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A Study on Low Streamflow and its Severity for Water Resources Preservation in Forested River Basin[1]

by

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低水流量に基づく低水度区分とその評価に関する一考察

テリヨノ　スダルマジ

Abstract

Clarification of the status of low streamflow and its severity in a river basin as one of the most important considerations for achieving sustainable water resources in adequate quantity (referred to as streamflow discharges), quality (referred to as suspended sediment production) and the timing distribution of water resources in a river basin was discussed. Water deficiency was shown to be closely related to the subjects of hydrology, meteorology and agriculture, of which this study emphasized low streamflow as a kind of water deficiency related to the field of hydrology.

Index of low streamflow severity *(SIL)* was referred to as the annual low streamflow severity *(ALS)* in which greater *SIL* grade indicates a more severe low streamflow severity. *ALS* lower than 200 mm *(SIL－1, SIL－2)* were slight and fair, whereas those greater than 200 mm *(SIL－3, SIL－4, SIL－5)* were moderate, hard and very hard severe of low streamflow respectively. The Atsuma River Basin, identified as *SIL－3*, was selected for this study because it is one of the representative low streamflow area in Hokkaido.

Potential streamflow discharges and suspended sediment production were used for expressing the hydro-orological conditions. The relation between *ALS* and specific streamflow discharges was used to estimate *ALS* in each selected Sub-Basin. A simple model assessment of the hydro-orological condition was established by comparing streamflow discharge and suspended sediment production. The rank of hydro-orological conditions, in descending order are as follows : (1) Shoshiutsu, (2) Shuruku, (3) Chikapeppu, (4)

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Atsuma, (5) Shoroma, (6) Merukunnai, (7) Ukuryu, (8) Onikishibe and (9) Habiu Sub-Basin.

Precipitation has a significant influence on low streamflow, while other factors were geological structures, morphological features and local river basin characteristics. The augmentation of low streamflow was accepted as an important consideration for improving the hydro-orological conditions. Several river basin management practices have been carried out in the Atsuma River Basin. A great fluctuation of streamflow discharges might be reduced or at least minimized so as to control and improve the seasonal distribution of water yields.

Key words : Water resources, Annual low streamflow severity, Index of low streamflow severity, Hydro-orological condition, Streamflow discharge, Suspended sediment production

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Introduction

The distribution of water resources on the earth's surface is inequitable. Some areas repeatedly suffer from severe low streamflow or drought, while others experience high streamflow or flood due to a wide variation of physiographic characteristics and environmental conditions. Although areas have similar conditions, (climatic factors, geological structures and geomorphological features), modification through human misuse or mismanagement may, however, cause changes in the hydro-orological conditions.

Water resources have been the central issue of concern with natural and altered environments. The rapid growth of water usage without proper assessment may lead water shortages. Therefore, water resource development planning should consider water' s spatio—temporal distributions. The spatial term should be interpreted as an unequal distribution of water resources within river basins or regions, whereas the temporal term means the fluctuation within definite periods or seasons. In a river basin that suffers from perceivable severe low streamflow, it is necessary to both plan and implement water resources management for seasonal streamflow distribution control, promotion of multipurpose water use and preservation or improvement of the hydrological conditions.

Streamflow discharge in any river basin is the primary source of water resources. Recent studies of low streamflow in relation to water shortage or drought, (in terms of magnitude, duration and severity) have been frequently neglected. Therefore, knowledge concerning low streamflow should be studied further due to its importance in the planning of water resource development and allocation of streamflow discharge among the growing variety of competing uses.

A river basin as a geographic unit for hydrological studies has been the prominent approach for the last two decades. This scale provides a baseline of hydrological information for clarifying the hydro-orological conditions. Therefore, a river basin might be considered to be the proper geographic unit of areal dimension for the basic analysis of potential water resources and their management. This scale appears to be the most reasonable unit for performing hydro-orological studies based on the input-output relationships for clarifying low streamflow and its severity in the descending order of region, river basin and sub-basin.

The main objective of this study is to clarify the present status of low streamflow and its severity (on the scale of region, river basin and sub-basin) as one of the most important considerations to achieve sustainable water resources in adequate quantity (referred to as streamflow discharges), quality (referred to as suspended sediment production) and its timing distribution. This study is expected to provide basic consideration of water resource planning development, preservation and improvement of the hydro-orological conditions.

I. Study Method

1. Study Method

Streamflow hydrograph have been widely used as indicators for reflecting the input—output and waterflow processes of the hydrological cycle in a river basin. The relation between input and output is hypothetically outlined in Fig.1. The most important characteristics are the time of rise, time of falling limb and magnitude of both extremes (minimum and maximum), which are considered to be different from river basin to river basin. In this study, the fluctuation of streamflow discharges, their magnitude and period, was the main concern, but with an emphasize on minimum streamflow discharge. The two extremes of streamflow discharge within its seasonal distribution are normally recognized in term of low and high streamflow discharges. An illustration for describing spatio-temporal distribution of streamflow discharge in two river basins is given in Fig.2 (Salt R. and Manistee R.).

The utilization of water resources involves several prerequisites, such as quantity, quality and timing of delivery which determine its usability and affect its values — enhanced value and reduced value (Fig.3). Enhanced value means that water resources can be delivered on time to meet maximum water requirements. It would change to reduced value if water resources come from low streamflow which leads a water shortage. It would also be reduced value in a flood situation because water is wasted or carry damaging amounts of sediment or devastating debris downstream from the headwaters. Concerning the prerequisite of water quality, suspended sediment production, was observed

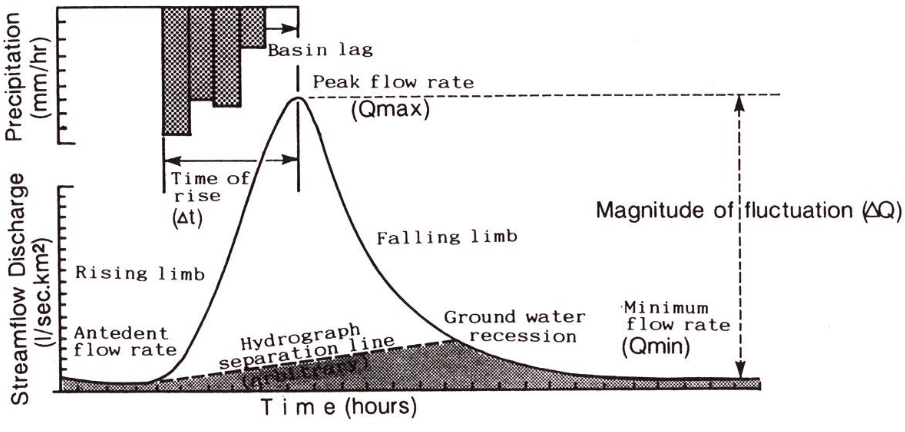


Fig. 1. Hypothetical Hydrograph of Streamflow Discharge in Response to Precipitation Occurrences (Redrawn from Hewlet, 1982)

related to streamflow discharges.

The framework of the study (Fig.4) consists of the basic approaches and procedures for clarifying low streamflow and its severity. The procedures initially begin with the areal scale ordering by proposing scale order of region, river basin and sub-basin. The compilation of a baseline of hydrological information and determination of regional low streamflow were performed using serial data measurement. A similar procedure was then applied in a selected river basin. Subsequently, a combination of serial and temporal data was used to clarify the phenomena of low streamflow and its severity on the sub-basin scale. The result was then used in a discussion of some aspects of river basin practices in relation to water resource preservation and the improvement of hydro-orological conditions.

The basic consideration for defining low streamflow and its severity was established according to the study objectives. Criterion for proper truncation level, determining the

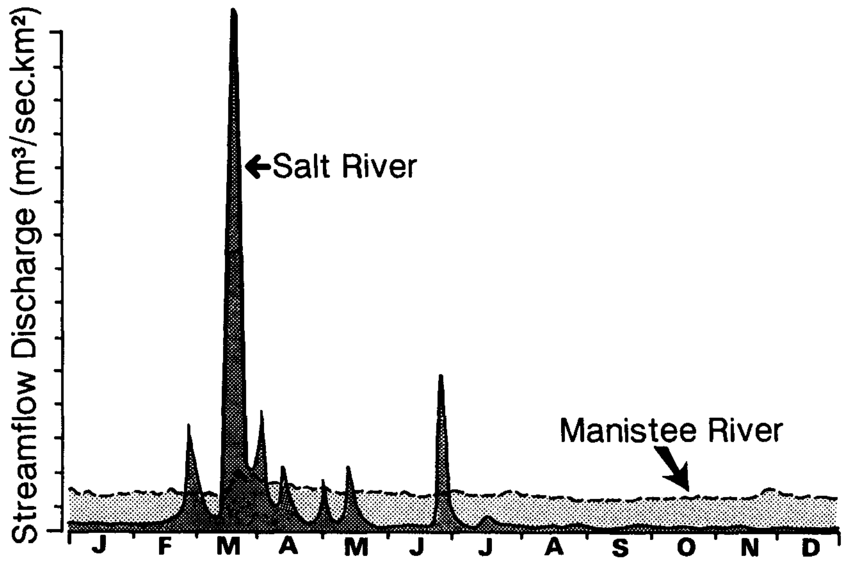


Fig. 2. Typical Hydrograph showing Streamflow Distribution in Different Physiographic Characteristics of two River Basins (Redrawn from Hewlet, 1982)

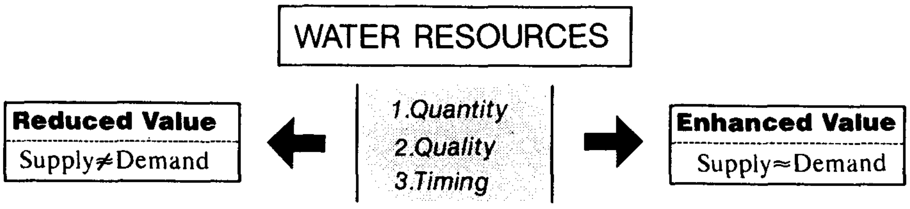


Fig. 3. Important Attributes of Enhenced and Reduced Values of Water Resources Referred to Supply-Demand Relationship

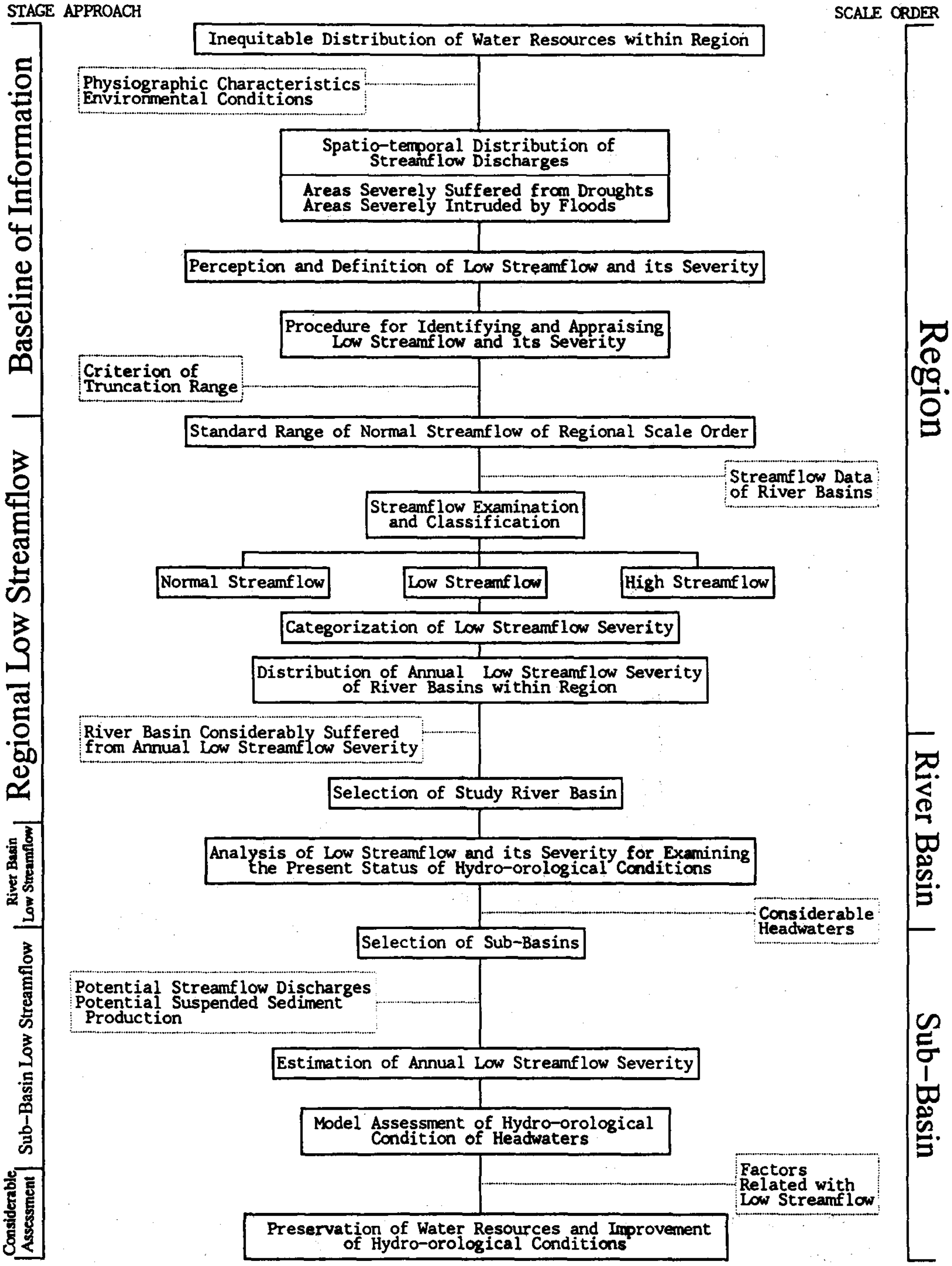


Fig. 4. Flow Chart of Study Method for Clarifying Low Streamflow and its Severity in Consecutive Approaches of Regional, River Basin And Sub-Basin Scale Orders

standard range of normal streamflow of streamflow series was determined. Therefore, it might be possible to develop perceptive procedures for recognizing and estimating low streamflow and its severity on the scales of region and river basin.

For classifying streamflow events in each river basin, a regional standard range of normal streamflow was determined by examining continuous long-term streamflow discharges of selected river basins located throughout the region. Streamflow events were classified as normal streamflow, low streamflow and high streamflow. The magnitude of low streamflow were subsequently categorized into several grades for expressing the severity of low streamflow in each river basin and their distribution within the region.

A river basin considered to suffer from severe low streamflow (referred to as low streamflow area) was selected for further study. An estimation of potential streamflow discharge and suspended sediment production was performed to clarify the present status of hydro-orological conditions of each selected Sub-Basin as variable source areas of water resources. This clarification will make possible to assess the potential for preservation of water resources or improvement of unfavorable hydro-orological conditions.

2. Study Area

On the regional scale, the examination of low streamflow and its severity was carried out in 70 river basins located throughout the Hokkaido region (Fig.5). The selected river basins are under the supervision of Civil Engineering Offices of Hokkaido Prefectural Government, such as Sapporo (Sa), Otaru (Ot), Hakkodate (Hk), Muroran (Mu), Asahikawa (As), Rumoi(Ru), Wakannai (Wa), Abashiri (Ab), Obihiro (Ob), and Kushiro (Ku). The selection of the observed river basins was mainly based on the availability of continuous long-term data of streamflow discharges and their geographic location within the region.

The distribution of selected river basins are 8 in Sapporo, 4 in Otaru, 12 in Hakkodate, 12 in Muroran, 5 in Asahikawa, 5 in Rumoi, 5 in Wakkanai, 6 in Abashiri, 6 in Obihiro and 7 in Kushiro. Surrounding each location was a range of areal dimensions of 9 – 281 km^2, 11 – 452 km^2, 20 – 238 km^2, 42 – 430 km^2, 20 – 366 km^2, 33 – 502 km^2, 139 – 544 km^2, 35 – 438 km^2 and 193 – 576 km^2.

II. Low Streamflow and its Severity

1. Concept and Definition of Low Streamflow

To describe low streamflow and its severity, it is obviously necessary to clarify the meaning of low streamflow. This requires a specific concept of the problem, restricted from other associated issues, to formulate the precise definition. The clarification of the concept and definition is very important to determine the analysis method which would be applied to low streamflow and its severity. A comparative examination of several hydrological studies was conducted and the results were used as a basic reference to clarify the proper meaning of low streamflow.

Low streamflow was conclusively found to be closely related to the terms water shortage and drought which are induced by a kind of water deficiency related to the hydro-meteorological ondition. The research hydrologist is mainly concerned with low streamflow, the research meteorologist mostly deals with abnormal precipitation, whereas the research agronomist is more interested in a kind of insufficient soil moisture for supporting agricultural crops. Some results of previous works by LINSLEY and FRANZINI (1964),

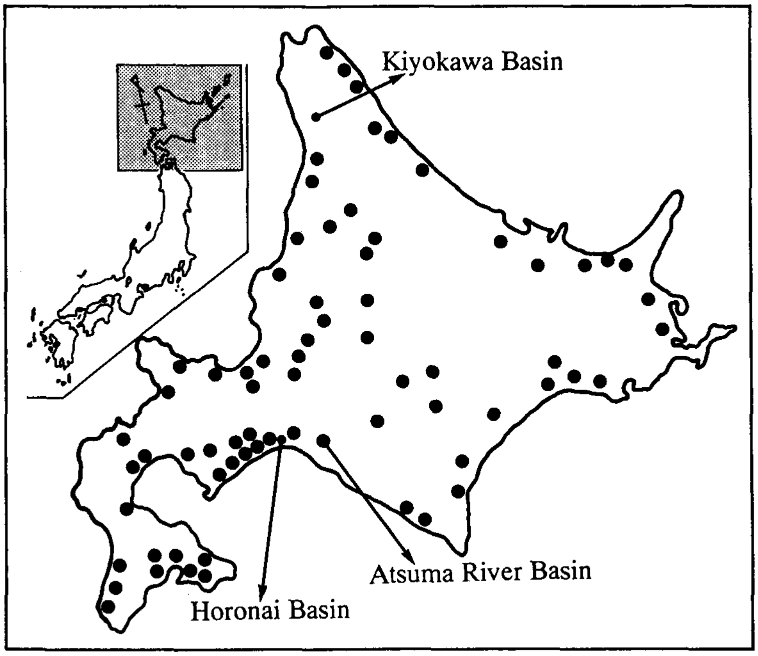


Fig. 5. Map of Hokkaido Region showing Location of Observed River Basins

HARR and KRYGIER (1972), LINSLEY et al. (1975), DRACUP et al. (1980), TAKEUCHI (1988), MOYE et al. (1988), CLEAVELAND and STAHLE (1989) were cited as shown in Table 1. From examining these studies it was found that the concept of low streamflow can be classified into three terms; hydrologic, meteorologic and agricultural water shortage or drought.

Considering the different ways of perceiving low streamflow, a certain set of decisions for defining the type of events had to be established. This set of decisions is determined from the following basic questions : (1) What is the focal point of the related water shortage or drought event (streamflow event – hydrologic drought, precipitation event – meteorologic drought or soil moisture event – agricultural drought), (2) What is the fundamental averaging period for the time series event (second, day, month, season, year), (3) How can the water shortage or drought events analytically distinguished from other events in the time series, (4) How are the scale orders of the study area to be considered in the study. According to this set of decisions, the previous works apparently suggested that water shortage or drought be referred as a specified need of water in the concept of a supply-demand relationship. Hydro-meteorologically therefore, it was conclusive that the basic significance of water shortage or drought is concerned with low streamflow, low precipitation and low soil moisture or combination of all three due to the fact they are closely interrelated.

To define low streamflow, there is still the problem with the time scale of the event. Several terms expressing the different magnitude of streamflow discharge in different time scales are proposed for dealing with the time scale of low streamflow events (Fig.6).

Table 1. Some Published Definitions of Drought and Low Streamflow Intended for Various Purposes

No.	Definition	Sources
1.	Drought can be defined in term of a fixed period of time with less than some minimum amount of rainfall, or in term of inadequate streamflow.	Franzini (1964)
2.	Low flow day is a day with average flow below 0.011 cubic meter per second per square kilometer.	Harr and Krygier (1972)
3.	Drought is a period during which streamflows are inadequate to supply established uses under a given water management system.	Linsley *et al* (1975)
4.	Drought is generally defined as a water shortage with reference to a specified need for water in a conceptual supply and demand relationship.	Dracup *et al* (1980)
5.	Drought is a low value of average streamflow or precipitation over a certain period.	Takeuchi (1988)
6.	Drought is a period when annual precipitation was less than 75% of the thirty – year normal precipitation.	Moye *et al* (1988)
7.	Drought is defined into surplus and deficit water : (1) Surplus water, if the runoff equal or greater than 120% of the long–term mean runoff, whereas (2) Deficit water, if the runoff equal or lower than 80% of the long-term mean runoff.	Cleaveland and Stahle (1989)

Basically, the proposed terms express relationships between the truncation range determined from the averaging period (mean, median, mode) associated with its scaling factor and the time scale units (second, hour, day, month, year). The magnitude of streamflow events classified lower than truncation range were referred to as scanty run-off, low flow, dry, low streamflow and drought for the time scale, there were second, hour, day, month and year.

The recent progress in hydrological studies clarified that precipitationless, low streamflow and low soil moisture could be closely interrelated. Precipitation is the main input into a river basin, streamflow is a major output from a river basin, whereas waterflow process within a river basin is affected by physiographic characteristics such as the geological structures, geomorphological features and other river basin characteristics. Therefore, a low streamflow event is actually the net result of cumulative interactions of the hydrological cycle within the river basin. Two approaches were considered for low streamflow analysis : (1) Analyze each individual component or (2) Analyze the interaction among three components as one hydrological system. These approaches, however, are closely interrelated and mostly inseparable. Therefore, they were combined to achieve a comprehensive approach in this study.

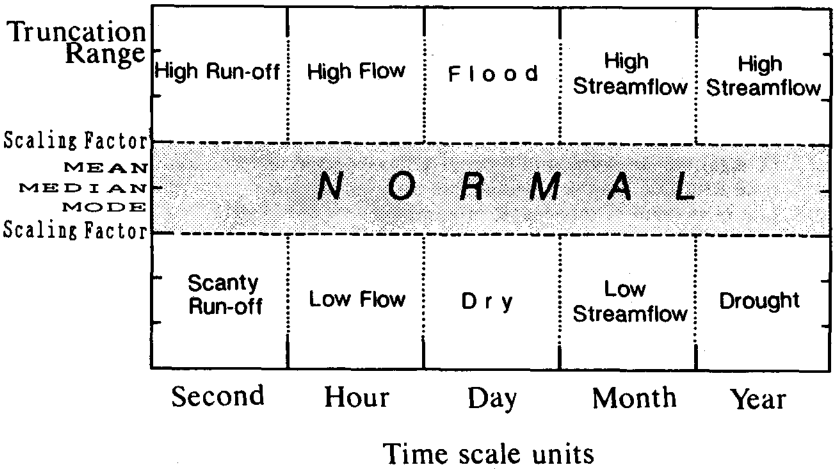


Fig. 6. Proposed Terminology and Criterion for Classifying Hydrological Events Based on Specified Unit of Magnitude and Time Scales

2. Procedure for Determining Low Streamflow and its Severity

A low streamflow event has been defined in terms of water deficiency below a specified minimum amount of average streamflow determined from a specified fundamental averaging period. Therefore, the definition requires three parameters ; duration (number of months for which the monthly streamflow is below long-term averaging period), magnitude (water deficiency in duration of which streamflow is below long-term averaging period) and severity (cumulative water deficiency of streamflow which is below long-term averaging period). These parameters were used as the basic consideration for determining low streamflow in the scale order of region and river basin.

To estimate a low streamflow event and its severity, based on the previous definition, a simple procedure was established consisting of consecutive steps for selecting month-base streamflow data, determination of averaging period and their level limits, determination of standard range of normal streamflow and the examination of streamflow series. The procedure refers to the nature of water deficiency abstracted from the concept of hydrologic water shortage or drought. The first decision was to select low streamflow as the parameter of basic variable, which was followed by decision on the time scale unit or duration used as fundamental averaging period. Because these variables are continuous in nature, with the exception of precipitation, it is obviously necessary to make a discrete separation of the continuous time series by employing an appropriate averaging period which then renders the data suitable for analysis purposes.

As a continuous time series, a streamflow event is recognized has having durations of the various time scales. Therefore, the averaging periods might vary from an event to day, day to month, month to season and season to year. The selected time scale unit determines the sample size of the events to be studied. Considering the practical analysis, streamflow data should be discretized on a monthly basis to determine a month-base low streamflow. For a given length of streamflow series, a short averaging period would result in a relative large number of low streamflow events. Adversely, a long averaging period leads to a small number of low streamflow events. The implication is that the mean annual streamflow for a year may be below the long-term normal flow, and thereby constitute a yearly drought. There is a possibility, however, that particular months within that year would be higher or lower than the normal streamflow and thus separate the single yearly high streamflow or drought into several month-base high or low streamflow events.

The component of long-term averaging period of a streamflow record is the truncation range and it is used to separate a streamflow time series into three categories of streamflow events. The truncation range was selected as an appropriate measure for the central tendency of a streamflow series. Parameters which are commonly used for measuring the central tendency of a time series is the value of mean, median or mode generated from a set data of a time series. As a time series record, all streamflow records are generally skewed; indicating mean value differs from the median. Unless the averaging period does not use the mode value, it is necessary to choose between two respecting values – mean or median. The value of mean was selected as the truncation range because this value is more sensitive to the extreme values of a serial data distribution compared with the median. The upper and lower level values of the truncation range (X_0) can be arbitrarily set to cut the series at several places of streamflow magnitude. Accordingly, the relation between truncation range and streamflow series is the basis for defining streamflow events.

The low streamflow event was then categorized by using a truncation range determined from the continuous long-term record of serial streamflow data discretized in month-base streamflow. The extreme low values of streamflow discharge was of primary interest. The use of mean value for determining truncation range must be used cautiously on grossly unrepresentative events included in the series, particularly if the serial data size is considerably small. Therefore, it is preferable that serial data should be free from unrepresentative extremes, such as low streamflow or high streamflow events. When the truncation range was determined, it was possible to categorize streamflow events based on whether they were above, inside or below the truncation range.

To express the low streamflow abstraction from a streamflow time series, the truncation range was simply formulated as the following :

$$\mathbf{X_0 = X_m - eS_d} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \mathbf{(1)}$$

where $\mathbf{X_0}$= truncation range, $\mathbf{X_m}$= mean value of streamflow series, $\mathbf{S_d}$= standard deviation, and **e**= elective scaling factor which usually ranges between **0 – 1.** Referring to the previous steps, a set of decisions for defining low streamflow are as follows : (1) The nature of water deficiency – streamflow, (2) The basic time unit of the data series analysis – month, (3) The truncation range which distinguishes low streamflow from normal and high flows – mean value of the time series and (4) The regionalization and standardization would be performed on both scale orders of region and river basin.

3. Criterion of Standard Range of Normal Streamflow and Classification of Streamflow Event

Streamflow discharges in each river basin are considerably different in their magnitude and seasonal distribution. Therefore, there is a need to establish a certain quantitative criterion for determining the average streamflow series which would be used as the standard range of normal streamflow.

The month-base mean streamflow was used as the basic value for determining the standard range of normal streamflow. Considering a wide variation of streamflow magnitudes, standard deviation was examined for determining the upper and lower limits of the standard range of normal streamflow. The **e** scaling factor was arbitrarily given with the constant of **0.5** and therefore the truncation range of normal streamflow could be expressed as the following :

$$X_0 = X_m \pm 0.5\ S_d \quad \cdots\cdots (2)$$

where X_0= standard range of normal streamflow, X_m= mean value of streamflow series and S_d = standard deviation. The criterion, X_0 was used to classify the month-base streamflow series based on its distribution. The proposed criterion for the month−base standard range of normal streamflow is outlined in Fig. 7. The figure X_0 is associated with both the upper limit ($X_m + 0.5S_d$) and lower limit ($X_m - 0.5S_d$) for categorizing streamflow events into high, normal and low streamflow. Streamflow events in each river basin were classified into three categories : (1) High streamflow ($X > X_0$), (2) Normal streamflow ($X = X_0$) **and** (3) Low streamflow ($X < X_0$).

To simply illustrate the phenomena of those events related to considerable streamflow magnitude and fluctuation, their relationship is shown in Fig.8 for expressing their attributes and likelihoods. These attributes and likelihoods express the relation between the magnitude (high, normal, low) and the fluctuation (low, high). In case of a considerably low fluctuation, the low and high streamflows might be being less likely whereas the normal streamflow was considered to be very likely. Conversely, for the high fluctuation, the low and high streamflows were considered to be very likely while the normal streamflow would be less likely. This likelihood of streamflow events might be presently useful and understandable.

III. Distribution of Low Streamflow and its Severity in Regional Scale

1. Determination of Standard Range of Normal Streamflow and Examination of Low Streamflow

To identify a low streamflow area within a large region such as Hokkaido, with its large variation in physiographic characteristics and environmental factors following its spatio-temporal changes, it is imperative to establish a regional standard range of normal streamflow. The continuous streamflow measurements (1979 − 1990) in 70 river basins distributed throughout Hokkaido was used by arranging serial streamflow data into a unit

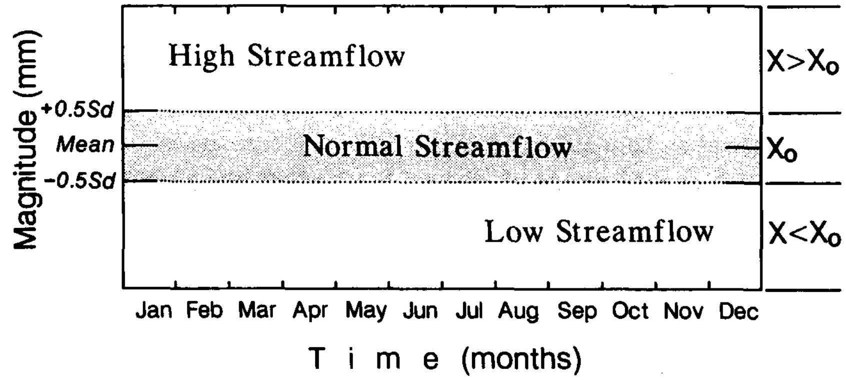


Fig. 7. Proposed Criterion of Standard Range of Normal Streamflow for Classifying Streamflow Events in Regional and River Basin Scales

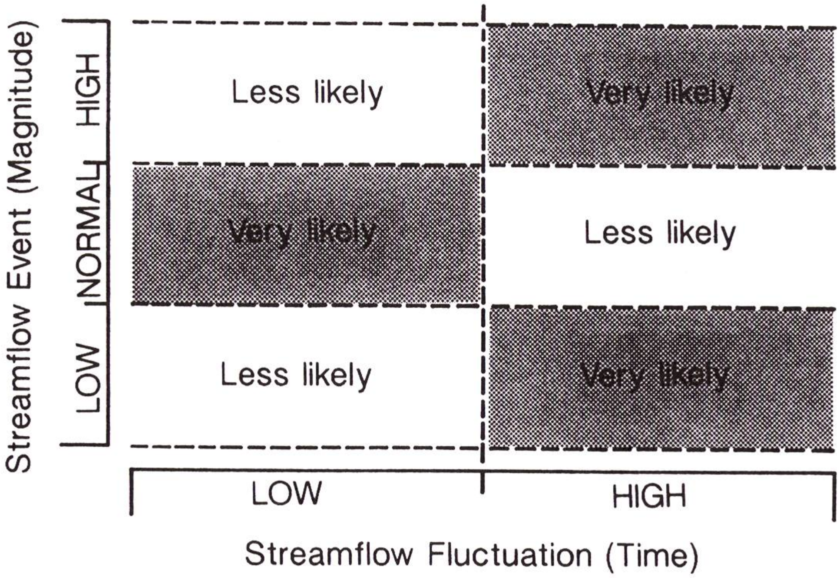


Fig. 8. Important Attributes and Likelihood of Classified Streamflow Events Referred to its Magnitude and Fluctuation

of mm equivalent of water depth. The arranged streamflow data was statistically examined (Table 2). The statistical parameters represent basic expression of mean (**A_v**) and standard deviation (**S_d**) values for each month within a year. The magnitude of minimum – maximum of mean streamflow was found to be 43 – 243 mm (1979), 45 – 250 mm (1980), 39 – 272 mm (1981), 42 – 301 mm (1982), 37 – 292 mm (1983), 37 – 282 mm (1984), 33 – 335 mm (1985), 36 – 364 mm (1986), 32 – 297 mm (1987), 36 – 334 mm (1988) and 39 – 241 mm (1989), 57 – 281 mm (1990).

The variation of streamflow data series was then examined by using the coefficient of variation (**C_v**). The range of **C_v** was found to be 38 – 123% indicating a significant variation of streamflow discharges among the river basins. Following the criterion previously determined, Fig. 9 shows the standard range of normal streamflow. The center line indicates mean value while the upper (shaded area) and lower (white area) lines mark the range of normal streamflow. The clarification of annual low streamflow severity distribution was made possible through the examination of low streamflow events in each river basin within the region. Streamflow data series of each river basin were then examined by comparing them to the regional standard range of normal streamflow (Fig.10). It was learned that several streamflow deficiency – called month-base discrete streamflow deficiency *(MLS)* were found in Atsuma River Basin.

The month-base streamflow series were mostly low streamflow followed by a few months at normal range. These month-base discrete streamflow deficiencies were used to determine the annual severity of low streamflow. The only streamflow event reaching high streamflow was in August 1981, this was a period when a heavy rainfall hit the Hokkaido region and the maximum daily precipitation recorded was 166 mm with the total

Table 2. Basic Statistical Approach for Developing Regional Standard Range of Normal Streamflow Series

No	Year	Streamflow (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01.	1979	A_v	49	43	69	243	207	98	76	78	81	176	133	100
		S_d	38	34	55	144	172	80	39	96	69	67	61	39
		C_v (%)	77	80	80	59	83	82	52	123	86	38	46	39
		Upper	68	60	97	315	293	138	96	126	116	210	164	120
		Lower	30	26	42	171	121	58	57	30	47	143	103	81
02.	1980	A_v	62	45	63	214	250	87	54	81	104	103	124	107
		S_d	38	31	44	121	196	67	39	76	88	62	64	90
		C_v (%)	61	70	70	57	78	77	72	94	85	60	52	84
		Upper	81	61	85	275	348	121	74	119	148	134	156	152
		Lower	43	30	41	154	152	54	35	43	60	72	92	62
03.	1981	A_v	51	39	64	272	245	114	131	306	163	159	123	76
		S_d	32	32	40	175	188	91	137	188	89	89	70	54
		C_v (%)	63	84	62	64	77	80	105	61	54	56	57	71
		Upper	67	55	84	360	339	160	200	400	208	204	158	103
		Lower	35	23	44	185	151	69	63	212	119	115	88	49
04.	1982	A_v	62	42	60	281	301	90	62	81	84	91	116	89
		S_d	36	35	35	152	251	68	56	87	58	61	69	40
		C_v (%)	59	84	59	54	83	76	90	107	69	67	59	45
		Upper	80	60	78	357	427	124	90	125	113	122	151	109
		Lower	44	25	43	205	176	56	34	38	55	61	82	69
05.	1983	A_v	53	37	62	292	133	97	89	98	139	128	101	72
		S_d	32	29	37	193	125	75	76	91	98	85	59	43
		C_v (%)	61	77	58	66	94	78	85	93	71	67	59	60
		Upper	69	52	81	389	196	135	127	144	188	171	131	94
		Lower	37	23	44	196	71	60	51	53	90	86	72	51
06.	1984	A_v	47	37	42	226	282	89	84	54	83	90	81	64
		S_d	40	32	43	124	203	95	84	53	93	58	50	37
		C_v (%)	84	86	102	55	72	107	101	98	112	64	62	57
		Upper	67	53	64	288	384	137	126	81	130	119	106	83
		Lower	27	21	21	164	181	42	42	28	37	61	56	46
07.	1985	A_v	40	33	63	335	162	47	87	55	156	179	100	63
		S_d	37	33	43	168	155	50	57	40	137	128	49	30
		C_v (%)	92	97	67	50	96	106	66	73	88	71	49	47
		Upper	59	50	85	419	240	72	116	75	225	243	125	78
		Lower	22	17	42	251	85	22	59	35	88	115	76	48

Table 2. Continued

No	Year	Streamflow (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
08.	1986	A_v	48	36	57	364	269	86	86	61	134	88	102	59
		S_d	37	38	41	177	225	103	79	46	99	54	67	36
		C_v (%)	76	104	72	49	84	121	92	75	74	61	66	61
		Upper	67	55	78	453	382	138	126	84	184	115	136	77
		Lower	30	17	37	276	157	35	47	38	85	61	69	41
09.	1987	A_v	40	32	74	297	260	66	104	129	101	101	104	61
		S_d	26	24	43	171	221	80	75	90	92	68	56	36
		C_v (%)	65	76	58	57	85	121	72	70	92	67	54	60
		Upper	53	44	96	383	371	106	142	174	147	135	132	79
		Lower	27	20	53	212	150	26	67	84	55	67	76	43
10.	1988	A_v	50	36	61	334	253	103	50	116	97	117	147	103
		S_d	32	25	42	193	193	88	46	127	71	77	90	44
		C_v (%)	65	70	68	58	76	85	93	109	73	66	62	43
		Upper	66	49	82	431	350	147	73	180	133	156	192	125
		Lower	34	24	40	238	157	59	27	53	62	79	102	81
11.	1989	A_v	50	39	100	241	130	103	69	117	181	143	162	85
		S_d	35	28	58	121	132	101	59	78	108	91	89	39
		C_v (%)	71	74	58	50	101	98	86	67	60	64	55	46
		Upper	68	53	129	302	196	154	99	156	235	189	207	105
		Lower	33	25	71	181	64	53	40	78	127	98	118	66
12.	1990	A_v	51	57	113	281	150	67	85	137	168	146	180	136
		S_d	35	43	79	138	132	48	72	82	113	100	104	86
		C_v (%)	69	75	70	49	88	72	85	60	67	68	58	63
		Upper	69	79	153	350	216	91	121	178	225	196	232	179
		Lower	34	36	74	212	84	43	49	96	112	96	128	93

Remark: Upper and lower limits were obtained from Average ± 0.5 S_d of mean monthly streamflow data (derived from serial data of 70 rivers data in the Hokkaido Region)

precipitation reaching 463 mm. This heavy rainfall produced a huge amount of streamflow discharges, equal to 437 mm water depth for the same period in August.

2. Examination of Low Streamflow Severity and its Distribution

Referring to month-base discrete streamflow deficiency *(MLS)* previously examined, the cumulative streamflow deficiency, referred to as *CWD*, was obtained by calculating *MLS* as described in Eq.3, whereas annual low streamflow severity was obtained by using Eq.4.

$$\mathbf{CWD} = \sum_{i=1}^{n} \mathbf{MLS}_{(i)} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

$$\mathbf{ALS} = \mathbf{CWD}/\mathbf{N} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

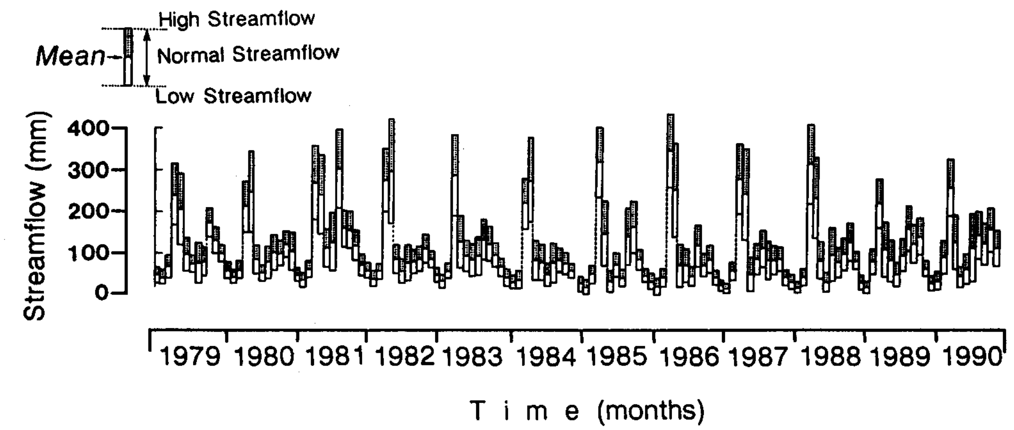


Fig. 9. Regional Standard Range of Normal Streamflow Established from 70 River Basins in Hokkaido Region

The annual low streamflow severity *(ALS)* was obtained by dividing *CWD* by each period of streamflow measurement *(N)*. The magnitude of *ALS* is used to express the present status of low streamflow, because it is easy to calculate and quite easy to understand. The estimation of low streamflow and its severity in each river basin was firstly done on a regional scale (Table 3). The magnitude of *ALS* in Hokkaido was found to be 0 − 505 mm with the mean value of 119 mm.

The results disclose that there were river basins which did not suffer low streamflow, but there were many river basins identified has having suffered from severe low streamflow. Following the *ALS* examination, it is preferable to develop a technique for rapidly recognizing low streamflow severity. It might be made by classifying *ALS* magnitude into several ranges and specific grades. *ALS* magnitude was classified into five grades for severity index of low streamflow *(SIL)* based on an interval difference of 100 mm. Referring to the range of *ALS* magnitude, these grades were *SIL−1* (<100 mm), *SIL−2* (100 − 200 mm), *SIL−3* (200 − 300 mm), *SIL−4* (300 − 400 mm) and *SIL−5* (>400 mm). The higher number in these grades indicate greater low streamflow severity. Put into practice, this index will be useful because it combines a certain range of quantitative values and understandable verbal expressions.

The *AMS* observed in 70 river basins in Hokkaido was found to be 1300 mm with a range from 309 mm (Shikaribetsu − Eastern Hokkaido) to 3246 mm (Shokanbetsu − Northern Hokkaido). The relation between annual mean streamflow *(AMS)* and *ALS* associated with *SIL* is outlined in Fig.11. It was used to identify how severe the low streamflow was in each river basin. The figure shows that river basins having a large amount of *AMS* reveal low *SIL*, whereas high grades of the low streamflow severity index were mostly found in river basins with low *AMS*. It was found, however, that even though some river basins had almost similar *AMS* magnitude, they were classified into different *SIL* due to their different *ALS* magnitude. This was caused by considerable differences in the fluctuations of their streamflow discharge.

The *AMS* of river basins classified into *SIL−1* and *SIL−2* was found to be 803 − 3246

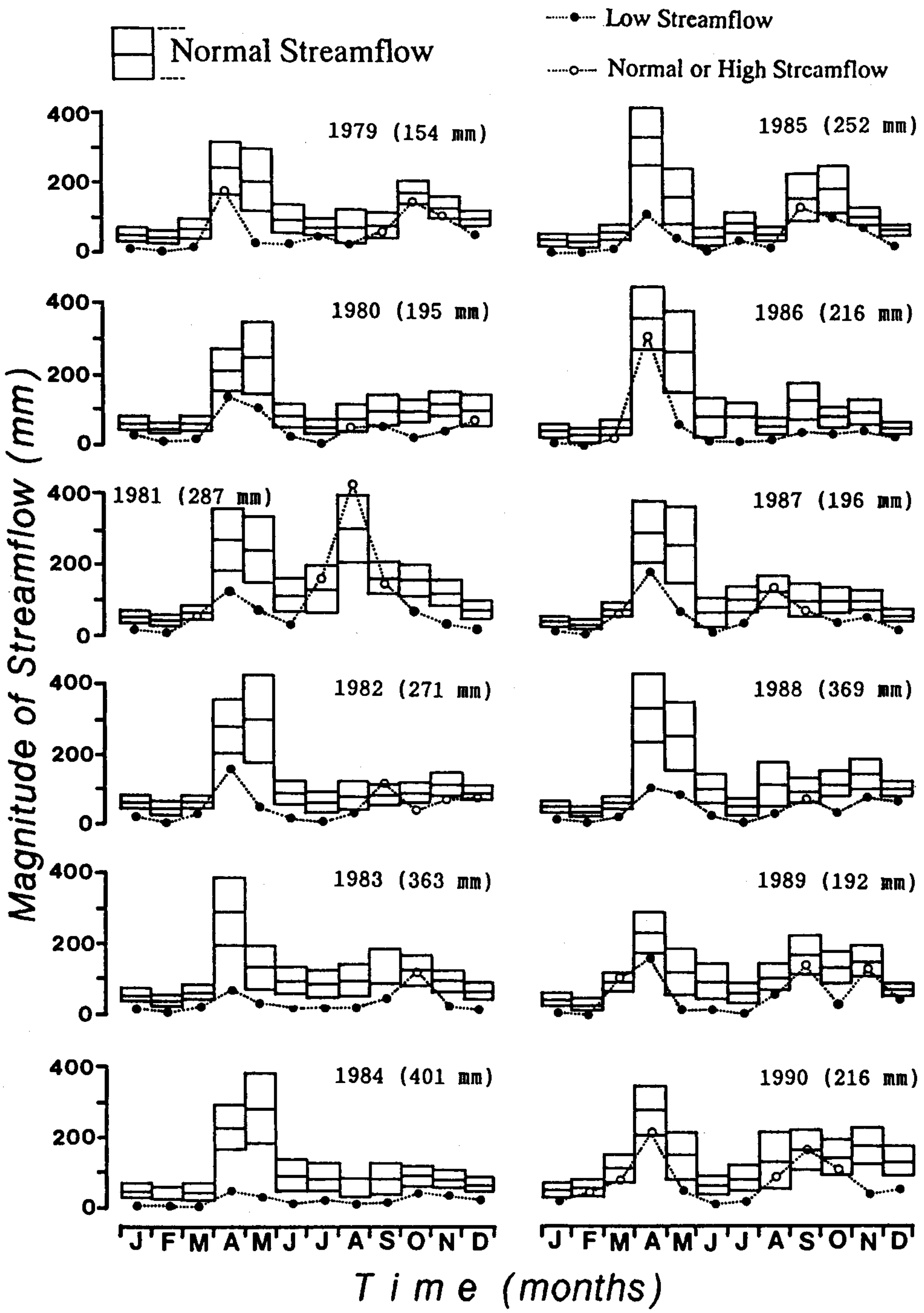


Fig. 10. Magnitude of Water Deficiency of Low Streamflow in Atsuma River Basin Examined from Regional Standard Range of Normal Streamflow

Table 3. Examination and Grading of Low Streamflow and Low Streamflow Severity of River Basins in Hokkaido

No.	Basin Code	Area (km^2)	River	Period (year)	AMS (mm)	CWS (mm)	CWD (mm)	AHS (mm)	ALS (mm)	SIL
01	Sa−101	281	Toubetsu	79−90	1468	222	936	19	78	1
02	Sa−111	108	Shinkawa	79−90	1412	65	83	6	7	1
03	Sa−114	25	Bibai	79−81	1427	234	118	78	39	1
04	Sa−119	38	Naie	79−85	1000	30	924	4	132	2
05	Sa−120	9	Ponwenbetsu	79−90	864	45	3025	4	252	3
06	Sa−122	239	Toppu	80−90	2019	609	372	55	34	1
07	Sa−125	24	Tonebetsu	81−90	1556	413	512	41	51	1
08	Sa−129	13	Hidarimatasawa	87−90	1241	113	395	28	99	1
09	Ot−202	398	Youichi	79−90	1637	785	592	65	49	1
10	Ot−209	136	Hourikabu	79−90	1349	173	1148	14	97	1
11	Ot−212	362	Shubuto	79−90	1427	188	573	17	48	1
12	Ot−213	51	Asari R.	79−90	1530	617	1127	51	111	2
13	Hk−303	232	Washinosu	79−90	1876	552	0	46	0	1
14	Hk−309	117	Shiriuchi	79−90	2319	1466	118	122	11	1
15	Hk−314	58	Matsukura	79−90	1182	763	1178	64	98	1
16	Hk−315	33	Shiodomari	79−90	1124	106	1378	9	115	2
17	Hk−317	38	Kameda	79−84	851	16	1076	3	179	2
18	Hk−319	176	Ishizaki	79−85	1736	535	277	76	46	1
19	Hk−350	101	Kunebetsu	81−90	2394	2309	150	231	17	1
20	Hk−352	92	Oshamambe	83−90	2175	950	0	119	0	1
21	Hk−353	11	Obarubetsu	84−90	835	31	518	52	86	1
22	Hk−354	452	Atsusawabe	84−90	1172	134	613	19	88	1
23	Hk−355	109	Oono	85−90	1256	116	310	19	52	1
24	Hk−356	22	Mena	85−90	691	35	2102	6	350	4
25	Mu−405	277	Abira	79−90	636	0	3450	0	288	3
26	Mu−407	238	Atsuma	79−90	706	4	3113	0	259	3
27	Mu−417	118	Shikibu	79−89	2191	603	112	55	10	1
28	Mu−418	29	Tomakomai	79−89	1519	223	946	20	86	1
29	Mu−420	71	Shiraoi	79−90	3066	2519	0	210	0	1
30	Mu−421	107	Osaru	79−90	1641	260	281	27	23	1
31	Mu−422	237	Iburi	79−90	1196	4	310	0	26	1
32	Mu−423	205	Yuufutsu	79−89	916	10	2004	1	182	2
33	Mu−425	25	Betsubetsu	79−90	1901	910	513	76	47	1
34	Mu−428	53	Noboribetsu	79−90	1867	418	502	38	46	1
35	Mu−431	20	Mukaebetsu	79−90	1141	295	1920	25	160	2
36	Mu−432	55	Samani	79−90	992	138	1716	12	156	2
37	As−503	135	Furano	79−90	639	47	3353	4	279	3
38	As−505	90	Henbetsu	79−90	1176	46	1458	4	122	2
39	As−507	430	Ushishubetsu	79−82	1031	86	367	22	92	1
40	As−510	144	Inuushibetsu	79−90	1522	171	891	14	74	1
41	As−512	42	Karifu	79−85	1429	245	196	35	28	1
42	Ru−606	200	Haboro	79−90	1578	166	666	14	56	1
43	Ru−612	20	Mochikubetsu	79−90	1721	396	586	33	49	1
44	Ru−613	188	Obirabeshi	79−90	1751	350	388	32	35	1
45	Ru−614	86	Shokanbetsu	79−90	3246	1827	40	152	3	1

Table 3. Continued

No.	Basin Code	Area (km²)	River	Period (year)	AMS (mm)	CWS (mm)	CWD (mm)	AHS (mm)	ALS (mm)	SIL
46	Ru−616	366	Okinai	86−89	1675	1551	267	388	67	1
47	Wa−705	220	Kitamihorobetsu	79−90	1198	1158	1158	22	97	1
48	Wa−707	280	Tokushibetsu	79−82	1560	269	75	18	19	1
49	Wa−708	502	Horobetsu	80−90	1223	70	997	16	91	1
50	Wa−710	33	Kishibetsu	83−90	1242	174	622	21	78	1
51	Wa−711	216	Sarufutsu	85−89	1403	71	160	19	32	1
52	Ab−803	291	Okoppe	79−90	940	97	1641	8	137	2
53	Ab−810	544	Shari	79−90	1021	90	1413	2	118	2
54	Ab−811	173	Saroma	79−90	1075	21	904	75	75	1
55	Ab−814	518	Muka	79−90	418	33	5706	3	476	5
56	Ab−816	139	Shibetsu	79−84	517	5	2015	0	336	4
57	Ab−818	259	Saromabetsu	79−90	523	0	3129	0	261	3
58	Ob−907	116	Obihiro	79−90	803	18	2312	2	193	2
59	Ob−911	438	Rekifune	79−90	1718	483	626	40	52	1
60	Ob−915	427	Urahoro	79−82	466	283	1906	71	477	5
61	Ob−916	35	Nishihiro	79−90	2426	1319	48	110	4	1
62	Ob−917	155	Urahoro	79−83	1163	675	302	135	60	1
63	Ob−919	255	Shikaribetsu	83−90	309	26	4040	4	505	5
64	Ku−1004	79	Betsuho	79−90	788	0	2798	0	233	3
65	Ku−1013	576	Akan	79−81	1051	11	382	4	127	2
66	Ku−1014	420	Shibetsu	79−90	1086	0	1011	0	84	1
67	Ku−1015	193	Nishibetsu	79−90	1072	64	1421	5	118	2
68	Ku−1020	220	Shoro	79−90	849	33	2755	3	230	3
69	Ku−1021	637	Akan	82−90	1216	8	1305	1	145	2
70	Ku−1022	347	Charo	82−90	760	11	2350	1	261	3

Remark :

1. AMS = annual mean streamflow, CWD = cumulative water deficiency, CWS = cumulative water surplus, AHS = annual high surplus, ALS = annual streamflow deficiency, SIL = severity index of low streamflow
2. Severity Index of Low Streamflow (SIL) was indexed into five classes as : (1) <100, (2) 100 − 200, (3) 200 − 300, (4) 300 − 400, (5) >400 mm
3. Streamflow data was derived from Annual Precipitation, Water Stage and Discharges, published by Hokkaido Civil Engineering Association

mm with an *ALS* range of 0 − 182 mm. Meanwhile, river basins classified into *SIL−3, SIL−4* and *SIL−5* ; were found to be 309 − 940 mm with *ALS* range of 130 − 505 mm. Referring to this relationship, an *ALS* lower than 200 mm *(SIL−1, SIL−2)* might be interpreted as slight and fair because the low streamflow might be easily compensated from their normal and high flows period. Meanwhile, an *ALS* greater than 200 mm *(SIL−3, SIL−4, SIL−5)*, should be referred to as moderate, hard and very hard low streamflow severity.

Streamflow distribution is quite inherent in nature due to its various geographic locations which include other factors ; especially environmental ones such as precipitation distribution. Seen on a regional scale, *SIL* can be a useful expression for describing low streamflow severity and its distribution within a region. For this reason, the *SIL* of each river basin was arranged on the map in Fig.12, showing the geographic location and various *SIL* grades. The bigger size of the circle means greater low streamflow severity in each

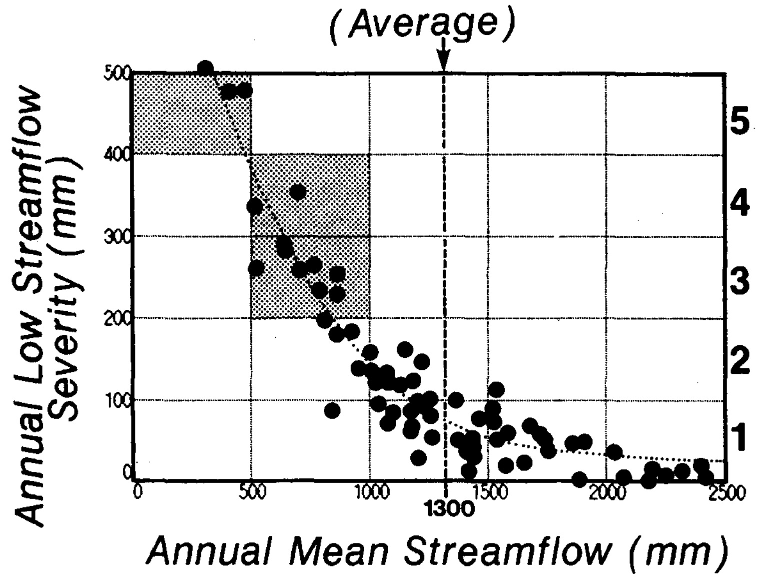


Fig. 11. Relation between Annual Mean Streamflow and Annual Low Streamflow Severity

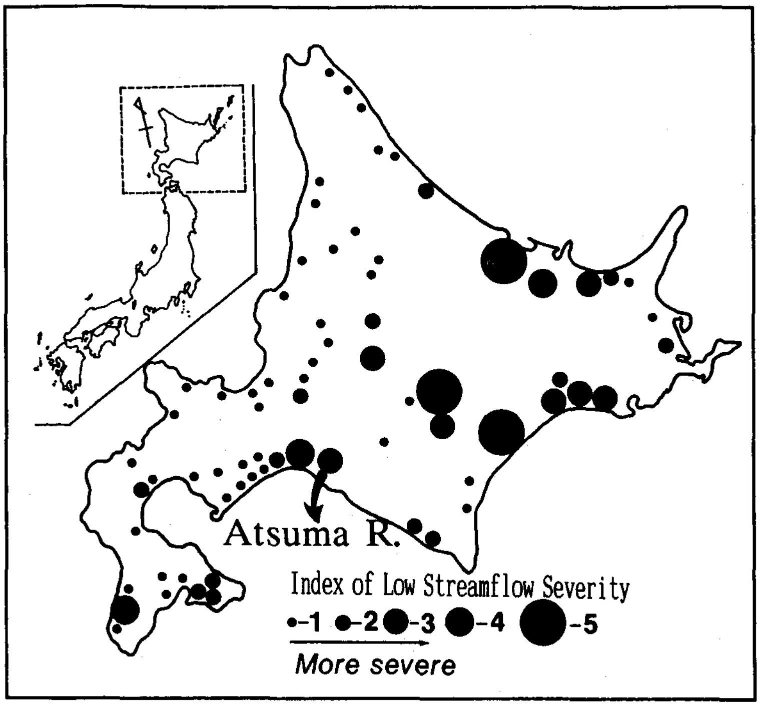


Fig. 12. Distribution of Annual Low Streamflow Severity Expressed by its Indexes in the Regional Scale Order

river basin. It was found that most of the river basins suffered slight and fair, whereas about 20% of the observed river basins suffered moderate, hard and very hard low streamflow severity. This map will be useful, when selecting a river basin for further studies of low streamflow phenomena and its severity related to factors affecting low streamflow events.

IV. Hydrological Analysis of Low Streamflow in River Basin Scale

1. Selection and Description of Hydrological Condition of Selected Study River Basin

The magnitude of *AMS* in Atsuma River Basin was found to be 706 mm for 1979−1990 period. The cumulative water deficiency *(CWD)* was 3113 mm, and therefore the *ALS* magnitude was found 259 mm. Referring to *AMS* and *ALS*, the Atsuma River Basin was determined to have moderate low streamflow severity *(SIL−3)*. For this reason, the Atsuma River Basin was selected as representative of a low streamflow area in the Hokkaido region. The geological structures in Atsuma River Basin are mostly composed of tertiary mudstone which is a typical structure commonly found in the Hokkaido region. This structure is also found in the eastern region of Kalimantan − Indonesia, which was another reason for selecting the Atsuma River Basin as the study area.

The Atsuma River Basin is located in the southern part of central Hokkaido, occupying approximately 406 km² in total area. Geographically, it lies 42°43′15″ north latitude and 141°152′53″ east longitude. The main river is 36 km long originating on Mt. Yubari, the northern mountainous part, and then flows in a southern direction into the Pacific Ocean (Fig. 13). The Atsuma River passes through densely forested areas in the upstream part; agricultural farmland, residential areas, newly developed industrial parks and resort areas located in the middle and lower parts.

According to the long-term meteorological observation, nearly 70% of the precipitation is rainfall and falls in an eight month time period (April-November). Snowfall most often begins at the end of November or in the beginning of December which is completely melted by the end of March or the beginning April of the following year. The mean annual precipitation is 916 mm and the maximum is 154 mm (August) while the minimum is 22 mm (February). The mean annual temperature is 5.9°C with a minimum of −8.4°C and a maximum of 20.1°C. During winter, the temperature may fall to nearly −25.7°C whereas in summer it may reach 34.2°C.

Referring to past geological surveys, the upstream part consists of a tertiary mudstone area, while from the middle to lower part is composed of quaternary glacial sediment laid down during the pleistocene era. The discontinued geological structure is overlaid by newly erupted volcanic ash about 3 − 5 m in depth especially in the lower part. The lowest part possesses spreading peat land with shallow surface soil about 10 − 30 cm in depth. The geological structures provide a base for soil profile formation, and therefore has a major influence upon the hydro-orological conditions. From the field impression and soil sampling, the developed soils were mostly clay and clay-loam which might be easily eroded. The topography has altitude range of 5 − 618 m a.s.l, whereas the mean slope was found to be 1.03°. The stream network in the Atsuma River Basin is a dendritic pattern established within semi-radial river basin shape characterized by many short first order streams followed by a fairly straight forward pattern and partially meandering river. In addition, streamflow data (1988−1989) observed in Kiyokawa Basin (Hokkaido Univer-

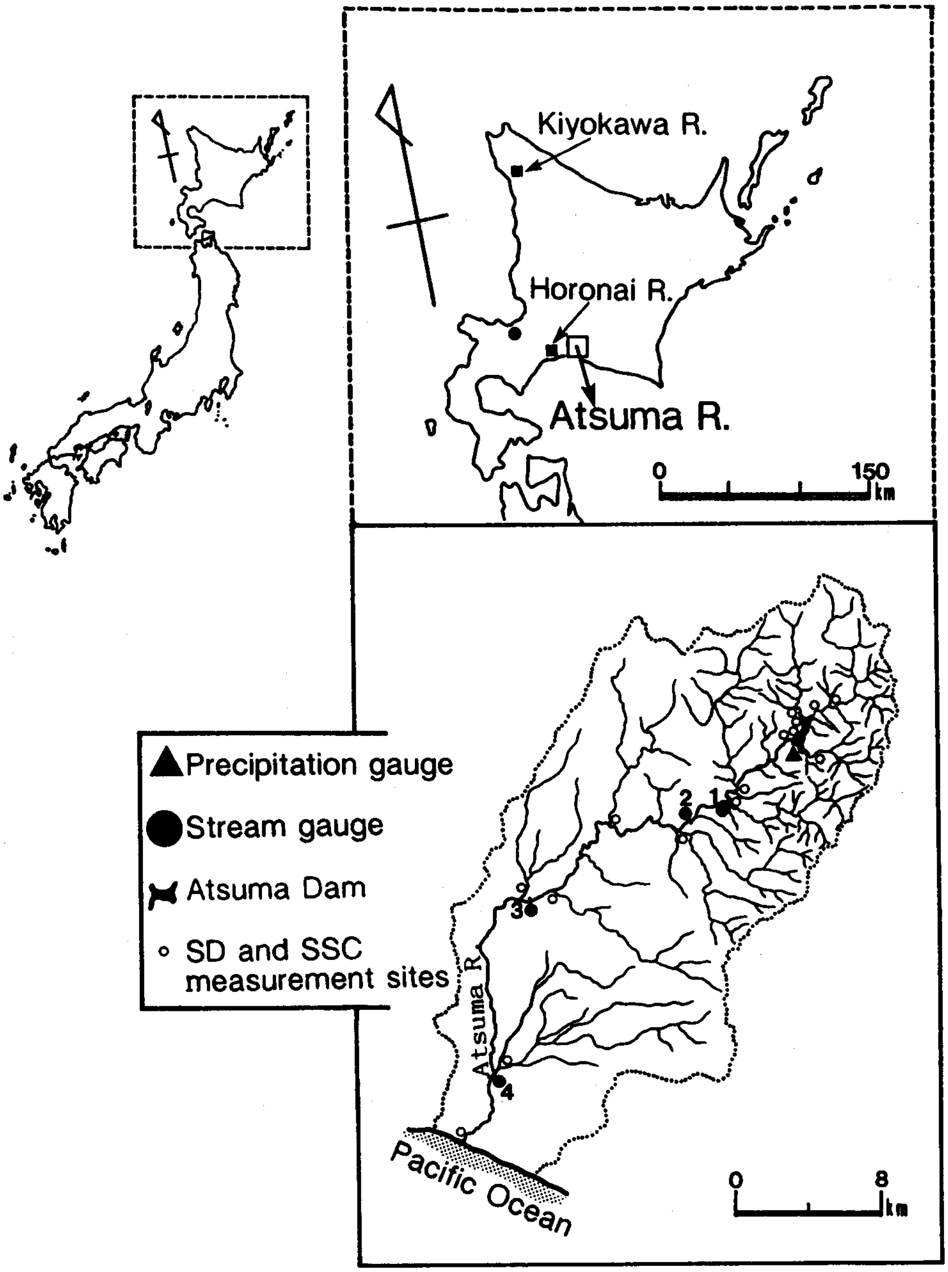


Fig. 13. Location Map of Study River Basin showing Geographic Location, Water Reservoir, Hydro-meteorological Stations and the Sites of Streamflow Discharges (SD) and Suspended Sediment Concentration (SSC) Measurements

sity, Teshio Experiment Forest) and Horonai Basin (Hokkaido University, Tomakomai Experiment Forest) were also used for clarifying streamflow discharges fluctuation in different geological conditions.

To clarify the spatio-temporal changes of streamflow fluctuation, all streamflow records are arranged in Fig. 14. In vertical direction, the dimension of river basin areas are arranged in the following order : 1.8 km^2 (Kiyokawa), 10.4 km^2 (Horonai), 14.9 km^2 (AHSR−1), 110.0 km^2 (AHSR−2), 238.0 km^2 (AHSR−3) and 350.7 km^2 (AHSR−4), whereas the horizontal direction is the time scale in hour, day, month and year. AHSR−1, AHSR−2, AHSR−3 and AHSR−4 are the sites in the Atsuma River Basin where automatic hydrometric streamflow recorders are installed. Referring to these figure, it can be seen that streamflow discharges within the shorter time scale shows a tendency for higher fluctuation, whereas the larger areal dimension produces a greater amount of streamflow discharges. The fluctuation tendency might be divided into two types : a low fluctuation, as revealed by streamflow discharges in Horonai Basin, or high fluctuation, as observed in Kiyokawa and Atsuma River Basins.

Furthermore, the original mean daily record of streamflow discharges was rearranged by making the ratio of daily discharge to its mean value associated with the frequency of each streamflow discharge so as to clarify the probability of various streamflow events and describe the present status of the hydrological condition in the Atsuma River Basin. This

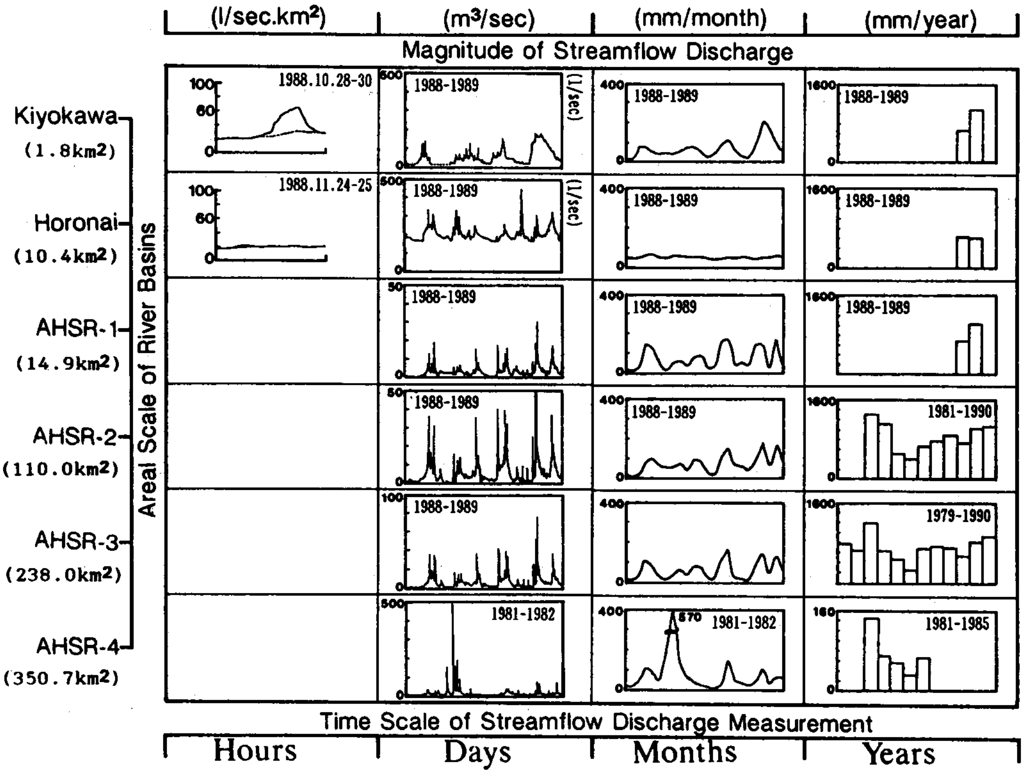


Fig. 14. Various Performance of Streamflow Discharge Rates in Different Areal Dimensions and Time Scale Measurement

is especially true in the probability of various magnitude of streamflow occurrences in relation to low streamflow events. The mean value on each AHSR was found to be 0.40 m^3/sec, 2.81 m^3/sec, 5.18 m^3/sec and 8.05 m^3/sec. The probability exceedence of the events were scanty runoff, low runoff, mean runoff and high runoff. The scanty and low runoff might be classified together as low streamflow, whereas the mean and high runoff as normal and high streamflows. Probability greater than each mean value was found to be 38.3%, 34.7%, 34.5% and 29.2% for AHSR−1, AHSR−2, AHSR−3 and AHSR−4 respectively. In other words, the probability occurrence, which was less than the mean values, was greater than the probability which was greater than the mean value. Therefore, a large fluctuation in the streamflow discharge distribution is a characteristics of the Atsuma River Basin.

To indicate streamflow fluctuation by using a river basin regime, the ratio of maximum and minimum streamflow discharges were arranged to express a specific coefficient for determining streamflow discharge fluctuation, the magnitude of month-base extreme values of mean daily streamflow discharges are presented in Fig. 15. This coefficient is easy to obtain, useful and has been widely used in hydrological studies for describing the fluctuation of streamflow discharges. The coefficient of river basin regime (dimensionless ratio of maximum and minimum streamflow discharges) was found to be 8.2 − 17.0 (AHSR−1), 5.0 − 29.9 (AHSR−2), 6.6 − 30.7 (AHSR−3) and 2.7 − 21.6 (AHSR−4) with its mean of 11.3, 13.9, 17.0 and 12.9, respectively. The coefficient of river basin regime was extremely large, providing further evidence of the large fluctuation of streamflow discharges in the Atsuma River Basin.

2. Standard Range of Normal Streamflow and Low Streamflow

As previously mentioned, the Atsuma River Basin was recognized to be a low streamflow area of moderate low streamflow severity, with the possibility that seasonal low streamflow events might frequently occur. To quantify the magnitude and period of low streamflow events, the standard range of normal streamflow is required as was performed earlier on the regional scale. Streamflow data series in the AHSR−3 site was used for establishing the standard range of normal streamflow in the Atsuma River Basin. The *AMS* was found to be 707 mm with extreme magnitudes of high and low streamflows being 1227 mm (1984) and 277 mm (1981). In order able to clarify annual streamflow fluctuation, the cumulative month-base streamflow is outlined in Fig. 16. Examining the cumulative magnitude, streamflow discharge was considered to be mostly induced by precipitation. This phenomena might be clarified by the fact that during high streamflow, precipitation depth was 1537 mm (1984), whereas during low streamflow, precipitation was recorded at 653 mm (1981).

The extreme annual streamflows (1981 and 1984) were selected and arranged in a standard range of normal streamflow (Fig. 17), intended to clarify the annual low streamflow fluctuation and classify streamflow events. It was learned that during a high streamflow period (1981), month-base streamflow was mostly normal and high. Conversely, the month-base streamflow was mostly low within the low streamflow period (1984). Most of seasonal fluctuation showed a different magnitude of low streamflow severity. Adversely, however, they also have seasons where streamflows were greater than the standard range of normal streamflow.

Seasonally, it shows a minimum level, mostly during peak of winter, and sharply

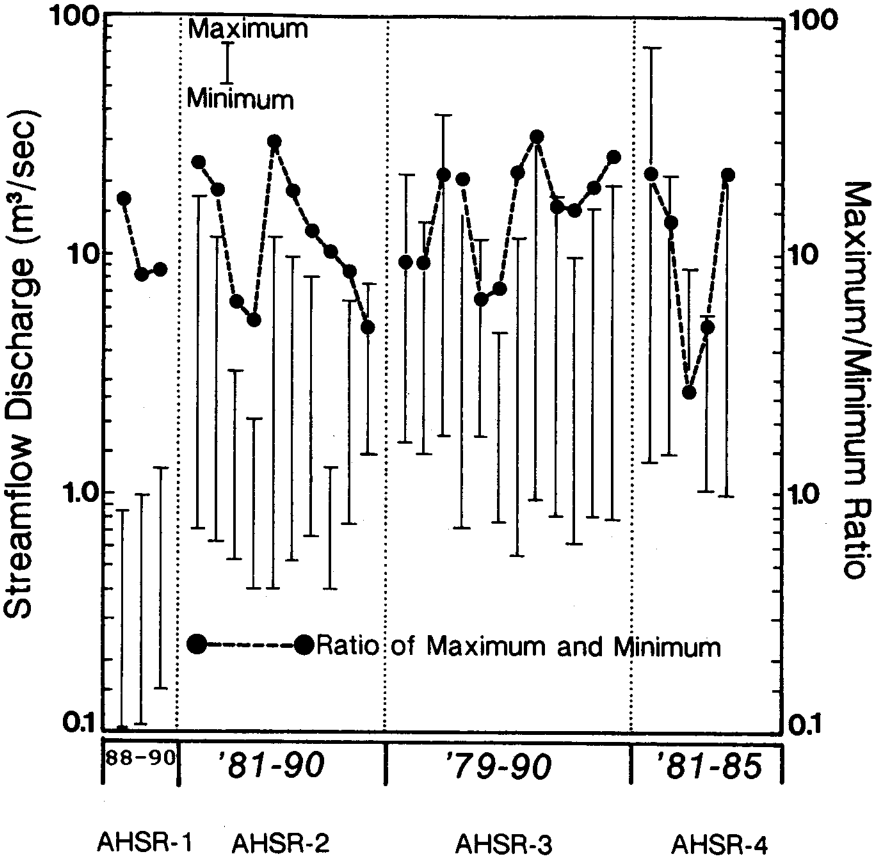


Fig. 15. Coefficient of Basin Regime Based on Extreme Values of Mean Daily Discharge Rates Measured at 4 Hydrometric Stations in Atsuma River Basin

increases to maximum in late winter. In contrast, after immediately decreasing in early and mid spring season, the standard increased during summer until late summer. Finally, after reaching a peak magnitude in late summer, it gradually decreases in late summer and through the fall season until the beginning of winter.

To estimate the water deficiency and excessive flows, following seasonal changes of streamflow discharges, month-base streamflow discharges of each year were examined using the predetermined standard range of normal streamflow. On an annual basis, streamflow deficiency was found to be 9 mm (1979), 28 mm (1980), 23 mm (1981), 17 mm (1982), 99 mm (1983), 215 mm (1984), 54 mm (1985), 9 mm (1986), 31 mm (1987), 51 mm (1988), 35 mm (1989) and 14 mm (1990).

Considering the impending severe competition for limited water resources, low streamflow analysis of any river basin should refer to the month-base order to precisely determine potential water resource availability, and more importantly how severe the low streamflow will be. Referring to the examination of month-base streamflow event on frequency and magnitude, low streamflow events were mostly found in April and September — December.

The standard range of normal streamflow, however, is considered to be comparatively high in April and August – October. Accordingly, the low precipitation within these periods in any month of any year might induce low streamflow occurrences. For this reason, a considerably large low streamflow magnitude might be found during these periods due to streamflow discharges being extremely high in April generated from melting snow and

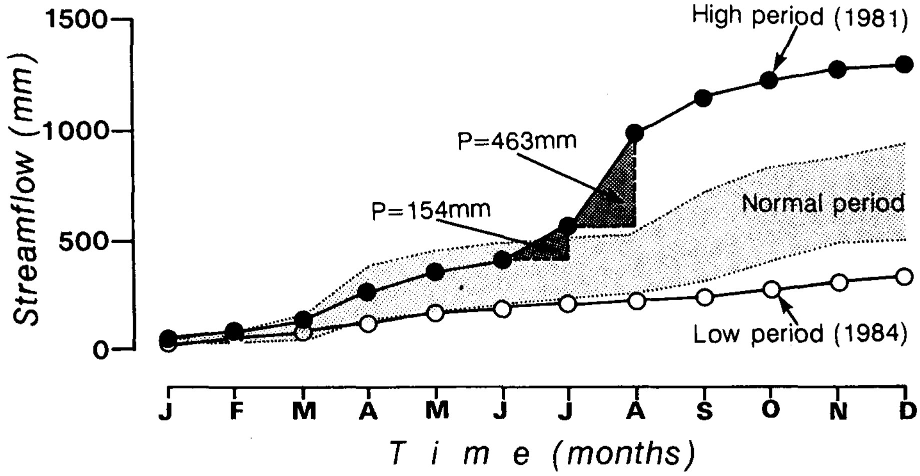


Fig. 16. Cumulative Mass Curve of Streamflow Discharges in Atsuma River Basin Classified into Low, Normal and High Period

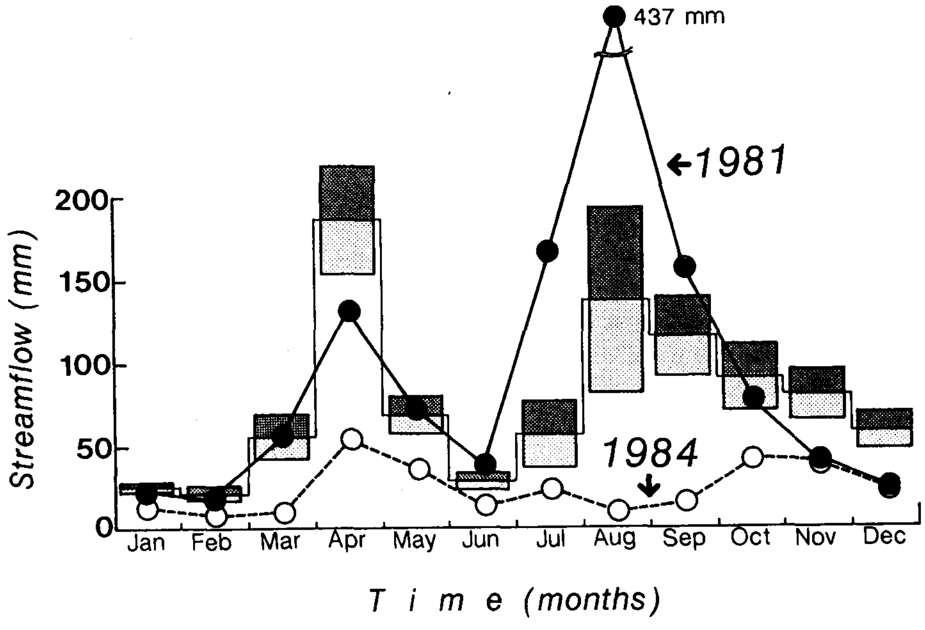


Fig. 17. Examination of Month-base Annual Low Streamflow Deficiency Using Areal Standard Range of Normal Streamflow

during August — October, induced by high precipitation. The lowest *ALS* magnitude was found in 1981 which was only 23 mm. Meanwhile, the streamflow magnitude was very low in the period of 1984 with an *ALS* of 215 mm.

The magnitude of standard range of normal streamflow within a certain period was remarkably high, while in other periods it was low. Considering the natural condition of streamflow discharges, the most important aspect, which should be carefully studied, is how to determine the respectable standard range of normal streamflow so it is possible to balance potential water supplies and the real water requirements. As the streamflow distribution in every river basin is considerably different, the criterion which should be used for examining low streamflow events should also meet each study objective.

V. Hydro-orological Condition of Variable Source Areas

Morphologically, the Atsuma River Basin can be divided into 18 Sub-Basins of which 9 of them — Atsuma, Shoshiutsu, Merukunnai, Shoroma, Onikishibe, Shuruku, Habiu, Ukuryu and Chikapeppu were studied to be observed (Fig. 18). The selection was based on their location as headwaters of variable source areas of water resources, topographical condition and vegetation cover. They occupy areas of 29.1 km², 13.1 km², 9.8 km², 25.5

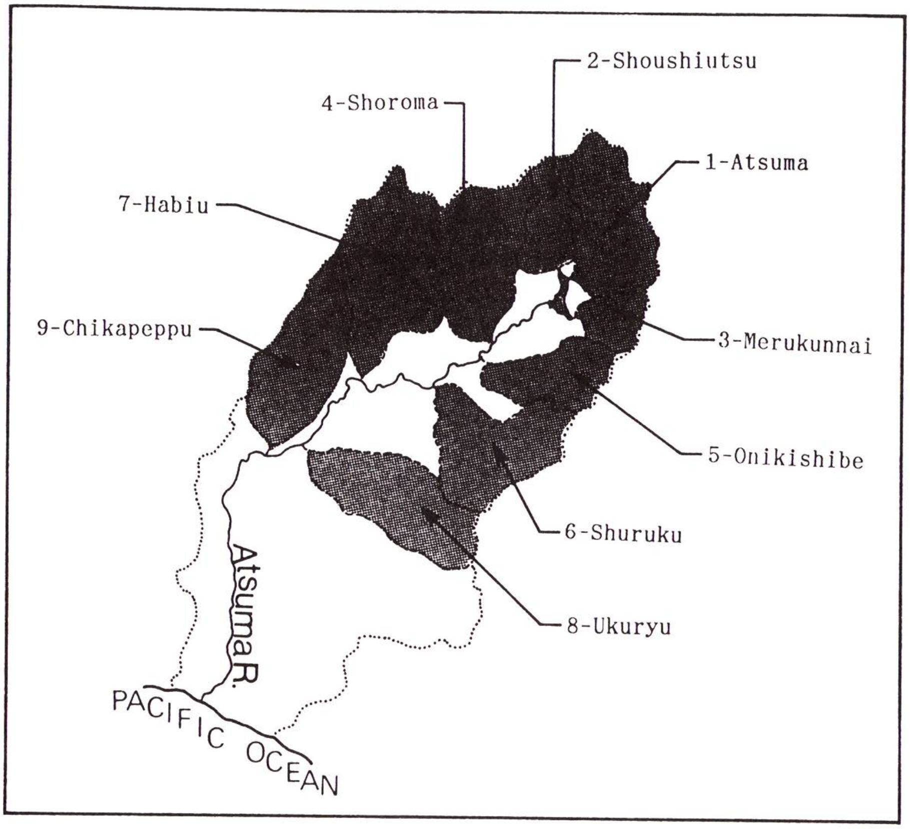


Fig. 18. Selected Sub-Basins of Atsuma River Basin to be Observed for Assessing Hydro-orological Condition

km², 14.9 km², 26.8 km², 40.2 km², 27.9 km² and 31.3 km² respectively. The measurement of streamflow discharge and suspended sediment concentration were carried out at each outlet of the selected Sub-Basins.

Regarding water resource preservation, land-use patterns should also be adequately investigated. The present land-use pattern and its transformational trend in Atsuma River Basin, which was considered to be in a conversion process from forested land to other uses, has been expanding from the downstream part moving up to middle and upstream parts. It was simply classified into several categories (Fig. 19). At the present time, the situation is still favorable, which forested land occupying nearly 73% of total river basin area. The forested land is composed of enrichment planting and forest plantation (35%), undisturbed natural forest (61%) and others (4%).

As previously mentioned, potential water resources should be considered for their quantity, quality and timing distribution. With regard to these points, an attempt to enhance the maximum value of water resources might be achieved if the potential water resource can be predicted from streamflow discharges measured within the water variable source areas. The term of variable source areas was used to describe the most important headwaters of the river basin, and therefore Sub-Basins located in the upstream part should be designated as headwaters of the river basin. Moreover, water quality was found to be related to suspended sediment concentration. Due to the fact eroded soils are transported by streamflow discharges and then deposited in lower reaches, especially at the dam sites, identification of the main source of suspended sediment production is exceedingly important.

1. Streamflow Discharges and Suspended Sediment Production Measurement

Streamflow discharge measurement was carried out by using a rotating current meter of streamflow velocity at segments of sectioned channel widths. Subsequently, the magnitude of streamflow discharges was obtained by multiplying streamflow velocity by each area of cross sectional channel width sections. The streamflow discharge measurements were undertaken from July 1990 to July 1992. In this period measurements were taken at least once a month during the times of precipitation and no precipitation. The frequency distribution of streamflow discharge is outlined in Fig. 20. The magnitude ranged greatly from 272.9 – 4397.3 l/sec (Atsuma), 100.9 – 1764.9 l/sec (Shoshiutsu), 54.9 – 938.3 l/sec (Merukunnai), 200.1 – 1515.1 l/sec (Shoroma), 79.0 – 2004.8 l/sec (Onikishibe), 82.7 – 1862.6 l/sec (Shuruku), 211.2 – 2190.7 l/sec (Habiu), 145.6 – 1666.2 l/sec (Ukuryu) and 155.1 – 2255.7 l/sec (Chikapeppu). These wide ranges indicate a great variation between maximum and minimum streamflow discharges (Appendix Photo–1, Appendix Photo–2). Referring to the frequency distribution, potential streamflow discharge was found to be less than 500 l/sec, even though at times they were greater than 2000 l/sec. The maximum was almost 10 – 20 times greater than the minimum. A large amount of streamflow discharges was found during precipitation period and shortly after precipitation occurrences ceased, while little occurred during non-precipitation periods.

In previous studies, erosion has been defined as soil and rock fragments detached from their initial resting place by various erosive agents such as raindrop impact, melting snow and surface flow along topographic slopes or flowing streamflow discharges. With regard to streamflow discharges, suspended sediment concentration was observed by taking samples of stream water using vinyl bottles at the same time and sites of the streamflow

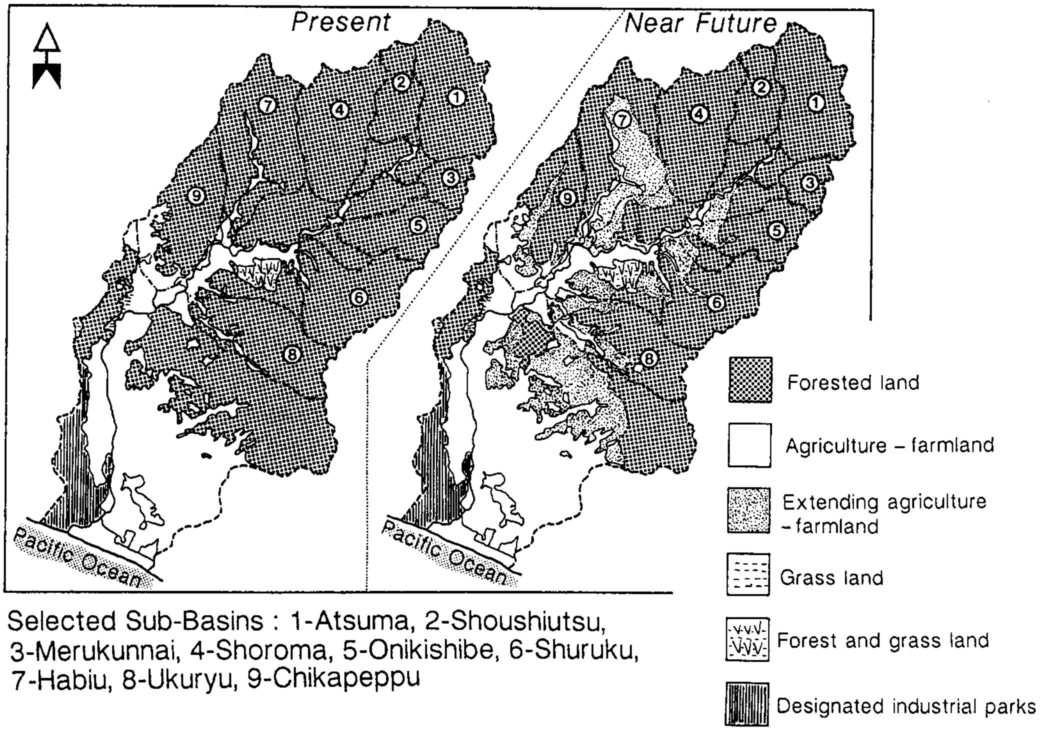


Fig. 19. Present Land-use of Atsuma River Basin and its Perspective Transformation

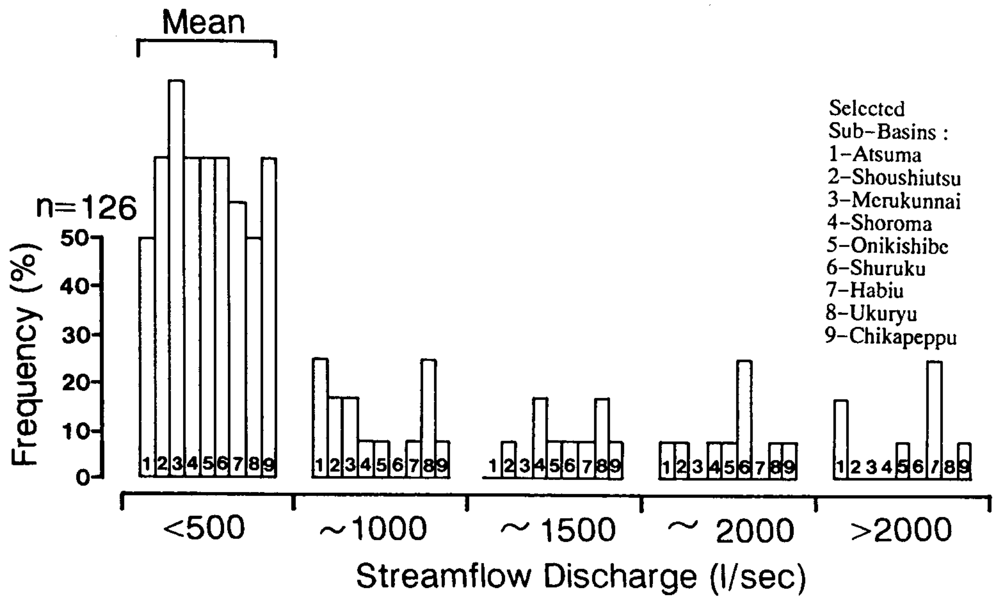


Fig. 20. Frequency Distribution of Potential Streamflow Discharge at Selected Sub-Basins in Atsuma River Basin

discharge measurement. The water samples were then analyzed by a simple gravimetric method and the results were specified in terms of part per million (ppm) scale unit. The magnitude range was found to be 54 – 512 ppm (Atsuma), 60 – 680 ppm (Shoshiutsu), 64 – 485 ppm (Merukunnai), 54 – 500 ppm (Shoroma), 31 – 498 ppm (Onikishibe), 49 – 397 ppm (Shuruku), 69 – 671 ppm (Habiu), 43 – 443 ppm (Ukuryu) and 18 – 799 ppm (Chikapeppu). Suspended sediment was not always higher following precipitation occurrences as was the case with streamflow discharges (Fig. 21). Potential suspended sediment concentration was found to be less than 200 – 400 ppm, although at times they were lower than 100 ppm or greater than 600 ppm, whereas the maximum was approximately 5 – 10 times greater than the minimum.

Concerning sources of suspended sediment production, some erosion processes and numerous sources are discussed. Geological erosion and soil erosion are terms usually used for describing the erosion process. Water course erosion which appear in stream-bank or channel erosion were also used in this study. Geological erosion is the erosion which scars the earth's surface creating mountains, flood plains, deserts and deltas under natural conditions, whereas soil erosion consists of surface erosion and soil mass movement. Meanwhile, water course erosion is the erosion of stream bank and stream-bed caused by flowing water. Surface erosion is individual soil particles detached from the soil surface and either moved down slope by raindrop splash (sheet erosion) or carried in suspension by surface flow (rilling and gullying), whereas mass soil movement is a simultaneous movement of large quantities of soil under the influence of gravity and is also often lubricated by large amounts of water. Soil particles are detached by rainfall and carried away by surface runoff. This may take place in the form of sheet erosion with a thin sheet of water flowing down a gentle upland slope. Rill erosion is another form with surface

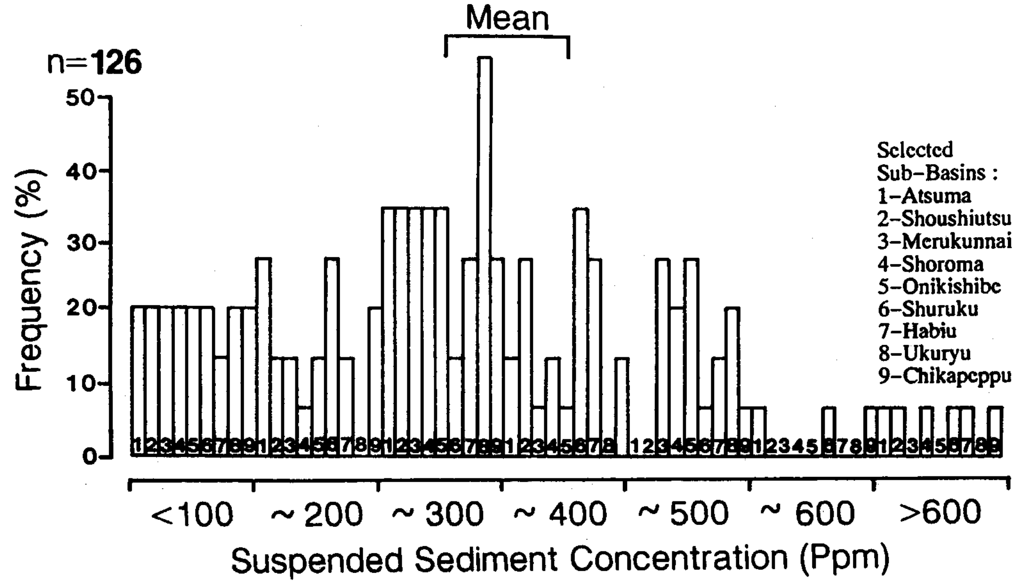


Fig. 21. Frequency Distribution of Potential Suspended Sediment Concentration at Selected Sub-Basins in Atsuma River Basin

flow occurring in a small incision in the land surface, while gully erosion is the dissection of soil surface by a deep cut in the land in which a channel is formed below an uncut reach, thus creating a sudden break in the surface slope.

Soil erosion usually begins when raindrops strike the exposed ground surface. Several trillion raindrops annually bombard each hectare of land in areas where annual rainfall is about 1000 mm (1m). Therefore, precipitation falling on one hectare has a volume of about 10,000 m^3, a mass of about 10,000,000 kg, and falls with an impact energy of 200 – 300 MJ. Accordingly, unless ground surface is protected by vegetational stands, impacting raindrops may detach tremendous amount of soil. Most soil eroded by water is then transported down slope by surface flow. While flowing, the surface flow might also detach and transport additional soils along its travel route.

Regarding sediment sources and erosion processes, soil erodibility and susceptibility should be precisely understood. The first factor corresponds with the intrinsic characteristics of soils whereas the later is mainly affected by extrinsic characteristics of soils or land environment. Soil erodibility is recognized as the inherent susceptibility of soil to accelerate soil movement which might be determined on the basis of soil characteristics alone (soil structure and aggregate stability) and does not take into account any other site factors. Soil structure is generally recognized as the manner in which soil particles are assembled in aggregates to which the cohesive nature of finer particles and or natural forces organize and retain the soils so fine-textured soils are cohesive and difficult to detach. In this study, the only data that could be observed was the percentage fraction of fine materials (ϕ <15mm) of the soils of the average ranged from 20 to 50% in 36 soil samples taken inside the Atsuma River Basin. It may be initially presumed that the soils in the Atsuma River Basin were potentially erodible if raindrop impact was strong enough to detach soil aggregates.

The susceptibility of soils might be connected to the ground surface cover and slope steepness. Vegetational stands have been widely accepted as a significant factor for controlling erosional intensity in accelerated erosion. Soils under good stand cover may be improved by accumulated organic materials with possible macro-pore formations, undergo structural improvement, increases the infiltration capacity, and experience a decrease in erosion potential. The vegetational cover also dissipates raindrop impact energy, reduces soil detachment, decreases transport capability by splash, lowers the rate of soil sealing and consequent surface flow. It might also slow streamflow velocity so that the flows are less erosive and reduce the capacity to transport sediment. Therefore, vegetational cover might be seen as a quite effective means of reducing the rate of erosional intensity.

Referring to field observations, numerous major sources of sediment production were the inter-rill areas, rills, and stream-banks. Eroded soils transported by waterflow are indicated by the suspended sediment load which is the amount of eroded soil material being transported on the downslopes, and finally into the stream channels. The inter-rill erosion uniformly removes soils, so it is usually inconspicuous compared with the more obvious rill or gully erosion. In the initial step, the rate of inter-rill erosion is usually only slightly affected by the steepness of the inter-rill surface and is relatively uniform over the whole slope. Accordingly, inter-rill areas are usually not rilled because the surface flow has not attained a tractive force sufficient to detach the soil particles. Soil detachment in rill erosion is initiated by concentrated surface flow, and occurs only within a small portion of the ground surface. It may develop where surface flow concentrates due to minor topographic variations.

Once rilling begins, it may increase rapidly as surface flow accumulates, and therefore rill erosion increases with slope length. Rills typically progress upslope by a series of intensely eroding heatcuts or knickpoints. This phenomenal process might lead to hillslope failure as shown in Appendix Photo−3. The eroded soils are then transported into the nearest stream channels and become one of the prominent sources of suspended sediment production. The other type considered to be an important source is water course erosion which was significant at several stream-bank site (Appendix Photo−4). It was frequently observed along stream−banks where many fallen trees, bank collapses and channel widening had occurred; especially in the middle and upper reaches of the headwaters. During low streamflow period, the eroded soils exerted from bank collapses are likely to be deposited in the bed of stream channels, and when flood occurs it is remobilized and transported into the down-slopes.

Stream-bank erosion might occur when grains or assemblages of grains are removed from bank sides by streamflow discharges. This process consists of two distinct events; namely detachment and entrainment. Sufficiently strong forces of lift and drag exerted on banks by streamflow discharges might detach and entrain grains directly from intact soils, but more the common behavior is for grains to be loosened and even detached prior to the entrainment by weakening and weathering processes. Another possible source is land preparation for agricultural crops during the growing season, particularly in the middle and lower reaches.

As previously recognized, the Atsuma River Basin is still well covered by good vegetational stands comprised of mixed forests of broad leaved and needle trees. Compared to unvegetated or fallow state, the slopes covered by a good stand of close growing vegetation experience an increase in erosion resistance. The vegetation cover not only protects soil surface directly, but roots and rhizomes of plants bind soils and introduce an extra cohesion over and above any intrinsic cohesion that stream-bank materials have. Slope steepness probably has the greatest effect on soil erosion which occurs in several topographic conditions. Steepness especially affects surface flow velocity − one major factor in soil surface detachment and transport capability. However, the slope of the whole of Atsuma River Basin was found to be gentle. Therefore, it might be presumed that soil erosion susceptibility in the Atsuma River Basin is considerably low. Highly erodible land and low susceptibility are important characteristics of the Atsuma River Basin in relation to the examination of erosional rate intensity.

2. Estimation of Potential Streamflow Discharge and Suspended Sediment Production

Potential streamflow discharge and suspended sediment production in each Sub-Basin were extrapolated in the unit of ton/day (Table 4), whereas the maximum of specific suspended sediment production was expressed as kg/ha.day. For examining erosional intensity, standard erosion rates provided by previous studies were used. Realizing that only a limited amount of water resources are available in a low streamflow area, they must be utilized as efficiently as possible by allocating the proper quantity with an adequate quality at the time required. Most of the Sub-Basins have potential streamflow discharges less than 500 l/sec (0.5 m^3/sec). This means that they have only limited potential because streamflow discharges are less than 43,200 ton/day in any selected Sub-Basin. However, during high streamflow period, they might produce streamflow discharges greater than 172,800 ton/day. Meanwhile, the mean potential suspended sediment production was found to be approximately 300 ppm, even though it may be less than 100 ppm or greater than 600 ppm. Based on the potential streamflow discharge, potential daily suspended sediment production might reach 13.0 ton (for the potential streamflow discharge of 43,200 ton/day) or 51.8 ton (for the potential streamflow discharge of 172,800 ton/day). The procedure for expressing potential streamflow discharge associated with suspended sediment production in quantitative values is considered to be simple and understandable. The result is expected to be beneficial for assessing the hydro-orological conditions.

Prior to the assessment of hydro-orological condition, it is important to consider the possible relation between specific streamflow discharges, annual low streamflow severity, percentage of forested areas and areal dimension of the Sub-Basin (Table 5). The relationship between annual specific streamflow discharge and its *ALS* for continuous long-term measurement in the Atsuma River Basin was established to estimate the *ALS* in each selected Sub-Basin in which streamflow discharge was only temporarily observed (Fig. 22). The lower specific streamflow discharge tends to have a greater *ALS*. By plotting temporal streamflow discharge measurement, Sub-Basins of Atsuma, Shoshiutsu, Merukunnai and Onikishibe had *ALS* less than 200 mm/year. In contrast, Shoroma,

Table 4. Extrapolated Prediction of Potential Streamflow Discharge and Suspended Sediment Production at Selected Sub-Basins in Atsuma River Basin

Hydro-orological Item	Selected Investigated Sub-Basins								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Sub-Basin area (km²)	29.1	13.1	9.8	25.5	14.9	26.8	40.2	27.9	31.3
Streamflow discharge (SD)									
- Maximum (ton/day)	379.9	152.5	81.1	117.5	173.2	160.9	188.0	143.9	194.9
	(4)	(3)	(1)	(2)	(3)	(3)	(3)	(2)	(3)
- Minimum (ton/day)	23.6	8.7	4.7	13.6	6.8	7.1	18.2	12.6	12.3
	(4)	(1)	(1)	(2)	(1)	(1)	(3)	(2)	(2)
Suspended sediment production (SSP)									
- Maximum (ton/day)	125.0	32.8	42.5	40.4	65.7	63.9	58.2	59.2	82.7
	(4)	(1)	(1)	(2)	(3)	(3)	(2)	(2)	(4)
- Minimum (ton/day)	1.6	0.8	0.5	1.2	0.7	0.7	1.5	1.5	2.2
	(3)	(1)	(1)	(2)	(1)	(1)	(2)	(2)	(4)
- Maximum Specific SSP Discharge (kg/ha.day)	43.0	25.0	43.4	16.5	44.1	23.8	14.5	21.2	26.4
- Grade of Erosion Intensity	(3)	(3)	(3)	(2)	(3)	(3)	(2)	(3)	(3)

Remark :

1. Data analyzed from 14 times measurements on each Sub-Basins
2. Selected Sub-basins : (1) Atsuma, (2) Shoushiutsu, (3) Merukunnai, (4) Shoroma, (5) Onikishibe, (6) Shuruku, (7) Habiu, (8) Ukuryu, (9) Chikapeppu
3. Extrapolation of streamflow discharges was done by multiplying its time scale, whereas suspended sediment concentration was extrapolated based on both time scale and relating measured streamflow discharges
4. Values in parenthesis ( ) represent the magnitude grade of both SD and SSP, SD – Maximum : (1) < 100, (2) 100 – 150, (3) 150 – 200, (4) > 200; Minimum : (1) <10, (2) 10 – 15, (3) 15 – 20, (4) > 20, SSP – Maximum : (1) < 40, (2) 40 – 60, (3) 60 – 80, (4) > 80; Minimum : (1) < 1.0, (2) 1.0 – 1.5, (3) 1.5 – 2.0, (4) > 2.0
5. Grade of Erosion Intensity (kg/ha. day) : (1) < 2 – hardly discernible, (2) 2 – 20 – slight, (3) 20 – 60 – moderate, (4) 60 – 200 – severe, (5) 200 – 800 – very severe, (6) > 800 – exceedingly severe erosion (based on the recent literature on surface erosion studies).

Table 5. Estimation of Annual Low Streamflow Severity in Selected Sub–Basins with Different Areal Dimension and Percentage of Forested Area

Parameter	Selected Sub–Basins								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Area (km²)	29.1	13.1	9.1	25.5	14.9	26.8	40.2	27.9	31.3
Forested Areas (%)									
- Present	100	100	100	100	96	97	92	93	73
- Near Future	100	100	100	97	90	85	54	69	55
Specific streamflow discharges (l/sec. km²)	34.0	36.4	28.3	22.7	37.0	24.7	21.7	22.4	23.7
Estimated Annual Low Streamflow Severity (mm/year)	105	70	189	271	61	241	285	275	256

(1) Atsuma, (2) Shoshiutsu, (3) Merukunnai, (4) Shoroma, (5) Onikishibe, (6) Shuruku, (7) Habiu, (8) Ukuryu, (9) Chikapeppu

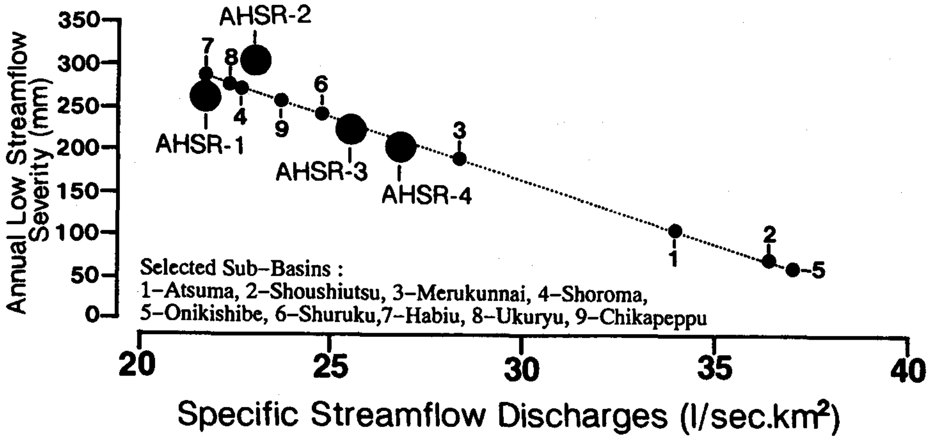


Fig. 22. Estimation of Annual Low Streamflow Severity at Selected Sub-Basins Using Long-term Streamflow Discharge Measurement

Shuruku, Habiu, Ukuryu and Chikapeppu had *ALS* greater than 200 mm/year. This kind of linkage between temporal and serial data measurement is considered to be useful due to the lack of long-term data measurement in Sub-Basins within a river basin. Further, by considering the method of data collection, especially the timing of field observations following the precipitation occurrences, a better estimate of the relationship between serial and temporal measurement might be established.

Considering the input – output approach to a streamflow – precipitation relationship and river basin characteristics, it can be seen that potential water resources are limited in amount and availability and will fluctuate with seasonal changes. For this reason headwaters, which are usually intended for water storage sites, must be conscientiously administered so as to preserve areas for water resources. As a land-use pattern transformation plan is developed, it should take into account that the removal of forested areas might lead to a decreasing low streamflow and a large increase in the amount of peak streamflow discharge immediately after precipitation occurrences.

To clarify how important headwaters are in relation to the water resources, specific streamflow discharges obtained from temporal measurement and estimated *ALS* in each selected Sub-Basin were arranged with their percentage of forested areas (Fig. 23 and Fig. 24). It was learned that a greater percentage of forested areas produced a greater specific streamflow discharge. In this study however, specific streamflow discharge was referred to as the average of streamflow discharges of both serial and temporal data measurements. It might be possible to use specific streamflow discharges referred to as the specified minimum condition of streamflow discharges of both serial and temporal data measurements to more properly express the role of forested areas in the low magnitude of streamflow discharge. Referring to previous relationship, headwaters retarded the fast releasing process of streamflow discharges generated by precipitation. As an implication is that the *ALS* in a Sub-Basin having greater percentage of forested areas was lower than a Sub-Basin with a smaller percentage of forested areas.

At the present time, most water needs have been supplied by utilizing streamflow discharges from headwaters and water reservoirs. However, if the progressive demand reaches several times greater than the existing potential supplies, the area would suffer from a severe water shortage during certain seasons of low streamflow. Accordingly, from a management aspect for achieving desired sustainable water yield, it is exceedingly important to manage headwaters properly from hydrological point of view. On the management of headwaters, the dimension of areal unit management should be properly identified, even though it will not be so easy to decide the most proper unit. Concerning this problem, *ALS* and dimension of Sub-Basin areas are arranged in Fig. 25. The figure indicates that a larger Sub-Basin expresses a higher possibility to be affected by a greater *ALS*. For this reason, it might be suggested that a smaller dimension for headwaters management would be better than a larger one. However, the decision on this management

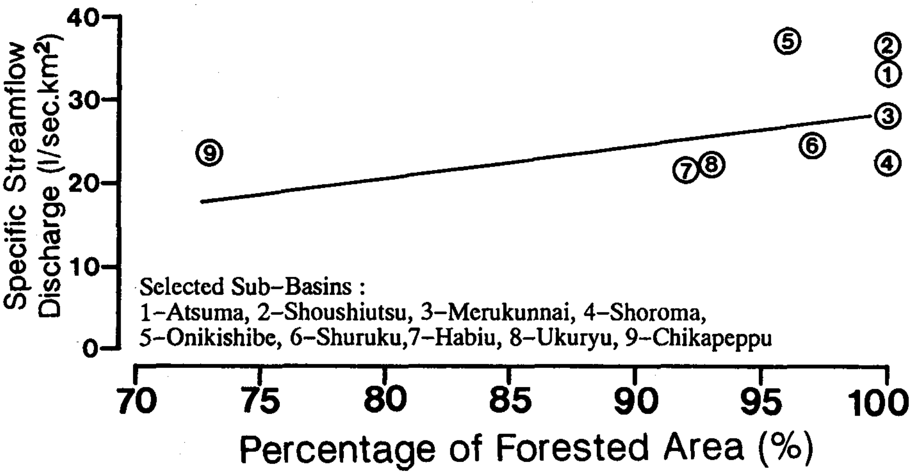


Fig. 23. Relation between Specific Streamflow Discharges and Percentage of Forested Areas at Selected Sub-Basins

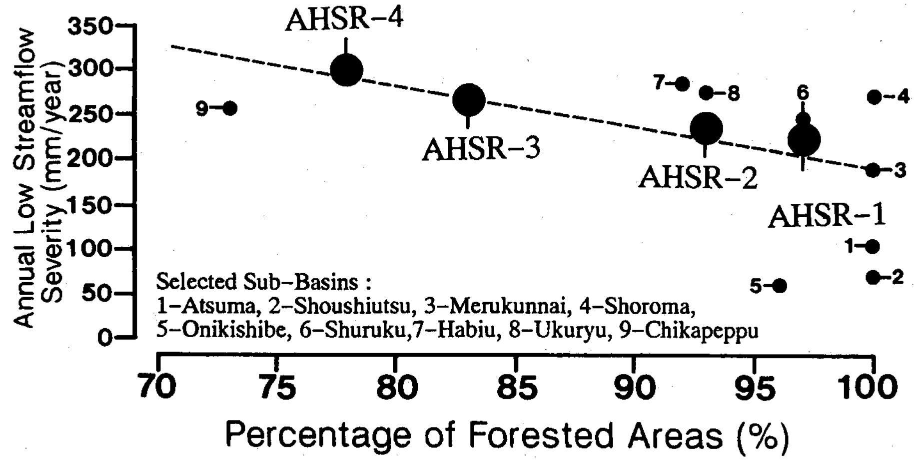


Fig. 24. Relation between Annual Low Streamflow Severity and Percentage of Forested Areas Referred to Temporal and Serial Streamflow Measurements

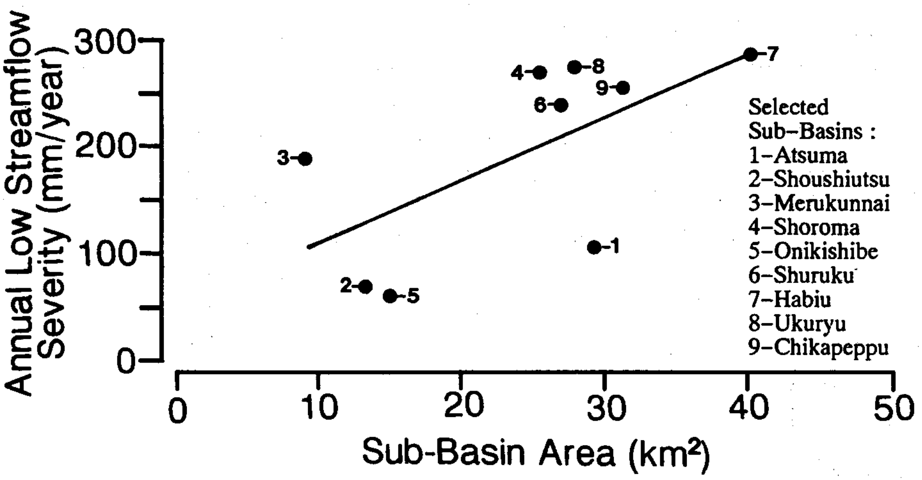


Fig. 25. Relation between Annual Low Streamflow Severity and Areal Dimension of Selected Sub-Basins

unit can not stand alone, and therefore should be connected with other considerations.

VI. Factors Related to Low Streamflow

Streamflow fluctuation was considered to be induced by the seasonal distribution of precipitation and the physiographic characteristics of the river basin in relation to the waterflow process. Accordingly, factors responsible for a low streamflow event should be clarified as the main and associated factors. The representative physiographic characteristics of the river basin are the geological structure and geomorphological features of the river basin.

1. Regional Precipitation Distribution

Precipitation depth varies in both vertical and horizontal changes, therefore each area receives different amounts of precipitation. The region is usually divided into several areas using isohyetal lines, determined from synoptical measurement of precipitation to estimate the regional or areal precipitation depth. Precipitation measured throughout the Hokkaido region for the last two decades, as illustrated with isohyetal lines, are arranged with previously examined *SIL* is outlined in Fig. 26. Moreover, river basin areas and the *ALS* within certain precipitation depths is shown in Fig. 27. It was learned that *ALS* less than 100 mm and 100 – 200 mm appeared in river basins having areal dimensions of <100 km^2 and 100 – 200 km^2. Conversely, *ALS* of 200 – 300 mm, 300 – 400 mm and >400 mm were mostly found in the river basin with areal dimension of 300 – 400 km^2, 400 – 500 km^2

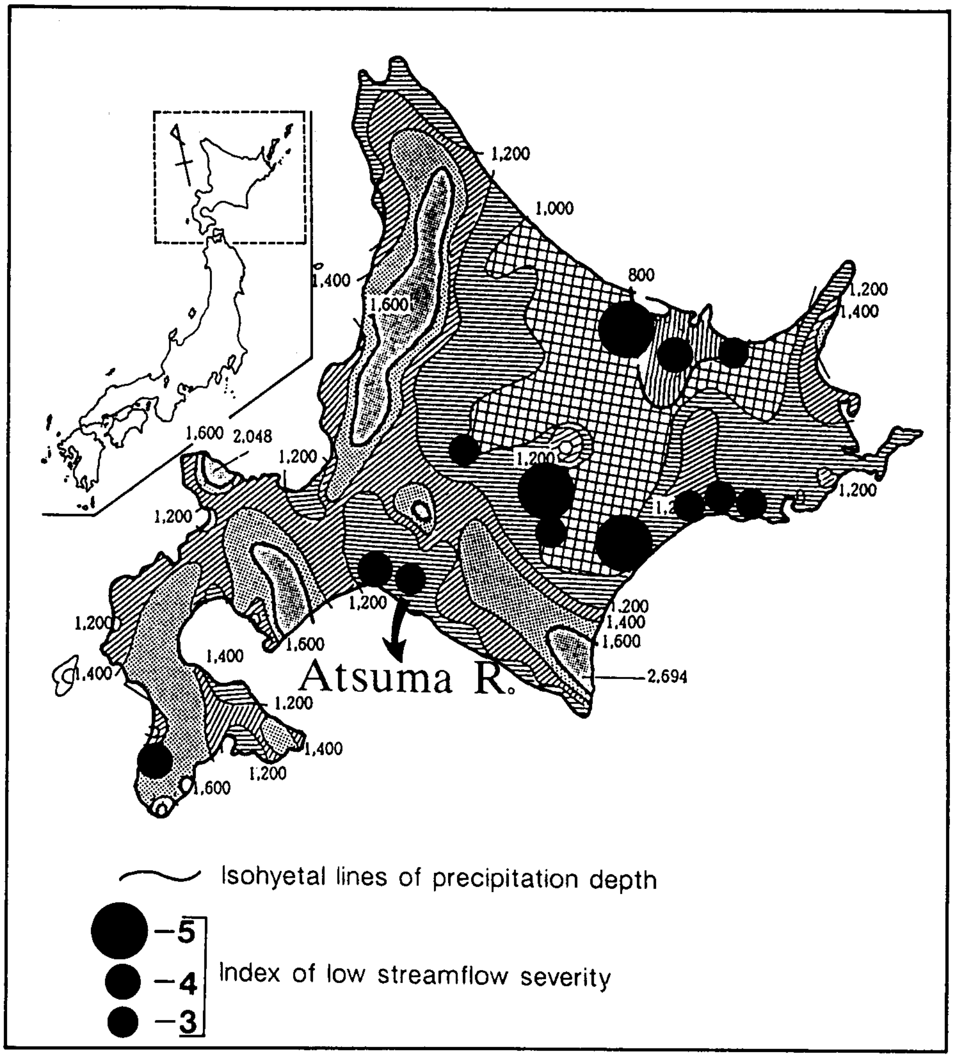


Fig. 26. Distribution of Regional Precipitation and Relatively Severe Low Streamflow Areas (River Basins) in Hokkaido Region

and >500 km². However, it could also be observed that there was a number of river basins despite having areal dimension of 100 – 200 km² and 200 – 300 km² were suffering from *ALS* of 300 – 400 and >400 mm. The isohyetal lines were set at precipitation depths of 800 mm, 1000 mm, 1200 mm, 1400 mm, 1600 mm, but some local areas were 2048 mm (western part near the Japan Sea) and 2694 mm (southern part near the Pacific Ocean).

The isohyetal lines show that eastern Hokkaido received much less precipitation than the western region. To express the relation between the depth of precipitation and annual low streamflow severity, the following river basins were categorized into low streamflow areas : Mena R. (Hk–356) of *SIL–4*, Abira R. (Mu–405 of *SIL–3*, Atsuma R. (Mu–407) of *SIL–3*, Furano R. (Ask–503) of *SIL–3*, Muka R. (Ab–814) of *SIL–5*, Shibetsu R. (Ab–816) of *SIL–4*, Saromabetsu R. (Ab–818) of *SIL–3*, Urahoro R. (Ob–915) of *SIL–5*, Shikaribetsu R. (Ob–919) of *SIL–5*, Betsuho R. (Ku–1004) of *SIL–3*, Shoro R. (Ku–1020) of *SIL–3* and Charo R. (Ku–1022) of *SIL–3*, which has shown by the black circles in the figure. It can be simply stated that the higher annual low streamflow severity was found mostly in areas with lower precipitation.

As ascertained earlier, *SIL–3*, *SIL–4* and *SIL–5* were mainly found in areas having annual precipitation of <1000 mm and 1000 – 1200 mm, whereas *SIL–1* and *SIL–2* were 1200 – 1400 mm and 1400 – 1600 mm respectively. It can be understood that the fluctuation of streamflow discharges in such river basins is intense related to the precipitation distribution and the river basin areal dimension. However, it should be noted there were some river basins, despite receiving precipitation of 1400 – 1600 mm/year, were categorized as *SIL–3* and *SIL–4*. In contrast, despite having <1000 mm or 1000 – 1200 mm/year precipitation, some river basins were classified as *SIL–1* or *SIL–2*. This phenomenon indicates that low stream-

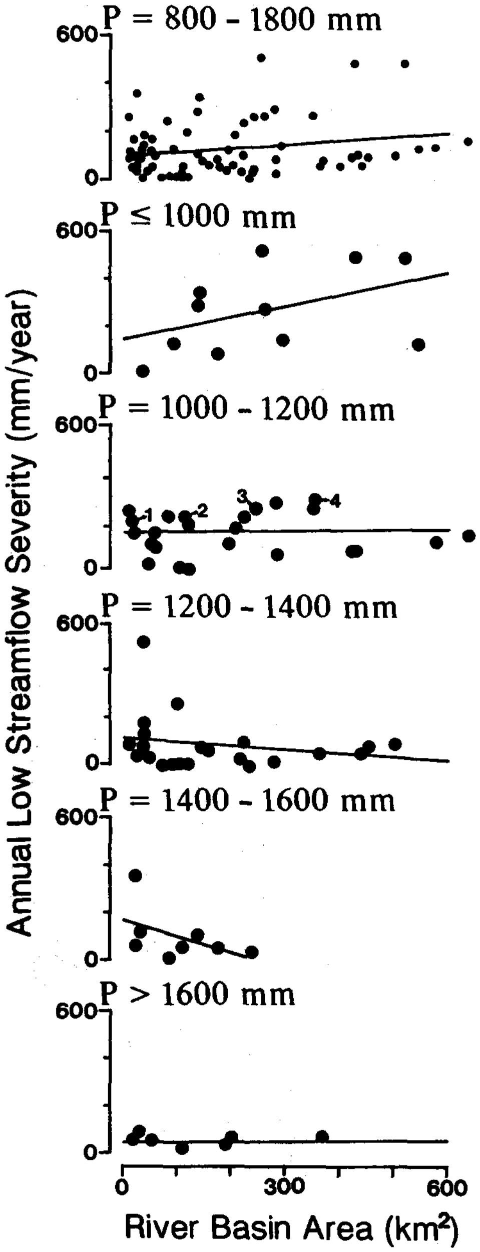


Fig. 27. Relation between Areal Dimension of River Basin and Annual Low Streamflow Severity Index Classified in Similar Precipitation Depth

flow is not only initiated by low precipitation, but that there are other factors involved with low streamflow events.

2. Physiographic Characteristics

Low streamflow may also be caused by the quickness of waterflow process. A river basin may quickly release the hydrological input (precipitation) into hydrological output (streamflow discharges). Other considerable water loss may occur through the evapotranspiration process. Accordingly, despite a river basin having high precipitation and a large amount of *AMS*, it is still highly possible to suffer severe low streamflow. In this study, physiographic characteristics which considered to be related with waterflow process were the geological structure, dimension of river basin area and typical river basin shape.

The larger river basin would be expected to have a high *SIL*, but due to the topographic divide of its geomorphological features it does not always coincide with the hydrologic divide in ground subsurface, which might be larger than the topographic divide. Therefore, there might be a water leakage into adjacent river basins. This phenomena is very important because streamflow discharge which is converted to equivalent water depth is referred to river basin area and was used in the previous analysis. Another reason is that evapotranspiration magnitude in a larger river basin, which would be expected to have plain topography, might be larger than a smaller river basin characterized by steeper topographical conditions. Although an exact conclusion could not be completely drawn, this outcome at least indicates a phenomenon that low streamflow severity occurs in a relatively larger river basins more frequently.

A consecutive hydrograph for two small forested basins, a tertiary mudstone area (Kiyokawa Basin – Hokkaido University Teshio Experiment Forest) and a quaternary volcanic area (Horonai Basin – Hokkaido University Tomakomai Experiment Forest), are depicted in Fig. 28. Streamflow discharge of the tertiary mudstone area shows a higher fluctuation compared with the quaternary volcanic area. The most reasonable explanation that the quaternary volcanic area provides a high infiltration capacity and basin storage capability. Therefore, the main contributing source of streamflow dis-

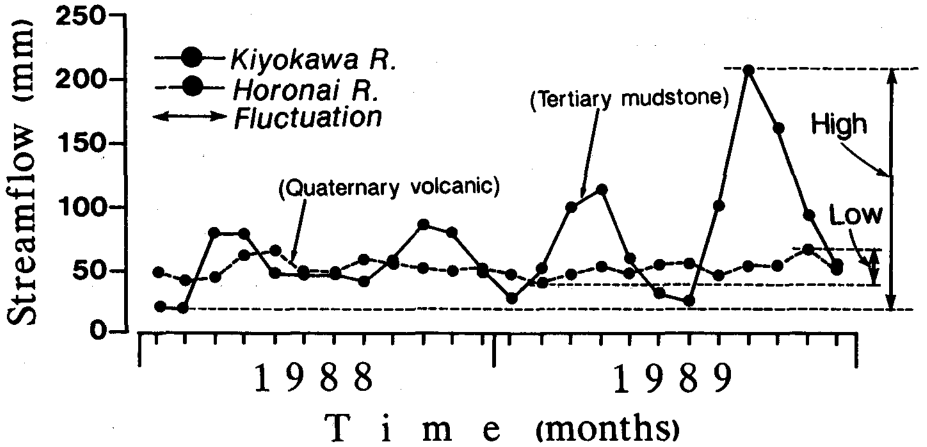


Fig. 28. Fluctuation of Streamflow Distribution in Discernible Different Geological Conditions

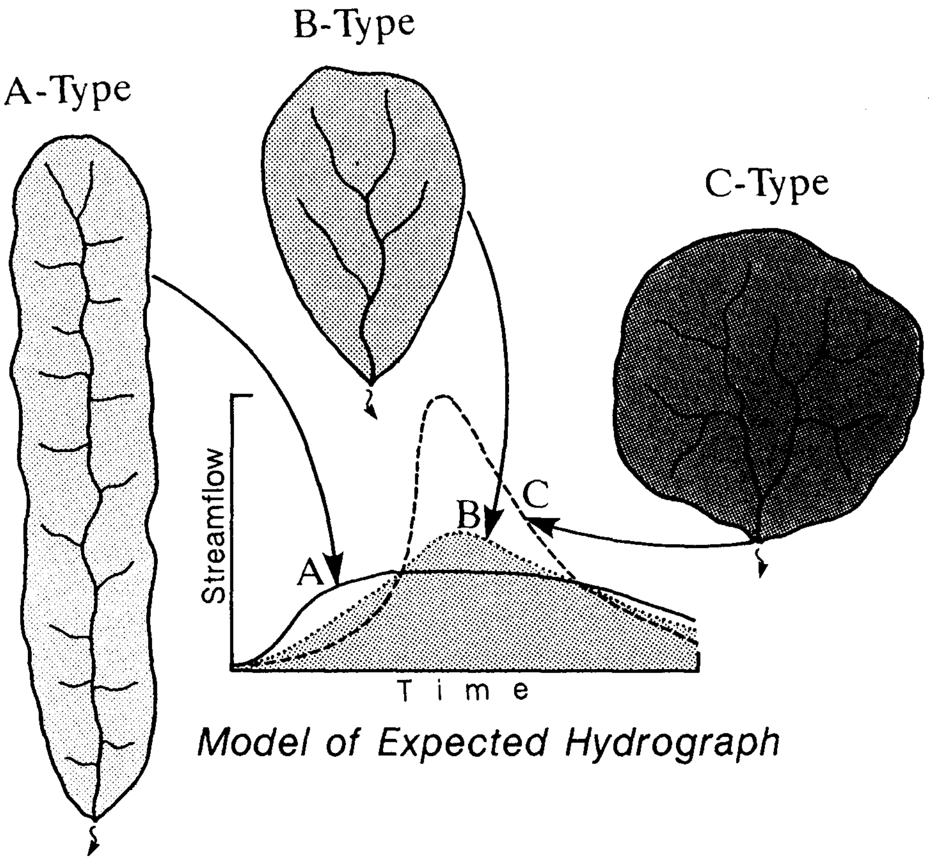


Fig. 29. Typical River Basin Shape, Drainage Network and Model of Each Expected Hydrograph

Table 6. Morphometric Characteristics of Observed River Basins

River Basin	SIL	Channel Length(L) Total (km)	Main Stream (km)	Area (A) (km^2)	R_f (A/L^2)	R_d (L/A)
Toubetsu	1	202	73	281	0.05	0.72
Yuufutsu	2	135	38	205	0.14	0.66
Atsuma	3	274	36	238	0.19	1.15
Yanbetsu	4	200	32	139	0.14	1.44
Shikaribetsu	5	655	28	255	0.32	2.57

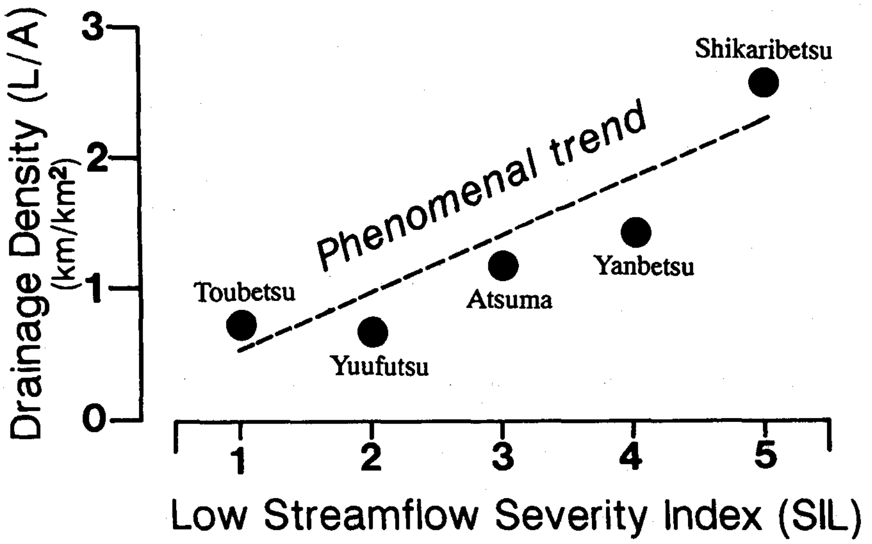
R_f – River basin form factor, R_d – Drainage density

charge appears to be groundwater flow and subsurface flow which is released slower than the rapid surface flow. Adversely, the tertiary mudstone area was recognized has having low infiltration capacity and river basin storage capability, thus promoting surface and subsurface flow proportionally to be the main contributing sources of streamflow discharge with a smaller proportion of groundwater flow. However, despite the ground surface providing high infiltration, if the next ground layer is impermeable, it would also induces a great subsurface waterflow. As a consequence, the river basin would be incapable of storing the input of falling precipitation for a prolonged resident time.

Considering a streamflow discharge travel route, from headwaters to river basin outlet, the shape or outline form of the river basin and its drainage density may conceivably affect streamflow discharges distribution. In the various river basin shapes, a long narrow river basin with low drainage density would have attenuated peak or flood discharge periods, whereas a rotund river basin with high drainage density would be expected to have sharp peaks or flood discharges. As shown in Fig. 29, *A* type is likely to promote relative stable and low fluctuation due to its prolonged travel time from the headwaters, particularly in the vertical direction, to the final release point of the river basin. By contrast, *C* type tends to mobilize and discharging streamflow in both horizontal and vertical directions simultaneously. Meanwhile, *B* type is a cross between the *A* and C types.

A simple measure for expressing morphological characteristics is the form factor (R_f) and drainage density (R_d). The form factor was found from the ratio of river basin area to the square of main stream channel, whereas drainage density was drawn from the ratio of main stream channel length to the river basin area (Table 6). The relation between form factor and drainage density associated with *SIL* are arranged in Fig. 30. The areal dimension (A) occupied by these river basins were similar : 281 km^2 (Toubetsu), 205 km^2 (Yuufutsu), 238 km^2 (Atsuma), 139 km^2 (Yanbetsu) and 255 km^2 (Shikaribetsu). Meanwhile, the total length of stream channel of all orders (L_t) are considerably different of 202 km, 135 km, 274 km, 200 km and 655 km, whereas main stream channel (L_m) was found to be 72 km, 37.8 km, 35.7 km, 31.6 km and 28.2 km, respectively. The form factor (A/L_m^2) was found to be 0.05, 0.14, 0.19, 0.14, 0.32 respectively. Whereas drainage density (L_t/A) was 0.72 km/km^2, 0.66 km/km^2, 1.15 km/km^2, 1.44 km/km^2 and 2.57 km/km^2 for the river basins of Toubetsu, Yuufutsu, Atsuma, Yanbetsu and Shikaribetsu. A greater value of R_f tends to have a higher R_d, showing that the more rotund river basin shape was characterized by a large number of various stream orders. This trend clarifies that the greater drainage density induced higher *SIL*. Returning to waterflow process, the greater index of *SIL* was initiated by a large fluctuation of streamflow discharge and this fluctuation might be partially influenced by river basin shape and its drainage density.

Hydrographs observed in the Atsuma River Basin (Mu−437) of *SIL−3*, Iburi River Basin (Mu−422) of *SIL−1* and Tomakomai River Basin (Mu−418) of *SIL−1* are arranged in Fig. 31. This figure shows that streamflow discharges in the Atsuma River Basin had extreme fluctuations compared to the others. The most discernible difference between the Atsuma River Basin and the two others is the geological condition – the Atsuma River Basin is tertiary mudstone and the other two are volcanic ash. In case of the Atsuma and Tomakomai River Basins, their areal dimension are different, 238 km^2 and 29 km^2, respectively. This might also be responsible for their streamflow discharge fluctuation. In the case of the Atsuma and Iburi River Basins, they are almost similar with Iburi River Basin occupying 237 km^2 area. Despite this fact the Iburi River Basin also shows a high fluctuation, while streamflow discharges remain relatively high within the period of low streamflow when compared with the Atsuma River Basin.



Selected Sub-Basins :
1-Atsuma, 2-Shoushiutsu, 3-Merukunnai, 4-Shoroma,
5-Onikishibe, 6-Shuruku,7-Habiu, 8-Ukuryu, 9-Chikapeppu

Fig. 30. Relation between Drainage Density and Low Streamflow Severity Index

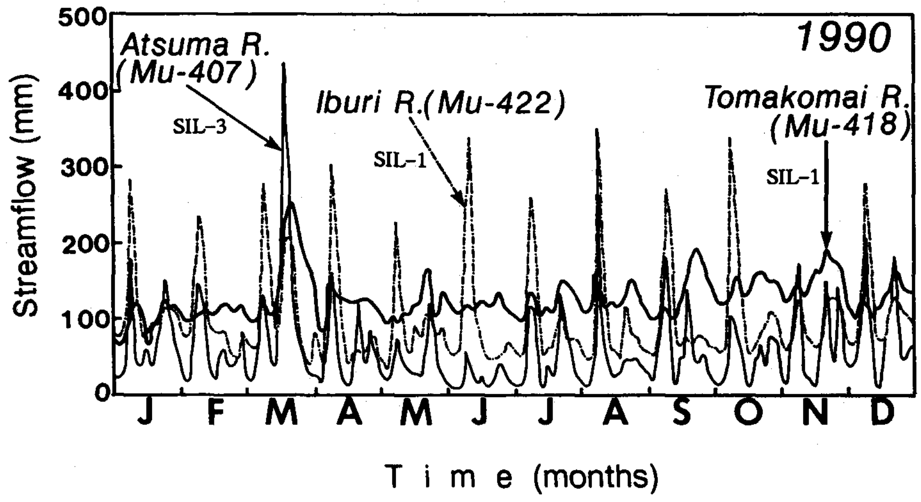


Fig. 31. Month-base Streamflow Distribution in River Basins with Different Index of Low Streamflow Severity

3. Local Characteristics of River Basin

After examining factors on a regional scale and studying the spatio-temporal changes, the hydrological events should be measured as a local problem (river basin or sub-basin) due to wide variation of local characteristics. There are many factors to consider simultaneously and interdependently that work in the waterflow processes, it is quite difficult to signify exactly which factors are responsible and have the greatest influence. Nevertheless, factors to be focused in the study of a river basin might be precipitation, hydraulic conductivity, infiltration capacity and morphological features.

As on a regional scale, precipitation was considered to be the main factor related to low streamflow and its severity. The relation between streamflow and precipitation is shown in Fig. 32 which shows their departure from the month-base mean value. The figure shows that the main hydrological output (streamflow discharge) is almost entirely dependent on the precipitation pattern. Therefore, the waterflow process within the river basin was considered fast when there was not adequate retardation due to river basin incapability to store precipitation water for a prolonged resident time.

To clarify the basin storage capability, an estimation of the fluctuation of river basin storage is necessary. This requires an estimation of water loss through the evapotranspiration process for performing a water budget examination. Evapotranspiration rate was estimated using Penman-Monteith Model (1965) partially modified and combined with another method by RAMPISELA et al (1990), which has been successfully applied in a small forested watershed. The method can be briefly summarized as follows :

$$E=\frac{\Delta(R_n-G)+\rho_a C_p(e_a^*-e_a)/R_a}{\Delta+\gamma+(1+R_c/R_a)} \qquad \cdots\cdots(5)$$

where E = evapotranspiration rate, λ = latent heat for vaporization, Δ = the slope of the saturation water vapor pressure at the air temperature, R_n = net radiation flux, G = soil heat flux, γ = psychrometric constant, ρ_a = density of the air, C_p = specific heat of air at the constant temperature, e_a = vapor pressure of the air, e^*_a = saturated vapor pressure at the temperature of the air, R_a = aerodynamic resistance and R_c = canopy resistance.

The available energy (R_n − G) was considered to be equal to the net radiation (R_n) due to the soil heat flux (G) which might be negligible for a soil surface when covered with a

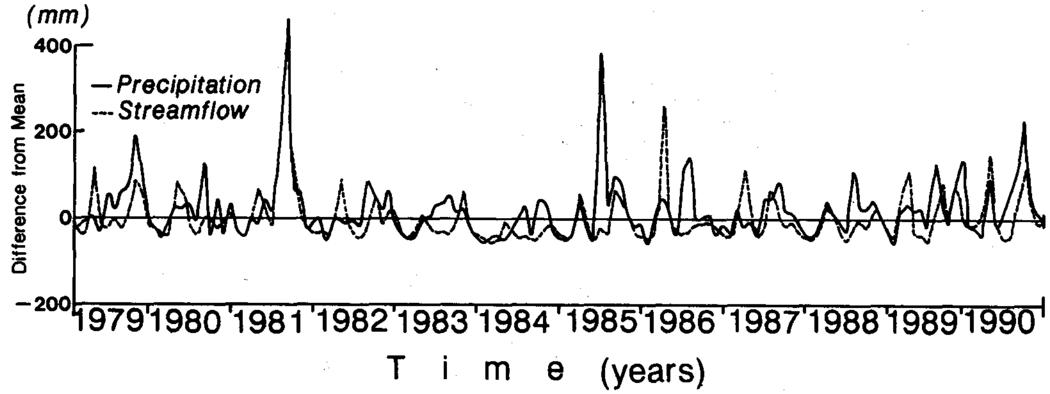


Fig. 32. Dimension of Month-base Distribution of Precipitation and Streamflow Departures from its Average Values

kind of crown-closed forest. Moreover, there are two unknown parameters in the equation namely R_a and R_c which could not be measured directly, and therefore were estimated as follows :

$$R_a=\frac{[\ln((z-d)/z_0)]^2}{k^2 u_{(z)}} \cdots\cdots(6)$$

where z = reference height of anemometer, d = zero plane displacement, z_0 = roughness length, k = von KARMAN's constant and $u_{(z)}$ = mean wind speed at z height.

$$R_c=\frac{S\times a_{(t)}\left[1-A\cos\left(2\pi\frac{D-M}{365}\right)\right]}{1-B(e_a^*-e_a)} \cdots\cdots(7)$$

where D = number of days, since the 1st of January, M = number of the day when R_c is a minimum, A = annual amplitude of the modulation of canopy resistance, B = dependence of canopy resistance on the water vapor pressure deficit, $a_{(t)}$ = diurnal variation factor at time (t) of the day and S = multiplied factor of $a_{(t)}$ to match the total annual rate.

The external monthly water budget (water balance) of the Atsuma River Basin is outlined in Fig. 33, by arranging major hydrological components for depicting the distribution of input – precipitation (P) and output – streamflow (Q), evapotranspiration (E). An estimation of the flux of basin storage (ΔS) is summarized in Table 7 and shown in Fig. 34. The positive value means storage increment, whereas a negative value denotes a discharging process of the available river basin storage. On the month-base estimation, there were a large number of negative flux storages (ΔS), showing that storage releases to streamflow discharge or water loss through evapotranspiration were greater than precipitation. Seasonally, the negative flux was primarily found within the periods of February – June and September – November.

In the February – June period, the deficit storages might be caused by a large amount of streamflow discharge generated by snow melting, or when the precipitation depth of snowfall was considerably low. During the period of September – November, low streamflow and water loss through the evapotranspiration process were responsible for the

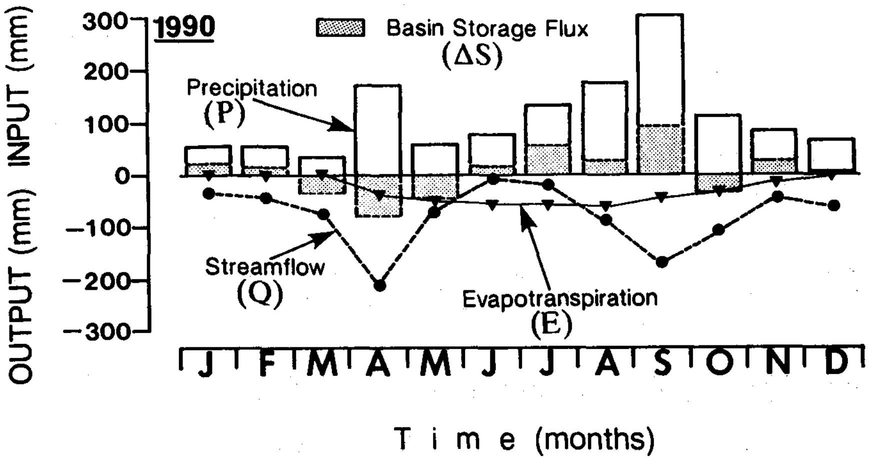


Fig. 33. Performance of External Monthly Water Balance for Atsuma River Basin based on Input-Output Components Values

Table 7. Estimation of River Basin Storage Flux (ΔS) in Atsuma River Basin

Years	Components	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	Precipitation (P)	48	60	69	79	39	128	94	140	141	266	155	54
	Streamflow (Q)	20	22	26	180	37	37	60	33	68	152	113	63
	Evapotranspiration (E)	0	0	0	35	59	60	62	65	47	41	9	0
	$\pm\Delta S = P - Q - E$	28	38	43	−136	−57	31	−26	42	26	73	33	−9
1980	Precipitation (P)	50	27	78	100	98	107	64	205	30	117	35	105
	Streamflow (Q)	36	16	23	147	115	35	17	53	61	34	50	80
	Evapotranspiration (E)	0	0	0	36	68	66	60	56	46	35	9	0
	$\pm\Delta S = P - Q - E$	14	11	55	−83	−85	6	−13	96	−77	48	−24	25
1981	Precipitation (P)	41	31	73	61	115	85	217	548	140	135	47	59
	Streamflow (Q)	21	19	55	131	71	36	165	437	154	76	39	23
	Evapotranspiration (E)	0	0	0	56	57	53	68	63	44	35	2	0
	$\pm\Delta S = P - Q - E$	20	12	18	−126	−13	−4	−16	48	−58	24	6	36
1982	Precipitation (P)	72	21	52	76	62	71	53	160	116	92	139	58
	Streamflow (Q)	26	14	36	160	50	22	8	40	116	41	75	76
	Evapotranspiration (E)	0	0	0	53	68	57	63	68	45	32	8	0
	$\pm\Delta S = P - Q - E$	46	7	16	−137	−56	−8	−18	52	−45	19	56	−18
1983	Precipitation (P)	37	23	27	70	78	104	109	127	85	77	43	28
	Streamflow (Q)	21	18	30	73	36	26	29	24	56	129	31	25
	Evapotranspiration (E)	0	0	0	74	57	44	54	64	46	24	5	0
	$\pm\Delta S = P - Q - E$	16	5	−3	−77	−15	34	26	39	−17	−76	7	3
1984	Precipitation (P)	16	30	32	22	39	75	103	36	118	113	41	26
	Streamflow (Q)	13	7	9	53	35	12	22	9	15	41	38	23
	Evapotranspiration (E)	0	0	0	39	61	64	69	68	45	29	2	0
	$\pm\Delta S = P - Q - E$	3	23	23	−70	−57	−1	12	−41	58	43	1	3
1985	Precipitation (P)	34	26	43	112	42	17	163	106	172	159	80	52
	Streamflow (Q)	10	9	18	116	49	6	36	22	130	104	69	22
	Evapotranspiration (E)	0	0	0	50	62	55	63	68	43	29	5	0
	$\pm\Delta S = P - Q - E$	24	17	25	−54	−69	−44	64	16	−1	26	6	30
1986	Precipitation (P)	62	11	81	120	91	36	198	218	71	79	83	37
	Streamflow (Q)	18	10	31	317	69	28	22	28	46	45	48	35
	Evapotranspiration (E)	0	0	0	48	54	57	54	64	47	24	4	0
	$\pm\Delta S = P - Q - E$	44	1	50	−245	−32	−49	122	126	−22	10	31	2
1987	Precipitation (P)	60	41	94	52	67	36	120	120	160	89	89	56
	Streamflow (Q)	25	15	58	183	69	11	38	136	73	40	53	22
	Evapotranspiration (E)	0	0	0	46	73	69	71	64	52	39	10	0
	$\pm\Delta S = P - Q - E$	45	26	36	−177	−75	−44	−11	−80	35	10	26	34
1988	Precipitation (P)	34	28	52	101	88	69	42	183	95	101	117	84
	Streamflow (Q)	16	11	23	106	78	27	7	33	64	35	78	73
	Evapotranspiration (E)	0	0	0	79	83	67	55	69	46	31	9	0
	$\pm\Delta S = P - Q - E$	18	17	29	−84	−93	−25	−20	81	−15	35	30	11
1989	Precipitation (P)	47	16	89	105	91	100	54	203	105	70	161	214
	Streamflow (Q)	22	15	115	169	24	24	9	74	149	43	140	61
	Evapotranspiration (E)	0	0	0	71	68	59	68	70	50	40	17	0
	$\pm\Delta S = P - Q - E$	25	1	−26	−135	−1	17	−23	59	−84	−13	4	153
1990	Precipitation (P)	55	54	36	171	57	78	132	176	305	113	85	67
	Streamflow (Q)	35	45	74	214	50	8	22	90	171	111	45	62
	Evapotranspiration (E)	0	0	41	53	56	58	62	44	34	12	9	0
	$\pm\Delta S = P - Q - E$	20	9	−38	−84	−46	14	52	24	90	−32	28	5

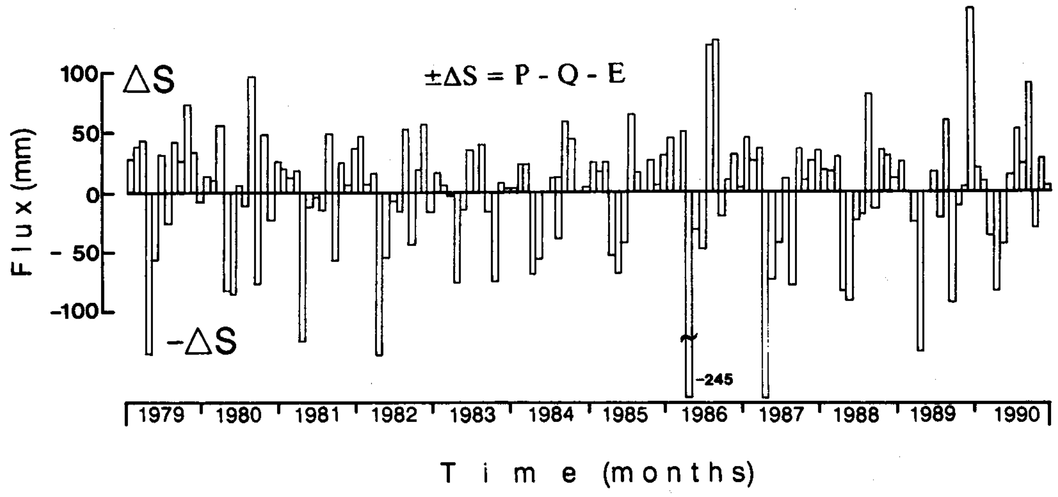


Fig. 34. Long-term Month-base Basin Storage Flux on Annual Basis showing Repeatedly Deficit River Basin Storage Occurrences

deficit storages. As previously ascertained, the Atsuma River Basin was incapable of storing precipitation input for long resident time. During low precipitation periods, the discharge of river basin storage lead to a deficit due to no precipitation input.

Soil under natural conditions was also considered to be related to the waterflow process. It might be partially described through the magnitude of infiltration capacity, hydraulic conductivity and other physical soil characteristics that express land permeability. Infiltration capacity was found to have a very wide range of values, 12 – 660 mm/hour (Fig. 35), of which sites covered by adequate vegetation revealed a greater capacity than bare sites. The mean range of soil moisture was found to be 16.7 – 33.6% and hydraulic conductivity ranged from 0.063 to 1.466 mm/sec, whereas the percentage of fine soil materials ($\phi < 0.15$ mm) was 22.2 – 53.8%. The moisture retained in the soils under the condition of no precipitation was significantly high, which was believed to be due to the high percentage of fine soil materials in the geological structures. This hold the water firmly in the soil pores. As to hydraulic conductivity, which expresses the soil or land permeability, some studies give a standard value ranging normally from 10^{-1} to 10^{-2} mm/sec for sandy soils, and 10^{-3} – 10^{-6} mm/sec for the clay soils.

Hydraulic conductivity is obviously affected by soil structures as well as by its textures. It will be greater if soil is highly porous, fractured or aggregated than if it is tightly compacted or dense. Consequently, it would not only depend on the total porosity but also and primarily on the sizes of conducting pores. Gravely or sandy soils with large pores can have a hydraulic conductivity much greater than a clay soils. Cracks, worm holes, and decayed root channels are present naturally in the field and may affect waterflow in the soils in different ways, depending on direction and condition of the waterflow process. Accordingly, it should be noted that the hydraulic conductivity does not in fact remain constant due to various chemical, physical and biological processes.

The result of hydraulic conductivity test are shown in Fig. 36 and express a tendency that the deeper layer has a lower rate than the preceding layer. Comparing this to

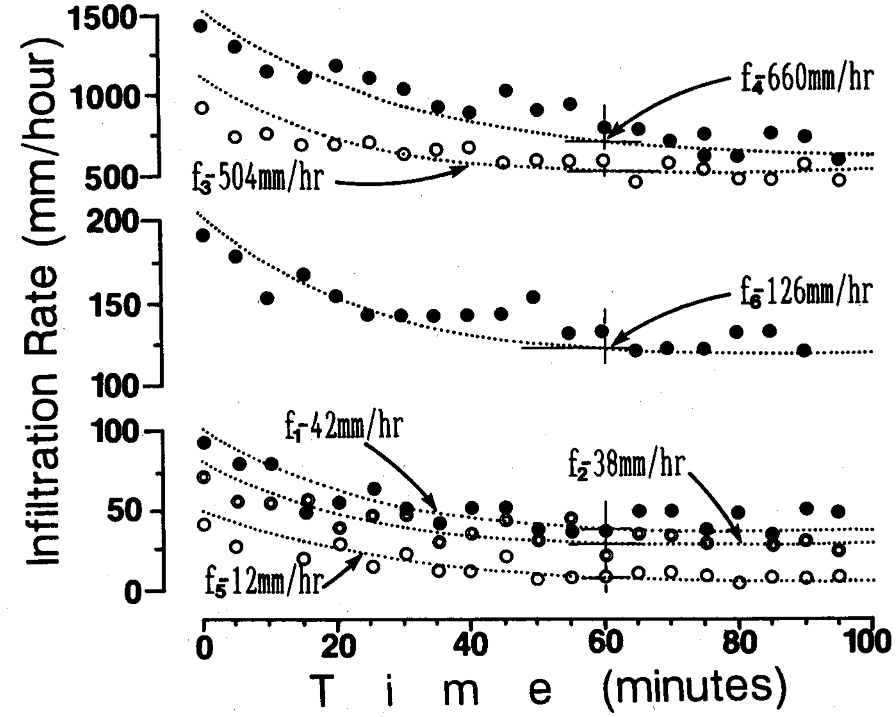


Fig. 35. Infiltration Capacity Observed at Several Sites in Atsuma River Basin

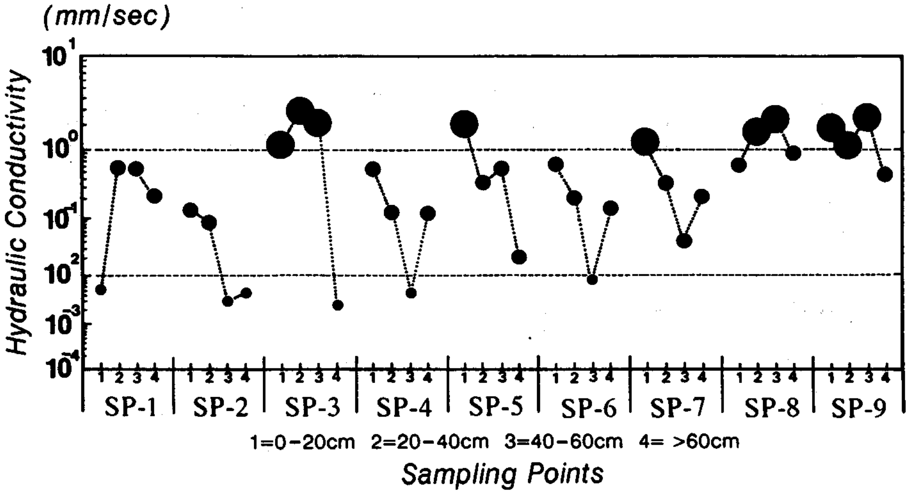


Fig. 36. Magnitude of Hydraulic Conductivity Observed at Several Sites in Atsuma River Basin

previous studies, hydraulic conductivity observed in the Atsuma River Basin was considered to be significantly high. It is imagined that the observed layers would relatively tolerate the vertical waterflow in the soils fast into the deeper layers.

The examination of the previous factors related with streamflow events reveal that the physical characteristics of a river basin likely induce the occurrence of low streamflow due to its fast waterflow process. After precipitation falling, it would infiltrate into the soils encompassing the ground surface and percolated into subsurface soils. Subsequently, infiltrated and percolated water would flow laterally above the preceding impermeable layer due to the soil layers being saturated. The impermeable layer formation might be explained by examining the result of soil profile observation (Fig. 37). Most of profiles were found to consist of shallow soil layers and a significant existence of impermeable bedrock under developed soil layers, even though it was frequently quite difficult to classify soil layers directly in the field. The depth of developed soils ranged from 45 – 70 cm before reaching the significantly impermeable layer or bedrock.

The processes of discharging basin storage is influenced by the morphological features of the river basin ; primarily river basin shape and drainage network. They were considered to affect streamflow discharges traveling from the headwaters to downstream. As ascertained earlier, there are two extremes of basin shape which induce different time lapses in producing peak streamflow discharge after precipitation occurrences. It was recognized that the shape of the Atsuma River Basin should be classified as a typical shape which would be expected to have a potential for sharp peak discharge (Fig. 38). Physi-

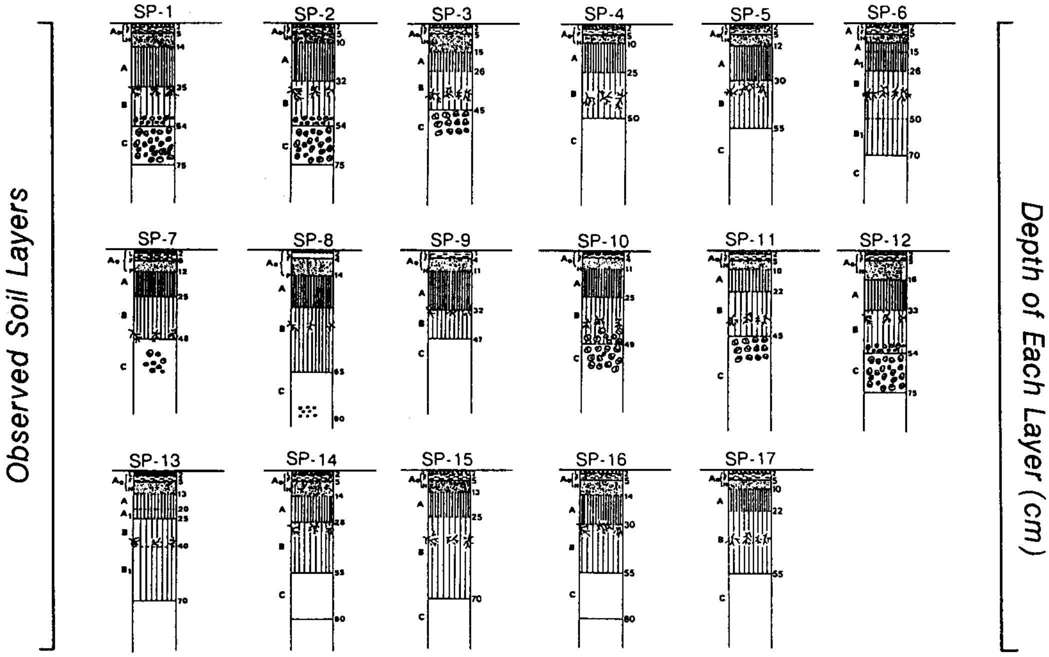


Fig. 37. Soil Profiles Observed at Several Sampling Points in Atsuma River Basin

cally, the shape of Atsuma River Basin is semi-radial in form. The main stream channel lies in the center and is fed by many branches to the left and right sides of the main stream channel composing a dendritic drainage network.

The synoptical measurement of streamflow discharges in consecutive sites from upstream to downstream show a similar pattern and its distributions with a gradually increasing of peak discharges magnitudes following the precipitation occurrences (Fig. 39). The similar pattern clearly indicates that the contribution sources of streamflow dis-

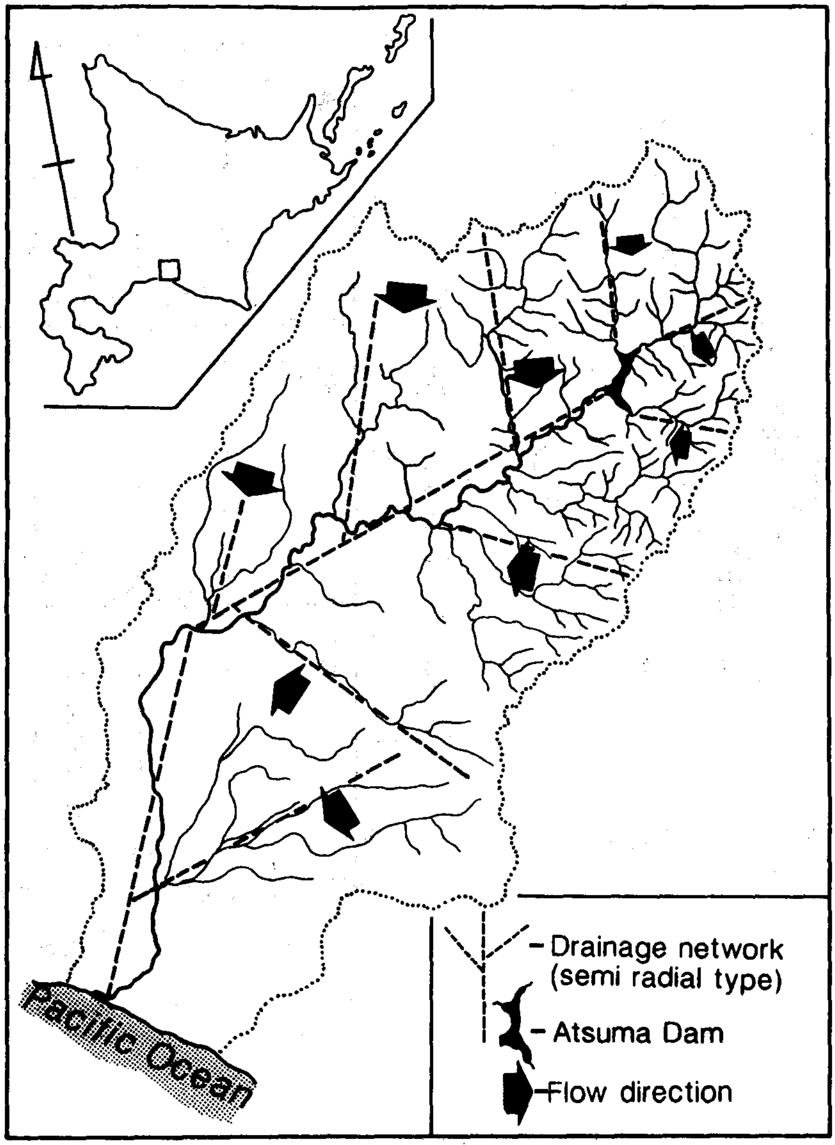


Fig. 38. Dimension of River Basin Shape and Drainge Network of Atsuma River Basin Featuring Rapid Streamflow Discharges

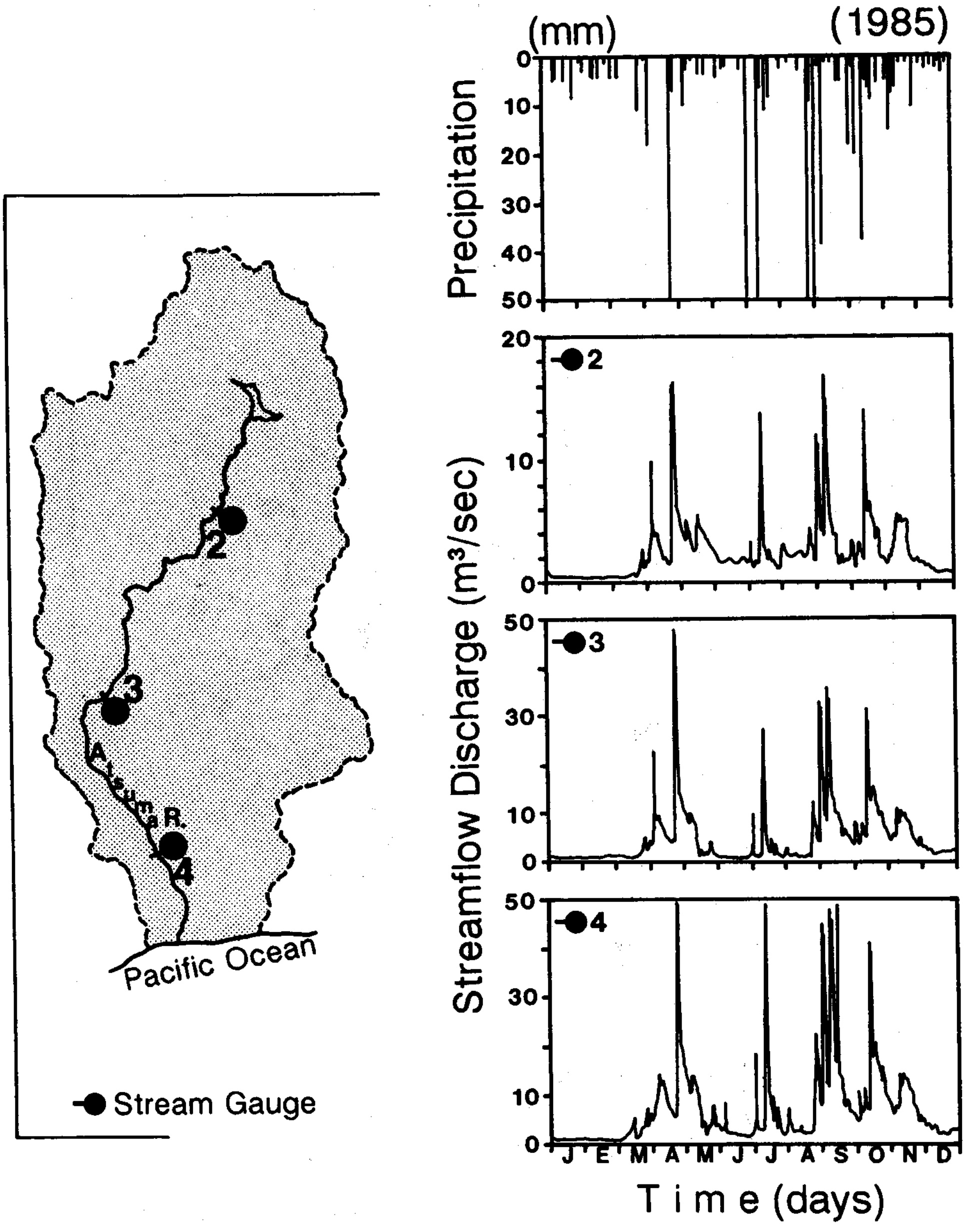


Fig. 39. Synoptical Measurement of Streamflow Discharge in Consecutive Hydrometric Stations from Upstream to Downstream Parts of Atsuma River Basin

charges from variable source areas flow quickly in a short time lapse rate. Such processes were observed in headwaters which generally were characterized as first or second order streams. In particular, the longitudinal profile of the Atsuma River was observed to be relatively gentle. Therefore, the travel time might be relatively slower compared with streamflow discharges from headwaters at the zero, first or second order streams in the main stream channel. Accordingly, the releasing process of river basin storage, which is mostly fast in headwaters areas, should be considered to be a significant point in relation to the alternatives of river basin practices intended for water resource preservation and improvement of the hydrological conditions.

VII. Implementation of Water Resources Preservation

Some areas are already short of water, while others may soon be out of water supply due to the poor distribution of water resources. Accordingly, the availability of water resources to satisfy various requirements will undoubtedly be more severe in the next decades. Anticipating this problem, one alternative is to limit development in the areas which might cause a sharp increase in demand for water resources. A second alternative is to import water from adjacent or nearby areas that have a surplus of water resources. However, these alternatives may be undesirable, and some effort to find other ways for augmenting and or regulating water resources are already underway. These are referred to as the preservation and improvement of seasonal distribution of water resources.

With regard to erosional problem, sediment yield originating from river basins has been widely used as a basis for assessing erosion rates or land degradation. Records of sediment yield, which might be primarily observed from suspended sediment production, have frequently been collected as a part of hydrological monitoring programs and should be readily available for such assessment. Forested lands, which are usually located in headwaters, have been confirmed as valuable resources for various purposes, of which one, is the water resources it produces. Therefore, any river basin should able to produce the desired amount of water in adequate quantity, quality and proper timing when required ; while at the same time producing other desired products. However, managing a river basin under a variety of uses and climatic conditions, topography, soils and vegetation involves a tremendous number of interdependent problems. To promote water resource preservation, especially in low streamflow river basins, a wealth of knowledge on procedures and techniques, which would be implemented according to the local conditions of the river basin, must be assembled.

Practical river basin management can play an important role with increasing environmental pressures for greater productivity and multipurpose use of forested lands. Unfortunately, headwaters management that could improve a water yield have not received the recognition it deserves. Most of the past efforts in river basin practices have been directed at only rehabilitating damaged or deteriorated river basins by repairing previous mismanagement or abuses. For this reason, preservation of water resources, improvement of water yield (adequate quantity, quality and its timing distribution) should be conducted simultaneously with rehabilitation. Therefore, efforts to quantify pertinent hydro-orologic parameters, develop river basin prescriptions, and practical actions to improve water yield must be achieved. An understandable prescription of the present status of hydro-orological conditions is expected to provide basic information for the preservation or improvement of water yield and its control.

Prior to the assessment of practical management aspects of water resources in any river basin, the characteristics of desired water products that must be available and how they are delivered should be considered first. The variability of annual streamflow, as well as the seasonal variation, present a major problem in water resource management. Some years or months are dry due to low streamflow, while other years or months are excessively wet. In those areas with a wide variation, both annually and monthly, improvement of streamflow discharge distribution becomes exceedingly important ; particularly related to the problem of how to successfully deal with the severity of low streamflow.

As it has been clarified in previous chapters, low streamflow severity is primarily caused by low precipitation associated with other factors. This baseline of information may be used when the improvement of seasonal streamflow distribution is implemented. Improvement, referred to here means increasing low streamflow while simultaneously with retarding the excessive high streamflow. The principles might be summarized as the follows : (1) Managing the rates of streamflow discharges generated from snow melting or heavy rainfall, (2) Improving the capability of water storages in the soils and providing water storages in the ground surface and (3) Altering the rates of subsurface flow and retarding streamflow discharges from headwaters.

1. Model Apportionment and Classification of Potential Water Resources

Long-term streamflow record was used for interpreting the seasonal distribution of water yield in the Atsuma River Basin. The serial record was arranged into mean, minimum and maximum on a monthly basis which was then specified into May – October *(M – O)* and November – April *(N – A)*. The *M – O* period was recognized to be high demand one due to irrigation needs for agricultural farmlands, while *M – O* period was categorized as low demand because of no agricultural activities (Fig. 40). Streamflow apportionment constitutes of 51 – 49% (Mean), 42 – 58% (Minimum) and 59 – 41% *(Maximum)* of *M – O* and *N – A* periods. In cases where requirements within the *M – O* period could not be satisfied, streamflow discharges of the *N – A* period should be maintained by retarding streamflow discharges from headwaters by creating artificial water reservoirs or any other proper basin practices.

Water resources in any river basin should able to serve more than one requirement and utilized efficiently to meet various requirements. A strategy, which refers to the concept of multipurpose uses, is usually based on a compromise. Success in joint usage however, depends upon the extent to which requirements are compatible with each other. Therefore, it is helpful to review the kind of water requirements and to consider ways in which those uses may be coordinated in an acceptable agreement. In following joint use principles, consideration is given to two possible extreme conditions : no water storage is able to be jointly used, or unlimited storage is available for joint use for at least more than one use. The common water requirements found in any river basin may be simply classified as follows :

(1). Irrigation needs for agricultural farmlands

This requirement is usually seasonal with a peak demand during summer and almost no demand in the winter. They do not vary greatly although low depth precipitation years may create a greater irrigation demand. Unless agricultural land is increased, mean annual demand will remain nearly constant.

(2). Domestic water supplies

These requirements are more nearly constant throughout the year, but a seasonal maximum is usually considered during the summer and may normally increase slowly from year to year.

(3). Hydroelectric power generation

This requirement is commonly seasonal depending on the type of area served and flexibility is usually possible in coordinating power needs with other uses.

(4). Recreational and wildlife conservation nature

Recreational and conservational reservoir should remain nearly full during the recreation season to permit boating, fishing, swimming, and other water sports. It also provides water for preserved nature or protected wildlife.

Power generation was considered to be compatible with domestic water supply, irrigation needs for agricultural farmland as well as with recreational and conservational use of nature. Conversely, domestic water supply and irrigation needs an exact volume which can not be jointly used and must be allocated to each water use. The optimization of water resource usage might be achieved by synthesizing water requirements to estimate the total amount required after adjusting for seasonal variation. The synthesis should be a good agreement that is compatible with the requirements, whereas every other requirement that is incompatible must be receive an allocation. If the available water resources can not satisfy requirements within each time period when its required, timing improvement of seasonal water yield distribution will be necessary. In the case of the Atsuma River Basin, the peak of water demand was recognized has being the period of $M-O$ which is the growing season of agricultural crops. Therefore, the most reasonable alternative is to retard the amount of streamflow discharge during $N-A$ period, which might be achieved

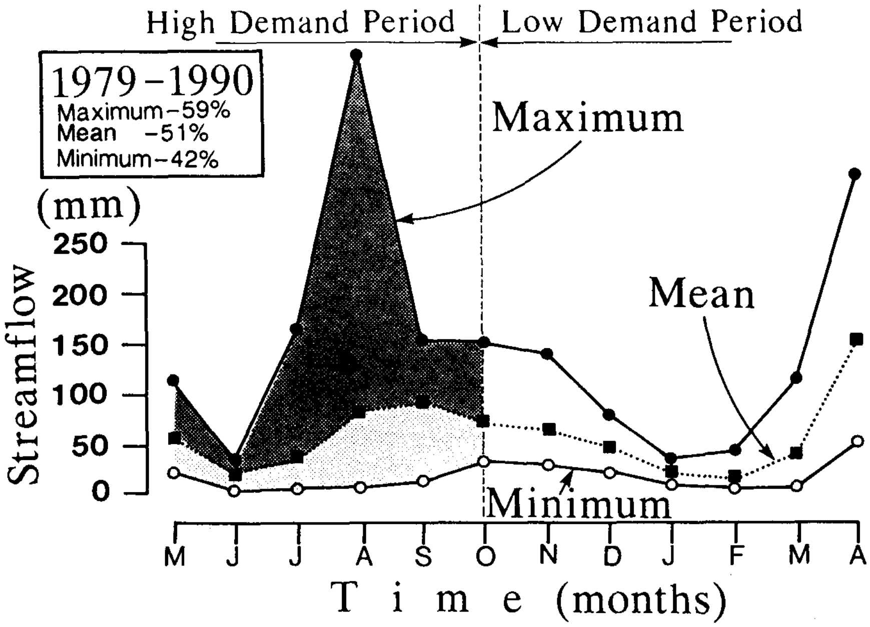


Fig. 40. Model of Potential Water Resources Apportionment into Perceivable Timing Requirements in Atsuma River Basin

in several ways that are acceptable to river basin practices.

2. Model Assessment of Variable Source Areas of Water Resources

To achieve a sustainable water resources in low streamflow areas, preservation and improvement of streamflow distribution might be necessary. Prior to its implementation, however, an understanding scheme of variable source areas of water resources is required. This might be done by clarifying the present status of hydro-orological condition of each Sub-Basin. For this purpose, the distribution of potential streamflow discharge and its suspended sediment production should be adequately recognized prior the establishment of appropriate planning of water resource development and its management; especially in the preservation aspects of hydro-orological conditions at a certain operational field level.

To assess the present status of hydro-orological condition a simple model assessment was established. The parameter of specific streamflow discharge was used for expressing potential water resources, whereas specific suspended sediment production was intended to express the erosion rate intensity. Headwater areas should the primary concern for preservation and or improvement of the hydro-orological conditions. The selected parameters were connected to the forested areas because they were seen as the most important component of headwaters (Fig. 41). The present arrangement used for clarifying spatial distribution of hydro-orological conditions in the Atsuma River Basin is considered to be simple, quick to perform and beneficial for clarifying the present status of hydro-orological conditions.

To perform a comparative examination of hydro-orological conditions among the selected Sub-Basins, a simple relation between potential streamflow discharge and suspended sediment production ranks was established. The abscissa was designated to reveal ascending rank of potential streamflow discharge, whereas the ordinate was

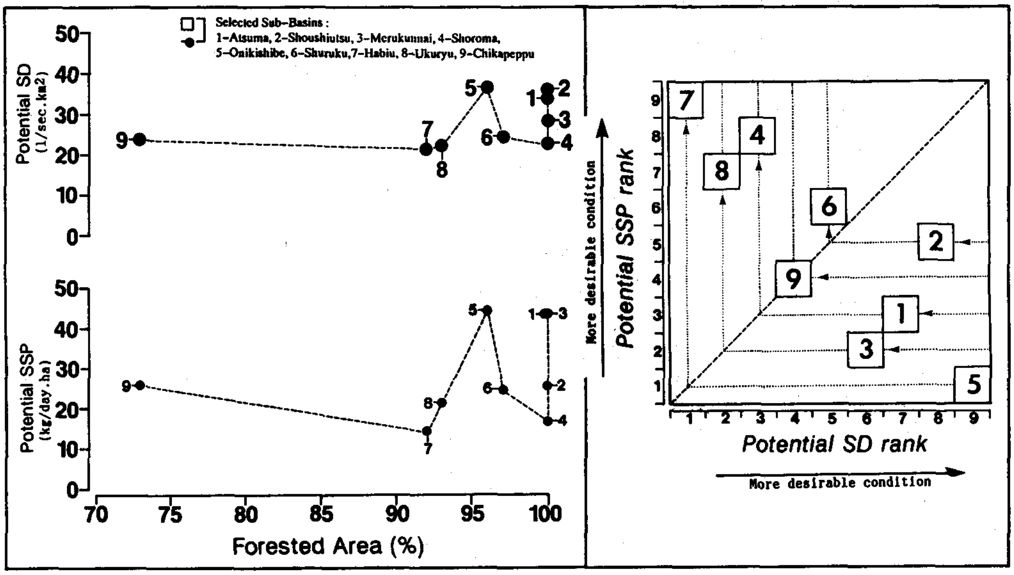


Fig. 41. Hydro-orological Assessment Model Referred to Potential Streamflow Discharge and Suspended Sediment Production at Selected Sub-Basins

intended to disclose the descending rank of potential suspended sediment production. In practical analysis, the higher potential streamflow discharge indicates the more desirable condition which means the abundance of water resources available in Sub-Basins. Adversely, the higher rank of potential suspended sediment production reveals the more objectionable condition due to its high rate of erosional intensity.

The hydro-orological conditions of each Sub-Basin were then assessed by examining their position in the combination ranks of each coordinate point. The assessment should first consider the potential streamflow discharge which is then followed by potential suspended sediment production. As a result, hydro—orological conditions of selected Sub-Basins were ranked in a descending order : (1) Shoshiutsu, (2) Shuruku, (3) Chikapeppu, (4) Atsuma, (5) Shoroma, (6) Merukunnai, (7) Ukuryu, (8) Onikishibe and (9) Habiu Sub-Basin. After carefully examining the status of hydro-orological conditions, it is expected that the planning of water resource development, management, preservation and improvement might be properly established in connection to the present status of hydro-orological conditions of each Sub-Basin.

The model assessment which basically refers to the ranking system is considered to be very useful because it is simple and quick to perform and is also applicable for the limited field observation data. Referring to the establishment principle of the model for assessing headwater conditions, the model might be easily modified with other parameters considered to be decisive factors in relation to headwater conditions.

3. River Basin Management Practices and Perspective of Water Resources Preservation

Water resource development planning and its management should be established taking into account the meteorological, hydrological and erosional conditions. Many terms have been quite indeterminately used in relation to potential water resources such as water need, water demand or water requirement, as was used in this study. However, these terms should be interpreted as the amount of water resources which could be used rather than the amount that would be used. As the hydrological condition is expressed as annual low streamflow severity *(ALS)*, the guideline for management practices and preservation of water resources should be to reduce the annual low streamflow severity, in order that the hydrological condition could be placed in the lower grades of the low streamflow severity index *(SIL)*.

For this purpose, management for increasing water yield should be applied, when reservoir storage and water needs are not fully met, by minimizing high streamflow and increasing low streamflow discharges. In some conditions, however, a large amount of rainfall will produce high rates of streamflow discharge. In such situations, it might be considered a good opportunity to reduce high streamflow discharges induced by prolonged rainfall so as to increase the available storage above and below the ground surfaces. Since streamflow discharges are expected to be primary source of water supplies, augmentation during low streamflow periods should be accepted as one of the most relevant alternatives to counter low streamflow severity. Accordingly, an attempt to augment low streamflow discharges should take into consideration the proper river basin practices for improving and increasing efficient uses of available water resources by conservation, preservation or regulation which would then permit greater use.

Vegetational stands may able to keep water storage in the soils and rock at nearly maximum levels, because it normally promotes high infiltration capacities. When natural conditions do not work favorably, a complementary hydro-technical work might be necessary. By applying hydro-technical work as part of river basin practices, a large fluctuations in streamflow discharges might be reduced or at least minimized. Several basin management practices observed in the Atsuma River Basin are briefly summarized in Table 8. These practices may be classified as : revegetation work, hillside work, channel work, river work, conservation work and areal access within the river basin.

Vegetation cover in the Atsuma River Basin is mostly natural forest of broad-leave stands (Appendix Photo−5). Revegetation work has been performed to establish mixed forest and revegetating open spaces caused by limited logging. Several serial intercepting small dams have been constructed on first order streams within the headwaters (Appendix Photo−6). By retarding the fast released streamflow discharges, it is expected to prevent suspended sediment production that occurs when soils are eroded from steep slopes or stream-banks and are then transported by streamflow discharges. With regard to limited potential water resources in the Atsuma River Basin as low streamflow area, there were a typical medium sized screen dams constructed on second order streams intended to retard streamflow discharges (Appendix Photo−7). As shown in the photos, there was an impressive difference between magnitude of streamflow discharges during low and high flow periods as well as suspended sediment production. Moreover, for fulfilling water requirements, which is primarily for irrigation needs of agricultural farmland, there was a water reservoir constructed on the third order stream (Appendix Photo−8).

As was discussed previously, the magnitude and distribution of streamflow discharges in the Atsuma River Basin completely depends on precipitation. In addition, several types of soil erosion are considered to be the main sources of suspended sediment production which, as a temporal event, have a long cumulative effect on the river basin characteristics. Precipitation and streamflow discharges were considered to be the main erosive agent because they are likely to be the most influential agent for washing, eroding and transporting away loosened surface soil particles into the lower parts of various slopes and the nearest stream channels.

The eroded soils are transported by streamflow discharges, which mostly originate from stream-bank erosion, down the steep slope of hilly areas and prepared agricultural land to be delivered down-streams. This matter should be given serious consideration due to possible severe loss of water reservoir capacity at the dam site. The present status of erosional condition in the Atsuma River Basin might be estimated by examining the chronological record of sediment yields deposited at the Atsuma Dam. It was learned that the decreasing rate of sediment storage capacity was 43%, 5 years after construction and reached 8% after 15 years. A sharp decline in accumulated sediment yield in the Atsuma Dam was found during 1977 − 1978 period, from 223×10^3 m^3 to 195×10^3 m^3, due to a vast wash load of previously accumulated sediment by high streamflow discharges. The decrease of sediment storage capacity induced a decreasing rate of designated water storage capacity of 2% after 5 years and reached 3% after 15 years.

Projecting rapid growth of various developments, it is certain that some forested areas will be converted to other uses. This may be first occur in private forests because of monetary incentives for owners of private forest to convert their land rather than reserving it for conservation purposes. The forest removal might be started from nearby stream

Table 8. Some Management Practices in Atsuma River Basin Related to Low Streamflow

Type of Practices	Location	Purpose
Revegetation Work		
– Planting needles trees under natural forest by using strip line techniques	Middle and upper reaches	Developing mixed forest
– Planting trees at open bare sites due to natural damage or limited logging	Middle and upper reaches	Covering bare sites from raindrop impacts
Hillside Work		
– Slope stabilization using concrete structure, wire net or grass	Steep slopes	Preventing probable slope failures
– Flow retardation by intercepting ditch or dams	Steep slopes and zero or first stream order	Controlling surface run–off
Channel Work		
– Streambank stabilization using concrete structures or wire netted stones	Collapsed bank at meandering points of second order stream	Preventing channel bank collapse or erosion due to flowing streamflow
– Serial intercepting small dams	Stream channel of first order stream	Controlling and retarding fast released runoff
– Various single low screen dam	Stream channel of second order stream	Controlling and retarding debris movement especially suspended sediment load
River Work		
– River bank stabilization using concrete structures	Collapsed river bank of third order stream	Preventing river bank collapses and important properties
– Water reservoir dam	Middle reach of third order stream	Collecting and controlling water resources and timing discharges
– Regulator dam for agricultural irrigation	Downstream of third order stream	Controlling and regulating water diversion for agricultural purpose
Conservation Work		
– Allocating certain forested areas for natural sanctuary zone of water resources preservation and wildlife home range	Upper reaches above dam site	Preventing natural function of headwaters and providing natural condition for protected wildlife
– Developing utilizable spaces for recreation activities	Middle reach	Providing natural space for outdoor recreation
Areal Access		
– Forest areal access of semi permanent road	Middle and upstream areas	Improving access through the river basin for management purposes

networks which are mostly owned by individuals and would increase toward hilly areas. Supposing most private forest was completely converted to other uses, the remaining would be about 40% of total forested land (29% of total river basin area) under the ownership of Hokkaido Prefectural Government.

To deal with the impending scenario, the upper part of water reservoir site should be designated as an unchangeable reserve to preserve headwaters for water harvesting areas. This is based on the fact that headwaters are considered exceedingly important as buffer sites for the preservation of water resources and the existing water reservoir which would then be expected to maintain the water supplies, particularly for agricultural farmland. This should be possible because, as previously mentioned, most of this area belongs to the Prefectural Government of Hokkaido.

As streamflow discharges are considered to be the predominant source of water resources, potential water supply estimation should refer to streamflow discharges in each Sub-Basin. The present status of hydro-orological conditions clarified in this study might be used for the benefit of planning and developing each zone area. Thereafter, the headwaters of river basin should be managed under reasonable principles of headwater preservation so as to secure against possible water shortage. Inadequate streamflow discharges and water storage provided in water reservoirs need augmentation of low streamflows, which might be achieved by improving the timing distribution of streamflow discharges, to enhance better seasonal distribution.

Conclusion

Spatio-temporal distribution of water resources affects some areas with severe low streamflows or water shortages. The clarification of low streamflow and its severity, include conception, definition, examination procedure, model assessment, a case application and alternatives for preserving and improving hydro-orological conditions, is outlined in Fig. 42. The clarification is expected to provide basic consideration of the preservation and or improvement of hydro-orological conditions.

Water deficiency was shown to be closely related to the subjects of hydrology, meteorology and agriculture, of which this study emphasized the field of hydrology. It then defined a low streamflow event as streamflow deficiency below the specified minimum amount of standard range of normal streamflow. Annual low streamflow severity *(ALS)* was the annual mean of cumulative streamflow events which were lower than the standard range of normal streamflow. Severity index of low streamflow (*SIL*) was determined from *ALS* and categorized as *SIL−1* (<100 mm), *SIL−2* (100 − 200mm), *SIL−3* (200 − 300mm), *SIL−4* (300 − 400mm) and *SIL−5* (>400mm). These grades indicate that the greater *SIL* the greater low streamflow severity. There were 57 river basins categorized into *SIL−1* and *SIL−2,* whereas 13 other river basins were *SIL−3, SIL−4* and *SIL−5.*

Considering the magnitude of annual mean streamflow *(AMS),* an *ALS* lower than 200 mm *(SIL−1, SIL−2)* was categorized as *slight* and *fair,* whereas an *ALS* greater than 200 mm *(SIL−3, SIL−4, SIL−5)* were *moderate, hard* and *very hard* of low streamflow severity, respectively. Considerably large amounts of *AMS* revealed low *SIL* whereas high *SIL* was found mostly in river basins with low *AMS.*

Referring to the magnitude of *AMS* and *ALS, SIL−1* and *SIL−2* may be revived by their excessive flows during normal and high streamflow periods. Therefore, *SIL−3,*

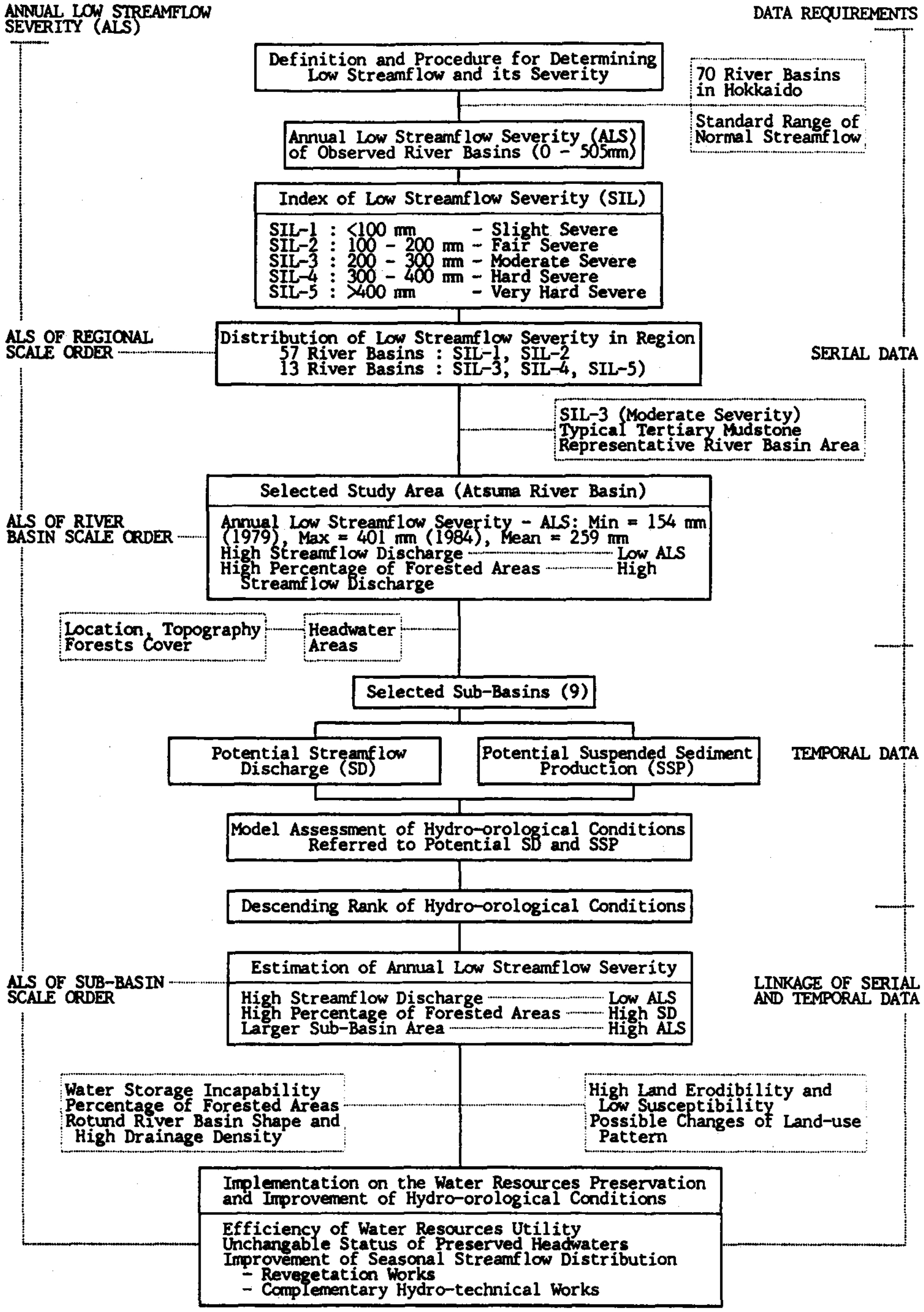


Fig. 42. Clarification of Low Streamflow and its Severity in the Region River Basin and Sub-Basin Scale Orders for Water Resources Preservation and Improvement

SIL−4 and *SIL−5* should be the first priority in further studies of low streamflow and its severity. There were two types of streamflow fluctuation, typical low fluctuation as seen in the Horonai Basin while high fluctuation was seen in the Kiyokawa and Atsuma River Basins *(AHSR−1, AHSR−2, AHSR−3, and AHSR−4).*

The Sub-Basins of Atsuma, Shoshiutsu, Merukunnai, Shoroma, Onikishibe, Shuruku, Habiu, Ukuryu and Chikapeppu were selected to be observed because they were considered the most important headwaters. These selections were based on location, topographical conditions and vegetation cover. Potential streamflow discharges and suspended sediment production were considered to be the proper parameters for clarifying hydro-orological conditions. Streamflow discharge fluctuation was completely dependent on precipitation whereas suspended sediment production was related to temporal events. Several types of erosion (stream-bank erosion, steep slope erosion in hilly areas, soil erosion on land preparation) were considered to be primary sources of suspended sediment production.

Most of selected Sub-Basins had potential streamflow discharge less than 500 l/sec ($0.5 m^3/sec$) which means they had potential for less than 43,200 ton/day in any selected Sub-Basin, whereas during high streamflow period they might produce greater than 172,800 ton/day. Meanwhile, the average of suspended sediment concentration was observed to nearly 300 ppm, although in some cases there might be less than 100 ppm or greater than 600 ppm. Therefore, potential suspended sediment production might reach 13.0 ton/day (for a potential streamflow discharge of 43,200 ton/day) or 51.8 ton/day (for a potential streamflow discharge of 172,800 ton/day).

Sub-Basins of Atsuma, Shoshiutsu, Merukunnai and Onikishibe might suffer an annual low streamflow severity less than 200 mm/year, whereas Shoroma, Shuruku, Habiu, Ukuryu and Chikapeppu were greater than 200 mm/year. The higher percentage of forested areas produced higher specific streamflow discharges when headwaters retarded streamflow discharges. The annual low streamflow severity in a Sub-Basin having a higher percentage was lower than in a Sub-Basin with a lower percentage of forested areas. Moreover, a larger Sub-Basin had a greater possibility to suffer a higher *ALS*. Accordingly, it might be suggested that a smaller unit of areal dimension for headwater management would be better than a larger one.

Most *SIL−3, SIL−4* and *SIL−5* were found in river basins areas having annual precipitation of <1000 mm and 1000 − 1200 mm whereas *SIL−1* and *SIL−2* were 1200 − 1400 mm and 1400 − 1600 mm respectively. Another factor was physiographic characteristics of the river basin ; especially geological structures, morphological features and local characteristics. Streamflow hydrograph observed in tertiary mudstone areas had high fluctuations compared with quaternary volcanic areas due to different water storage capabilities. Low streamflow severity in larger river basins was more frequently found. *SIL−1* and *SIL−2* mostly appeared in areal dimensions of $<100 km^2$ and 100 − 200 km^2, whereas *SIL−3, SIL−4* and *SIL−5* were in 300 − 400 km^2, 400 − 500 km^2 and $>500 km^2$, respectively. River basin shape and the drainage network were closely related to the quickness of the water storage releasing process from headwaters into stream channels. The greater R_f (river basin form factor) and R_d (drainage density) partly induced streamflow discharge fluctuation, which obviously determines the severity of low streamflow.

The water resource characteristics studied were quantity, quality and timing distribution. The annual and seasonal changes of streamflow discharge associated with suspended sediment production may present a major problem in water resource management. Accordingly, its is important to minimize high streamflows and increase low streamflows to with prevent soil erosion and subsequent sediment production. The present land-use patterns were found to be still favorable ; with forested land occupying nearly 73% of the total area located in the headwaters. Due to the limited potential of water resources after adjusting for seasonal changes, the headwaters of a river basin must be administered and preserved as the areas for harvesting water resources.

If hydro-orological conditions are unable to satisfy water requirements, complementary hydro-technical work should be introduced to improve them. Several river management practices were undertaken consisting of revegetation work, hillside work, channel work, river work, conservation work and areal access. An understandable clarification of hydro-orological conditions would complement basic studies for improving seasonal water yield distribution and control. In the improvement of hydro-orological conditions that it to be done, selected Sub-Basins were proposed in the descending order of (1) Habiu, (2) Onikishibe, (3) Ukuryu, (4) Merukunnai, (5) Shoroma, (6) Atsuma, (7) Chikapeppu, (8) Shuruku and (9) Shoshiutsu.

The kind of linkage between temporal and serial data measurement was considered to be useful due to the common lack of long-term data measurement in small basins. Further, by considering the method of data collection, especially the timing of field observations following precipitation occurrences, a better estimate of the relationship between serial and temporal measurement might be established for many purposes; especially to estimate the annual low streamflow severity *(ALS).* Moreover, the model assessment, which basically refers to the ranking system, was applicable because it is simple and quickly performed for the limited field observation data. In regard to the principle of establishing a model for assessing headwater conditions, the model might be easily modified with other parameters which are believed to be the decisive factors in relation to the headwater conditions.

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要　　約

地球上の水資源分布は地域的に大きな偏りをみせ，過酷な水不足に見舞われる地域もあれば，一方で洪水害を被る地域もある。水資源には限りがあることから，その多目的有効利用や水源地帯における水供給能の維持，あるいは改善が重大な課題である。本論の研究目的は，適切な量と質と時期での持続可能な水資源利用を目指すための，最も重要な水文指標である低水流量と低水度の現況を明らかにすることである。

水不足に関しては水文学，気象学，農業水利学の課題としてこれまでも詳しく研究されてきた。本論では低水流量を水文学的に水不足の一種として定義づけ，平年流量の標準範囲より低位なものとした。そして地域スケール，流域スケールの順に適用し検討することとした。なお，平年流量の地域標準範囲については，北海道の70流域の流量データより求めた。

年低水値（ALS）は平均流量の標準範囲により検討した低水状況から求め，5段階の低水度(SIL)区分を行った。すなわち，SILが高いほど厳しい低水状況を示すものとしたが，上記70流域の約20%に当たる13流域がSIL-3，4，5と評価された。地域スケールでの年平均流量(AMS)は1300 mmとなる(道東・然別：309 mm～道北・暑寒別：3246 mm)。AMSとALSについてみると，AMS 803～3246 mmでALS 0～182 mmの流域がSIL-1と2に，そしてAMS 309～940 mmでALS 130～505 mmの流域はSIL-3，4，5に区分された。すなわちAMSの高い流域はSILが低く，逆にAMSの低い流域はSILが高い値を示す。このAMSとの関連から，ALS 200 mm以下の流域はSIL-1（slight）と2（fair）に，またALS 200 mm以上の流域はSIL-3（moderate），4（hard），5（very hard severe）に区分できた。

SIL-3，4，5の流域について，その低水状況を更に検討するため，SIL-3の厚真川流域をとりあげた。これは，当流域には主に第三紀泥岩が分布しており，インドネシア・東カリマンタンと同様に北海道低山丘陵地を代表する地質であること，さらに近未来の土地利用形態の変化によって低水状況の悪化がもたらされ，流域管理・流域森林施業上の課題が現出すると予想されることから，低水流域の代表として取り上げたものである。

低水度は基本的に河川流量の変動に左右されるが，その流量変動は以下の2タイプに区分できる。ひとつは火山地域の幌内川流域にみられる低変動タイプであり，一方は清川流域や厚真川流域などの第三紀層地域にみられる高変動タイプである。後者は最大流量と最小の差が極めて大きく，これは流域貯留力が小さいことに起因すると考えられる。

厚真川の上流水源流域について，位置関係，地形条件，植生被覆状況などから9小支流域について水文調査を実施し，流量と浮遊砂量を各支流域の水文条件を示す指標として用いた。支流域の流量変動幅は大きく(最大／最小＝10～20)，また多くの支流域ではポテンシャル流量は5001/sec（43,200 ton/day）以下となっていた（ただし高水期には172,800 ton/day以上）。

一方，浮遊砂濃度は100 ppm以下～600 ppm以上とバラツキが大きいが，平均的には約300 ppmとなっていた。従って，浮遊砂量は13.0～51.8 ton/dayの流出が見積もられた。

つぎに，ポテンシャル流量と浮遊砂量を用いた簡易評価モデルを考えた。すなわち，厚真川流域の4観測地点における継続観測データに基づいて得られたALSと流量との関係から，短期間観測による支流域のALSを概算した。この結果，アツマ，ショウシウシ，メルクンナイ，オニキシベ支流域のALSは200 mm/year以下で，残り5支流域のALSは200 mm/year以上であると見積もられた。

水源地域においては，各支流域の森林率が高いほど流量は増加し，浮遊砂量は減少，そしてALSも低下することが認められた。これに従い，調査対象9支流域について量と質の両面からの森林水文状況評価が行われた。

低水流量と低水度に関しては，当然のように降水量が重要な影響力を持ち，SIL-3，4，5の流域の多くは年降水量が1200 mm以下（SIL-1，2の流域は1200～1600 mm）となっている。しかし，降水量の大きい地域にもSIL-3以上の流域が分布し，この要因として地理学的特質，とりわけ地質や地形などの流域特性が挙げられた。第三紀泥岩流域の流出ハイドログラフは第四紀火山噴出物流域に比べ，変動幅が大きい。さらに，流域面積が大きいほどSILが高い傾向が見られた。また，流域形状係数（Rf）が高く谷密度（Rd）も高い円形を呈する流域では，SILに影響するような変動幅の大きい流況となっていた。

水資源に関する流域水文特性としては流量，水質，流出時期の三つを考える必要があり，流量と浮遊砂量の年単位，あるいは季節単位での変化実態に基づいた流域管理が行われるべきである。したがって水不足により水需要が満たされない場合には，水供給量を増加させるような流域管理がされるべきである。さらに，土壌侵食やそれに伴う浮遊砂生産の抑止による質的対策と，高水流量を遅らせ低水流量を増大させるような時期的対策を組み合わせた施策が講じられねばならない。

厚真川流域における現在の土地利用状況は流域面積の73%が森林により被覆されているが，開発が進展すると現在の森林域の40%（流域面積の29%）しか残らないとも予想されている。そこで，水源地帯は森林で被覆され水貯留域となり得るため，水源涵養域としての位置づけを強化する必要がある。とりわけ水源地帯の最上流域は，おもに農耕地や居住域への水供給を維持するための緩衝地帯，すなわち不可変な保安林としての流域施業が必要となる。

低水指標による流域評価手法は低水流量を増加させる試みや，潜在的な水資源域を改善するための流域地帯区分に有効と考えられる。また，水源森林流域においてはこれまでにも緑化工や山腹工，渓間工などの森林保全対策が数多く実施され，森林機能の強化が行われてきたが，これらの実績評価も本手法によって可能になると考えられる。また，この森林水文状況に関する流域評価手法は，水供給の季節変動を極力抑制する流域管理をする上での一助となるものと考えられる。

Photo 1. View of High Runoff at a Selected Sub-Basin in Atsuma River Basin

Photo 2. View of Scanty Runoff at a Selected Sub-Basin in Atsuma River Basin

Photo 3. View of Hillslope Failures in Upstream Part of Atsuma River Basin

Photo 4. View of Streambank Collapse in Upstream Part of Atsuma River Basin

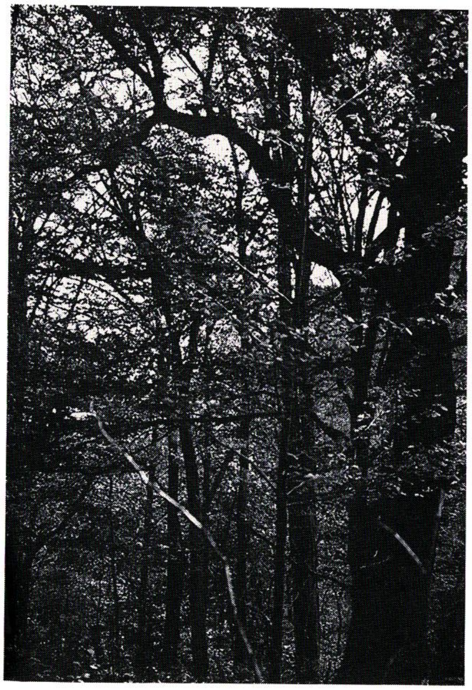

Photo 5. A Scene of Major Vegetation Cover -Natural Forest in Atsuma River Basin

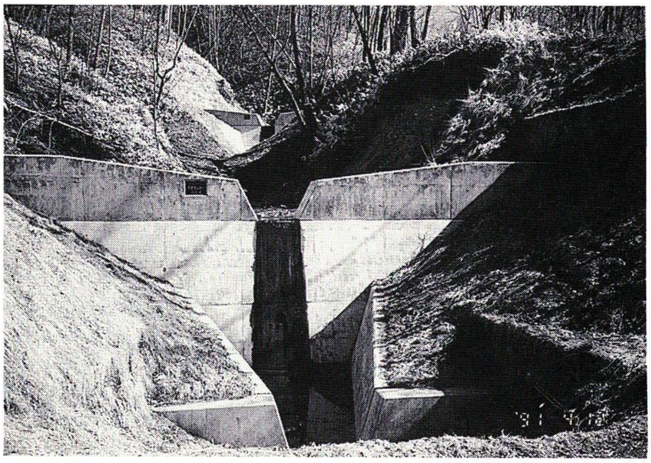

Photo 6. View of A Serial Intercepting Dams Constructed at First Order Stream on Upstream Headwaters in Atsuma River Basin

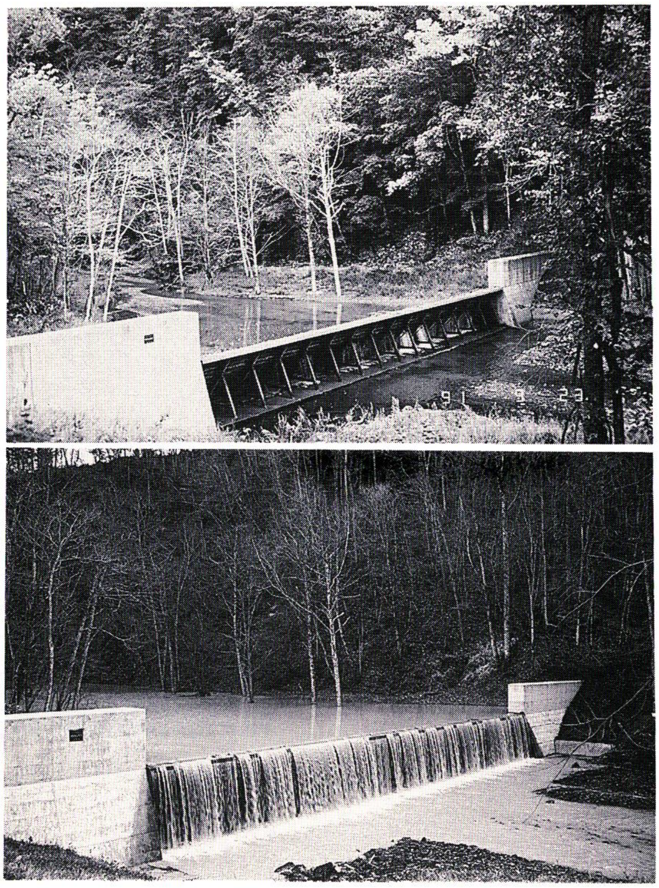

Photo 7. View of Typical Dam of River Work Designated for Soil and Water Conservation Performed at Second Order Stream on Upstream Part of Headwaters in Atsuma River Basin

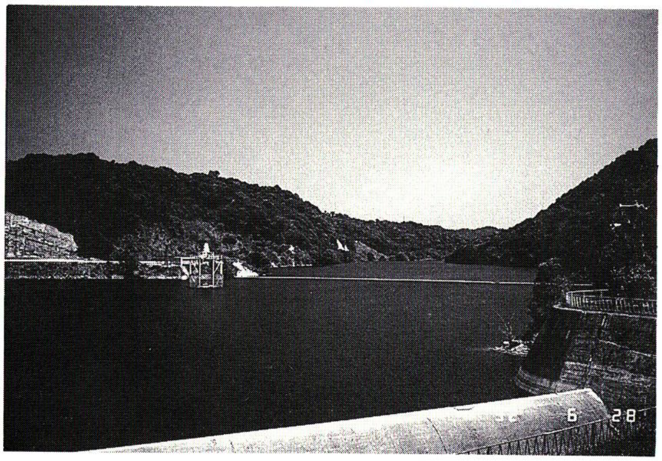

Photo 8. View of Water Reservoir Dam Located in Middle Stream of Atsuma River Basin