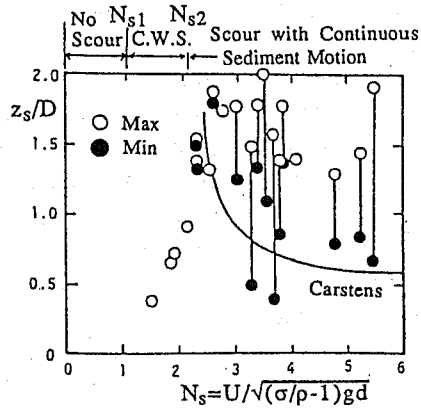
Fig.7.4.6 Scour around bridge pier

A lot of works were done for prediction of scour depth. Among them, the formulas by Laursen & Toch (1956) and Tarapore (1962) give an envelope of the previous data (as shown in Fig.7.4.7) and convenient to use for protection works.

$$\frac{z_s}{D} = K \left(\frac{h}{D} \right)^{0.3} \qquad (7.4.14)$$

where K=1.5 for rectangular-shape pier; and K=1.35 for circular pier.

$$\frac{z_s}{D} = \begin{cases} 1.35 & \left(\dfrac{h}{d} \geq 1.15 \right) \\ 1.17 \left(\dfrac{h}{D} \right) & \left(\dfrac{h}{d} \leq 1.15 \right) \end{cases} \qquad (7.4.15)$$

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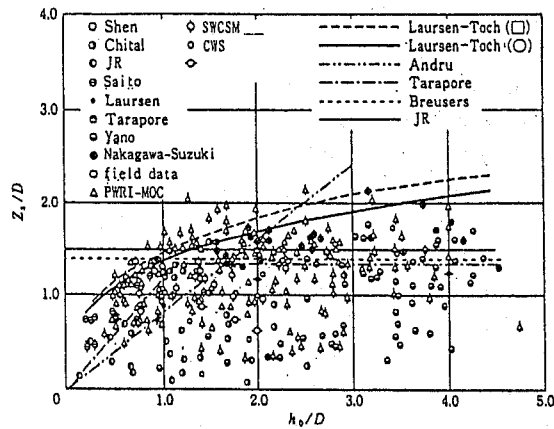
Fig.7.4.7 Scour depth around bridge pier

After Eq.7.4.13 or Fig.7.4.6, the sediment supply from the upstream of the structure should be carefully considered. For example, the sediment supply is stopped or appreciably decreased by dams or erosion control works, local scour may become serious. On the other hand, armor coat formation prevent from progress of scouring. Rip-rap works are effective for protection of piers from scouring.

7.5 River Landscape and Management
7.5.1 New/emerging concepts for river management
In Japan, the river law was revised in 1997, which demonstrates that river management should include environmental aspect as well as flood control and water resources development. The environmental aspect includes ecological viewpoint as well as human amenity and recreation. In order to meet these multiple objectives, functional management by construction of structures is no longer effective, instead, the physical and ecological situations of rivers should adjust to compromise multiple objectives. For this purpose, the concept of "river landscape" is necessary.

On the other hand, the impacts on some local place in a river influence larger scale aspects. Then, we have to recognize the hierarchy of scales as follows: "reach", "segment", "corridor", and "river basin". A reach may be defined as an interval in a river including a pair of characteristic units of bed morphology such as alternate bars, shoot and riffle and so on. A segment includes statistically homogeneous reaches. For example, a reach of fluvial-fan is a kind of segment composed of statistically homogeneous alternate bars. When we focus on the continuity of a river system from upstream mountain area to river mouth (sea), such a concept along a river is often termed a "corridor". Sediment transport problem should be considered along a river. When riverine eco-system is considered, migration of fish is one of important factors. Furthermore, sediment as well as water is collected from the watershed. Materials supporting eco-system may gather into a river from the watershed. Human activity develops on the watershed, or a river basin. Management of river system as well as water and sediment must be integrated and developed on the watershed or the river basin. Views on degraded scales must be upgraded again.

7.5.2 River landscape

The essential of river features is a closely interrelating system among water flow, sediment transport and geomorphology. Sediment transport is governed by the flow behavior and it causes channel and river-bed morphology. The flow is controlled by channel and bed morphology. Fluvial hydraulics provides methodology to describe the such a system. Previously, vegetation was considered simply as resistance factor, and it was like to be removed.

In these days, however, riverine vegetation is recognized as essential factors to play important roles in environmental functions of rivers, and it is often recognized that vegetation plays some hydraulic roles as similar as artificial structures. for flood protection such as groins and revetments. Furthermore, when we coexist with riparian vegetation, we have to consider even the growth of vegetation or its destruction during flood. The vegetation is one of important components of a river system. Hence, a river is characterized as an interrelating system among flow, sediment transport, morphology and vegetation (see Fig.7.5.1). And, such a system must be compromised among functions of flood protection, water resources utilization, human amenity and eco-system preservation. A "river landscape" is defined as a river system with multi-functions. River management must be a kind of landscape management, where river system is adapted to compromise among multiple functions by considering the dynamic characteristics of flow, sediment transport, morphology and vegetation.

Most of interactions shown by arrows in Fig.7.5.1 are described by open-channel hydraulics, mechanics of sediment motion, and fluvial hydraulics. And the followings are newly developed: (i) flow with vegetation; and (ii) growth and destruction process of vegetation (hydraulics of flow with vegetation).
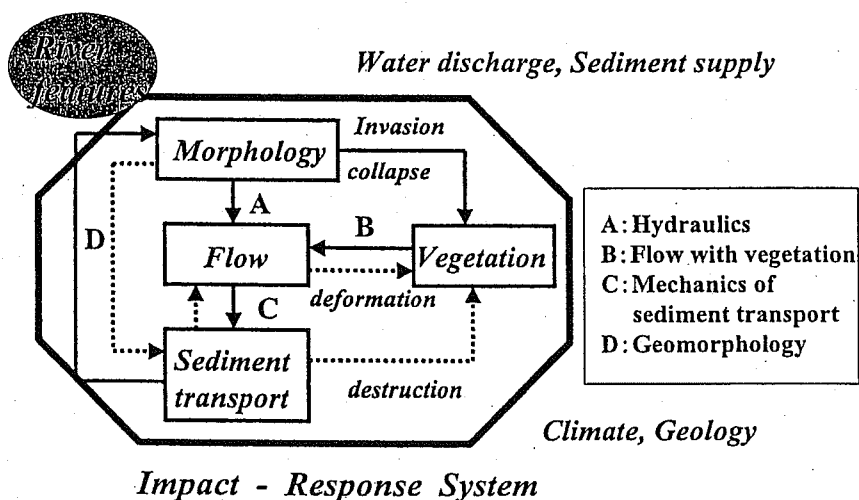

Fig.7.5.1 Interactions characterizing a river system

From the viewpoint of landscape description, respective functions should be evaluated. The functions for flood protection, and water resources utilities might be evaluated by conventional river engineering. To evaluate eco-system soundness is a

new topic. From the physical viewpoint, habitat suitability is focused on (habitat hydraulics).

In addition to description of the present situation of river system or river landscape, it is important to forecast the response of the system to various impacts (natural impacts such as heavy rainfall, morphological change by earthquake, and climate change; and human impacts such as erosion-control works, dam construction, river improvement, gravel mining and so on) from the viewpoint of river management. Various impacts are often represented by the change of sediment supply to the focused reach or segment and/or the time-series change of water-discharge.

7.5.3 Fluvial process in streams with vegetation

From a viewpoint of river-landscape management, description and forecast of fluvial processes in a stream with vegetation are important topics (Tsujimoto, 1999).

Vegetation is a kind of structure with complicated geometry to provide a boundary of flow. Usually, however, it is not necessary to know the local flow behavior around branches and leaves. Hence, the dimension of vegetation is neglected but the drag due to vegetation is taken into account (Shimizu & Tsujimoto, 1994). The drag due to vegetation is written as

$$F = \frac{1}{2}\rho C_D \lambda \mathbf{U}|\mathbf{U}| \qquad (7.5.1)$$

where F=drag due to vegetation per unit volume of water; $\mathbf{U}$=velocity vector; C_D=drag coefficient; and λ=projected area of vegetation elements per unit volume of water. In depth-averaged flow model,

$$\frac{\partial}{\partial x}(hU) + \frac{\partial}{\partial z}(hW) = 0$$

$$\frac{\partial}{\partial x}\left(hU^2 - h\nu_T\frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial z}\left(hWU - h\nu_T\frac{\partial U}{\partial z}\right) = -gh\frac{\partial(h+y_b)}{\partial x}$$

$$+\frac{\partial}{\partial x}\left(h\nu_T\frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial z}\left(h\nu_T\frac{\partial W}{\partial x}\right) - \frac{F_x h}{\rho} - \frac{\tau_{bx}}{\rho} \qquad (7.5.2)$$

$$\frac{\partial}{\partial x}\left(hWU - h\nu_T\frac{\partial W}{\partial x}\right) + \frac{\partial}{\partial z}\left(hW^2 - h\nu_T\frac{\partial W}{\partial z}\right) = -gh\frac{\partial(h+y_b)}{\partial z}$$

$$+\frac{\partial}{\partial x}\left(h\nu_T\frac{\partial U}{\partial z}\right) + \frac{\partial}{\partial z}\left(h\nu_T\frac{\partial W}{\partial z}\right) - \frac{F_z h}{\rho} - \frac{\tau_{bz}}{\rho}$$

$$F_x = \frac{1}{2}\rho C_D \lambda U\sqrt{U^2 + W^2}; \quad F_z = \frac{1}{2}\rho C_D \lambda W\sqrt{U^2 + W^2}$$

$$\tau_{bx} = \rho c_f U\sqrt{U^2 + W^2}; \quad \tau_{bz} = \rho c_f W\sqrt{U^2 + W^2} \qquad (7.5.3)$$

where x, y=longitudinal and lateral coordinates; U, W=longitudinal and lateral

component of depth-averaged flow; F_x, F_y=longitudinal and lateral components of drag due to vegetation per unit volume of water; h=flow depth; y_b=bed level; v_T= depth-averaged kinematic eddy viscosity; τ_{bx}, τ_{bz}=longitudinal and lateral component of bed shear stress; and c_f=coefficient of bed shear stress ($=n^2 g/h^{1/3}$ when Manning's coefficient n is applied (m-s unit)). Shimizu & Tsujimoto (1994) and Tsujimoto (1999) employed a k-ε turbulence model to evaluate the eddy viscosity, but Eq.7.3.20 can be applied approximately without applying a k-ε model.

Based on the solution of the above-mentioned flow analysis, the sediment behavior and morphological change can be estimated (**7.3 & 7.4**). The following fluvial process appearing around vegetated areas are some of essential elementary events for landscape changes:

(i) When a stream is accompanied with vegetation zones along side banks, concentration of flow into the main channel and lateral transport of bed materials from the main channel to the vegetated zone promote degradation of the main channel (Tsujimoto & Kitamura, 1996a) and deposition on the floodplain. In case of suspended sediment, lateral turbulent diffusion of suspended sediment contributes to deposition on the floodplain. Even in case of bed-load, organized fluctuation promoted by existence of vegetation zone brings about the net flux of lateral transport of bed load (Tsujimoto, 1996)

(ii) Around an isolated vegetated area, the flow is retarded and the sediment deposit around it. When sediment is transported in suspension, deposition occurs downstream of the vegetated area (Tsujimoto & Kitamura, 1996b). While, when sediment is transported as bed load, deposition appears at the upstream of the vegetation (Tsujimoto, 1999). When the vegetation is very dense, a scour hole is formed at the upstream of it.

When a long-term transition of river landscape is focused on, we have to consider repetitions of floods and dry seasons, or the frequency and the magnitude of floods. Morphological changes and destruction of vegetation occur during a flood, while growth of vegetation and/or enlargement of vegetated area occur during a dry season. Since vegetation growth is closely related to the relative height of land above the water level (Tsujimoto, 1994), morphological change during submergence within flood period affects the vegetation. Up to now, we don't have detailed models to describe neither growth of vegetation (or expansion of vegetated area) nor destruction of vegetation. For the former, sediment-deposited and dried up area is assumed to be covered by vegetation during a dry season after the flood; and for the latter, vegetation on the area eroded during flood is assumed to be destructed.

Figure 7.5.2 is a example Tsujimoto & Kitamura (1996a) focused on. A stream bordered by vegetated zone along side banks as shown in Fig.7.5.2(a) is postulated, and it is assumed that no sediment is supplied from the upstream end and that the elevation of the downstream end is postulated to be fixed for example by a sill structure. Then, the zone of bed-load transport and subsequent degradation (rotational degradation) taking place is limited in the center lane of the channel as illustrated in Fig.7.5.2(b, c). In a low stage period after the flood, the water may be conveyed in the entrenched part of the channel, and the portion where no sediment was transported during the flood forms a terrace. Vegetation may encroach onto the terrace during a low stage period (see Fig.7.5.2(d)). Hence, when the next flood comes, the flow is more concentrated in the entrenched portion (see Fig.7.5.2(e), (f)), and bed degradation is concentrated in a

narrower lane at the center. After the second flood, a new terrace is formed (see Fig.7.5.2(g)), and this terrace might be covered by vegetation during the subsequent low stage period. Repetition of such floods and low stage periods forms a multi-terrace morphology.
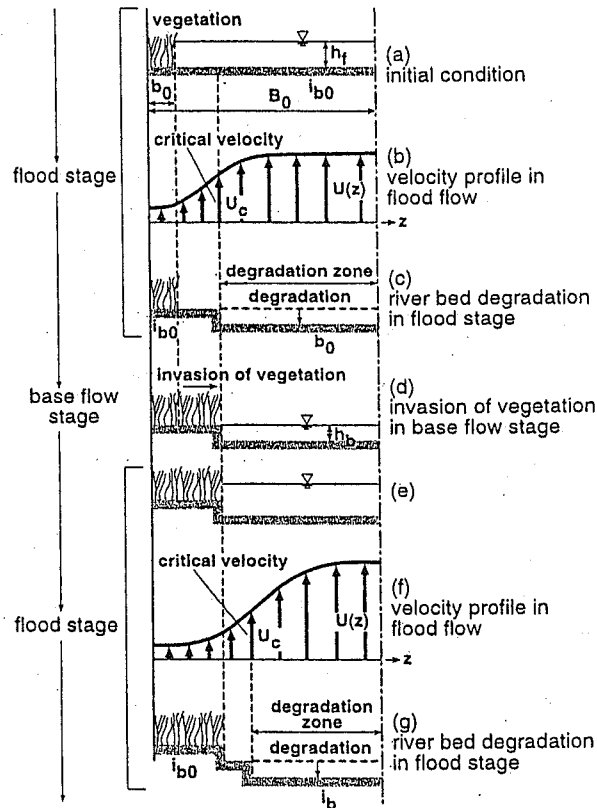
Fig.7.5.2 Degradation of stream with vegetation under repetition of flood and low-stage water

7.5.4 Landscape degradation and its restoration

Recently, river-landscape degradation in the river reach at downstream of dam and reservoir has been focused on. Dam stops sediment and sediment supply to the downstream reach is appreciably decreased. In addition, operation of a dam changes the frequency and the magnitude of floods. Some examples of scenarios of river landscape degradation is as follows:

(1) A dam stops sediment, and river-bed degradation occurs. Armour coat formation changes habitat for benthos. The relative height of floodplain increases, and vegetation grows more or is rarely destroyed by flood.

(2) A dam controls flood, and the frequency of flood decreases. The chance for vegetation to be destroyed is ultimately decreased. If the daily discharge from the dam is decreased, fine sediment deposit in a main channel, and it changes habitat.

The above-mentioned eco-system degradation is explained in a guideline (in editing)

of new Environmental Assessment in Japan (Environmental Assessment Law was established in 1997). All the effects of a dam on the environments of downstream reach cannot be preliminarily removed nor reduced. Hence, it is necessary to monitor the quality of eco-system and if necessary restoration of landscape is important in a following-up project. In order to reduce the effects of impacts or restore the reverine eco-system after a dam construction, the transition process of river-landscape responding to the impacts such as changes in sediment supply and water-discharge teime-series should be described through fluvial hydraulics and eco-hydraulics (habitat hydraulics). Particularly, habitat preservation is a key, and in order to assure it, an integrated sediment management along a river system must be considered.

7.6 Concluding Remark

Mechanics of sediment transport and fluvial hydraulics are explained under a new scenario of river management from viewpoints of safety against floods, water resources and eco-system preservation. A dynamic system of rivers composed of flow, sediment transport, morphology and vegetation must be sufficiently understood, and its response to various kinds of impacts should be reasonably forecasted. In a river management, assessment to reduce or mitigate the effects of impacts and repeating restoration through monitoring system are important strategies, and they are achieved by appropriate sediment management along a river. The contents of this text must support those strategies.

In this text, mechanics of sediment transport and fluvial hydraulics are systematically described. Equations those can be conveniently employed in river-management strategy are selected, and they are also useful to understand a river system. The author hopes that readers of this text can postulate various scenarios to understand the recent degradation of river landscape and also to restore it.

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Chapter 8

Irrigation system and watershed management
Hajime Tanji

8.1 Hydrological situation of paddy fields in a basin

In Japan, some basins or sub-basins that fulfil the following conditions should have strongly influenced by paddy irrigation. That kind basin is called a **paddy basin** here.

(1) Ratio of paddy field area to a basin is large.

(2) Ratio of irrigation water to water of a basin is large.

The main purpose of the lecture is as follows:

(1) To bring the light to a paddy basin, especially the irrigation structures and hydrologic characteristics of a paddy basin.

(2) To show conspectuses of irrigation water management of a basin scale or a sub-basin scale

8.2 Characteristics of paddy basins

Considering hydrologic characteristics of a paddy basin, a main remarkable point is water balance of a paddy basin has strongly influenced not only by rainfall but also by intake water. Therefore, the characteristics of a paddy basin should by classified on patterns of intake water.

Talking about water use in Japan, about 64% is agricultural water (1991). Inside of agricultural water use, 95.4% is for paddy fields, 3.7% is for upland fields and 0.9% is for animal husbandry. About sources for irrigation water, 88% is taken from rivers, 10.3% is taken from ponds and the rest 1.1% is taken from groundwater.

Karube et al. classified irrigation water resources in the world. **Figure 1** shows development of paddy fields under different rainfall levels.
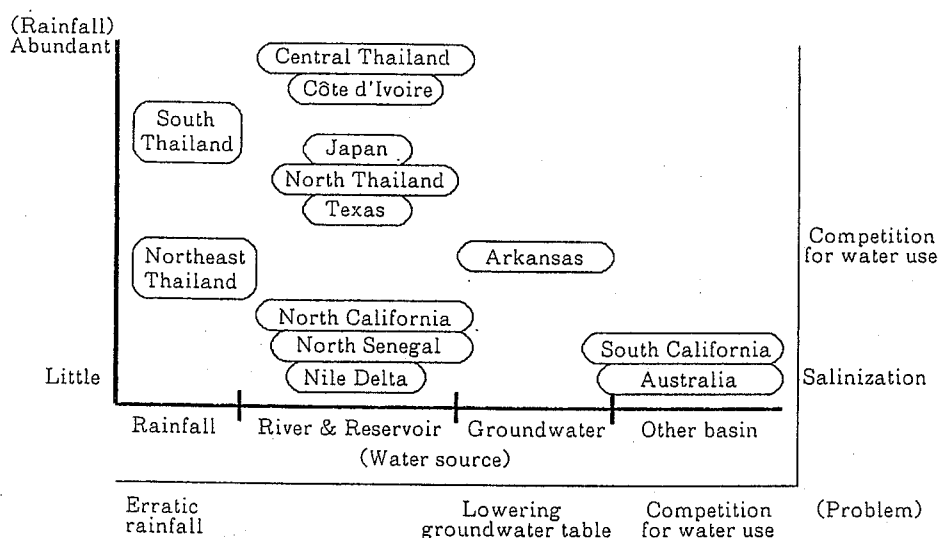
Figure 1 Development of paddy fields under different rainfall levels

8.3 Improvement of irrigation facilities
8.3.1 Typical irrigation system

Figure 2 shows a typical irrigation system in Japan. River flow is introduced to the main canal by the weirs and it is diverted to several tertiary canals. In some cases, farm ponds are constructed to control water flow corresponding to the water use. And pipelines with pumping station are often used in some areas. The water flow in dams, weirs, canals and farm ponds are controlled and managed by a water management center. Within an irrigation area, water is usually reused many times. Drained water is used again for paddy fields in downstream area. And also, a large number of tanks or ponds have been constructed in the districts where rainfall is not sufficient.
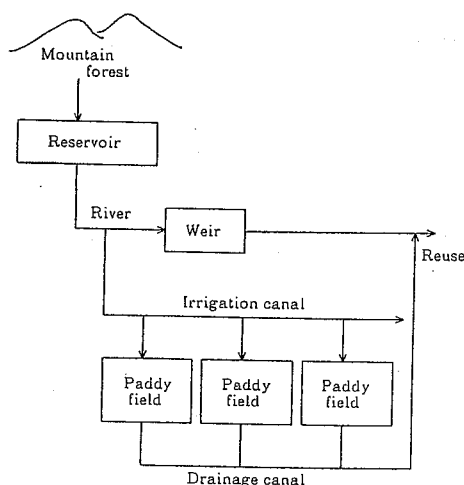
Figure 2 A typical irrigation system in Japan
(Hasegawa and Tabuchi,1995)

8.3.2 Irrigation facilities and irrigation organization

Considering irrigation water management compare to other water use, a strong characteristic can be shown in adjustment of water demand by end users and supply by an operator of the irrigation district. An irrigation system consists of main facilities managed by a land improvement district, end facilities managed by farmers and intermediate facilities managed by controllers. A land improvement district consists of farmers. A land improvement district selects representatives of farmers by a election and controller of intermediate facilities in turn.

An irrigation system is improved by two kinds of projects. Main and intermediate facilities are constructed by governmental or prefecture irrigation projects. End facilities are constructed with farmland consolidation. **Table 1** shows abovementioned relations.

Table 1 Organization and facilities of irrigation

kinds of facilities	dam intake weir main canal diversion	tertial canal intake outlet
controller	land improvement district	farmer
project	irrigation	rand consolidation

8.3.3. Land consolidation and separation of irrigation and drainage

Figure 3 shows an example of land consolidation in Japan. **Table 2** shows a change in irrigation system before and after land consolidation.
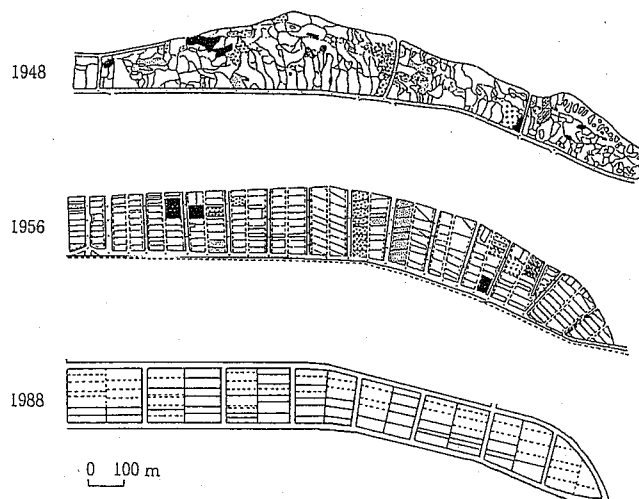
Figure 3 Example land consolidation in Japan (Kakurai, Chiba)
(Shinzawa and Koide, 1963, Tomita et al.,1989)

Table 2 Change of irrigation system before and after land consolidation

	before land consolidation	after land consolidation
irrigation drainage	combined	separated
channel	low intensity open canal	high intensity open canal or pipeline
maintenance cost	high	low
irrigation efficiency	low	high

8.3.4 Water balance of a paddy basin

Figure 4 shows the rainfall and intake at Gongen-Satte area of 50.8km². Considering the ratio of a total period, Intake is 65 percent in this basin. Looking in detail of input to the basin, **figure 5** shows a time series of rainfall and intake. In this figure, bars means intake and curved lines means intake plus rainfall. Therefore, rainfall can influence the water balance only the intensity of rainfall is larger than 3-5 mm/day. A part of rainfall can decrease the intake when it is used as equivalent intake water. This kind of rainfall is called effective rainfall. But from figure 5, this part of rainfall is only the sub-component of rainfall and cannot reach to a large part.
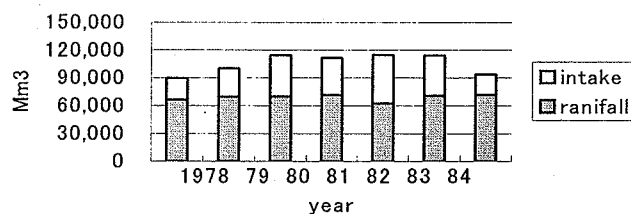
Figure 4 Rainfall and intake at Gongen-Satte area (11 Apr.-30 Sept.)
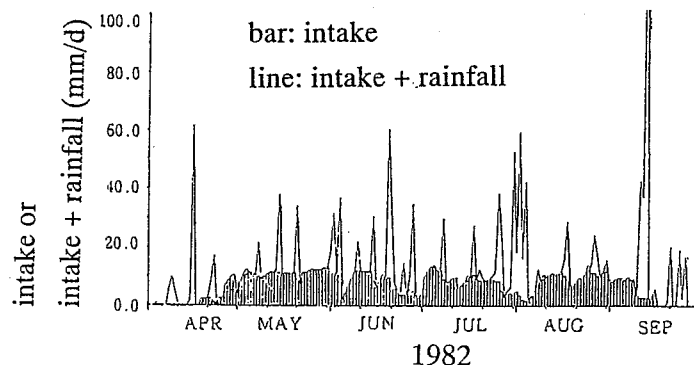
Figure 5 Time series of rainfall and intake at Gongen-Satte area (1982)

8.3.5 Irrigation and water management of the paddy field

A typical cultivation period of a paddy field is from the end of April to the beginning of September, which is shown as **Figure 6**. A harvest is set at the beginning of September for avoiding the season from the end of September to the beginning of October when many typhoons attack Japan Islands. A transplanting period of the rice is set at the end of April for waiting for enough temperature for breeding of the rise. The necessary irrigation period from the transplanting to the drainage for preparation of the harvesting is approximately 150 days. Therefore, at the only region where the temperature in the spring is high, the transplanting period can be changed earlier than at the end of April. In the several southern prefectures, the transplanting period is at the beginning of April and harvesting period is at the middle of August.

The another reason why irrigation period of the paddy field is fixed is the increase of side job farmers. Generally, transplanting and harvesting of the rice needs big labor of the cultivation. Then, the agricultural machines were developed for the labor reduction. The agricultural machines have been introduced. Though the agricultural machine reduced the labor of harvesting, the reduction of the labor of transplanting is yet little. The research for the direct seeding also advances for avoiding the concentrated labor of transplanting.

(1) Typical water management in Japan
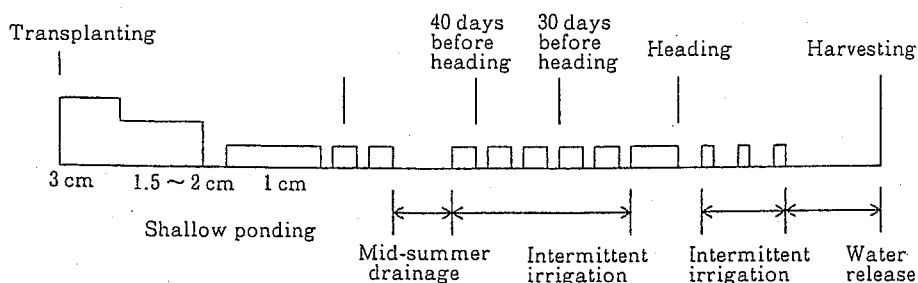
(2) Water management in California (Larry Farm)
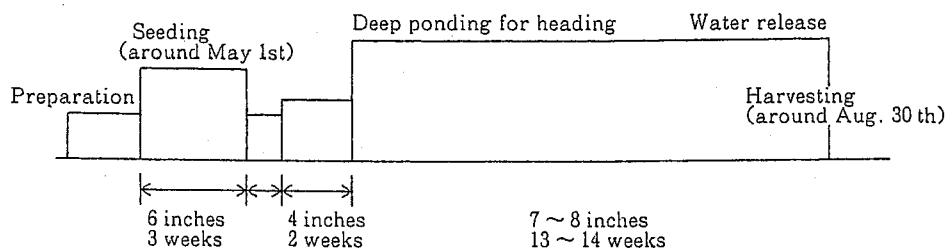
Figure 6 Examples of water management in Japan and USA
(Shiraiwa and Shimura 1991)

In the direct seeding, the labor can be reduced but the enough period for cultivation is difficult to take because the direct seeding needs more time than transplanting which the seed grow into small rice for transplanting.   This is the reason why the direct sowing does not spread in Japan in comparison with the country in South East Asia.   Farmers with side job often make rice transplanting on holidays, because the reduction of the labor of transplanting by machines is limited. Thus farmers with side job ordinary transplant rice on the holidays form the end of April to the begging of May, because the holidays are concentrated in the first week in May. As the result, the work of the rice transplanting is concentrated for the 7~10 day.

Figure 6 also shows water management in California.   In this case, ponding depth is deeper than that in Japan.   Deep ponding depth aims to put down weed.

Irrigation of a paddy field is supplied in order to maintain water depth of a paddy field.   Therefore, irrigation of the paddy field 1 sheet is equal to the drainage plus loss by evapotranspiration and infiltration.   when there is rainfall,   the part will be made effective, and the water use of irrigation will decrease.   Seasonal fluctuation of the water use except for the change of the rainfall and evapotranspiration are as   follows; a pudding period, an usual period, a midsummer drainage period, an usual period,   a drainage period for harvesting.   These periods are shown in Figure 7.

In and out flow of a   paddy field is shown in Figure 7.   At the present, irrigation and drainage canals have been almost separated at paddy   fields in Japan.   The separation of irrigation and drainage canals facilitated the water management. Especially, the separation became a decrease in the drainage damage.   However, there is some next defect.

1) The effective utilization of the rainfall decreased in comparison with old type channel of both irrigation and drainage use, and the wide-area water consumption increased.

2) The maintenance of the ecosystem of the agricultural canals became difficult.   In the future, the utilization of the IT technology will be used in the water management.

Therefore, double use channels may be restored.

Double cropping of rice is difficult except   Okinawa Prefecture and Kochi Prefecture.   In the region with small snows in the winter, field crop can be planted on a
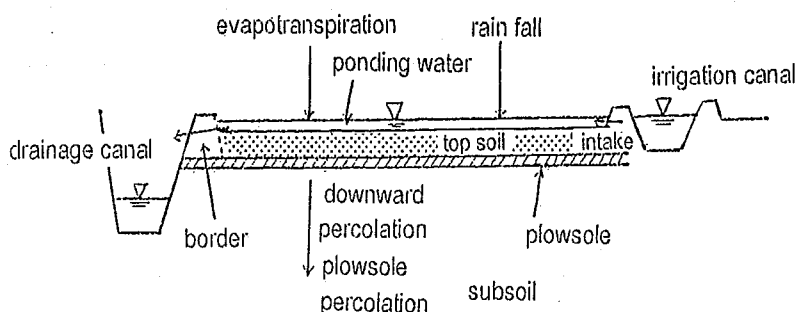
Figure 7 Water management and water balance of a paddy field

paddy field in the winter term. The time of paddy farming in the summer is limited when the farming is done in the winter.

8.4 Water management of a paddy basin
8.4.1 Water management at normal time
Irrigation water management of a paddy basin consists of two categories:

One is water management at normal time, when intake water of the root of irrigation system is mostly enough to fulfil the sum of requested water. The aim of water management is to control the diversions, to keep the water depth of a open channel, to keep the pressure of a pipeline, to minimize the maintenance cost and to control the demand. Actual water management procedure depends on the type of irrigation facilities, water resource condition and drainage control. **Table 3** shows the main difference of management depend on the type of facilities.

The other is water management at a drought time, when intake water of the root of irrigation system absolutely lacks in the volume of the sum of the requested water.

Table 3 Type of irrigation water management

facilities	open channel	open channel	pipeline
power	gravitational	gravitational	pumping
irrigation /drainage	separated	combined	separated
intake pattern	demand maximum	demand maximum	demand adjustment
water right	custom	custom	notified
example	Sanuki in Kinu River	Ota in Watarase River	Gongen- Satte in Tone River

8.4.1.1 Open channel with separation of irrigation and drainage: Type A
Historical irrigation system consists of intake weirs and main open gravitational canals. In the system, irrigation and drainage canals are not separated and reservoirs are the scale of ponds. After an irrigation project and land consolidation, a dam has constructed and irrigation and drainage canals are separated. This type A is the most typical irrigation system in Japan now.

But there are some variations. In one case, if water resources are not sufficient to separate of irrigation and drainage canals, some canals are designed as combined canals of irrigation and drainage. Merit of combined canals is not only to reuse drainage from irrigation but also to collect runoff discharge. Ota irrigation district in Watarase River basin is this type B.

In another case, if maintenance cost is expensive, pipelines are preferred to open

channels. Recently irrigation projects of pipelines are increasing in suburbs areas. In Kanto district, almost all except one irrigation projects are this type C now. Gongen-Satte area of Tone main weir district is this type C.

In water management of main facilities of type A, an intake weir at the root of irrigation system usually takes the maximum intake-able discharge of river flow with upper limit of the sum of requested water confirmed by the water right. In other words, this operation rule is shown as follows:

(1) When river flow is larger than the sum of requested water, the intake weir is controlled to take the sum of requested water.

(2) When river flow is smaller than the sum of requested water, the intake weir is controlled to take the all of river flow.

(3) Correction of the above rule: When pass-by discharge of river flow is set, this value is first discounted from river flow in operation.

Intake discharge of Sanuki weir (m³/s)
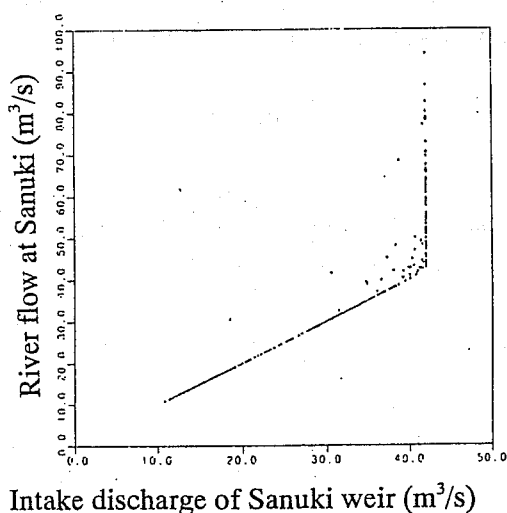
Figure 8 Relation between the river flow and intake discharge
Sakuni intake weir (Jan.1st to Dec.31th of 1976)
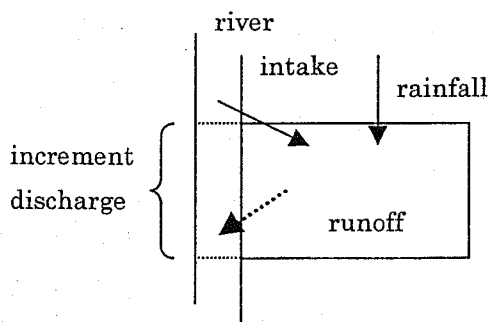
Figure 9 Outline of runoff system

Hosyakuji
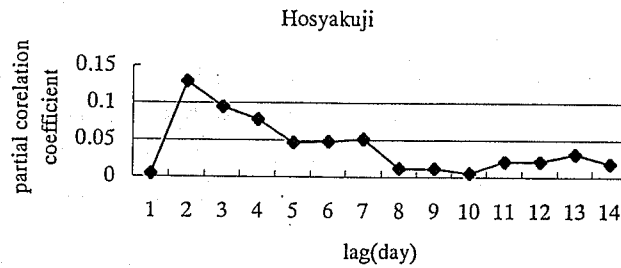
Figure 10 Statistic unit hydrograph

1974
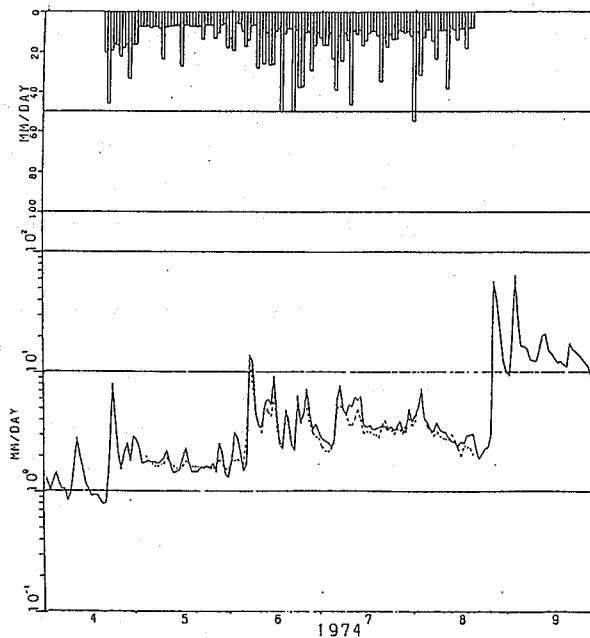
Figure 11 Measured and estimated river flow
(Houshakuji paddy basin,A:1197km2,lag:13,high cut:90m3/s)
(Data:1971-1975,1977-1980,1 of Apr.-30 of Sept.)
(Solid line : measured, Dot line : estimated)

Figure 8 shows the relation between the river flow and intake discharge of Sanuki intake weir in Kinu River. From this figure, Sanuki intake weir belongs to type A. Characteristics of rainfall runoff has strong influenced by intake. By making a statistic unit hydrograph treating intake as rainfall plus intake and output as increment of river flow in the sub-basin, the constant term has a large value. The reason why is that intake water in almost constant when river flow is larger than the sum of requested intake. **Figure 9** shows an outline of runoff system at the sub-basin between Sanuki and Houshakuji. In this case, runoff discharge is measure as increment of the discharge

between Sanuki and Houshakuji. **Figure 10** shows a statistic unit hydrograph and **figure 11** shows the measured and estimated river flow.

8.4.1.2 Open channel without separation of irrigation and drainage: Type B

Ota intake weir in Watarase River is type B. In this case, Basic characteristics of intake and runoff are similar to type A. But intake diversion of inner district has changed to utilize runoff depend on the distribution of rainfall at small drought.

8.4.1.3 Pipelines: Type C

Gongen-Satte irrigation area of Tone main weir is this type C. Type C has a strong inducement to utilization of water because (1) the total amount of intake water throughout one irrigation season is limited and (2) irrigation always causes consumption of electric power because of pipeline system with pumping stations. **Figure 12** shows the relation between intake discharge and rainfall. In this impulse response, an input is taken as rainfall and an output is taken as intake discharge. Therefore, the response shows the utilized parts of rainfall instead of pumping discharge. **Figure 13** shows the measured and estimated intake. Two lines coincide well from April to the middle of July. From the end of July, two lines separate a bit. The reason should be the effect of the midsummer drainage.

A runoff characteristic is calculated here. **Figure 14** shows the modeled basin. **Figure 15** shows impulse response of rainfall and runoff. Equivalent rainfall means rainfall plus intake, which is considered to equivalent rainfall. To calculate impulse response, high-cut filters are introduced to avoid nonlinear response data. High-cut filters are introduced in output, discharge, or input, rainfall. High-cut filters of rainfall cut not only nonlinear response data but also the influence of pure rainfall when the cut value is set low. In this case the response represents the relation between intake and runoff and in other case the response represents the relation between the equivalent rainfall and runoff. Form figure 0, influence of intake to runoff continues in shorter time than the other case.

Estimated and measured discharges are shown in **Figure 16**.
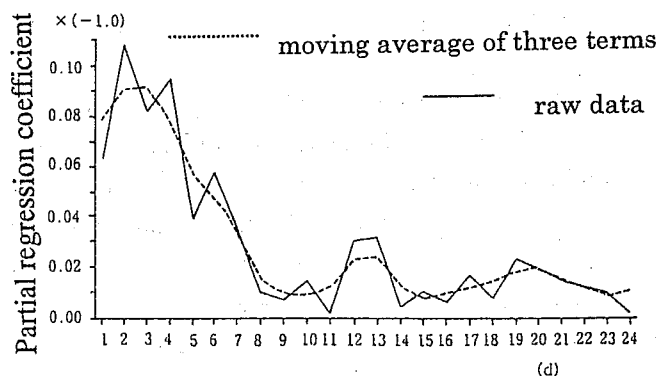
Figure 12 Impulse response between equivalent rainfall and runoff

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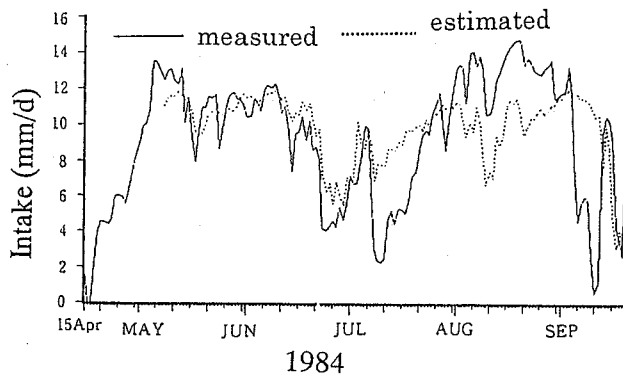
Figure 13 Estimated and measured intake
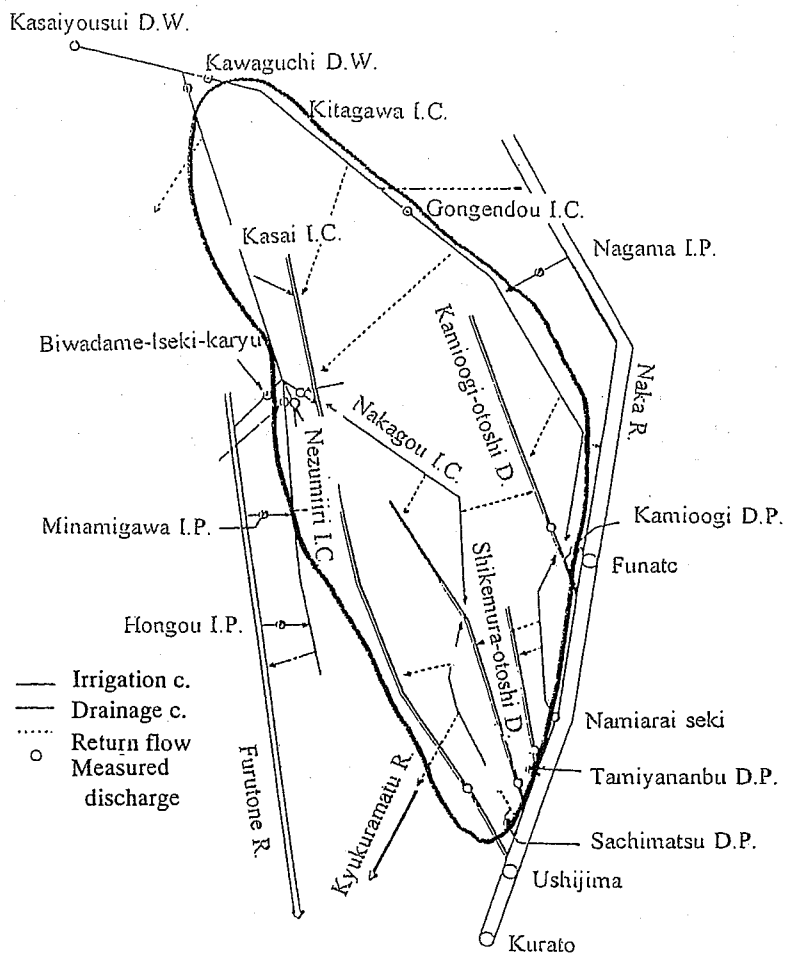
Figure 14 Runoff modeled area of pipeline irrigation system

139
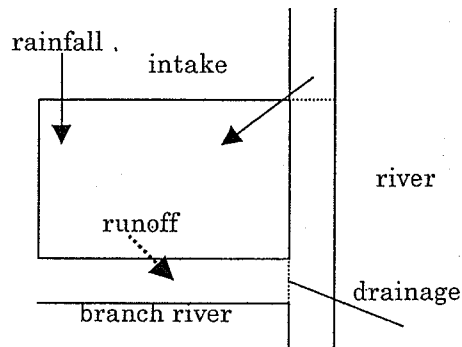
Figure 15 Outline of runoff system
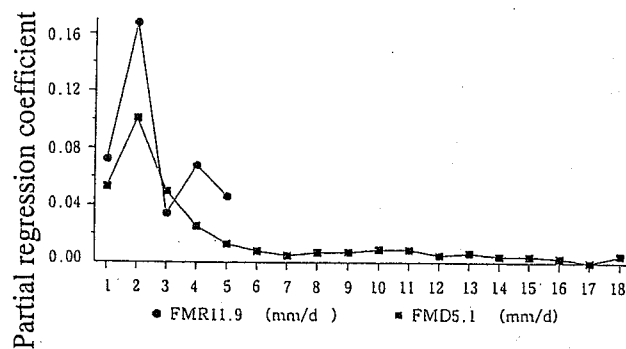
Figure 16 Impulse response between equivalent rainfall to runoff
(FMR: rainfall high-cut filter -   intake response)
(FMD: discharge high-cut filter – rainfall response)
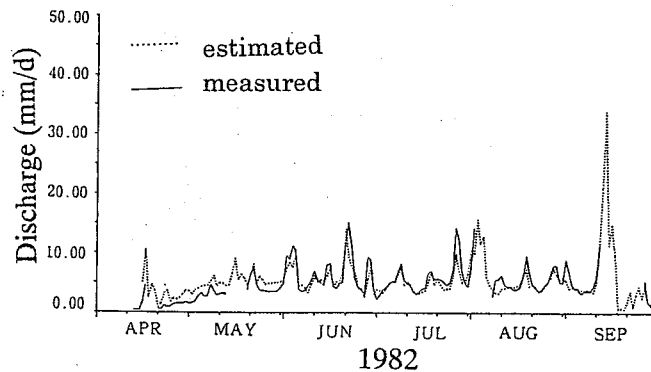
Figure 17 Estimated and measured discharge

8.4.2 Water management at drought
8.4.2.1 Intake restriction

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At drought, a River Managing Authority request restriction of intake water. The restriction is usually ordered as percent, for example 10 or 15 percent

8.4.2.2 Water management inner a land improvement district

After following restriction of intake discharge or when rack of intake occurs, the land improvement district must restrict intake to each paddy fields and change allocation of water to each paddy field. At that case, there are two levels of restriction strategies.

(1) When the rack is small: The irrigation district asks farmers to reduce drainage from the outlet of a paddy field. When intake is difficult because the water level of an irrigation channel is low, which is caused by the rack of intake from a river, filling up the water level by setting small weirs in an irrigation channel is recommended.

(2) When the rack is large: Rotation of irrigation is recommended by a land improvement district.

8.4.2.3 Increase of water management labor

Even at a strong drought time, the decrease of crop is very rare cases because usually the rack of water resources is compensated by manual high quality water management. The objects of irrigation projects are not only to add water supply but also to decrease laborious works of water management.

8.4.3 Environmental use of irrigation water

Environmental use of irrigation water is very important today to maintain a landscape of irrigation and drainage channels, bio-diversity, multipurpose use of irrigation water and hydrologic cycle of a basin. In this case, multipurpose use means water for washing vegetable, for conveyance of wasted snow and for maintain water quality of a canal.

When we talks about environment use, irrigation water means not only the water consumed by crop but also the water pass-through irrigation canals.

8.5 Charecteristics of Watarase River Basin
8.5.1 Outline of the downstream basin of Watarase River

Watarase River is a tributary stream of Tone River. Wtarase Riber flows togaher Omoi River at Watarase retarding basin and connect to Tone River. Reviewing Watarase River from the view point of irrigation, looking from the upstream part to the downstream part, a large intake weir first appears at Takatudo point. Takatudo point is the border between the upstream basin and the middle stream basin from irrigation. Watarase River flows almost parallel to Tone River at the interval between the just upstream point of Watarase retarding basin and Takatudo. Considering the land elevation of the sandwiched basin and the left bank basin, the contours can be drawn almost parallel to each other. The vale of the contour decrease to the direction from Watarase River to Tone River. Rainfall runoff of the left bank basin flows into Watarase River. That of the sandwiched basin flows into Tone River through Wtarase River.

The land elevation of the right bank basin of Watarase River is lower than the bottóm
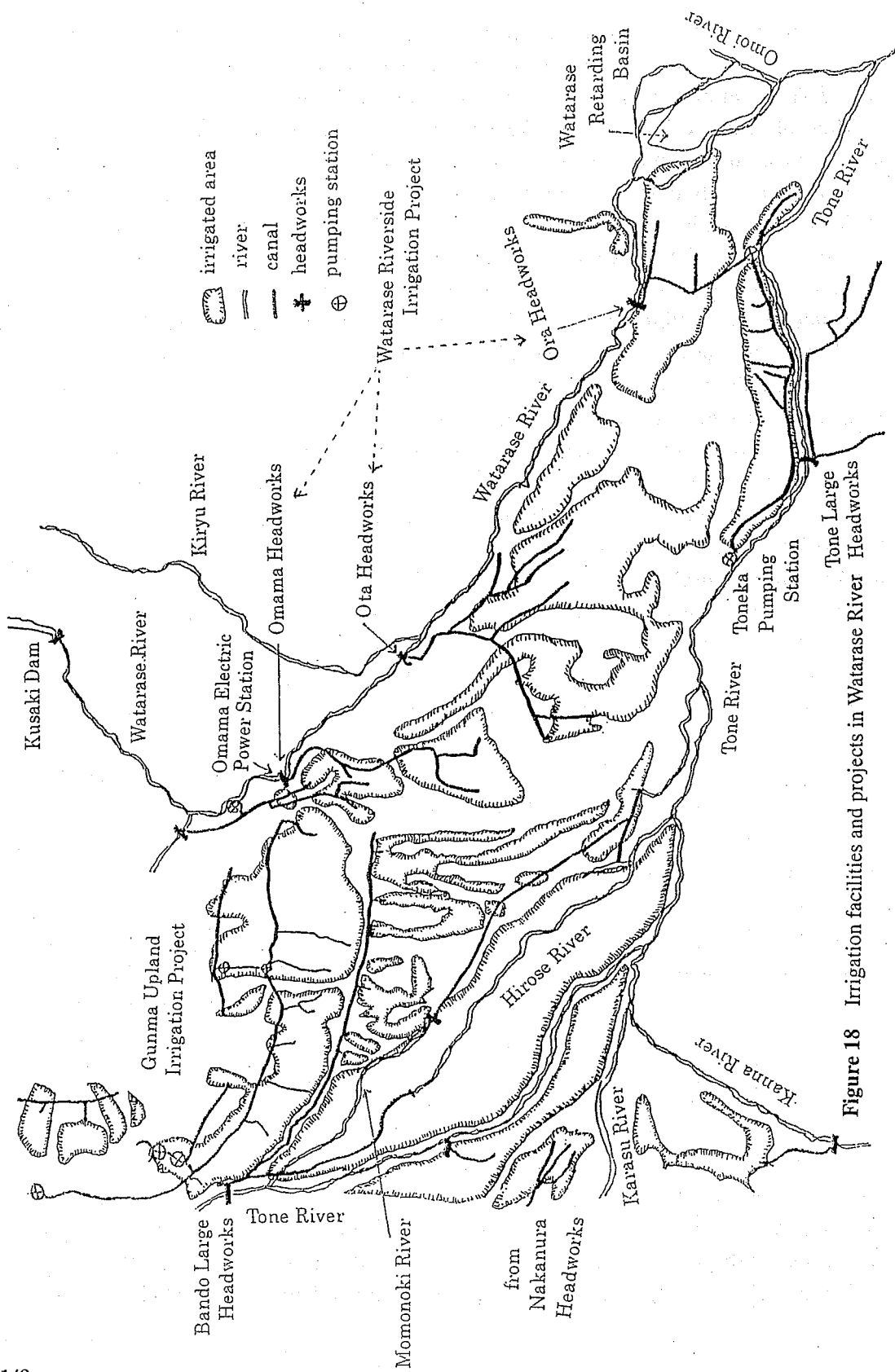
Figure 18 Irrigation facilities and projects in Watarase River

of Watarase River and higher than the bottom of Tone River. Land form of this basin contains flat areas. Paddy fields are developed and irrigated by gravitational irrigation. Otherwise the land level of the left bank basin is higher than the bottom of Watarase River. Land form of this area is steep and this area contains little flat land. paddy fields are few. Besides, irrigated paddy field are very few because pumping irrigation is necessary. Considering the location of an alluvial fan, the right bank basin locates at the edge of the fan. The left bank basin locates near the root of the fan, which is the reason of abundant use of groundwater.

Watarase River basin belongs to Tochigi and Gunma Prefectures. At some parts, Watarase River overlaps the boundary of two prefectures. From the land form, the right bank basin is flatter than the left and contains much farmlands. Experssint this on the prefecture level, the partial basin of the Watarase River in Gunnma Prefecture contains much farmlands.

Figure 18 shows irrigation facilities and irrigation projects in and around Watarase River. In Watarase River, there are three irrigation weirs and irrigation areas. Drainage of Omama intake weirs and Ota intake weirs flow into Tone River. Drainage of Oura intake weir flows into Watarase River. The runoff systems of Watarse River are the type of **Figure 15**. Discharge of drainage canals or drainage rivers is not measured here. Therefore water balance cannot calculate. Description of Watarase River must be limited to outline of facilities and farm lands.

Around Watarase River Basin, to the west, there are two irrigation project areas. Gunmma Upland Irrigation Project locates in the northern area, which irrigate upland crops and consumption of water per an area is one order smaller than that of paddy fields. Bando Large Intake Weir contains several irrigation sub-areas. Taishou and Hirose-momonoki irrigation areas are contained.

To the south, Tone Large Intake Weir withdraw water from Tone River for irrigation, domestic use and industrial use. Gongen-Satte area belongs to this weir.

8.5.2 Outline of irrigation facilities and organization
8.5.2.1 Outline of weirs

In Watarase Basin, because of the flood risk, historically irrigation facilities were small scales. But in 1970's, small weirs are corrected and reformed into three large weirs. These weirs are Omama Headworks, Ota Hewadworks and Oura Headworks. Therefore, irrigation systems in Watarase River Basin consist of historical irrigation canals, new constructed intake weirs and connection canals. Of course historical canals are re-constructed in a new design, the route of the canals are the same. Outline of main weirs is shown as Table 4. On three weirs, Omama is not an actual weir on a river. Omama is a direct intake tunnel form the river at a flume point. Table 5 shows dimension of irrigation canals. In table 5, discharge (mm/d) shows irrigation capacity per an area. Yabutuka aimed for upland crop irrigation. Except the area, discharge is
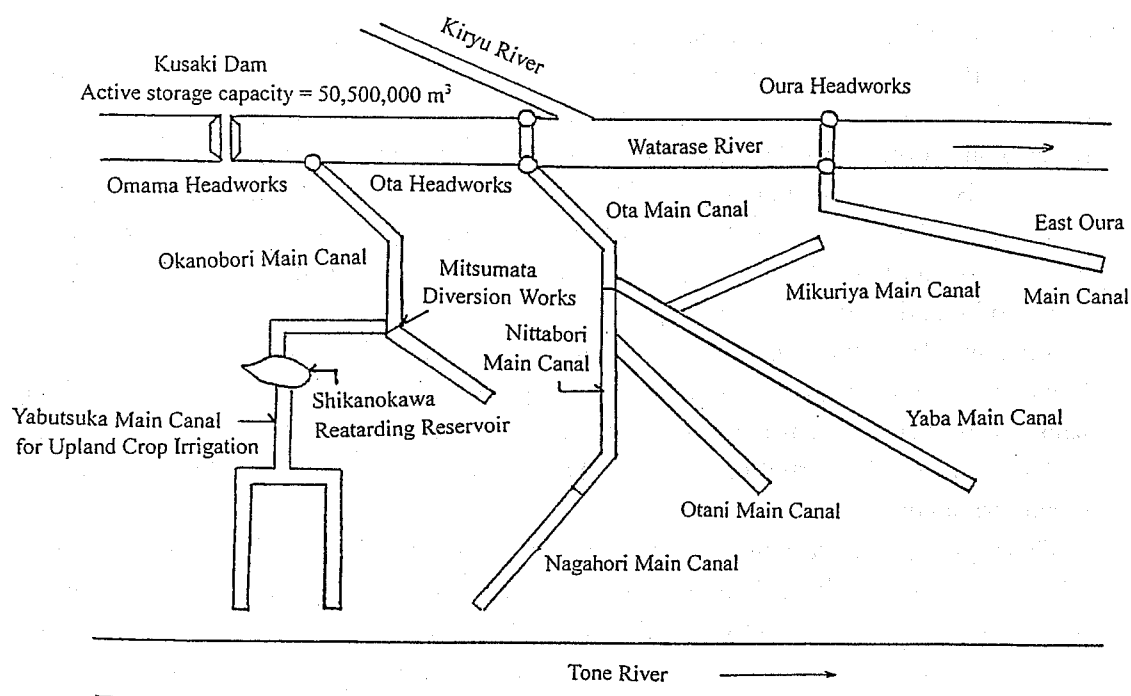
Figure 19 Outline of main irrigation canals in Watarase River

Table 4 Outline of main intake weirs in Watarase River

Intake weir	Place	Old weirs	Type	Intake	Lowest intake water level T.P.m	Dimensions of main facilities	
Omama	Takatudo, Omama town, Yamada gun	Okanobori	Direct inflow tunnel	1.99 m3/s	146.927 m	intake tunnel stilling basin convyance tunnel scour tunnel control gate control balb intake gate	53.0 m 23.0 m 993.0 m 58.0 m 1.2 mx1 D1,600mmx2 2.7 m x1
Ota	Hlrosawa-cho, Kiryu city	Machi Yaba Mikuriya	Floating type of concreat	21.03 m3/s	80.41 m	draw-door spillway scour gate intake gate spillway-door high scour-door hight	134.0 m 35.0 mx3 20.0 mx1 2.85 mx2 2.35 m 3.15 m
Oura	Oohima, Tatebayashi city	Oura Itakura Akabane	Floating type of concreat	6.43 m3/s	18.5 m	draw-door spillway scour gate intake gate spillway-door high scour-door hight	126.0 m 40.0 mx2 40.0 mx1 3.6 mx2 4.2 m 4.3 m

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Table 5 Outline of main irrigation canals in Watarase River

Cannel Name	Type	Aim Paddy	Area ha	Discharge m3/s	DIscharge mm/d	Length km Total	Open	etc.	Structure	Slope	Main facilities
Okanobori	Main C.	Y	1,180	1.99	14.6	4.0	0.0	4.0	pipeline	0.417%	spillway x1 pond x1
Yabutuka	Main C.	N	860	* 0.98	9.8	12.1	0.1	12.0	pipeline	1.333%	spillway x1 pond x1
Oota	Main C.	Y	6,640	21.03	27.4	2.9	2.0	0.9	3sides c.	1/500 ~ 1/1,000	spillwayx1
Nittabori	Main C.	Y	2,990	* 9.95	28.8	4.8	4.6	0.2	3sides c.	1/800 ~ 1/1,600	spillwayx1
Ohtani	Main C.	Y	1,220	* 4.08	28.9	7.6	5.9	1.7	3sides c. + block	1/700	spillwayx1
Nagahori	Main C.	Y	560	* 1.81	27.9	3.2	2.5	0.7	3sides c. + pipeline	1/1,000 ~ 1/3,300	spillwayx1
Yaba	Main C.	Y	3,610	*10.94	26.2	8.8	5.2	3.6	3sides c. + pipeline	1/700 ~ 1/1,400	spillwayx1
Mikuriya	Raw Water C.	Y	1,400	* 4.00	24.7	3.4	0.9	2.5	3sides c. + pipeline	1/500	spillwayx1
East Oura	Main C.	Y	1,800	6.43	30.9	4.2	4.0	0.2	3sides c.	1/2,500	pond x1
Total			9,620			51.0	25.2	25.8			

* double count   3sides c.:3sides concreat channel

approximately 15 to 30 mm/d. On farm level, consumption of water is usually 20 to 25 mm/d. Therefore allowance for management water seems to be 5 to 10 mm/d. In design of open channel, allowable seepage is smaller than 10 percent. Therefore, actual average seepage should be smaller than 5 percent. But considering operation loss caused by diversion and change of intake, the allowance is small.

8.6 Statistic unit hydrograph

Considering rainfall-runoff as a multiple regression model, a runoff characteristics can be given as a unit hydrograph. Taking runoff time series as an output and rainfall as an input, a multiple regression model can be given. In that case, parameters of a unit hydrograh are the partial regression coefficient and a constant term of multiple regression model shows a kind of base now.

In actual model building, there are two remark points.

(1) Some data contains the response with strong non-linearity. These data should be omitted.

(2) Independent of input data must be considered. For this purpose, used input data are not effective rainfall but rainfall.

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Chapter 9

River Basin Management and Water Quality
- Agriculture and Non Point Sources -
Hiroyuki Kawashima

Abstract
I will present the relation between river water quality and land use in its basin.
Agricultural activity, the number of livestock and population density in the basin affect
much influence on the river water quality. Nitrogen balance is the key concept to
interpret this relationship.

9.1 Introduction
River water quality in developing countries tends to deteriorate with the economic
development. Industrial and domestic wastewater is the one of the cause of water
pollution of the river. These sources are called "point source", because the generating
point of the source is easily identified. On the other hand, there are pollution sources
called "non-point source" whose generating point is difficult to be specified.

Nitrogen is the one of the pollutant and is closely related with Eutrophication. Nitrogen
is also cause of shallow ground water pollution by nitrate. The amount of nitrogen
generated from non-point sources is the closely related with the agricultural activity. In
this chapter, I want to explain how to estimate the amount of nitrogen generated in the
basin.

9.2 Agriculture and Nitrogen Cycle
The agriculture is significant industry for developing countries. Generally, the
population growth rate of developing countries is high. Developing countries will
continue to increase food production in order to meet their population increase.
Agriculture will be significant industry for developing countries even in the twenty-first
century. Nitrogen is the most important fertilizer. In order to get more crops from the
limited arable area, much fertilizer is required. However, increasing use of nitrogen
fertilizer becomes a cause of Eutrophication of the rivers, lakes and bays.

The nitrogen circulates in the biosphere. Nitrogen cycle occurs both in the ocean and
terrestrial ecosystems. The concept of nitrogen cycle is shown in **Fig.1**. Some bacteria
fix nitrogen from the atmosphere. Fixed nitrogen becomes organic nitrogen. Some

bacteria decompose the organic nitrogen, and it becomes ammonia nitrogen (NH_4–N). This decomposition occurs both in the aerobic and anaerobic conditions. The ammonium nitrogen is oxidized, and becomes the nitrite nitrogen (NO_2–N). Nitrite nitrogen becomes nitrate nitrogen (NO_3–N). This process is called nitrification. Nitrifying bacteria carries out this. N_2O generates in this process. N_2O is a greenhouse gas. This is also related with the ozone layer destruction in the stratosphere. Generally, the oxidation rate of NO_2–N is higher than that of NH_4–N oxidation. Therefore, the concentration of NO_2–N in the ecosystem is lower than that of NH_4–N and NO_3–N. NO_3–N becomes molecular nitrogen (N_2), which returns to the atmosphere. Denitrifying bacteria, which are anaerobes, contribute this process. Denitrification occurs in the anaerobic condition. N_2O also generates in the process of denitrification.

Plants intake NH_4–N, NO_2–N and NO_3–N. The animal eats the plant. The animal excretes urea or NH_4–N. Both plants and animals become the organic nitrogen when they died. Human is also in the nitrogen cycle. The organic nitrogen decomposes again by the microorganism, and it becomes NH_4–N. Like the above processes, the nitrogen circulates in the ecosystem. In usual ecosystem, the concentration of NH_4–N, NO_2–N and NO_3–N is relatively low. Inorganic nitrogen concentration often limits the growth of the plant. Today, mankind produces nitrogen fertilizer by fixing atmospheric nitrogen industrially and supplies this to the croplands in order to increase the production. This disturbs natural nitrogen cycle.

9.3 How to Estimate Nitrogen Load from Basin
Unit load *per capita* is convenient method for the estimation of the amount of pollution load generated from the basin. The unit load *per capita* means the amount of load generated one human or livestock per unit time. Similar concept is used for the load from farmland. The unit load from farmland means the amount of unit load per unit area unit time. The values of the unit loads are determined by experiment. When population, numbers of livestock, and area of farmland are given, it is easy to estimate the amount of load generate in the basin. Typical values of unit loads for nitrogen are shown in **Table 1**.

9.4 Nitrogen Fertilizer Input and Yield
The relationship between nitrogen yield and nitrogen fertilizer input is shown in **Fig.2**. The countries which population is over 10 million in 1990 are considered. Input means the sum of natural fixation, manure and industrially fixed fertilizer. When the fertilizer input increases, the yield increases. The input of the Western European countries is abounding. The nitrogen input in the New Continent such as U.S.A., Canada, Australia

is relatively low. The fertilizer input is a little for the developing countries especially in Africa. The input is increasing in the Asian countries. Some of input nitrogen is denitrified in the arable land. Generally, the denitrification rate in the field is slow. The denitrification rate in paddy field is higher than the field. The rest of nitrogen, which is not harvested or denitrified, is discharged to the environment. The nitrogen emission to the environment increases according to increase of input, since the harvesting nitrogen rate tends to decrease gradually. Leached nitrogen becomes a cause of nitrate pollution in the nearby groundwater. Increase of fertilizer input is an effective in order to increase the production from limited cultivated acreage. The nitrogen fertilizer input will increase with the increase in the population in the developing countries.

Part of the nitrogen fertilizer applied to the farmland is taken to the crop and is harvested. While some part of the nitrogen is denitrified in the field, some part remains as an organic substance in soil and some part is leached out from the field. NH_4-N is adsorbed in the soil, and is hardly leached out. Since little NO_3-N is adsorbed in the soil, NO_3-N is easily leached out from the field. When NH_4-N change NO_3-N by nitrification, applied nitrogen fertilizer is easily leached out.

9.5 Livestock Farming and River Water Quality
The effect of the increase of livestock farming on nitrogen cycle is discussed. The Tone River basin is examined as an example. The change of the population in the Tone river basin is shown in **Fig.3**. The change of the farmland area is shown in **Fig.4.** Population and the area of farmland have been almost constant, however, the number of livestock had increased (**Fig.5**). Especially, the numbers of poultry and swain increased rapidly in 1980s. The nitrogen sources generated in the basin are summarized in **Fig.6.** Waste from livestock was the major source of nitrogen in this basin. **Fig.7** shows the difference between the amount of nitrogen generated in the basin and nitrogen load to the Tone River. The amount of nitrogen load generated in the basin had increased gradually, and nitrogen load to the Tone Rive has been lower than that of generated. The amount of difference seems to be self-purified in the basin.

9.6 Nitrogen Cycle in Tokyo Bay
I want to explain the effect of the rapid urbanization on nitrogen cycle here. The Tokyo Bay basin is examined as an example. The nitrogen flow in the basin in 1990 is illustrated in **Fig.8.**The population in the Tokyo Bay basin increased from 6 million in 1920 to 26 million in 1990. Except for the stagnant period around the Second World War, the population has been increased. The farmland has been decreased. Especially, the decrease of the field is remarkable. Since the food shortage was serious, the

cultivated area had increased right after the Second World War. The historical change of the nitrogen demand and the supply are shown in **Fig.9**. The amount of demand is estimated from cultivated area, and the supply is estimated from the amount of human excreta. Before the Second World War, nitrogen demand surpassed the supply. It was common to recycle the human excrement into the farmland in Japan. The nitrogen deficiency had continued even in around the metropolitan area like Tokyo before the Second World War. After the Second World War, the chemical fertilizer has been widely used in Japan. In addition to this, generating nitrogen rate exceeded the demand by the concentration of the population. Since the farmland was decreased by the urbanization, the nitrogen demand also decreased. In 1990, 274.1[ton day-1] of nitrogen as food have entered the basin to sustain the population in the basin. It is obvious that the circulation of the nitrogen became impossible, from the material balance. The concentration of the population to the metropolis makes the cycle of nitrogen impossible.

9.7 How to Reduce Nitrogen Fertilizer Application

It is important to reduce the amount of industrially fixed nitrogen fertilizer use for sustain natural nitrogen cycle. However, the reduction is difficult, because food demand increases with the increase in the population. Next three is considered in order to reduce the nitrogen fertilizer use, while increased food production is maintained.

1) The cultivated acreage increases.
2) Increase the efficiency of nitrogen fertilizer uptake by the crop.
3) Recycle use of excreta from human and livestock for compost or manure.

At present, the forest area is about 4 billion ha in the world. If the forest is changed to arable land area, the increased production is possible without increasing use of nitrogen fertilizer. However, the forest can absorb the carbon of the atmosphere. Until now, mankind has been changed forest to farmland. In the twenty-first century, it is not permitted that the forest changes to the farmland in large scale. It is impossible to plan the increased production of the food by the increase in cultivated area.

The nitrogen fertilizer taken by the crop lowers with the increase of the nitrogen fertilizer input as shown in **Fig.2**. Generally, about 1/3 of put into fertilizer is taken to the crop. Increase of nitrogen uptake efficiency is effective to reduce nitrogen fertilizer use. It is important that application of fertilizer in the time when the crop needs the fertilizer. The slow-acting fertilizer is effective. With the rapid development of the

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computer-control technology, the automatically fertilizer level control becomes possible. In the future, the development of this technology is expected.

Recycling of human and livestock excreta as a fertilizer can reduce the industrially fixed fertilizer. In the developed country, organic fertilizer becomes popular. The tendency is favorable for the environment and it is important to intensify this tendency.

Tabel.1   Pollutant load factory of nitrogen

	Load	Units
Man (excreta)	9	g-N/capita/day
Man (sewage)	3	g-N/capita/day
Poultry	2	g-N/head/day
Swine	40	g-N/head/day
Cattle	290	g-N/head/day
City	1219	kg/km²/year
Forest	393	kg/km²/year
Paddy field	1012	kg/km²/year
Upland field	3293	kg/km²/year
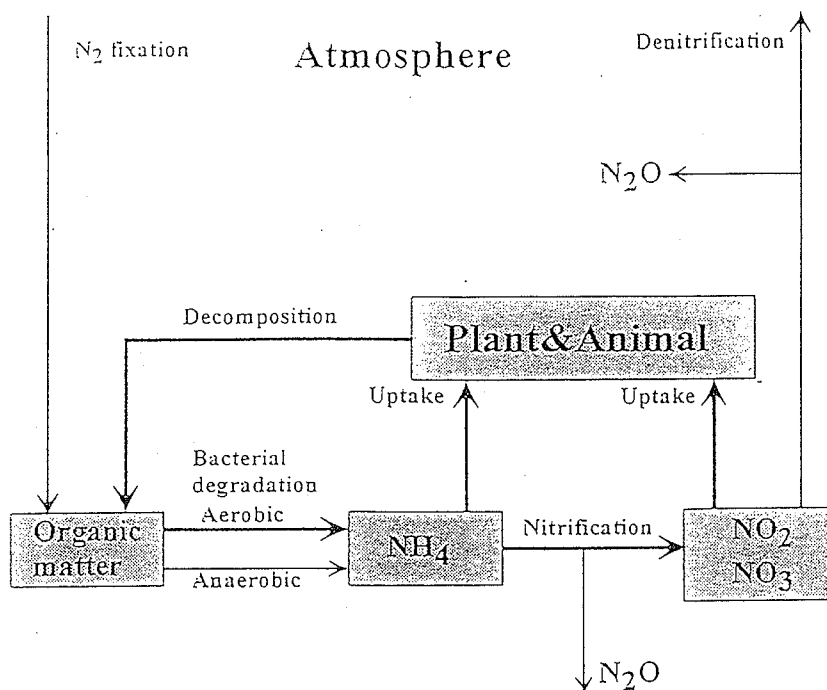
Fig.1   Biological transformation in the nitrogen cycle.
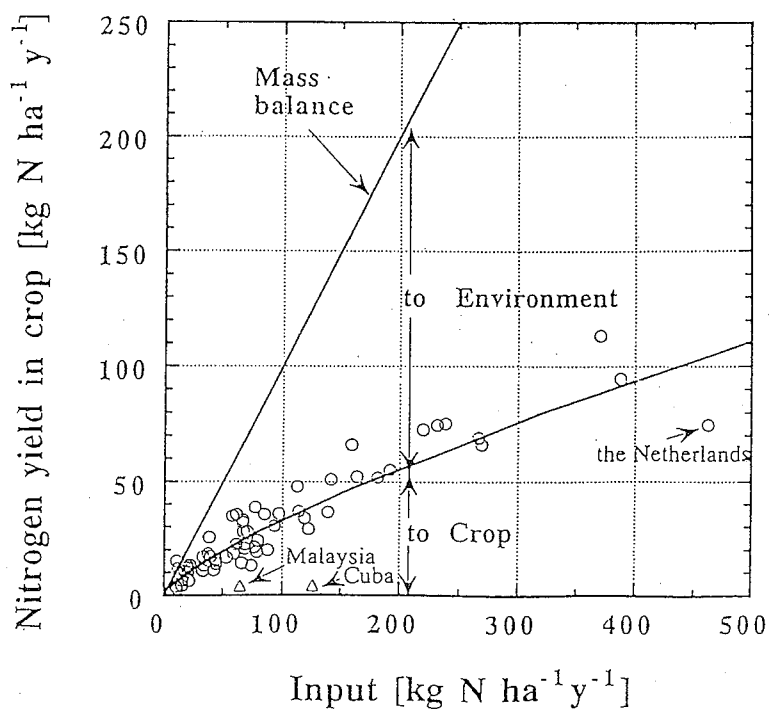
Fig.2   Plot of nitrogen crop yield and nitrogen fertilizer input in 65 countries.
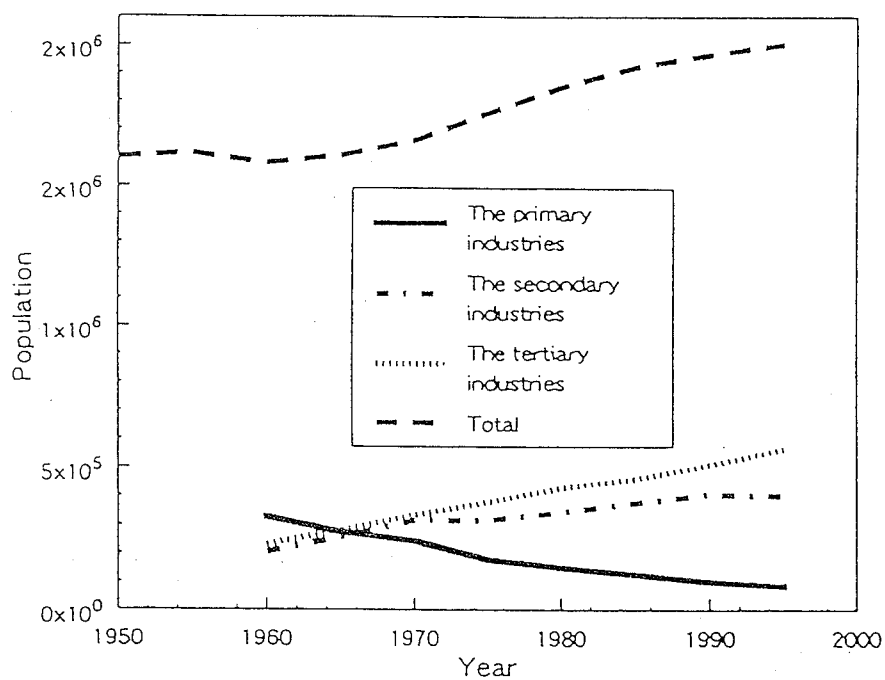
Fig.3   Population in different industries
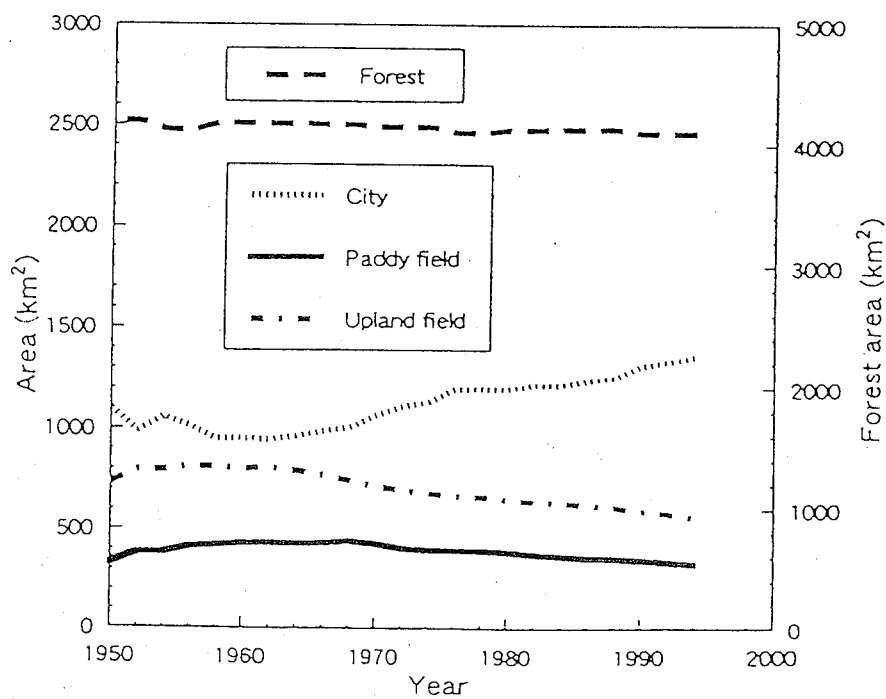
Fig.4   Land use in the basin
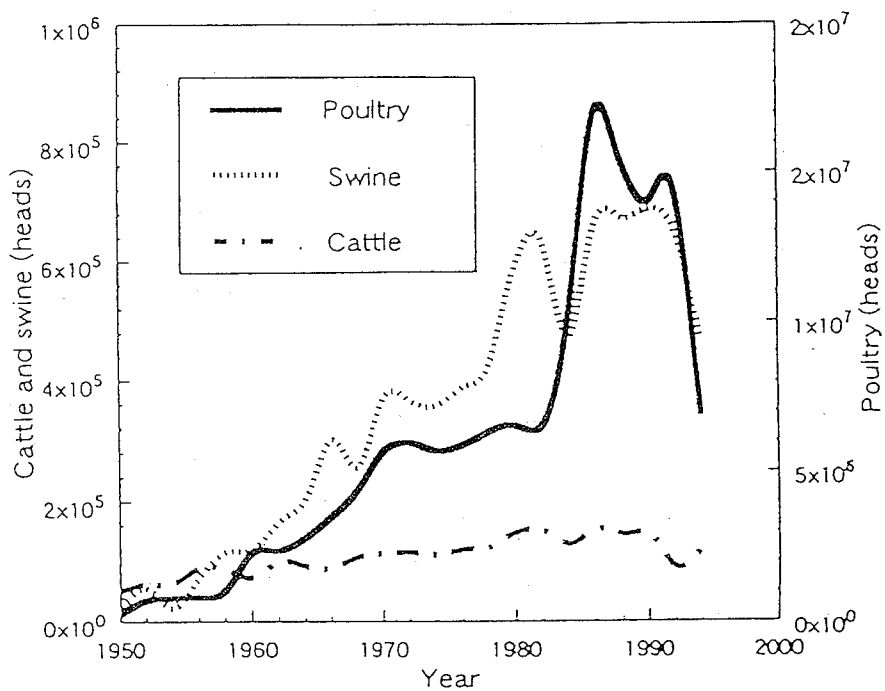
Fig.5　Number of livestock
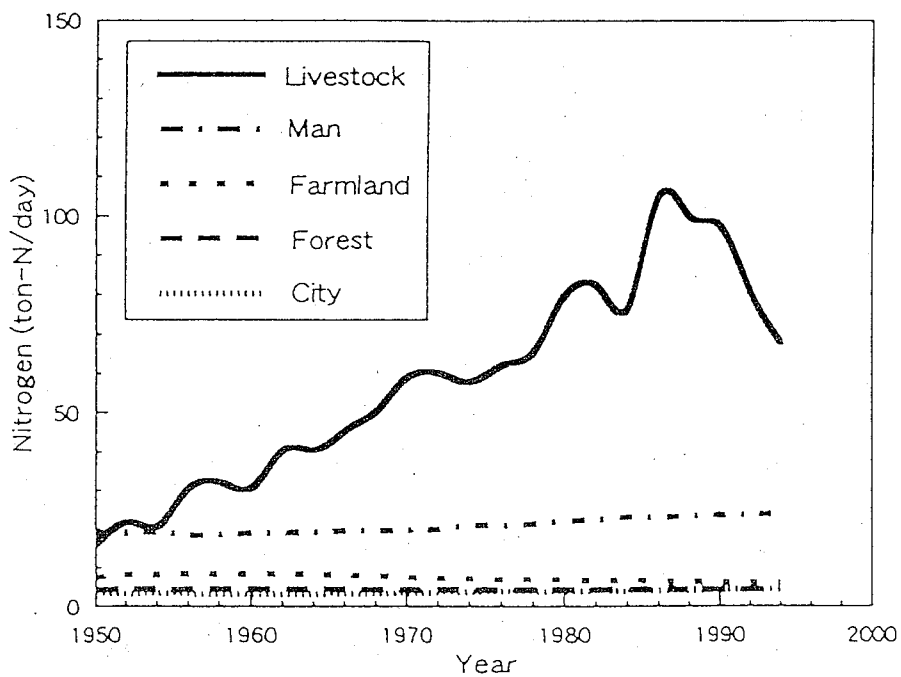
Fig.6　Nitrogen generation from different sources
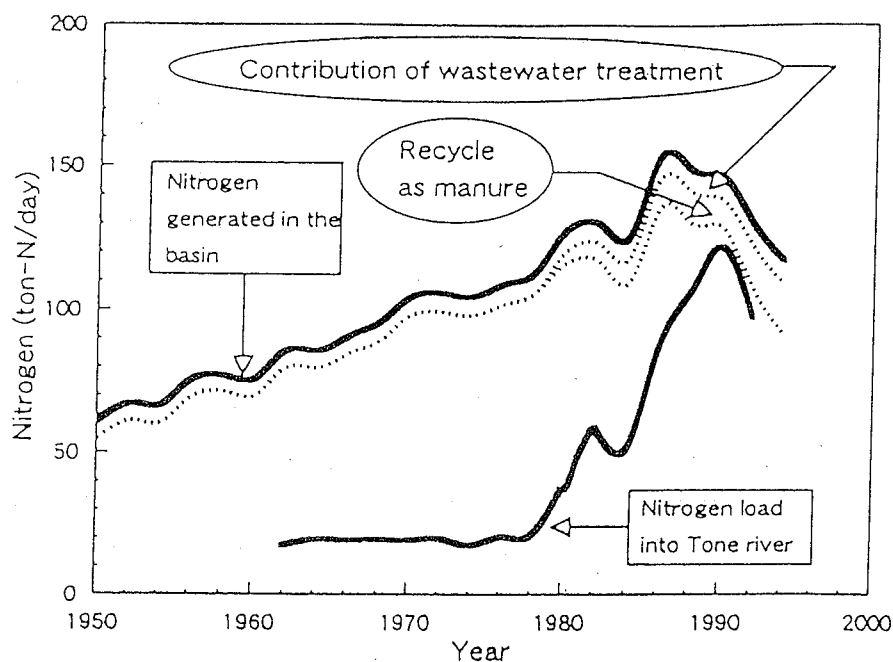
Fig.7 Nitrogen generated in the basin and nitrogen load into Tone River.
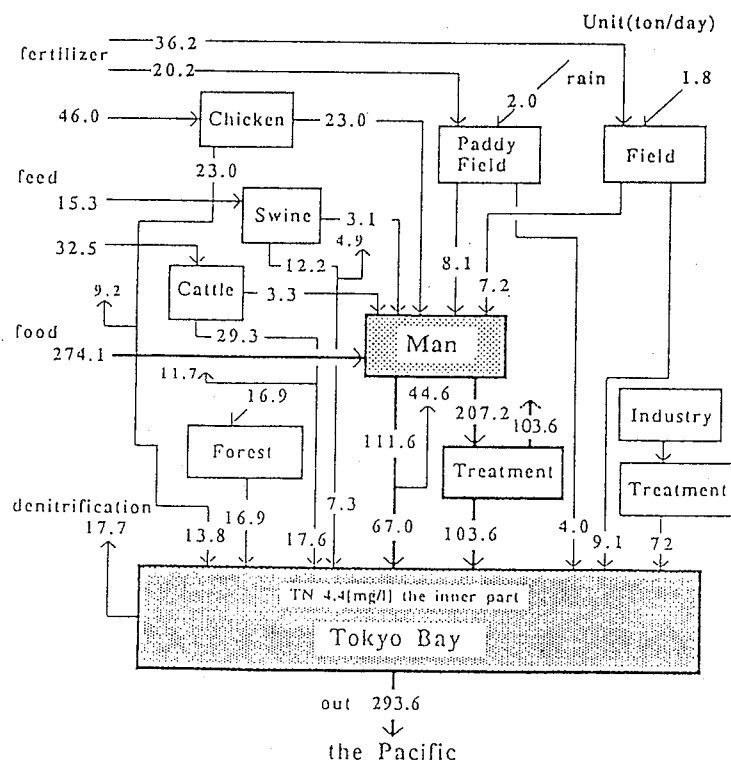
Fig.8 Nitrogen budget in Tokyo Bay and its basin in 1990. Unit: [ton day^{-1}]

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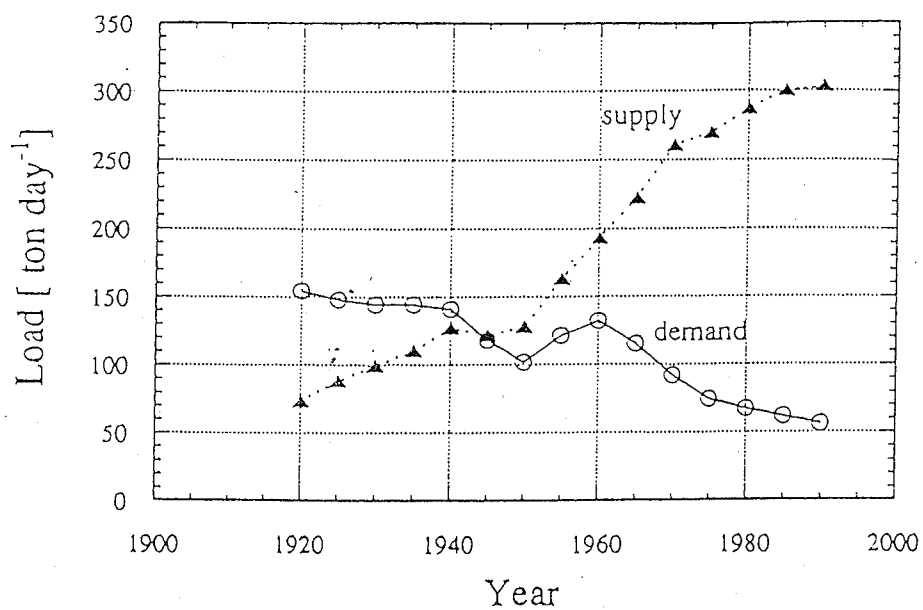
Fig.9   Nitrogen supplied as manure and fertilizer demand in the basin of Tokyo Bay.

Chapter 10

Watershed Management and Conservation of Ecosystems
Goichiro Takahashi

10.1 Introduction

In this lecture I focus on works which are installed in streams for the prevention of disasters caused by flood and debris flow, etc. Specifically, these works I refer to are check dams, erosion control dams, ground sills, revetment (bank protection), spur dykes, channelization, etc.

These stream works are undoubtedly very important with respect to the protection of human lives and the conservation of farmland and many other kinds of engineering projects. As the potential for these kinds of disasters is very high in Japan, an extraordinary number of these works have been installed in streams all over the country. Almost all streams in Japan have experienced some change into artificial channels, and the variety of stream environments has hence been drastically reduced.

Much damage has occurred in Japan to the ecological function of streams. The coordination of channel alteration and ecological conservation must be considered more seriously.

Here, I consider some principles for the coordination based on an explanation of the concept of the stream environment and the role of physical features on the stream environment, and also introduce some trials as examples of specific works.

10.2 Concept of the Stream Ecosystem

Watershed management generally consists of the application of civil engineering works which alter the geomorphology of streams and land, and also hydrologic and hydraulic regimes. These physical changes have serious effects on the stream ecosystem. In order to consider conservation of the stream, we must understand the processes of the effects based on the stream ecosystem.

As far as stream ecosystems are concerned in relation to watershed management, the most important aspect is the role of the physical characteristics of streams on the stream ecosystem. A major concern in ecology has been the various relationships between living things and environmental factors. As for lotic ecology, ecologists have investigated the relationship between living things, and have had much concern about abiotic aspects, such as water temperature, flow velocity, the concentration of oxygen and many other chemical substances, etc. However, the role of dynamic stream geomorphology was not studied enough. It is only in the last two decades that the importance of the physical features of streams on the stream ecosystem has been recognized and studied. Here, I explain the significance of the physical features of streams, taking up some concepts.

10.2.1 Riparian zone

A riparian zone is a relatively narrow area of the interface between aquatic and terrestrial environments. In the case of a fully channelized stream, its watery area is clearly limited by dykes or artificial banks. The land surrounding the stream is thereby

divided into a watery area (the channel) and the dry area. Contrastingly, the borders of a channel flowing in an alluvial floodplain are naturally obscure. The channel width varies in accordance with the stream discharge. In other words, some parts are always under flowing water, and some other parts are dry sometimes and watery at other times. At such places it is very difficult to distinguish channel and dry land clearly. A floodplain is an area that is adjacent to channel and subject to channel water, and has different characteristics from that of a slope in terms of biological and physical features. This kind of area is the riparian zone, which touches or is close to the channel and is influenced by both aquatic and terrestrial environments. The riparian zone is not entirely a terrestrial environment as it is often covered with water, yet at the same time neither is it a stream environment. From an ecological point of view, the riparian zone is a very remarkable environment that has the characteristics of both terrestrial and stream environments. It thereby greatly contributes to the biological diversity.

10.2.2 Hyporheic zone

The hyporheic zone has recently caught the eye of ecologists because it is significant as a habitat for riverine lives. This zone is a sort of floodplain aquifer which is hydraulically connected to the channel i.e. water goes back and fourth between the channel and the zone (Fig. 1). It was after riverine invertebrates were collected from a well located 2km away from a channel that the hyporheic zone became the focus of attention.

The Hyporheic zone is thought to be very common in gravel bed rivers. A stream not only carries water but also conveys bed material load, i.e. boulders, gravel and sand, etc. The bed load is deposited in and around a stream, and the channel (the area of running water) exists on the bed materials. As the bed materials are relatively coarse and are not well consolidated, deposits are likely to be porous and permeable, thereby letting water flow under the ground. Ground water comes out as a spring and leakage, forming or feeding ponds and side pools in a floodplain.

Fig. 1 A.- The stream's function in its catchment is viewed simply as that of a pipe. B.- A contrasting view of the stream's function places the stream as an integral part of the catchment system. (Bencala 1993)

Otherwise, it directly springs out in a channel. This water may influence the water temperature condition at that place. Thus, the hyporheic zone causes environmental diversity as well as functioning as a habitat.

10.2.3 Riffle-pool structure

Riffles and pools are formed in a stream; they are thus quite common

topographical features to a stream, and have been studied by many scientists. However, they are very important elements in the stream ecosystem as well.

In stream geomorphology, a riffle-pool sequence is likened to a wave structure because it appears with a certain spatial interval regularity. Riffle-pool structure is closely related to bar formation (Leopold et al. 1964). A riffle is usually formed on alternate bars, and a pool is placed just below the riffle. The distance between riffles (wave length or spatial interval) is several times that of the channel width. In a steep mountain stream, it looks like a sequence of drops and small pools, and its wave length is very short. This feature is called a step-pool structure

Fig. 2 (After Takahashi 199*) Explanation of the Kani's system concerning reach types. Top row: Geometiric arrangement of riffle-pool sequence within a half wave of river meandering is a major point for distinguishing reach types of the Kani's system. Reaches with only one set of riffle and pool in the half wave are identified as "B", and others as "A". Middle row: Observing the flowing condition of riffles locating just up pools, there are three types: a) plunging with trampling manner on riffles, characterized by the dominance of white water caused by the mixture of abundant air bubbles, b) flowing down into pool still maintaining fast current velocity, however, the water surface is not trampling but wavy, c) water flows smoothly and the water surface looks tranquil, distinction of riffles and pools basically owes undulation of river bed. Bottom row: The realistic combination of the above tow distinction systems includes three patterns. "A" type of riffle-pool arrangement connects "a" type of flowing motion. On the other hand, "B" type connect "b" and "c" type. As a result, three reach types --Aa, Bb and Bc-- are to be identified.

(Whittaker and Jaggi 1982). The physical processes concerned with its formation are different from those of the riffle-pool structure.

Riffles and pools define the condition of running water. The complex relationship between topographical and hydraulic diversity caused by riffle-pool structure basically controls the stream ecosystem. Kani (1944, 1981), an entomologist classified riffle-pool features systematically in order to describe the habitat of aquatic insects. Kani's system (Fig. 2) is excellent with respect to that it corresponds to the habitat distribution of many aquatic insect species.

Generally, riffles, being shallow, are parts of fertility. They are exposed to more sunlight, leading to the proliferation of algae and small insects which are mostly algae eaters. Pools, on the other hand, function as the basic habitat for fish. Mizuno (1985) reported that the standing crops of fish rose by 60 to 120 times in weight after a large pool had been rebuilt in an altered river reach. According to Ruggles' rearing experiment of juvenile coho salmon (Ruggles 1966) a pool-like environment holds a high population density, the largest average size recorded in a riffle-like environment.

For smolt production, half-riffle and half-pool environments were excellent.

10.2.4 Land-water interaction and stream ecosystem

A watershed is a container of rock, gravel, soil and water, and it drains water. A stream is a major drainage medium. Sediments are also conveyed with water. While water is quickly drained, the movement of sediments is intermittent. The complex relationship between water and sediment movement forms various features of the stream environment.

Riparian zones, formed on a valley floor, alluvial fans and floodplains are relatively low, relatively damp areas. This characteristic arises from the process and nature of deposition. Deposition is driven by water flow and makes landforms, and landforms determine the flowing condition of water. This land-water interaction concept can be applied to the processes of hyporheic zones where ground water is concerned. The interaction between water and gravel is also recognized in the formation of riffle-pools. Riffle-pool structure is associated with bars, and bars are a typical feature in a stream formed by deposition.

Fig. 3 Relationships among landforms, geomorphic processes, fauna, and flora. A. Define habitat, range. Effects through flora. B. Define habitat. Determine disturbance potential by fire, wind. C. Affect soil movement by surface and mass erosion. Affect fluvial processes by damming, trampling. D. Sedimentation processes affect aquatic organisms. Effects through flora. E. Destroy vegetation. Disrupt growth by tipping, splitting, stoning. Create new sites for establishment and distinctive habitats. Transfer nutrients. F. Regulate soil and sediment transfer and storage. (after Swanson 1980)

The ecosystem of a stream is largely dependent on geomorphology and flowing conditions, which are just manifestation of the land-water interaction. Therefore, it is the land-water interaction that has the primary relation to the stream ecosystem. (Fig. 3).

10.3 Influence of stream engineering works

Since works for watershed management vary, their effects also vary considerably. But these effects can be divided into two categories: one is the disappearance of continuity in a watershed, the other is the devastation of the environmental diversity of a stream.

Japanese rivers have suffered from the construction of innumerable dams. The ones constructed in order to reserve water tend to be huge, resulting in the complete division of the river. Dams built for the control of erosion and sedimentation are relatively small; they are, at biggest, 30m in height, and mostly less than 15m. Furthermore, many of the dams whose purpose is not to accumulate but rather to prevent degradation of the stream bed are less than 5m. These are called ground sills or low dams.

These measures can be likened to falls. The most typical effect is that they

block the passage of fish. In fact, not only fish but also many other living things pass along a stream. Therefore, dams are an obstacle for them as well. In the case of a dam constructed in a valley, it may possibly act as a barrier for even a land animal moving along the stream.

A river is a kind of transportation route for many things. Water, sediments and other substances are conveyed from the mountains to the ocean and land. On the other hand, some creatures, like salmon for example, move up a river. They grow in the ocean and migrate to upstream reaches and die after spawning. This represents an upward transportation of nutrients, energy and substances. From an ecological point of view, this upward transportation has a significant function because nutrients and energy obtained in the ocean are supplied to upstream reaches, which are poor in nutrition and organic matters. This upward transportation of energy and nutrients contributes much not only to aquatic ecosystems but also to terrestrial ones in the upper part of a watershed. Dams make the transportation in a river slower, smaller, or less active. This influence might damage the entire ecosystem of a watershed in the long run.

Devastation to environmental diversity is complicated, and it would be difficult to describe it in detail. However, the scheme of the effects is simple on the whole.

As explained in the previous section, the stream ecosystem is maintained by the complicated relationships or diversity among geomorphologic, hydrologic, and hydraulic elements. The basic tendency of installing channel works is to simplify the complex; specifically, making the border between dry and riverine areas clear, straightening the course of the channel, etc. (Fig. 4). These works, even if the individual effect of each works might be small, accordingly destroy the complex relationships among the environmental elements, resulting in the devastation of the fundamental structure of the stream ecosystem as a whole.

Fig. 4 Typical channelized stream.

10.4 Principles of synthesizing watershed management and environmental conservation

Based on the explanation outlined earlier, we have concluded that the principles for holistic conservation of stream ecosystems can be outlined as follows (Ohta and Takahashi 1999). (Numbers at the head of each item do not represent priority.)

1) holistic conservation of biological community
2) importance of disturbance caused by bed load movement
3) conservation perspectives based on holistic point of view to a watershed
4) importance of prevention of disasters induced by debris flow and flooding, etc.

The last item is nothing but the most important matter in watershed management. In this section this item is left out because it is a matter of course.

10.4.1 Holistic conservation of biological community

The biological community is an overall set of lives in an area. Reference to conservation of the biological community includes conservation of the relationships between all possible combinations of lives.

When conservation of nature is taken into account, some specific species which are endangered or rare are often focused upon. Although the protection of such species is indeed important, it should not be because they are considered to be rare or valuable, but rather because they are a necessary part of the holistic system. A species does not exist independently at all. A more important point is to conserve the overall relationships among living creatures, including the rare species. Any individual species of population continues to live by feeding on other living creatures, and competing or having a symbiotic relationship with other species, etc. The key species which sustains an ecosystem may often be an very common species. Even if a rare species is emphasized for protection, the most important point is the conservation of the overall structure of relationships in the ecosystem.

To understand a biological community is very difficult. It requires much effort, and skill and experience in ecological research. In comparison to dealing with a biological community, doing research on a specific species or population is practical and rational. However, this approach is no more than an approach is no more than a step in the understanding of a biological community. It is important to orientate holistic conservation of a biological community by placing research into a specific species of population into an understanding of the entire biological community.

10.4.2 Importance of disturbance caused by bed load movement

As explained in section 2, the land-water interaction is the most important framework for the stream ecosystem. The interaction is induced by bed load movement, which includes debris flow, deposition, bank erosion, local scouring, abrupt or gradual change to the channel course, etc. These phenomena often cause serious damage to human activities. Stream works, the purpose of which is the prevention of such damage, have been designed to settle down or make moderate the bed load movement. It is evident that these works inevitably do much harm to the framework of the stream ecosystem. A basic contradiction can thereby be found between the coordination of environmental conservation and disaster prevention measures on a stream.

A complete solution will never be found as human activities are carried out on fluvial land, and a better solution can accordingly be a realistic goal. In Japan, officials in charge of watershed management and river engineering used to attach importance exclusively to disaster prevention. In order to aim at such a goal, a not superficial but rather a fundamental alteration to traditional methods is needed.

Paying more attention to the disturbance caused by bed load movement means to tolerate a risk that some facilities, such as roads and bridges, in and near a stream will suffer from destruction caused by debris flow or flooding. According to the ordinary method of stream engineering in Japan, even a small disaster must be avoided.

From now on, we should distinguish disasters; small disasters that are to be tolerated and serious ones which must be avoided. Another important matter regarding this goal is to give more land to a stream. In the past, people wanted larger areas for their farms in order to produce more, and officials tried to make streams as narrow as possible. In order to restore the freedom of streams, areas of farmland adjacent to such channelized streams should be returned to floodplain.

10.4.3 Conservation perspectives based on holistic point of view to a watershed

Conservation of the stream environment must be considered with relation to other environmental elements, even if the stream environment has a limited area and number of species or standing crops. A river system is a major path of energy, nutrients and many substances between terrestrial and ocean environments.

An individual plan for watershed management is usually applied to a limited area of a watershed. Especially as far as environmental care is concerned, conservation of all living things which inhabit the limited area is to be taken into account. The environmental care must not be considered independently, because the stream ecosystem in the limited area is connected to other environmental elements. It has some direct interactions with the lower and upper stream ecosystems, and indirect interactions with the ocean ecosystem. In the case of a stream within a mountain area, the stream ecosystem has a relation to the slope ecosystem.

This principle can be explained from another point of view. A stream system can be recognized as a hierarchical structure with regards to spatial scale. The hierarchy consists of a stream network level, a segment level, a reach level, a unit level and a microhabitat level (Frissel et al. 1986). The stream network level is the overall framework of a stream with a spatial scale of 10^3m order. A segment is a stream section which has a single stream order (usually 10^2m order). A segment can be divided into several stretches of relatively straight channel section, and each stretch is a component of reach level (10^1m order). A reach consists of a combination of riffles and pools (unit level, 10^0m order). And the smallest is the microhabitat level (10^{-1}m order) which relates to a single boulder or a small pot hole, etc. Each feature at different levels is closely related to both its own geomorphic process and ecological function. For example, a habitat for algae and aquatic insects almost completely corresponds to a small space of the microhabitat level, and the composition and distribution of species and populations are to be taken in connection to the structures greater than the segment level. Each level is autonomous as well as influenced by other levels in terms of both physical and ecological aspects.

Watershed management is basically planned based on the overall understanding of the watershed; however, an individual plan for a dam or channel works directs focus to a specific part of the watershed. When incorporating environmental care into an individual project, it is necessary to have a deep understanding of the hierarchical structure and relationships involved.

10.5 Some trials and clues

In the last section, I will introduce some trials. Perfect solutions which satisfy both conservation of the stream environment and disaster prevention may not ever be found. In the last two decades, Japanese civil engineers have gradually changed

their attitudes. Although they have carried out many trials, they mostly have not been successful. However, we can find some useful clues to improve environmental care through surveying those trials.

10.5.1 Near-nature stream works

The concept of 'near-nature' was introduced from Europe to Japan in the mid 80's. In Switzerland and Germany, restoration works to artificially channelized streams had been developed. The major aspects of these works are as follows:

working towards the healthy existence of living things, including humans

encouraging lesser order, more diversity (especially in the broader between land and water)

utilizing living materials in the projects (trees, grass) as much as possible rather than hard materials such as timber, rocks, and concrete

letting streams take their natural course

not hesitating to revise completed projects

disclosing information

Works based on the ideas behind the European projects have been established on many Japanese streams. Fig. 5 shows an example of one such project. This one is truly different from the traditional channel works (see Fig. 4), indeed. Looking at the near-nature stream works shows that they look very strange compared to natural streams. The strangeness is thought to come mainly from its hard texture. There surely are riffle-like and pool-like features; however, they are not genuine units but pseudo ones. The stream banks and parts of the stream bed are fixed with cement, and hence topographic change of the channel, accompanied by erosion and sedimentation will not occur. The small amount of gravel means the habitat for aquatic insects is bad, and immature development of riffles and pools can not sustain a large fish population. This is an example of a project that is not based on the essence of the stream nature, but rather only imitates a natural stream superficially. Similar cases are common in Japan.

Fig. 5 Channelized stream with 'environmental care'. The care does not essentially compensate for loss to the stream ecosystem because the banks and bed are almost completely fixed.

As for restoration of channelized streams, the following items come in for primary consideration:

widening the stream bed

not fixing the stream bed and banks with hard materials

The feasibility of these items depends on the importance of preventing disasters and the nature of land use around the stream. Both items would be difficult to achieve if the land adjacent to the stream has already been highly utilized. Even in a rural area, extensive explanation to land owners and people living near the stream

about the works is required in order to buy the land and to accomplish the restoration smoothly.

As mitigation or substitution of concrete bank protection, buried revetment or hidden revetment is useful (Fig. 6). This revetment provides a soft and permeable border area between land and water. It greatly improves the environmental diversity compared to the concrete revetment installed on top of banks. Planting trees on the stream bank is also good for the stream ecosystem. However, stands of
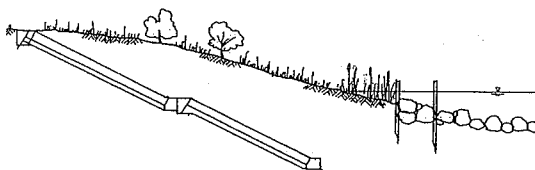
Fig. 6 An alternative method of revetment. Revetment made with hard materials is laid, and then covered with soil, which provides ecotone, and upon which vegetation hold.

timber may become a cause of unfavorable erosion and deposition, so the planting of trees should be carried out after careful consideration. A spur dyke is one of the traditional works for bank protection (Fig. 7). Spur dykes obstruct stream flow and accelerate scouring of the stream around themselves, and then possibly form pool-like features

without the necessity of fixing the bank completely when they are designed correctly.

10.5.2 Fishway

A fishway is a facility which is fixed to a dam or other river works which block the passage of fish, enabling fish to pass the obstacle (Fig. 8). Although there are some fishways attached to natural obstacles, such as a very turbulent stretch of a river, they are mostly attached to artificially made obstacles. Some fishways, in spite of the name, are actually designed for crabs, mammals, etc.

In this section, the explanation is limited to fishways which are attached to works which are for the control of sediment and erosion (to be called a 'sabo dam' hereafter). The structure of

Fig. 7 Spur dyke made of concrete protects the bank from erosion, as well as making a pool and riffle-pool like feature by obstructing the flow.
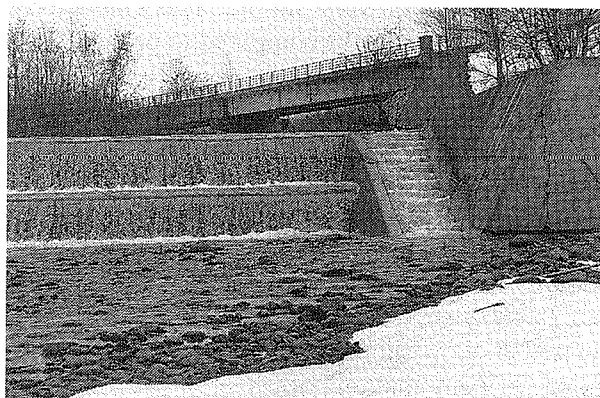
Fig. 8 Sabo dam and fishway. The fishway is not judged to be functional because of its violent flow and unsuitable position. (Most fish cannot find the fishway entrance.)

fishways at a sabo dam is almost the same as that of fishways at other dams because they all tend to block up the channel section. The pool-and-wire type is the most common types of fishway; on the other hand, other types such as the Denil type, the vertical slot type, and the Ice Harbor type have recently been distributed in Japan.

There is an essential limit with regard to the function of fishways. Provision of fishways at a dam does not ensure the continued existence of migratory fish at their original level of abundance, which the facilities were designed to do. These kinds of fishways, being almost all established by a set technique, would work well within their technical specifications if they are designed and installed properly. In reality, many fishways at sabo dams in Japan have some problems because of improper design or some other constraining situation.

The most remarkable point of sabo dams is that they are free from control of discharge, i.e. they do not need to reserve water. Sabo dams can take advantage of this characteristic in the design of both themselves and fishways. In satisfying the function of controlling sediment and erosion, the design and structure of sabo dams must can be free from those of other kinds of dams. In other words, sabo dams can be low, and need not block up the entire channel section. The method of installing a series of low dams is a system for erosion and sediment control based on this idea.

Fig. 9 View of a series of low dams. A fishway is attached to the dam at the bottom of the picture.

The series of low dams consists of three or more dams that each has a height of 1-2m, the distance between the dams being about 50m (Fig. 9). These dams are wider than the usual groundsills. By spacing the dams close together, the entire channel longitudinal profile is controlled, preventing secondary erosion and accelerating deposition. The dams are so low that provision of a fishway is very easy, and the structure is very simple. This characteristic is more advantageous in terms of the function of fishways compared to ordinary sabo dams. Extending the characteristics of the method of a series of low dams, Takahashi (1998) proposed alteration of the method (Fig. 10). In the proposed method, as each dam has an incision, it may not be correct to call them a set of dams, but rather they should be called a combination of long spur dykes. In any case, because of the existence of the incised

Fig. 10 A proposal to improve the method of a series of low dams (Takahashi 1997). Each dam is cut in the middle and the body of the dam near the incision slants downward. Water flows along the series of incisions while at a low level (A), and along the wider part (B) during flooding. As there are no drops, it is greatly advantageous for the passage of fish.

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passage, there is even less difficulty for fish than that of the series of low dams. This proposed method is not embodied yet at present. Although there are some problems yet to be solved in realizing this method, I am convinced that it works well.

10.5.3 Importance of trial-evaluation-feedback cycle
Environmental care in erosion and sediment control works in streams for disaster prevention is not established very well technically. Designing engineering projects based on the revision of the principles that are explained in section 4 requires discussion at a fundamental level before trials of real projects can begin. Many of the established or proposed methods and works are no more than trials.

The best solution has yet to be found, and may not be found in the future. In recognizing this situation, the most important matter is the effort to improve the technical level of the works. There is no guaranteed solution to this goal; the only way is trial and error. Since our understanding of the stream ecosystem and physical phenomena in a stream is limited, failure or unintended results can certainly arise. The first step is to monitor the situations before and after installing stream works, and then evaluation and recording the effects. Even if the result is bad, getting feedback for the next project is critical. This process of trial-evaluation-feedback is indispensable for improvement of our techniques.

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Part II

The Training Course in 2000

The Training course in 2000 Summer

Hydrology related to Headwater Management

Outline

"Head Water Area" is understood as both supplying a source of clean water and assisting in the prevention of flood/sediment disasters for living people downstream. Over-cutting of trees or industrial pollution sometimes damage to the surrounding environment of "Head Water". Japan has experiences such failures 100years ago. In the training course, We would like to focus on hydrological impacts of non-vegetation and the effects of both reforestation in steep slope and erosion control works in river-bed, in a watersheds damaged in the past with sulphurous acid gas caused by the refining factory of copper. Lectures are provided at the Faculty of Technology, Gunma University, Kiryu-city, Gunma Prefecture, and field training is to be done in the basin of the Watarase River, a tributary of the Tone River which is very important for Tokyo Metropolitan.

Objectives

Why we should pay attention to the circumstance of "Head Water Area" is lectured theoretically and empirically through hydrological analysis. It usually takes long years to recover devastated mountain. It just means that practical field works have to be evaluated scientifically and technologically by long-term survey and observation. Knowledge and wisdom obtained have to be expanded to countries with similar climate and topological condition. Trainees could learn significance of head water conservation through lectures, practices and field tours.

Course Contents
Lecturers

T.Ohta:	Graduate School of life and Agriculture, University of Tokyo
S.Kobatake:	Faculty of Technology, Gunma University
Y.Fukushima:	Institute for Hydrospheric-Atmospheric Sciences,

Nagoya University

Y.Kawano: Forestry Agency, Ministry of Agriculture

M.Nishi: Nikko Branch Office, Ministry of Construction

K.Honda: Asian Institute of Technology, Thailand

T.Tsujimoto: Graduate School of Engineering, Nagoya University

H.Tanji: Institute for Agricultural Engineering, Ministry of
                         Agriculture

H.Kawashima: Graduate school of life and Agriculture, University of
                         Tokyo

G.Takahashi: Toyama Prefectural University of Agriculture

Lectures

L.1-1 Typology of erosion processes and watershed management (T.Ohta)

Headwater areas in the world are roughly divided into two types geologically, namely continental type eroded area and island-arc type eroded area. In the former area, gravitation erosion predominates, while in the latter, surface erosion predominates. In this lecture, how to control watershed will be presented from the view point of erosion control.

L.1-2 Effect of human activities on head water (T.Ohta)

Once there were wide spread degraded land tracts in the central part of Japan. About one hundred years ago, the government established the River Law, the forest Law and Sabo Law, and people made every effort to recover forests. Conseqently, Japan has better forests and sediment-related disasters decreased.The Japanese experience will be explained in this lecture.

L.1-3 Histry of mountain devastation in the Watarase River (S.Kobatake)

Though mountain slope should be covered by forest climatically, the reason why it was devastated is explainned.

L.2 Hydrological processes in headwater (Y.Fukushima)

Hydrological processes such as rainfall, snowfall, infiltration, evaporation, snowmelt, overland flow, sub-surface flow, base flow and

river runoff formation, are theoretically and practically lectured by using lots of examples. Finally, how could we estimate the worth of forest coverage is discussed by using models.

L.3-1 Forest conservation project in headwater areas (Y.Kawano)

Taking consideration of the natural condition on our country such as about terrain, geology, climate and vegetation, etc, forest conservation works based on management of forests have been playing very important role in watershed management in Japan. So, the lecture reviews the history of development and the back-up system of forest conservation project in Japan. Especially, it presents systematically the technique such as the typical engineering works (hillside works, check dams, etc), the method of reforestation, etc , for rehabilitation of devastated land and forest in headwater areas.

L.3-2 Erosion control in Japan (M.Nishi)

Torrent control works are also carried out in devastated torrent in Japan. Field survey, planning, execution of works are introduced in detail.

L.3-3 Evaluation of Erosion Control Work using Remote Sensing and GIS (K.Honda)

Evaluation of erosion control work on forest recovery and water/sediment discharge is important. Forest recovery process was modeled using remote sensing. Also water and Sediment discharge model, which is linked with forest recovery simulation, were developed. Several scenario of erosion control work were evaluated using these models.

L&P.4 Runoff analysis of head water (S.Kobatake)

There are some classifications for runoff model, for example, distributed model vs. lumped model and conceptual model vs. physical model. Whatever runoff model we choose, the most important step in runoff calculation is estimation of effective rainfall. The way to estimate effective rainfall and some representative runoff models are introduced. Exercises are also included.

L&P.5 Sediment Transport and River Management (T.Tsujimoto)

In this course, it is firstly demonstrated how important the comprehensive control of sediment is for integrated river management including the views of disaster prevention, water resources development and eco-system preservation. Next, fundamentals of mechanics of sediment transport and fluvial hydraulics are lectured and some exercises are provided. Then, it is introduced how such basic knowledge and techniques contribute to understanding of rivers and river basins and their integrated management, and further exercises are provided as well.

L.6-1 Irrigation system and watershed management (H.Tanji)

Well-developed irrigation system requests well-managed mountain watershed. Irrigation system in Japan is explained in the relation with watersged management.

L.6-2 River basin management and water quality (H.Kawashima)

The relation between river water quality and land use in its basin is lectured. Agricultural activity, the number of livestock and population density in the basin affects much influence on the river water quality. Nitrogen balance is the key concept to interpret this relationship.

L.6-3 Watershed management and conservation of ecosystem (G.Takahashi)

Watershed management used to be considered and performed with respect to water resources, control of flood, erosion and sedimentation, etc. In order to keep desirable environment, ecological perspectives and activites should be incorprated into watershed management. Basic concept and some activities are introduced in this lecture.

Schedule   (July 24 - August 6, 2000)

July 24 (Mon)	Arrival at Narita Airport and move to Kiryu-city
25 (Tue)	Guidance, Lecture 1 at the campus of Gunma University
26 (Wed)	Lecture 2
27 (Thu)	Lecture 3
28 (Fri)	Technical tour to Ashio
29 (Sat)	Technical tour to Mt. Nantai
30 (Sun)	Inspect sights of Nikko
31 (Mon)	Lecture and Practice 4

August 1 (Tue)   Lecture and Practice 5
      2 (Wed)   Technical tour to the integrated Dam Control Office
      3 (Thu)   Lecture 6
      4 (Fri)   Technical tour to the Watarase Retarding Basin and Tone-Oozeki Barrage
      5 (Sat)   Move to Tokyo
      6 (Sun)   Departure from Narita

Participants

Mr. Evandri Ahmad, (Indonesia):
R&D Center for Informatic and Computer Science
Mr. Suy Sovann, (Cambodia):
Ministry of Water Resources and   Meteorology
Mr. Manoloth Soukhanouvong, (Lao PDR):
Department of Meteorology and Hydrology (DMH)
Ministry of Agriculture and Forestry (MAF)
Ms. Stephanie Bowis, (New Zealand):
West Coast Regional Council
Ms. Ubolwan Jenphanitsub, (Thailand):
Office of the National Water Resources Committee
The Secretarial of the Prime Minister
Mr. Nguyen Kim Tuyen, (Vietnam):
Hydrometeorological Service of Vietnam
Mr. Karma, (Buthan):
School of Science, Nagoya University
Mr. Adhikari Birendra Raj, (Nepal):
School of Science, Nagoya University
Ms. Myagmar Munkhtsetseg, (Mongolia):
School of Science, Nagoya University

Part III

Past Activities of the IHP

Training Course

Past Activities of the IHP Training Course

1. Past activities of the IHP Training Course
(1991-1998)

The *IHP Training Course in Asia and the Pacific Region* has been executed since 1991 by the Working Group for IHP Training Course, under the direction of the Sub-Committee for IHP, Japanese National Commission for UNESCO. The Training Course was aimed at giving the participants an opportunity to learn observation technology of hydrology and to have practical experience in hydrological observation in the field.

In the First to Sixth- sessions of the Training Course, the training began with two or three preliminary lectures to introduce the subjects to be studied throughout the remainder of the course schedule. After this introduction, students have been taken around to several specialized institutes, in the days following, to hear about what was actually done there, and to see modern instrumentation in general hydrology. It has been found, however, that this training approach possibly encourages passiveness on the part of the students because they spend an inordinate amount of time travelling daily to the host institutions where they can only listen and observe rather than participate actively.

Some innovations, therefore, was made at the Seventh-session, both in the educational content and in the schedule. Firstly, we decided to focus the training course on more clearly defined targets, and the first year's programme concentrated on Snow Hydrology. Secondly, we decided to include practice sessions such as a field programme to allow the students, themselves, the opportunity to carry out experiments and make relevant observations /analyses. Finally, we decided to prepare a newly edited textbook for the participants in the training course.

Last Japanese fiscal year which ended in March 1999 the Eighth-session was concentrated on Remote Sensing.

2.   First to Sixth- session on General Hydrology
(1991-1996)

2.1   T1 The First IHP Training Course, 1991

T1.1   Participants

Ms. Zhao Ling (China): Student of the Special Program of Sciences of Atmosphere and Hydrosphere,   Graduate School of Science, Nagoya University

Mr. Zhao Jing (China): ibid.

Ms. Hidajat Bernadia Irawati Tjandradewi (Indonesia): ibid.

Mr. Geng Biao (China): Student of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Ms. Sri Mulat Yuningsih (Indonesia): The Research Institute for Water

Mr. Roslan Bin Sahat (Malaysia): Resources Development, Department of

Public Works Hydrology Branch, Department of Drainage and Irrigation

T1.2   Schedule and Program
Opening lectures, held at Water Research Institute, Nagoya University, were given by the following specialists:

Takagi, F.   (Professor, Department of Civil Engineering, Faculty of Technology, Nagoya University): Runoff processes in river watersheds.

Fujiyoshi, Y.   (Associate Professor, Laboratory of Atmospheric Environment, Water Research Institute, Nagoya University): Precipitation and water resources in Asia, part 1.

Kato, K.   (Assistant Professor, ibid.): ibid., part 1.

Ishizaka, Y.   (Associate Professor, Laboratory of Atmospheric Physics, ibid.): ibid., part 2.

Ageta, Y.   (Professor, Laboratory of Hydrospheric Physics, ibid.): ibid., part 3.

Sakamoto, M.   (Professor, Laboratory of Aquatic Ecology, ibid.): The matter cycle and water quality in the hydrosphere, part 1.

Handa, N.   (Professor, Laboratory of Organic Geochemistry, ibid.): ibid.,part 2.

Ohta, K.   (Associate Professor, ibid.): ibid., part 3.

The Training Course was presented from March 2 to 19, 1992 according to the following schedule:

Mar. 2 – 3   Water Res. Inst., Nagoya Univ. (Nagoya)
             · Lecture on runoff processes in river watersheds
             · Lecture and Practice Session on precipitation and water
               resources in Asia
             · Lecture and Practice Session on the matter cycle and water
               quality in the hydrosphere

Mar. 4 – 6   Chubu Regional Construction Bureau, Min. of Construction
             (Chubu Region)
             · Technical tour of hydrological facilities for river control

Mar. 7- 8 (Sat-Sun): holidays

Mar. 9   Water Resources Res. Center, Disaster Prevention Res. Inst.,
             Kyoto Univ.
             · Laboratory experiment on evaporation from bare soil

Mar.10   Kiryu Experimental Catchment, Faculty of Agriculture, Kyoto
             Univ.
             · Meteorological and hydrological observations at a small
               catchment in hilly terrain

Mar. 11   (Kyoto to Tsukuba)

Mar. 12   Forestry & Forest Products Res. Inst., Min. of Agriculture,
             Forestry & Fisheries (Hitachi-Ohta)
             · Training on evaporation and soil moisture measurements,
               and hydrological observation

Mar.13   National Inst. for Environmental Studies, Environment Agency
             (Tsukuba)
             · Technical tour of research facilities for water quality
               conservation

Mar. 14-15   (Sat-Sun): holidays

Mar. 16-17   Public Works Res. Inst., Min. of Construction (Tsukuba)
             · Lectures on hydrological observations and models of water
               discharge

Mar.18   Forecast Dept. & Observation Dept., Japan Meteorological
             Agency (Tokyo)
             ·   Lecture and technical tour concerning short-range
                 precipitation   forecasting using radar and the AMeDAS
                 (automated meteorological data acquisition system).

Mar. 19   Meteorological Satellite Center, Japan Meteorological Agency
             (Kiyose)
             · Technical tour of Meteorological Satellite Center.

T2.1　Participants

Ms. Thapa, Arati (Nepal): Student of Special Program of Sciences of
　　　Atmosphere and Hydrosphere, Graduate School of Science,
　　　Nagoya University
Mr. Kayastha, Rijan Bhakta (Nepal): ibid.
Mr. Sarwono, Pitoyo Sudibyo (Indonesia): ibid.
Mr. Le Cong Thanh (Vietnam): ibid.
Mr. Xu Guangxiang (China): ibid.
Mr. Adisak, Suriyavanagul (Thailand): Electricity Generating Authority
Mr. Pham Van Tan (Vietnam): Network Operation Department,
　　　Hydrometeorological Service
Mr. Ekanayaka M. Wimalasena (Sri Lanka): Investigation Section,
　　　National Water Supply and Drainage Board
Mr. S. Mahmoud Borghei (Iran): Assistant Professor, Department of Civil
　　　Engineering, Sharif University of Technology

T2.2　Schedule and Program

　　　Opening lectures were given by the following personnel from the Water
Research Institute, Nagoya University:

Ohata,T.　　　(Assistant Professor, Laboratory of Hydrospheric Physics):
　　　　　　Precipitation and water resources in Asia, part 1.
Kato, K.　　　　(Assistant Professor, Laboratory of Atmospheric
　　　　　　Environments):
　　　　　　ibid., part 2.
Ishizaka ,Y.　　(Associate Professor, Laboratory of Atmospheric Physics)
　　　　　　ibid., part 3.
Terai, H.　　　(Associate Professor, Laboratory of Aquatic Ecology):
　　　　　　The material cycle and water quality in the hydrosphere.

　　　The Training Course was presented from March 1 to 18, 1993 according
to the following schedule.

Mar. 1- 2　　Water Res. Inst., Nagoya Univ. (Nagoya)
　　　　　　　　· Lecture and Practice Session on precipitation and water
　　　　　　　　resources in Asia
　　　　　　　　· Lecture and Practice Session on the matter cycle and
　　　　　　　　water quality in the hydrosphere
　　　　　　　　· Technical tour

Mar. 3- 5   Kanto Regional Construction Bureau, Min. of Construction
             (Nagoya to Tokyo, Kanto Region)
                 · Technical tour of hydrological facilities for river control

Mar. 6- 7 (Sat-Sun): holidays

Mar. 8- 9   Environmental Res. Center, Univ. of Tsukuba (Tsukuba)
                 · Observation and data analysis of evapotranspiration
Mar. 10-11   National Res. Inst. for Earth Science & Disaster Prevention,
             Science & Technology Agency (Tsukuba-Ichihara, Chiba)
                 · Laboratory experiment of rainfall
                 · Technical tour of an experimental hydrological catchment

Mar. 12-14 (Fri-Sun): holidays

Mar. 15-16   National Res. Inst. of Agricultural Engineering, Min. of
             Agriculture, Forestry & Fisheries (Tsukuba)
                 · Analysis of irrigation and drainage
                 · Study of experimental ground water facilities
Mar. 17   Forecast Dept. & Observation Dept., Japan Meteorological
             Agency (Tokyo)
                 · Lecture and technical tour for short-range precipitation
                   forecasting using radar and the AMeDAS
Mar. 18   Meteorological Satellite Center, Japan Meteorological Agency
             (Kiyose)
                 · Technical tour of Meteorological Satellite Center

2.3   T3   The Third IHP Training Course, 1993

T3.1 Participants

Mr. Kamal, Md. Syeeduzzaman (Bangladesh): Student of the Special Program
    of Sciences of Atmosphere and Hydrosphere, Graduate School of Science,
    Nagoya University.

Ms. Sipayung, Sinta Berliana (Indonesia): ibid.

Ms. He Kaiqing (China): ibid.

Mr. Zhu Yan (China): Department of Hydrology, Hohai University

Mr. Wu Yongxiang (China): Nanjing Institute of Hydrology & Water Resources,
    Ministry of Water Resources

Ms. Suva, Imelda Manalastas (Philippines): Bureau of Research & Standards,
    Department of Public Works & Highways

Mr. Dwivedi, Ashok Kumar (India): Hydrological Investigations Division,

National Institute of Hydrology, Roorkee

Mr. Ahmad, Bashir (Pakistan): Centre of Excellence in Water Resources
Engineering, University of Engineering & Technology, Lahore

T3.2 Schedule and Program

Opening lectures were presented by the following specialists from the
Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:

Kato ,K.   (Assistant Professor, Division of Water Cycle): Multi-scale cloud
                distributions in monsoon regions of Asia.
Tanaka, H.   (Professor, Division of Material Cycle): Cloud physics and
                chemistry in climate studies.
Ageta ,Y.   (Professor, Division of Water Cycle): Asian cryosphere and
                changes in water resources.
Nakawo, M.   (Associate Professor, Division of Water Cycle): Water cycle and
                stable isotopes.

The Training Course was presented from August 16 to September 2, 1993
according to the following schedule:

Aug. 16-17   Inst. for Hydrospheric-Atmospheric Sci., Nagoya Univ.
                (Nagoya)
                    · Lectures on the International Hydrological Programme.
                    · Lecture and Practice Session on precipitation and water
                      resources in Asia.
                    · Lecture and Practice Session on the matter cycle and
                water
                    quality in the hydrosphere.
Aug. 18-20   Chubu Regional Construction Bureau, Min. of Construction
                (Chubu Region)
                    · Technical tour of hydrological facilities for river control.

Aug. 21-22 (Sat-Sun): holidays

Aug. 23   Water Resources Res. Center, Disaster Prevention Res. Inst.,
                Kyoto Univ.
                    · Lecture on control of run-off water.
Aug. 24   Kiryu Experimental Catchment, Faculty of Agriculture, Kyoto
                Univ.
                    · Meteorological and hydrological observations at a small
                      catchment in hilly terrain.
Aug. 25   (Kyoto to Tsukuba)
Aug. 26   Forestry & Forest Products Res. Inst., Min. of Agriculture,
                Forestry & Fisheries (Hitachi-Ohta)

> - Training on evaporation and soil moisture measurements, and hydrological observation.

Aug. 27   Public Works Res. Inst., Min. of Construction (Tsukuba)
> - Lectures on hydrological observations and models of water discharge.

Aug. 28-29 (Sat-Sun): holidays

Aug. 30   Public Works Res. Inst., Min. of Construction (Tsukuba)
> - Lectures on hydrological observations and models of water discharge.

Aug. 31   National Inst. for Environmental Studies, Environment Agency (Tsukuba)
> - Technical tour of research facilities for water quality conservation.

Sep. 1   Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)
> - Technical tour of Meteorological Satellite Center

Sep. 2   Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)
> - Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.

2.4 T4 The Fourth IHP Training Course, 1994

T4.1 Participants

Mr. Sunil Adhikary (Nepal): Student of the Special Program of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Mr. Zhang Wan Chang (China): ibid.

Mr. Mohammad Rezwanul Islam (Bangladesh): ibid.

Mr. Birbal Rana (Nepal): Student of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

Ms. Y.K. Handapangoda (Sri Lanka): Teaching Assistant in Civil Engineering, University of Peradeniya, Peradeniya

Ms. Byambaagiin Oyunchimeg (Mongolia): Ministry of Nature and Environment, Institute of Water Problems, Ulaan Baatar

Mr. M. Fakhruddin (Indonesia): Puslitbang Limnology, LIPI, Bogor

Ms. Gadis Sri Haryani Bengen (Indonesia): Research and Development Center for Limnology, Indonesian Institute of Sciences, Bogor

T4.2   Schedule and Program

Opening talks were presented by the following lecturers from the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:

Kato, K.   (Assistant Professor, Division of Water Cycle): Asian monsoon and water cycle.
Handa, N.   (Professor, Division of Material Cycle): Carbon cycling with water cycle.
Terai, H.   (Associate Professor, Division of Material Cycle): Aquatic micro-organisms and water quality.

The Training Course was presented from August 15 to September 1, 1994 according to the following schedule:

Aug. 15-16   Inst. Hydrospheric-Atmospheric Sci., Nagoya Univ. (Nagoya)
    · Lecture on the International Hydrological Programme.
    · Lecture and Practice Session on precipitation and water resources in Asia.
    · Lecture and Practice Session on the biogeochemical cycle and water quality in the hydrosphere.
Aug. 17-19   Kanto Regional Construction Bureau, Min. of Construction (Nagoya to Tokyo, Kanto Region)
    · Technical tour of hydrological facilities for river control.

Aug. 20-21 (Sat-Sun): holidays
Aug. 22-23   Environmental Res. Center, Univ. of Tsukuba (Tsukuba)
    · Observation and data analysis of evapotranspiration.
Aug. 24-25   National Res. Inst. of Agricultural Engineering, Min. of Agriculture, Forestry & Fisheries (Tsukuba)
    · Analysis of irrigation and drainage.
    · Study of experimental facilities for ground water.
Aug. 26   National Inst. for Environmental Studies, Environment Agency (Tsukuba)
    · Technical tour of research facilities for water quality conservation.
Aug. 27-28 (Sat-Sun): holidays
Aug. 29-30   National Res. Inst. for Earth Science & Disaster Prevention, Science & Technology Agency (Tsukuba-Chiba Pref.)
    · Large scale rainfall experiment.
    · Technical tour of an experimental hydrological catchment.

Aug. 31	Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)
	· Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.
Sep. 1	Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)
	· Technical tour of Meteorological Satellite Center

2.5 T5 The Fifth IHP Training Course, 1995

T5.1 Participants

Ms. Meng Xiao (China): Student of the Special Program of Sciences of Atmosphere and Hydrosphere,   Graduate School of Sciences, Nagoya University

Mr. Talukder Abul Bashar MD. Alauddin (Bangladesh): ibid.

Mr. Liu Jing Shi (China): ibid.

Mr. Begkhutod Perapol (Thailand): ibid.

Mr. Bhatt Maya Prakash (Nepal): ibid.

Mr. Ma Xieyao (China): Student of Sciences of Atmosphere and Hydrosphere, Graduate School of Science, Nagoya University

T5.2 Schedule and Program

The Training Course was presented in three parts according to the following schedule: Part 1 from December 13 to 15, 1995, Part 2 from February 13 to 16, 1996 , and Part 3 from March 11 to 15, 1996.

<Part 1: Chubu Region>

Dec. 13-15	Chubu Regional Construction Bureau, Min. of Construction (Aichi and Gifu)
	· Technical tour of hydrological facilities for river control.

<Part 2: Kinki Region>

Feb. 13	Lake Biwa Res. Inst., Shiga Pref. (Otsu)
	· Lecture and technical tour for Lake Biwa.
Feb. 14	Branch Office of Kinki District of Public Works, Min. of Construction (Otsu)
	· Lecture and technical tour for mountain conservation.
	Dept. of Forestry, Kyoto Univ. (Otsu)
	· Lecture and technical tour of an experimental basin.
Feb. 15	Disaster Prevention Res. Inst., Kyoto Univ. (Uji)

· Lecture and technical tour on disaster prevention.
Hirakata Operation Center, Min. of Construction (Hirakata)
· Lecture on river water control.

Feb. 16   Section of River Management, Kyoto Pref. (Kyoto)
· Technical tour concerning river management.

<Part 3: Kanto Region>

Mar. 11   Inst. for Forestry and Forest Products, Min. of Agriculture,
Forestry and Fisheries (Hitachi-Ohta)
· Training on evaporation and soil moisture
measurement, and on making hydrological observation.

Mar. 12   National Inst. for Environmental Studies, Environment
Agency, (Tsukuba)
· Technical tour of research facilities for water quality
conservation.

Mar. 13   Public Works Res. Inst., Min. of Construction (Tsukuba)
· Lecture on hydrological observation and models of
water discharge.

Mar. 14   Forecast Dept. & Observation Dept., Japan Meteorological
Agency (Tokyo)
· Lecture and technical tour concerning short-range
precipitation forecasting using radar and the AMeDAS.

Mar. 15   Meteorological Satellite Center, Japan Meteorological Agency
(Kiyose)   · Technical tour of Meteorological Satellite Center

2.6   T6   The Sixth IHP Training Course, 1996

T6.1   Participants

Mr. Zulkefle bin Ghazali (Malaysia): Hydrology Division, Department of
Irrigation and Drainage
Mr. Rhoel C. Villa (Philippines): National Hydraulic Research Center, U.P.
College of Engineering
Mr. Luong Tuan Anh (Vietnam): Institute of Meteorology and Hydrology,
Hanoi Hydrometeorological Service of Vietnam
Mr. Atthaporn Buddhapolit (Thailand): Hydrology Division, Royal Irrigation
Department
Ms. Rungkarn Krishnamra (Thailand): Soil and Water Conservation Division,
Land Development Department

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T6.2 Schedule and Program

Opening lectures were presented at the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University by the following lecturers:

Kuraji, K.   (Professor, University of Tokyo): Hydrological characteristics of tropical forests.

Nakamura, K. (Professor, Institute for Hydrospheric-Atmospheric Sciences, Nagoya University): Remote sensing from space.

Tachikawa ,Y. (Professor, Kyoto University): Development of distributed rainfall-runoff model by using digital elevation models.

Takeuchi, K.   (Yamanashi University): The new thrust of IHP activities in Southeast Asia and Pacific, Asian/Pacific FRIEND (Flow Regimes from International Experimental and Network Data).

The Training Course was presented from August 19 to September 5, 1996 according to the following schedule:

Aug. 19-20   Inst. for Hydrospheric-Atmospheric Sciences, Nagoya Univ. (Nagoya)
- Lecture on International Hydrological Programme
- Lecture concerning forest effects on the hydrological cycle in tropical regions
- Lecture on precipitation measurement by remote sensing
- Lecture on hydrological modelling.
- Lecture on Asian FRIEND.

Aug. 21-23   Kanto Regional Construction Bureau, Min. of Construction (Kanto Region)
- Technical tour of hydrological facilities for river control.

Aug. 24-25 (Sat-Sun): holidays

Aug. 26-27   Environmental Research Center, Tsukuba Univ. (Tsukuba)
- Lecture and Practice Session on evapotranspiration measurements.
- Lecture on the role of the biosphere for climate systems.

Aug. 28-29   National Res. Inst. of Agricultural Engineering, Min. of Agriculture, Forestry & Fisheries (Tsukuba)
- Analysis of irrigation and drainage.
- Technical tour to an irrigated paddy field.

Aug. 30   Public Works Res. Inst., Min. of Construction (Tsukuba)
- Technical tour of research facilities for water quality conservation.

Aug. 31-Sep. 1 (Sat-Sun): holidays

Sep. 2-3	National Res. Inst. for Earth Science & Disaster Prevention, Environment Agency (Chiba Pref.)

Sep. 2-3   National Res. Inst. for Earth Science & Disaster Prevention, Environment Agency (Chiba Pref.)
                · Large-scale rainfall experiment.
                · Technical tour to the hydrological catchment basin.
Sep. 4   Forecast Dept. & Observation Dept., Japan Meteorological Agency (Tokyo)
                · Lecture and technical tour concerning short-range precipitation forecasting using radar and the AMeDAS.
Sep. 5   Meteorological Satellite Center, Japan Meteorological Agency (Kiyose)
                · Technical tour of Meteorological Satellite Center.

3.   T7   The Seventh IHP Training Course, 1998:
Snow Hydrology

The general aim of the IHP short course is to help participants develop their basic knowledge of hydrological systems and of their sensitivity to climate changes as well as to contribute to solving current global environmental problems. The cryosphere is most vulnerable to the projected global warming trend that has recently become a major concern in many countries. The seventh training course focuses on snow hydrology. The topics covered range from basic knowledge of the role of the cryosphere in the global environment to technical applications, including observations and measurements in snow packs.

3.1 T7.1 Participants

Mr. D. B. Chettri, Executive Engineer, Meteorology Unit, Div. Power, Ministry of Trade and Industry(Bhutan)
Mr. Liang, Zhongmin, Teacher, Dept. Hydrology, Hohai University (China)
Mr. Om Ratna Bajracharya, Senior Hydrologist, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)
Mr. Shiva Bhakta Prajapati, Hydrologist, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)
Mr. Aurangzeb Khattak, Assistant Director, WRRC (Pakistan)
Mr. Edvin Aldrian, M2, IHP Student, IHAS Nagoya University (Indonesia)
Mr. Dang Xuan Phong, M2, IHP Student, IHAS Nagoya University (Vietnam)
Mr. Li, Jianjun, M2, IHP Student, IHAS Nagoya University (China)
Mr. Yudi Iman Tauhid, M2, IHP Student, IHAS Nagoya University (Indonesia)
Mr. Bhuwan Chandra Bhatt, M1, IHP Student, IHAS Nagoya University(Nepal)

Mr. Zhou Shiqiao, M1, IHP Student, IHAS Nagoya University (China)

Mr. Kayastha Rijan Bhakta, Research Fellow, IHAS (Nepal)

Mr. Suresh Chandra Pradhan, Hydrological Assistant, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)

Mr. Keshav Raj Sharma, Hydrological Assistant, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)

Mr. Chok Bahadur Gurung, Hydrological Assistant, Dept. Hydrology and Meteorology, Ministry of Science and Technology (Nepal)

Dr. Dorji Wangdu, Head, Division of Geology and Mines (Bhutan)

Ms. Diraagiin Erdenetsetseg, Expert, Centre for Climate and Environmental (Mongolia)

Mr. Nozomu Naito, D3, Graduate Student, IHAS Nagoya University (Japan)

Mr. Fumio Nakazawa, M1, Graduate Student, IHAS Nagoya University(Japan)

Mr. Yosihiro Yoshioka, M2, Graduate Student, Nagaoka University of Technology (Japan)

3.2 T7.2 Schedule and Program

Lecturers

Ageta, Y.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University
Aoki , T.	Meteorological Research Institute
Goto-Azuma, K.	Nagaoka Institute of Snow and Ice Studies, National Research Institute for Earth Science and Disaster Prevention
Hayakawa, N.	Department of Civil and Environmental Engineering, Nagaoka University of Technology
Iida ,H.	Sediment Control Division, Department of Civil Engineering, Toyama Prefectural Government
Kamiishi , I.	Centre of Snow and Ice Technology, ARGOS Co. Ltd.
Kobayashi, S.	Research Institute for Hazards in Snowy Areas, Niigata University
Lu, M.	Department of Civil and Environmental Engineering, Nagaoka University of Technology
Mizuno, H.	Meteorological College
Nakawo, M.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University
Ohno, H.	Japan International Research Centre for Agricultural Sciences
Satow, K.	Civil Engineering, Nagaoka National College of Technology
Takeda, T.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University

Takeuchi, Y.   Nagaoka Institute of Snow and Ice Studies, National Research Institute for Earth Sciences and Disaster Prevention

Yokoyama, K.   Hokuriku National Agricultural Experiment Station

Schedule (9 March, 1998 - 22 March, 1998)

Mar. 9 (Mon) Arrival at Nagoya, Japan

Mar. 10 (Tues) (IHAS, Nagoya University)
- Guidance
- Lecture on Glaciers and the water cycle
- Lecture on precipitation process
- Lecture on synoptic conditions and snow fall precipitation process
- Icebreaker reception in the evening

Mar. 11 (Wed) (IHAS, Nagoya University)
- Technical Tour
- Move from Nagoya to Myoko (4 hour's train ride)

Mar. 12 (Thurs)
- Lecture on water circulation over the earth: the roles of snow and ice
- Radiation processes and remote sensing of snow
- Practice session for spectral albedo observations on a snowfield

Mar. 13 (Fri)
- Lecture on snowmelt hydrology
- Practice session for Hydrographical Observations
- Fabrication of the Endo-type snow-water content meter (1)

Mar. 14 (Sat)
- Lecture on metamorphism of deposited snow
- Lecture on snow changes in snow pack and melt water chemistry during snowmelt
- Lecture on heat budget of a snow pack

Mar. 15 (Sun) Technical bus tour to
- Niigata Experiment Laboratory, Public Works Research Institute
- Tohkamachi Experiment Station, Forestry and Forest Products Research Institute
- Nagaoka Institute of Snow and Ice Studies, National Research Institute for Earth
- Science and Disaster Prevention(Stay overnight at a Spa, Yomogihira Hot Spring, in the snowy region)

Mar. 16 (Mon)
- Technical bus tour continues to Myoken Weir, Shinano River
- Facilities for snow removal by melting in Nagaoka City

- Shinano River Work Office, Hokuriku Regional Construction Bureau
- Oukouzu Division Work, Shinano River and the Division Work Museum
- Arai Weir, Shinano River
- Fabrication of the Endo-type snow-water content meter (2)

Mar. 17 (Tues)	• Practice session for heat exchange over a snow surface
Mar. 18 (Wed)	• Practice session for snow pit observations
Mar. 19 (Thurs)	• Data handling exercise (reception in the evening)
Mar. 20 (Fri)	• Report preparation
	• Move from Myoko to Nagoya (train ride)
Mar. 21 (Sat)	• Closing ceremony
Mar. 22 (Sun)	• Departure from Nagoya

4. T8 The Eighth IHP Training Course, 1999 on Remote Sensing

Recently, the environmental problems attracts strong attentions. The spatial scales of the problems range from very local one to global one. Environmental problems have close connection to atmospheric and hydrospheric phenomena. For the atmospheric and hydrospheric sciences, satellite remote sensing is very useful and essential because of its capability to observe the atmosphere and hydrosphere in a big scale. For example, recently launched TRMM (Tropical Rainfall Measuring Mission) is providing us a unique three-dimensional rain structures regardless of the location over tropical and a part of midlatitude regions. ADEOS (Advanced Earth Observing Satellite) gave us beautiful images of global phytoplankton distribution over global ocean.

Ground-based remote sensing which includes radars and lidars is also useful for the atmospheric observation.

The lectures give: the basic theory of remote sensing, technogy and applications, and current Earth observation satellites, etc.

4.1 T8.1 Participants

Mr. Limsakul Atsamon: Institute for Hydrospheric-Atmospheric
    Scinences, Nagoya University, Japan
Ms. Jiang Cuiling: Institute for Hydrospheric-Atmospheric Scinences,
    Nagoya University, Japan
Mr. Aryal Deepak: Institute for Hydrospheric-Atmospheric Scinences,
    Nagoya University, Japan
Ms. Aranya Fuangswasdi: Ground Water Division, Department of

Mineral Resources, Thailand

Ms. Zainab Hashim: Hydrology Division, Department of Irrigation and
    Drinage, Malaysia

Mr. Wibowo Hendro: Puslitbang Limnologi-LIPI, Indonesia

Dr. Cheng Ming: Nanjing Institute of Hydrology and Water Resources,
    Ministry of Water Resources, China

Mr. Te Navuth: Ministry of Water Resources and Meteorology, Cambodia

Ms. Yuko Ogawa: Global Information and Early Warning Service, Food
    and Agriculture Organization of the United Nations, Italy

Mr. Thongdum Pengyai: Hydrometeorology Division, Meteorological
    Depart-ment, Thailand

Mr. Chhetri B. Tek: Institute for Hydrospheric-Atmospheric Sciences,
    Nagoya University, Japan

Mr. Haryoko Urip: Meteorological and Geophysica Agency, Indonesia

Ms. Li Zhuxiao: Institute for Hydrospheric-Atmospheric Sciences,
    Nagoya University, Japan

4.2 T8.2   Schedule and Program

List of lecturers and lecture titles

Prof. Y. Honda	Chiba University: Global vegetation observation II
Dr. T. Iguchi	Communications Research Laboratory, Ministry of Posts and Telecommunications: Active microwave measurement of rain and clouds from space I
Dr. T. Itabe	Communications Research Laboratory, Ministry of Posts and Telecommunications: Lidar proving of the atmosphere
Dr. K. Kajiwara	Chiba University: Global vegetation observation I
Prof. T. Koike	Nagaoka University of Technology: Soil wetness measurement from satellite microwave remote sensing
Dr. T. Kozu	Communications Research Laboratory, Ministry of Posts and Telecommunications: Active microwave measure- ment of rain and clouds from space II
Prof. K. Nakamura	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:

	Observation of atmosphere by radar
Prof. T. Saino	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:
	Ocean color observation by satellite
Prof. H. Shimoda	Tokai University:
	Current remote sensing technology for global warming monitoring
Dr. D. Short	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:
	The Tropical Rainfall Measuring Mission
Prof. K. Tsuboki	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University:
	Radar measurement of precipitation processes
Dr. S. Uratsuka	Communications Research Laboratory, Ministry of Posts and Telecommunications:
	Synthetic aperture radar and its applications

Schedule   8-21 March, 1999

Mar. 8 (Mon)	Arrival at Nagoya, Japan
Mar. 9 (Tues)	Guidance, lectures and reception at IHAS, Nagoya Univ.
Mar. 10 (Wed)	Lectures and technical tour in IHAS, Nagoya Univ.
Mar. 11 (Thurs)	Lecture and guidance of data analysis training
Mar. 12 (Fri)	Data analysis training
Mar. 13 (Sat)	Data analysis training (cont'ed)
Mar. 14 (Sun)	Move to CRL at Koganei, Tokyo
Mar. 15 (Mon)	Lectures
Mar. 16 (Tues)	Lectures and Technical tour at CRL
Mar. 17 (Wed)	Move to Tokai Univ. and lectures /Move to Chiba Univ.
Mar. 18 (Thurs)	Lectures
Mar. 19 (Fri)	Lectures and move to Nagoya
Mar. 20 (Sat)	Free day
Mar. 21 (Sun)	Departure from Nagoya

5. T9   The Ninth IHP Training Course in 1999, Summer
on Limnology

Limnology is a field of study on terrestrial water ecosystems such as lakes, rivers, reservoirs, ground waters and wetland. Human activities have been linked very closely to those water ecosystems and changed them directly or indirectly through global environmental changes. We have to learn basic

limnological processes and how to manage and conserve those water ecosystems with sustainable development through the next century.

Limnological studies in Japan only began in 1899 and we are celebrating their centennial history. The following programs have been prepared to welcome trainees of the IHP training course in limnology in the summer of 1999.

5.1 T9.1 Participants

A total of 8 participants of which 6 were selected and sent by UNESCO, 2 IHP students in the Special Graduate Course at the Institute for Hydrospheric-Atmospheric Sciences, Nagoya University*.

Mr. Abung Rachmann
    Research Institute for Water Resources Development (RIWRD),
    Indonesia
Dr. Arveti Nagaraju
    Department of Geology, Sri Venkateswara University, India
Dr. Chen Yuanfang
    College of Water Resources and Environment, Hohai University,
    P. R. China
Ms. Daram S. Enkhtsetseg
    Institute of Meteorology and Hydrology, Mongolia
Mr. Hossain Md Anawar*
    Institute for Hydrospheric-Atmospheric Sciences, Nagoya University,
    Japan
Ms. Lythi M. Hai
    Department of Water Resources and Environment, Institute of
    Geography, Vietnam
Mr. Mohd. Talha Mohd. Zaharon
    Environmental Health Section, Engeneering Services Division,
    Ministry of Health, Malaysia
Ms. Sirisampan Satiraporn*
    Institute for Hydrospheric-Atmospheric Sciences, Nagoya University,
    Japan

5.2 T9.2 Schedule and program

List of lecturers and lecture titles

Dr. Terai, H.   Institute for Hydrospheric-Atmospheric Sciences, Nagoya
                 University: Material cycling in deep and shallow water
                 ecosystems.
Dr. Ichino, K.   Faculty of International communication, Aichi University:

	Low-cost water treatment systems using constructed wetlands.
Dr.Yoshioka, T.	Institute for Hydrospheric-Atmospheric Sciences, Nagoya University: Current technology in limnology (1) Stable isotope ecology.
Dr. Okino, T.	Faculty of Sciences, Shinshu University: A historical review of limnology in Japan and a case study on Lake Suwa.
Dr. Kato, K.	School of Allied Medical Sciences, Shinshu University: Current technology in limnology (2) Microbial ecology.
Dr. Hanazato, T.	Suwa Hydrobiological Station, Shinshu University: Global environment and lake ecosystems.
Dr. Fushimi, H.	School of Environmental Sciences, The University of Shiga Prefecture: Water resources and environmental problems of Lake Biwa.
Dr. Sakamoto, M.	School of Environmental Sciences, The University of Shiga Prefecture: Eutrophication and management of freshwater environments.
Dr. Nakamura, M.	Lake Biwa Research Institute, Shiga Prefecture: Lake Biwa – Yodo River water systems: Evolving issues on integrated management of water quality.
Dr. Kumagai, M.	Lake Biwa Research Institute, Shiga Prefecture: Ecological inhomogeneity due to dynamic variability in Lake Biwa.
Dr. Nakajima, T.	Lake Biwa Museum, Shiga Prefecture: Evolution and distribution of cyprinid fish in East Asia during Neogene, and formation of the cyprinid fauna in Lake Biwa.
Dr. Walker,R.F.	Lake Biwa Research Institute, Shiga Prefecture: Current technology in limnology (3) Algal species classification by image processing.
Dr.Nakamoto,N.	Faculty of Textile Science and Technology, Shinshu University: Misunderstanding of slow sand filtration in Japan and the biological mechanism of its system.
Dr. Overmars,M.	UNESCO, Jakarta Office: Special Lecture: Current IHP activities in Asia Pacific Region.

Schedule 26 July – 8 August, 1999

July 1999

26 (Mon)	Arrival at Nagoya, Japan
27 (Tues)	Guidance, Lectures at IHAS (icebreaker reception in the evening)
28 (Wed)	Move to Suwa Hydrobiological Laboratory, Guidance and Lecture

29	(Thurs)	Field trip on Lake Suwa, observation and sampling
30	(Fri)	Chemical and biological analysis of water and sediment samples
31	(Sat)	Field trip to Lake Shirakoma, observation and sampling (reception in the evening)

August

1	(Sun)	Technical bus tour to Kurobe Reservoir and Nishina subalpine lakes
2	(Mon)	Lake Kizaki Laboratory, Travel to Hikone by train
3	(Tues)	Lecture at The University of Shiga Prefecture,Visit Limnological Laboratory, Move to Otsu
4	(Wed)	Lecture and Technical tour at Lake Biwa Research Institute
5	(Thurs)	Field trip to Lake Biwa on the research vessel "Hakken"
6	(Fri)	Technical tour to Lake Biwa Museum, Back to Nagoya
7	(Sat)	Closing Ceremony and Reception
8	(Sun)	Departure from Nagoya