SYNTHETIC REPORT
OF
THE JAPANESE TECHNICAL COOPERATION PROJECT
FOR
THE FORESTRY RESEARCH IN SÃO PAULO, BRAZIL

APRIL, 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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CONTENTS

I. Summary of Project

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The present project for cooperation was started in April, 1979 and concluded in March, 1983 after operation for 5 years according to the initial plan and aditional 2 years of extention.

The subjects and yearly plan for the research and cooperation were decided as shown in the record of discussion (R/D) signed in 1978, but revision was made in 1981 by a joint committee to make them fit for the actual state of cooperation as regards the actual situation in the field and tempo of receiving the cooperation.

The goal to be reached was further revised on the occasion of extention of contract in 1984 from the former "Establishing pertinent control techniques for water reservoir forests" to the present "Establishing researching techniques for controlling water reservoir forests properly".

The present report deals with the result of research cooperation reached in the period after said process and problems to be met by the Brazilian party in the future.

The research cooperation consists of the following four fields.

(1) Studies on Watershed Controlling Techniques
The studies are those for the most fundamental problems on water reservoir forest, and the cooperation for research techniques developed around the axis of forest hydrology lie in the nearest position to the target to be reached.

(2) Studies on Techniques for Bringing down Timber
The timber cut for proper control of water reservoir forest must be carried out without damaging the forest ground and suitable techniques for carrying out is necessary. It is the final goal of these studies to clarify "the relationship between methods of carrying out and disintegration and erosion of forest ground" by carrying out with various machines for the purpose. The cooperation for these studies was limited to the scope of carry-out techniques, considering the situations in the field.

(3) Studies on Techniques for Remote Sensing
Application of remote sensing techniques is considered the most effective in planning disposition and control of forest and culturing water reservoir forest in the water reservoir districts

scattered in a vast area.

(4) Studies on techniques for use of small-diameter logs

In the State of São Paulo and states nearby, many rivers have already lost their water reservoir forests. It is important for a positive silviculture in such area to establish techniques for effective utilization of small-diameter logs expected to be produced in the future when the forest will be deliverately recovered.

Summary of Results in Respective Fields and Problems

Basis of technical and research cooperation lies in cultivating men of talents as is generally accepted. In case of manufacturing articles or substances by operation of machines, it is easy to appraise the result of undertakings objectively, but in the case of cultivation of talented men, appraisal of the result is extremely difficult. This is especially so in the present case where the research is such that its fruit must be discussed based on lawfulness after accumulation of date for a long period. Therefore, the cooperation that was extended within a limited short period was directed to arrangement of basis of study rather than cultivation of talents, spending much of the time; and improvement of will for research and fixing of the awareness through such effort was our important work.

Nevertheless many papers have been published during the period of cooperation in each of the fields under the situation. It is a matter of discussion whether the result of research be appraised by the number of paper or their quality, but it would be premature to appraise the result of research itself, when the nature of the research is considered as mentioned above.

Studies on Watershed Controlling Techniques

In the field of watershed controlling techniques, studies on testing method for forest hydrology, method for judging denuded land being in danger of flood flow, method of applying simple hillside covering plants, etc. were subjects of cooperation.

Forest hydrology testing included method of meteorological observation and studies on forest evaporation and hydrological observation. Instruments for observation were all supplied to five observing stations located in characteristically appropriate positions in the state respectively climatically and topographically, and their installation was completed. Observing stations were established one each in a year, and Cunha station that was established at first has 5-year amount of accumulated data. Observation system has been set up by completion of the stations, and climatic characteristics around the stations is going to be clarified by comparison of the accumulated sets of data from all of the stations.

For study of forest evaporation, evaporation from Elliot Pine forest was observed, so that the evaporation characteristics by the type of forest be clarified. Observation of various factors concerned has been completed for 3 years, and many data were accumulated. Eucalyptus forest was selected as subject of next study, and observation equipments are being transferred and installed.

In the studies of hydrological observation, research cooperation was started by construction works such as installation of three sets of stream gauging weir, three sets of plane lysimeter, three sets of surface run-off plot, inside-forest rain gauge. The equipments planned have been completed 80% by the local expenditure by the state government and model infrastructure arrangement expenditure by Japan; and valuable observation data are being accumulated. Equipments still left uncompleted are two sets of stream gauging weir to be taken care of by the state government, and their early completion by Brazilian party is hoped for. It is noteworthy that the results of studies as explained in the following were obtained in spite of the project being enforced under considerably unreasonable conditions in cooperation such as simultaneous advance of two tasks of mutually different nature, construction of research equipment and conveyance of researching techniques.

Studies for method of judging denuded land being in danger of flood flow include three fields of study, method for judging land being in danger of flood, method for judging land in danger of erosion, and method for judging land in danger of collapsing. In the initial five years of cooperation, investigation of the actual state was all that was executed, and conveyance of researching techniques was undertaken energetically in the two years of extension as the major item during the period. The studies are successful only when the existing data concerned are effectively utilized, and we consider that the conveyance was almost completed by the techniques that will be explained in the following. Field survey was made along with interpretation of aerial photograph, and research cooperation on improving the accuracy of interpretation of aerial photograph was carried out with due result.

Studies on the method of applying simple hillside covering included studies on itself and selection of plants from among those used conventionally. Typical method of covering was conducted and exhibited in 1983, and simple method was applied on project scale in 1985. It is natural that the research techniques were conveyed to the counterpart as a result, but it was a large success that the working techniques were conveyed to the officers of Forestry Agency along with conveyance of techniques for contructing various equipments for hydrological observation. The fact that covering plants with a high adaptability in the field were selected from among the conventional plants gives an important guide for the working of this kind of covering in the future.

Studies on Bringing Logs down

Collection and transportation of logs by means of forestry machines was a first experience for the Forestry Agency. Therefore, they had practically no knowledge not only the studies on mechanical transportation but also handling of various kinds of transportation machines; and the research cooperation was started from guiding them to operate the machines provided. Conveyance of researching techniques was started only after they acquired the skill for operating machines. This was almost the first case of beginning at a very primitive level.

Therefore, so called technical cooperation to guide mechanical transportation techniques and research cooperation based on it were given side by side.

In the field of technical cooperation for transportation, aerial cable collection machines of mono-cable type, running sky type, slackline type, endless tailer type, high lead type, etc., tractor collection, mono-rail collection, forestry wagon collection, chute collection, etc. were taken up for technical cooperation; and learning by the field workers was mostly satisfactory.

In the field of research cooperation, research techniques on testing method of performances of forestry machines, working efficiency investigation and working setup, measurement of working intensity, studies on working safety, method of working cost analysis, etc. were the items of conveyance of the techniques, along with operation of machines provided.

The general machines for transportation provided could be manufactured in Brazil, technically speaking, and the techniques are expected to take root on future commercial scale, although machines for research must be excluded. Enrichment in research on aforesaid items is expected, for this purpose, so that the techniques will be developed properly.

Studies on Remote Sensing Techniques

In the field of remote sensing, method for investigating forest, forest analysis by means of aerial photograph, method for judging danger in denuded land, and data analysis by means of computor were the items of research cooperation.

Forest investigation was first planned through utilization of aerial photographs, but this was changed due to lack of aerial photographs as basic data; and ground survey was carried out. Volume table prepared independently in Brazil did exist, but it was something to be called a volume table of a large-scale type; and it was a problem to apply it to small area under changing environment from an area to another and it was necessary to check its adaptability to each of the areas. Research cooperation was started at this level, resorting to ground survey, by the reasons explained above, so that it will be the fundamental techniques in case of aerial photographs being available in the future. Concretely, the studies were undertaken on method of estimating accumulation of stand and amount of growth and method of preparing volume table of standing trees. This kind of studies based on a vast volume of data were not completed in the period of stay of the specialist, and they were completed recently after working in Japan under contact with the counterpart.

Cooperation on forest analysis by aerial photograph was carried out for utilization of aerial photographs for forest analysis in general. The items as subject were techniques for reading forest by aerial photographs and preparing volume table by aerial photographs. The former cooperation was carried out according to the request by the Forestry Agency with emphasis on the techniques of reading photograph as the basis of research, not as a cooperation to specific counterparts but as training of five officers in charge of remote sensing. Lectures and exercise were given, and this was extremely abnormal as research cooperation. However, it should be accepted very significant in terms of future development in research activity. The report that follows shows the content of training. Preparation of volume table by aerial photograph as the latter item was not for a specific area, but it was for conveyance of the techniques of volume table by utilization of aerial photographs in general. The report that follows is of a nature of operation manual as combined with said report.

As to method of judging denuded land being in danger, reading of denuding and cause of denuding by means of aerial photographs and analysis of cause of denuding by digitization in class II were the subjects of cooperation. Some of the denuded land and land in danger of becoming denuded are collapsed land or are in danger of collapse; and the techniques are for reading the surface cases for collapse by means of aerial photographs based on factors selected in advance. It is one of the results of extended application of remote sensing. As a result of cooperation, techniques for reading the photographs and analysis were conveyed. However, the techniques of reading themselves must be improved by training for long years, and further studies and practice are hoped for their technical development.

Analysis of causes of denuding by digitalization of class II was directed to the method of utilizing program for digitalization of class II prepared for analysis of causes of denuding. It is for preparing a program, for calculating cause items of digitalization of class II from the altitude data reading, on the computor FACOM 230-28, that was provided to the Forestry Agency; and this was conveyed sufficiently to the counterpart to the extent that he can understand it well.

As to analysis of data by computor, computor system and examples of utilizing it and graphic analysis by means of drum scanner were the subjects of research cooperation. In the former, data collected from various tests and studies were treated, and techniques for rapid treatment for statistical analysis, digital analysis, and simulation were conveyed along with developing research techniques for their expanded utilization by his own capacity. However, a large expense will be required for maintenance and renewal and culture of researching scientists will be difficult in the present facilities. Further considerations will be required in order that the organization be continuously expanded and necessary budget and manpower be secured. As regards the latter item, drum scanner is a computor for graphic analysis, and analysis of various graphs can be made rapidly when the basic performance and procedure of handling are understood. The report that follows is believed to be useful also as an operation manual.

Studies on techniques for utilizing and working small-diameter logs

One of the items chosen for research cooperation was improvement of lumbering and chemical utilization of small-diameter logs. A considerable amount of accumulation was existing in the field, and the cooperation was directed to a limited field.

As to the improvement of lumbering, the conventional lumbering steps with double round saw at its center was changed and a lumbering plant was constructed based on a series of production steps from setting of saw teeth to product lumber with a twin band saw at its center. Cooperation by the specialist was made with emphasis on conveyance of techniques. As a result, in saw setting, two workers were cultured to the stage of mastering the techniques, and in lumbering, techniques for a series of lumbering operation including electronic control of band saw was completely conveyed. The present project is originally for cooperation in research, but in the present field, research and development were entrusted to the autonomous effort, limiting cooperation only to conveyance of techniques. As a result of present cooperation, lumber yield, production in unit time, quality of product, etc. were remarkably improved.

As to the chemical utilization, the existing techniques held by the scientist of Forestry Agency are of a considerably high level, and the machines provided with analytical instruments as their center, training after receipt of the machines, conveyance of operating knowhow for the machines by specialist for a short period, etc. were sufficient to bring a fruitful result. The scientific level in this field is high and a great stride in research can be expected in the future through contact with IPT and other organizations and conducting joint studies.

The following report describes the techniques conveyed and the result of study during the period; and its content is so arranged that it will be a guide for Brazilian party advancing their independent course in research, with the present result as the basis. We sincerely hope particularly that sufficient consideration be given to research organization, securing scientists, and budget for research so that the technology and research techniques conveyed by the present cooperation would take firm root in Brazil and contribute to further properity of the country.

II. Watershed Management Technical Research

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II-1 Summary of Watershed Management Technical Research

II-1-1 Background and Objective

The state of Sao Paulo was covered in 1850s with natural forest of high trees more than 80%, but in 1985 8% only. The figure is only about 20% even if artificial forests and low-tree forests are included, and the area of forests has remarkably decreased.

On the other hand, the region along the high way connecting Sao Paulo and Rio de Janeiro, two large cities in Brazil, belongs to the watershed of Paraiba River; and industrial development for manufacturing and others in the region is very active. Production in the region is as much as about 40% of the total production in Brazil. The land in the region is mostly utilized as farms for coffee or sugar followed by utilizing as pastures, but farms and pastures in slopes are apt to form denuded land or eroded land owing to the acid nature of the soil, dryness, lack of organic matters, over-grazing, etc.; and low permeability of the soil and surface erosion are causing soil loss in many places, causing also flood and turbidity of river water. Much water of high quality is demanded in the watershed of Paraiba River for supplying it to the industry and residents in rapid increase in population, and security of the water is an important subject of the state government.

Brazilian government advanced a grace policy in tax system for plantation since 1966 with said background, but according to the survey in 1974 the area of artificial plantation in the state of Sao Paulo was only 2.6%. In order to arrange the forests in important places for security of water in quality and quantity, coping with the increased utilization of slopes in the future, it is necessary to have results of scientific research that is sufficient to persuade people of the necessity of forest for the purpose.

The present state of forest in the state of Sao Paulo is not in desirable situations for maintenance of water and soil, and it is necessary strongly to enforce culturing and arranging of forest with an object of securing water and soil. The existing forests are mostly located in water reservoir area that is important for securing water and soil, and their maintenance and control should be conducted with a sufficient consideration. The state-owned forest on Serra do Mar along the eastern coast, that is preserved as natural virgin forest, suffered in 1966 by a slope collapse near Caraguatatuba and lately by devastation result from air pollution near Cubatao; and there are several cases where not only maintenance and control of the forest but also prediction of danger of devastation, or action of erosion control work, depending on the case, is required. Also existing forests are in conditions requiring controlling techniques to avoid flood, water pollution, soil loss, slope collapse, etc.

With said situation as background, studies on watershed management techniques in this project were directed as their first objective to confirm the best of the tree kinds to be arranged in the forest in the watershed and of the working method by means of qualitative and quantitative appraisal of the functions of forest to maintain water and soil. The subject "method of forest hydrological test" named in the execution program is meant for said purpose, and hydrographical observation, evapo-transpiration observation, etc. are included. With a second objective studies were carried out for selecting key districts that is necessary in changing devastated land into forest so that districts expecially requiring arrangement of forest can be selected. The subjects in the execution program named "Method of predicting area in danger of erosion", "Method of Predicting area in danger of slope collapse", and "Method of predicting area in danger of flood" are included in the methods of investigation for predicting area in danger of devastation and flood. With the third objective, studies were carried out for conservation of soil and water by simple works using materials and plants available in Brazil, so that devastated land be changed into forests. The subject in the execution program named "Method of simple forestry conservation structures application work" corresponds to said studies.

Each of the subjects having watershed controlling study as their objects are indispensable for watershed management in the mountainside in Sao Paulo, but no systematic study was undertaken in Brazil in the past. In order to establish means of preventing devastation of inclined land and damage by soil loss and flood caused by the devastation, by means of culture of forest there, the studies enumerated in this project must strongly be advanced.

II-1-2 Research Subjects and their Contents in Watershed Management Department

The subjects for research in the watershed management department and their contents of execution are as shown in page 3.

As has been described in the preceding paragraph, the studies in watershed management department can roughly be divided into three subjects: method of forest hydrological tests, method of investigation for predicting area in danger of devastation and flood, and method of simple forestry conservation structures application work. The contents of execution under the subjects will be described as follows:

(1) Method of Forest Hydrological Tests

Hydrological tests are meant for comparing the route of water running in a watershed from rainfall to final stream flow in terms of quantity and dependency on the conditions of forest; so that the effect of forest on the function of concervating water and soil in the watershed be analyzed. As to the content of the study, forest-watershed experiments must first be enumerated whereby the function of forest is grasped by the amount of water running out from the watershed and data be prepared as a comprehensive index for comparison with result of other various observations. Secondly, "meteorological observation" can be enumerated whereby characteristics of rainfall be grasped that can cause flood and soil loss as its center of study. Thirdly, "evapotranspiration observation" can be enumerated whereby water balance by the kind of trees under certain conditions be clarified.

(2) Method of Predicting Area in Danger of Devastation and Flood

Under this subject of study method of predicting area in danger of devastation or flood are sought by means of statistical analysis of the relationship between various conditions of the slope and watershed such as topography, geology, vegetation, etc. and devastation or flood. The studies are used for forecasting devastation and flood in case of felling forest in the watershed, or on the contrary, for estimating the effect of culturing forest on devastated land.

Method of investigation for predicting area in danger of devastation was studied by classifying devastation concretely for erosion and collapse.

"Method of predicting area in danger of erosion" that was directed to inland farms and pastures where surface erosion is feared, and it will be useful in forecasting the danger of felling forest land and in confirmation of the effect of forest zone formation on land where erosion is advancing. "The method of predicting area in danger of collapse" that is directed to the steep slope on the mountain range on the eastern coast aims at forecasting slope collapse caused by a concentrated heavy rain and preventing loss of human lives by protective works in the place of possible danger or taking evacuating action. "The method of predicting area in danger of flood" for indicating watershed in danger of flood in case of heavy rain can be utilized in judging the necessity of conservation of forest in the area of danger or of silviculture in pasture.

(3) Method of Simple Forestry Conservation Structures Application Work

The studies were meant for developing simple method of treating hillside by means of timber and other available materials for silviculture on devastated pasture or collapsed steep slope, and it included "Studies on selection of plants". for selection of trees and grasses that can be applied for replanting in Brazil, and "Studies on selection of structure", for selection of structures suitable to the local conditions. These studies can be utilized for cilviculture on eroded land or restoration of collapsed slope.

II-2 Studies on Forest Hydrological Testing Methods

II-2-1 Studies on Meteorological Observation

(1) Object of Study

The studies are conducted with an object of grasping the local meteorological characteristics in the State of São Paulo differing by the topography and altitude so that basic data for clarifying various phenomena encountered in studying "Forest hydrological testing method", "Method of investigation for predicting area in danger of devastation and flood", "Method of simple forestry conservation application works", etc. that are carried out in rainy zone on coastal mountain range.

(2) Progress and Result

Before a meteorological observatory is opened and accurate data of observation are obtained, the following works must be completed: 1. selection of location for setting meteorological observation field, 2. working for observation field, 3. installing instrument screen and foundation for meteorological instruments, 4. installation of the instruments and calibration, 5. construction of fence, etc.

Before starting construction of observation field, the central meteorological observing station of DAEE (State Waterworks Bureau), located in Campos do Jordão 200 km to the west of São Paulo City (State Park; where experiment site for mechanical felling and transportation will be established), was inspected. The following observation instruments were found in a circular field of 20 m diameter.

Wind direction and speed	...	biplane wind vane, 3-cup anemometer and Dines pressure tube anemometer. (daily recording)
Temperature and humidity	...	bimetal thermograph (daily recording), hygrograph (daily recording), Fuss type maximum minimum thermometer, glass thermohygrometer
Railfall	...	Pluviograph (daily recording), rain gauge
Sunshine	...	Cambell-Strokes sunshine recorder
Atmospheric pressure	...	Fortin type mercury barometer, aneroid barometer
Evaporation	...	Evaporigraph (daily recording) large-scale evaporimeter

Most of the instruments were made in Germany. Although they were of old types, they were well maintained. Daily routine observation was taken care of by a worker on site.

(1) Opening central meteorological observing station

The shape of observation field and arrangement of the instruments in Cunha station were similar to those in DAEE. Arrangement of instruments is shown in Fig. II-1. Similar set of instruments was arranged in each of the several stations established by the Forestry Institute. Specifications of the instruments are shown as follows as they have connection with the systems of observation and maintenance after starting observation.

Recording wind vane and anemometer (with 4.5m steel pole)

detector : wind direction ... tail vane, mechanically coupled to recorder

wind speed ... propellers with alternate current generator

measuring range:
wind direction ... marked at 16 points

wind speed ... 2 - 60 m/s

accuracy : wind direction ... ± 5 degree or less

wind speed ... ± 0.5 m/s at 10 m/s max.

recording system: cyphone pens

chart drive : quartz clock

continuous recording period : 1 month

power supply for clock : 1.5 V (drycell) x 5

Long-term thermo-hygrograph

detector : temperature ... bi-metalic strip

humidity ... human-hair

measuring range: temperature . -20 - +40°C

humidity ... 0 - 100%

accuracy: temperature ... ± 1°C max.

humidity ... ± 5% max.

recording system: cyphon pen, 2 pens type

chart drive : quartz clock

power supply : 1.5 V (dry cell) x 5

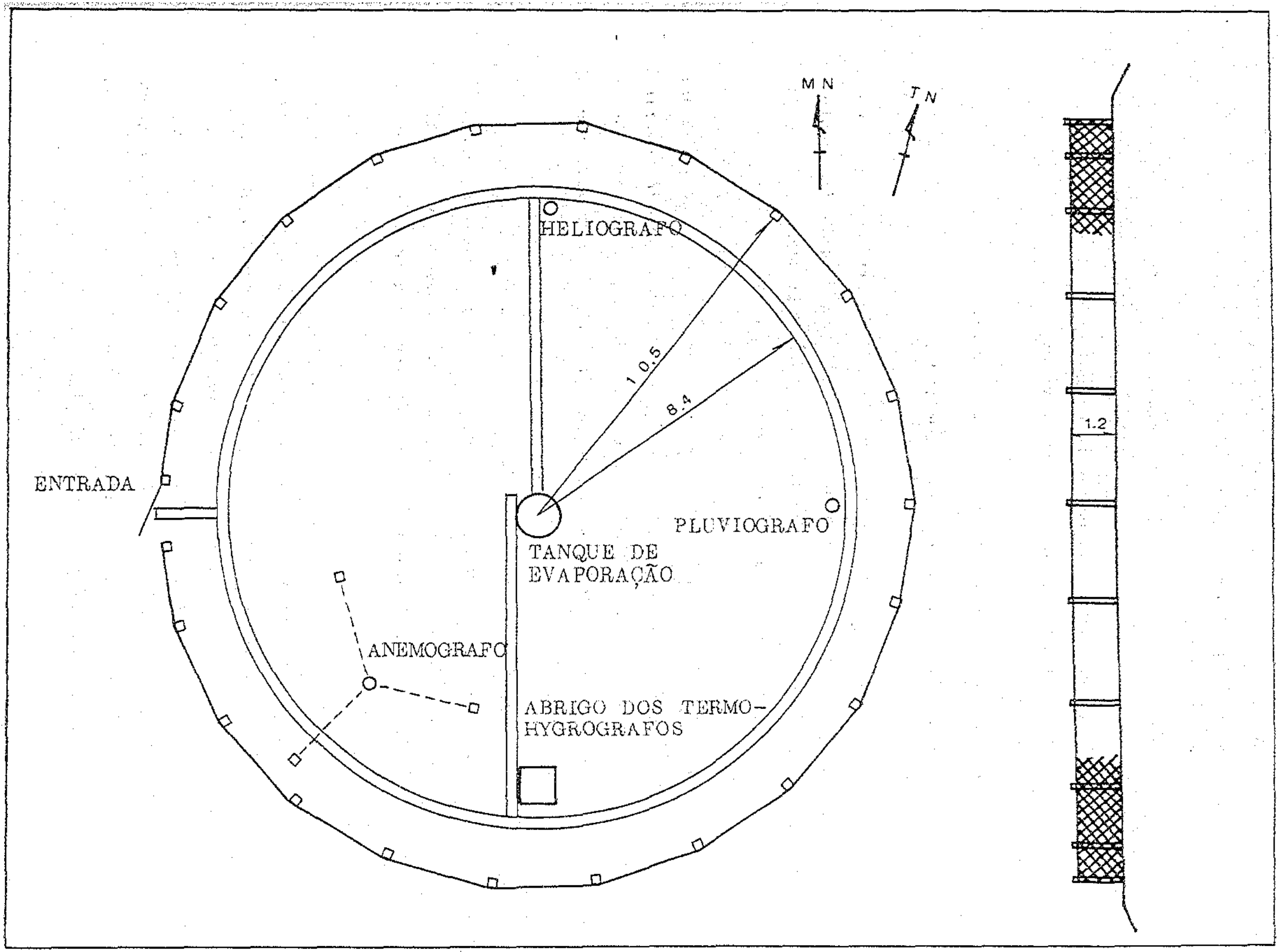


Fig. II-1 Arrangement of instruments in Central Meteorological Observatory in Cunha Experiment Site

Long-term recording rain gauge

detector : tipping bucket, 0.5mm per pulse

recording system: pulse counting event recorder

chart drive: quartz clock

power supply : 1.5 V (dry cell) x 8, x 5

Heliograph (Jordan Sunshine Recorder)

type: printing on photosensitive paper

Large-scale evaporimeter (120 cm aperture)

water level measurement: hook gauge

The second central meteorological observing station was opened in Viveiro de Taubate. Viveiro de Tautabe is located on a hillside 16 km to the south of Taubate City that is 130 km to the east of São Paulo City. The place is in the watershed of Rio Una that is a branch of Rio Paraiba, and it will be the action base for conducting "investigation for judging land in danger of devastation and flood" and "application of simple covering works" in the watershed of Rio Una, the meteorological observation data obtained there being utilized for the investigation and study.

The kind of instruments arranged there were similar to those in Cunha observatory, but the field was set in octagonal shape. The arrangement of instruments is shown in Fig. II-2. Table II-1 shows the form used for arrangement of the data observed.

For the benefit of the power supply to the meteorological stations in Reserva Estadual de Cunha and Viveiro de Taubate, a AC/DC converter manufactured by the counterpart was installed; and measuring instruments were operated by AC power source thereafter. Although a heliograph and an evaporimeter were installed in each of the two observatories as explained above, no observer was stationed there; and daily observation of sun shine and evaporation seemed difficult.

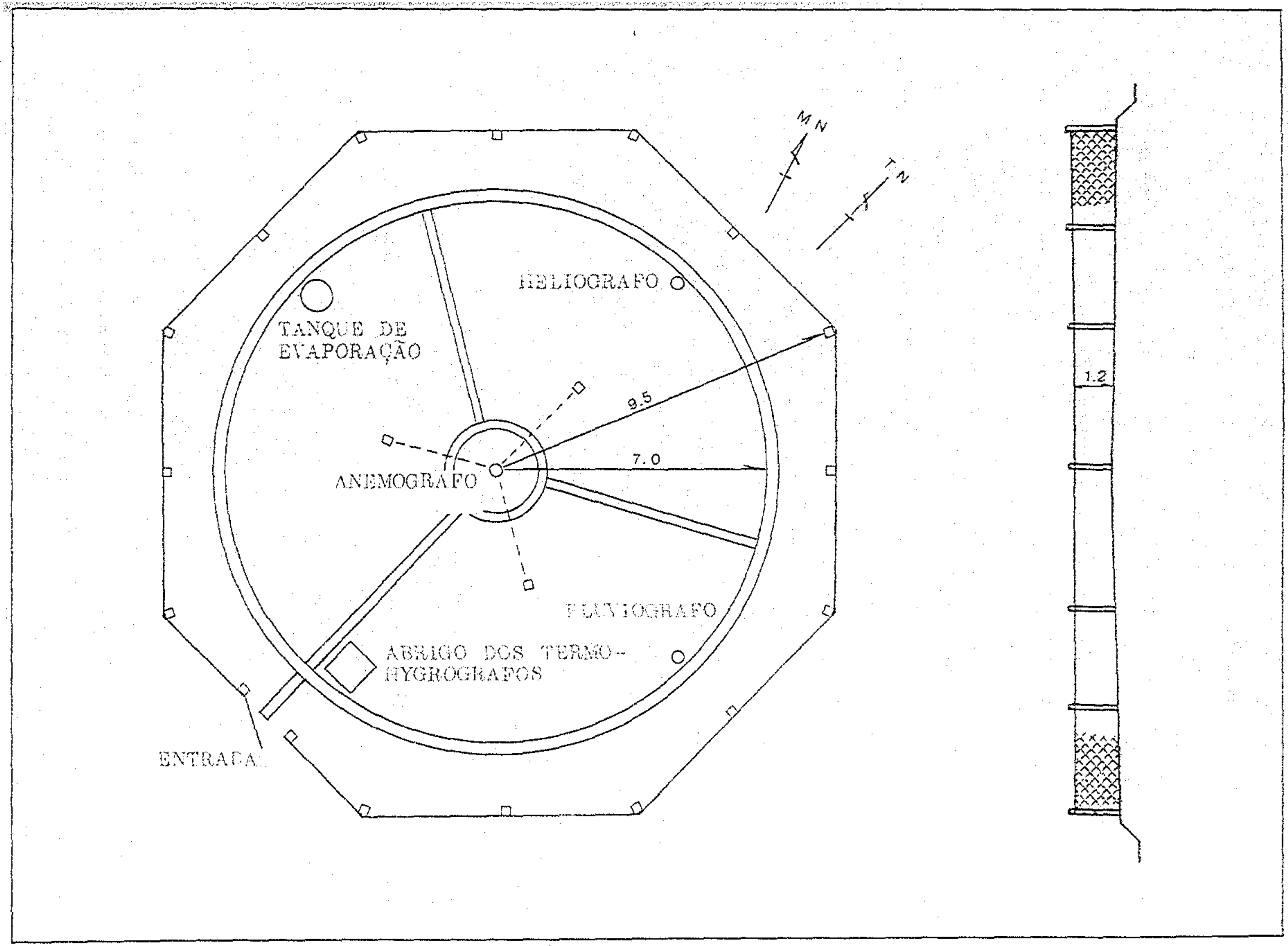


Fig. II-2 Arrangement of Instruments in Central Meteorological Observatory in Taubate Nursery

According to the initial plan, observatories were expected to be opened in Tupi, Avaré and Assis in addition to Cunha and Taubate, but this was changed to opening in Carlos Botelho and Sete Barras instead of Tupi and Avaré.

Carlos Botelho is located in the state park in the southern part of the state, about 200 km from São Paulo City. Most of the area, 39,000 ha in total, occupies the headstream region in Serra do Paranapiacaba, being covered with tropical rain forest and supplies an important part of water needed in low land agricultural zone in Ribeira and Paranapanema.
The forestal scenery with much undulation at 60 - 900 m above sea level is beautiful, and it is loved by people for recreation and natural education.

Estação Esperimental in Assis is located far to the west of São Paulo City, 460 km. It takes care of 4,800 ha of forest land on a gentle slope, consisting of 1,000 ha of Elliott pine forest, 1,500 ha of Eucalyptus forest, and rest area of brush-land. It is in charge of silviculture, breeding, and resin production; and its activity in business as well as investigation and research is the largest in the state.

The items of observation in Carlos Bolelho and Assis are five of wind direction, wind speed, air temperature, humidity, and rainfall.

(2) Change after opening meteorological observatories

In the observing station in Reserva Estadual de Cunha, solarimeter, net radiometer, and evaporigraph were installed in September, 1983; and measuring instruments were powered by AC source thereafter. In Carlos Botelho and Assis, the power supply was changed into AC shortly after opening, except anemometer

(3) Observation system and data processing

Digitizer (Muto Model T III-1215) and personal computor (Canon, Model BX-1) are used for data reading. Investigation of the accuracy of reading was carried out, and the result is as follows:

Wind speed (m/s)					
Digitizer	2.3	3.4	4.7	7.7	10.5
Naked eyes	2.1	3.4	4.6	7.6	10.5

Temperature (°C)					
Digitizer	14.0	17.3	20.2	24.4	28.2
Naked eyes	13.8	17.0	20.1	24.1	28.0

Humidity (%)					
Digitizer	35	50	65	72	91
Naked eyes	35	50	65	72	92

The values of wind speed measured by instrument were slightly different from those with naked eyes, but the difference was within the range of error, considering the system of measurement being in pen tracing. The values of air temperature by digitizer were always higher by 0.1 - 0.3°C than those with naked eyes. This seemed to be due to adjusting the zero point at grade humidity zero on the same recording chart. The values of humidity were practically the same by the two kinds of readings. Those for wind direction and rainfall were the same by the two kinds of readings, and no problem was noticed.

(4) Result of Observation

The State of São Paulo that is located in the southeastern part of Brazil belongs to the subtropical zone, and the climate there is as follows in general. Average air temperature is 20°C in low land along the coast of Atlantic Ocean, 17°C in inland hill and undulating hill, and 20°C in low plain. Monthly average of air temperature is low in June and July but high in January and February, but the annual difference is about 10°C.

The annual rainfall is as small as 1,000 - 1,200 mm in the inland plain and 1,200 - 1,500 mm on hillside and undulated hill, showing a comparatively simple rainfall distribution in a wide range. They have much rain generally on the Atlantic coast, especially in the west part of the State including the watershed of Rio Paraiba where characteristic distribution of rainfall as shown in the diagram (Fig. II-3) can be seen. Rainfall in inland side hills is 2,000 mm, on the hillside of Serra do Mar facing the ocean, 2,000 - 4,500 mm, on the hillside opposite to ocean, 1,500 - 2,000 mm, in low land along Rio Paraiba, as small as 1,200 mm, and on Serra da Mantiqueira, 1,600 - 2,000 mm. Rainfall is generally high in January and February but is low in June to July, and dry and wet seasons are clearly divided.

Table II-2 - 13 show the result of observation in the stations in Cunha, Taubate, Carlos Botelho, and Assis by months. The average, maximum, and minimum of air temperature and relative humidity in the table show monthly averages of daily average, daily maximum, and daily minimum respectively. The values of wind speed is an average of daily maximum. Those noted (N.P) show that they are not processed yet.

Now let us look at the result on the climate in Reserva Estadual de Cunha where observation was started early and the station is acting as of forest hydrological observation.

Fig. II-4 shows the monthly average, maximum, and minimum of air temperature. The hottest month in Cunha throughout a year is February and the coldest July. The annual average air temperature is 16.6°C. The annual difference is 7°C and is smaller than that of Tokyo (larger than 20°C). The annual peak of air temperature may not always appear in February. It may appear during September to January. The bottom of annual minimum appears in July or August. The record minimum since the start of observation was -0.9°C. The grass land in Reserva Estadual de Cunha turns all white in such a case by frost, and it is a striking scenery in subtropical zone.

Monthly average of relative humidity (Fig. II-5) is 80 - 85% in the rainy season but below 80% in the dry season.

The value in the figure for February is low in spite of being in rainy season. This is due to exceptionally small rainfall in February, 1982, raining 5 mm or more only on 6 days.

The average annual rainfall was 2,107 mm in 1980 - 1983, and 62 - 71% of rainfall was observed during rainy season. Fig. II-6 shows the monthly rainfall in Cunha during October, 1980 to April, 1985. Fluctuation of monthly rainfall from year to year is generally large, excepting beginning (October to November) and end (March to April) of rainy season and July. The ratio of maximum/minimum in January and February is 5.3 and 8.6 respectively, showing that the fluctuation in rainfall is large. Especially, they had a heavy rainfall on January 23 and 24, 1985 that amounted to 435 mm in total, and it caused a serious flood. 270 mm of 24-hour rainfall is estimated at the largest of that of 40 years. The manners of rainfall are different between in the rainy and the dry season. Generally, the rainfall in the rainy season is often a shower that may accompany thunder, but in the dry season uniform rain that may last a whole day long.

Wind is weak all the year round, and the frequency of calm day is about 50% in a year.

(3) Future Outlook and Problems

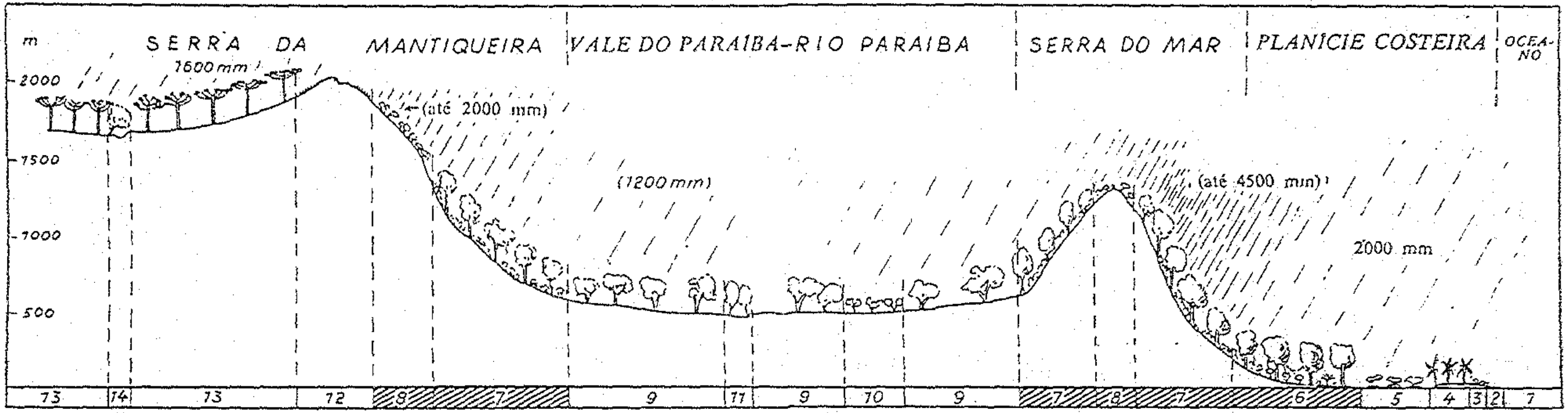
The following matters can be indicated as problems on meteorological observation.

(1) Improving Observing Organization

One observer shall be stationed in observing stations where nobody is at present.

(2) Maintenance of the Instruments

Because of the problems of the number and handling of standard instruments, it seems difficult to entrust maintaining instruments to all observers. Periodical patrol by assistant researcher is necessary for inspection and calibration of the instruments and training for the observers in situ.



(K.Hueck AS FLORESTAS DA AMERICA DO SUL 1972)

Fig. II-3 Schematic diagram of rainfall distribution by topographic change

Table II-1 Daily original register of meteorological observation

INSTITUTO FLORESTAL - Dados Meteorológicos													
LOCAL:			LATITUDE S.			LONGITUDE W.		ALTITUDE m.				DATA /19	
			UMIDADE RELATIVA DO AR EM %										
DIA	03h	06h	09h	12h	15h	18h	21h	24h	MEDIA	MAX. ABS.	MIN. ABS.	TOTAL	MAXIMA EM 60 MINUTOS
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
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16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
MEDIA													

Table II-2

Station: Cunha 1980

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January									
February									
March									
April									
May									
June									
July									
August									
September	13.4	18.7	8.2	89	99	71	1.8	E.SE	83.0
October	16.1	21.8	10.8	88	99	68	2.7	SW	256.5
November	17.2	21.6	13.3	88	99	65	2.5	E	176.5
December	20.0	26.0	15.4	84	98	58	2.9	NE	194.0

Table II-3

Station: Cunha 1981

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	18.3	22.7	13.9	84	96	62	1.8	E	264.5
February	20.0	26.6	13.4	81	98	53	1.9	E	202.5
March	19.4	24.4	14.8	85	98	62	1.7	NE	295.5
April	16.2	21.7	11.3	84	98	63	1.9	E	384.5
May	15.0	22.3	8.2	80	97	54	1.4	E	72.0
June	12.7	20.8	5.8	76	96	49	2.3	N	52.0
July	11.5	18.6	5.0	77	97	51	1.8	E	32.0
August	13.3	21.2	6.3	77	97	50	1.5	E	16.0
September	15.6	24.3	8.4	74	96	43	2.2	E	38.5
October	16.1	20.8	11.9	85	95	67	1.9	S	138.0
November	19.2	24.1	14.9	83	95	64	1.7	SE	252.0
December	19.2	23.8	14.9	82	96	64	1.8	SE	456.5

Table II-4

Station: Cuhna 1982

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	17.6	22.1	13.6	81	92	62	1.2	S	346.5
February	20.1	26.6	14.7	60	77	33	1.3	SE	192.0
March	18.7	22.8	15.8	86	93	71	1.0	S	314.0
April	15.8	20.0	11.2	82	93	64	1.3	S	164.5
May	13.1	19.7	7.1	81	95	55	1.7	S	32.5
June	15.5	22.1	9.9	78	94	54	1.9	E	140.0
July	13.5	21.3	7.3	78	94	51	1.5	SE	72.0
August	15.2	22.5	8.7	79	95	52	1.8	E	133.0
September	14.9	21.3	9.4	77	91	52	2.1	S	133.0
October	18.2	23.7	13.7	74	86	53	2.4	S	194.5
November	20.6	25.4	16.7	77	89	58	2.2	SE	214.5
December	19.3	23.5	16.2	81	90	63	1.7	S	373.0

Table II-5

Station: Cuhna 1983

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	20.6	25.1	17.0	80	90	61	2.6	NE	200.0
February	20.5	26.2	16.0	78	90	56	1.9	NW	165.5
March	21.7	27.5	17.3	76	89	53	2.2	N	352.5
April	16.0	20.8	11.2	83	96	63	2.1	NE	230.0
May	14.0	21.0	7.6	80	96	54	1.9	NW	152.0
June	14.2	20.5	9.5	76	89	53			193.0
July	13.6	21.3	7.3	73	92	46	1.5	NE	51.0
August	12.3	20.2	5.9	76	94	47	1.9	NE	29.5
September	13.5	17.9	10.0	84	93	66	2.2	NE	256.5
October	15.3	19.4	11.5	83	92	65	1.6	NE	131.5
November	17.1	23.2	11.5	78	93	51	2.8	NW, NE	132.0
December	18.4	23.0	15.0	82	93	62	2.5	NW	420.5

Table II-6

Station: Cunha 1984

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	20.2	26.9	14.8	75	92	48	1.4	N	172.5
February	19.9	26.8	19.9	78	93	51	1.2	NE	61.5
March	18.4	24.0	13.6	82	93	58	1.0	NE	248.0
April	15.9	21.5	11.0	81	92	60	0.9	NE	156.5
May	15.5	23.2	10.2	79	92	52	1.0	NE	72.5
June	12.8	21.6	6.9	78	92	47	1.0	NW	7.0
July	13.2	21.1	6.7	78	93	49	0.9	SW	47.5
August	13.5	19.5	8.9	79	91	59	1.1	SW	113.0
September	13.7	20.9	7.3	79	92	50	1.3	W	95.0
October	16.5	22.4	11.8	80	92	58	1.2	W	(N.P)
November	17.4	21.9	13.7	82	92	62	1.3	W	182.5
December	17.7	22.7	13.6	82	92	63	1.2	NW	245.5

Table II-7

Station: Cunha 1985

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	18.1	21.5	15.5	86	92	71	(N.P)	(N.P)	907.0
February	19.7	25.5	16.0	82	91	59	〃	〃	529.5
March	19.7	24.5	16.1	83	92	62	〃	〃	483.5
April	17.7	23.3	13.6	81	92	58	〃	〃	289.0
May									
June									
July									
August									
September									
October									
November									
December									

Table II-8

Station: Taubate 1 9 8 1

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January									
February									
March									
April									
May									
June									
July									
August									
September									
October	19.3	25.3	14.9	80	99	55	(N. P)	(N. P)	(N. P)
November	22.9	29.6	17.8	80	100	53	〃	〃	〃
December	22.0	27.5	17.5	81	100	59	〃	〃	〃

Table II-9

Station: Taubate 1982

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	21.6	27.4	17.2	80	100	57	(N. P)	(N. P)	(N. P)
February	23.0	31.6	18.7	77	99	46	〃	〃	〃
March	22.4	27.7	18.9	81	97	59	〃	〃	〃
April	18.9	25.3	14.0	78	98	51	〃	〃	〃
May	15.5	24.0	9.2	79	99	46	〃	〃	〃
June	16.8	24.1	11.7	84	100	57	〃	〃	〃
July	15.8	24.7	9.7	78	99	47	〃	〃	〃
August	18.1	26.4	12.1	77	97	47	〃	〃	〃
September	18.9	26.8	12.9	74	95	42	〃	〃	〃
October	21.1	28.0	16.1	78	96	51	〃	〃	〃
November	23.8	30.6	19.2	78	97	51	〃	〃	〃
December	22.3	27.8	18.8	82	97	59	〃	〃	〃

Table II-10

Station: Carlos Botelho 1982

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January									
February									
March									
April									
May									
June									
July	16.9	21.8	12.7	75	94	49	(N. P)	(N. P)	—
August	17.2	22.6	12.8	76	93	54	〃	〃	23.5
October	16.9	21.6	13.3	79	94	56	〃	〃	41.0
September	18.2	23.1	14.1	91	94	61	〃	〃	179.0
November	20.3	25.0	16.9	83	94	64	〃	〃	246.0
December	20.1	23.8	17.2	82	94	65	〃	〃	164.0

Table II-11

Station: Carlos Botelho 1 9 8 3

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	(N. P)	(N. P)	(N. P)	(N. P)	(N. P)	(N. P)	1.4	S	356.5
February	〃	〃	〃	〃	〃	〃	1.7	S	136.5
March	〃	〃	〃	〃	〃	〃	1.9	S	87.5
April	〃	〃	〃	〃	〃	〃	1.6	S	84.0
May	〃	〃	〃	〃	〃	〃	1.5	S	207.5
June	〃	〃	〃	〃	〃	〃	1.4	S	275.0
July	16.8	21.5	13.0	79	92	59	1.7	S	29.0
August	16.6	21.9	13.0	75	90	54	1.5	S	16.0
September	14.1	16.8	11.9	90	95	78	1.7	S	228.0
October	(N. P)	(N. P)	(N. P)	(N. P)	(N. P)	(N. P)	1.7	S	109.0
November	〃	〃	〃	〃	〃	〃	1.5	S	108.0
December	〃	〃	〃	〃	〃	〃	1.4	S	27.0

Table II-12

Station: Assis 1984

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	25.6	33.0	20.0	70	93	42	1.0	E	96.5
February	25.7	33.7	20.3	70	92	39	1.0	NW	76.5
March	24.0	31.0	19.3	72	91	46	2.0	N	149.5
April	—	—	—	—	—	—	1.1	N	94.0
May	21.1	29.0	15.9	76	94	44	0.9	E	—
June	19.5	28.7	13.1	70	92	36	1.2	E	—
July	19.5	28.7	13.9	66	89	33	1.6	W	—
August	18.6	26.5	12.8	70	90	40	1.7	N	62.5
September	18.7	27.6	12.7	67	89	33	1.4	N	77.5
October	23.7	33.1	17.1	63	87	31	1.8	SE	31.0
November	24.4	32.3	18.8	69	91	38	1.7	SE	67.5
December	23.2	30.0	18.5	75	91	48	1.4	NE	279.5

Table II-13

Station: Assis 1985

Month	Air temperature (°C)			Relative humidity (%)			Mean daily max. wind speed (m/s)	Most frequent wind direction	Amount of precipitation (mm)
	mean	max.	min.	mean	max.	min.			
January	23.8	30.3	19.2	73	90	48	(N.P)	(N.P)	92.0
February	24.5	31.8	20.3	75	91	15	〃	〃	111.0
March	23.9	30.9	19.8	77	92	49	〃	〃	168.5
April	22.7	29.6	18.2	74	92	48	·	〃	122.5
June	18.5	27.5	13.0	73	92	40	〃	〃	68.5
May	15.9	24.9	10.3	71	91	36	〃	〃	(N.P)
July									
August									
September									
October									
November									
December									

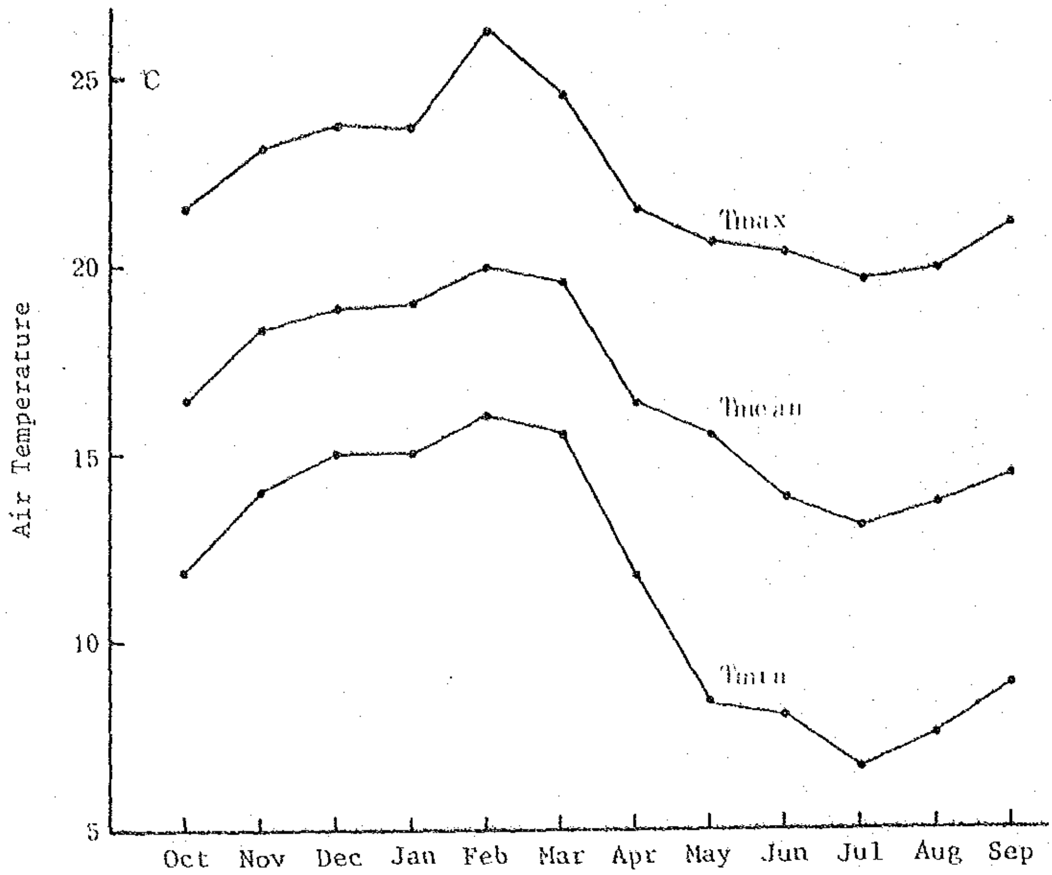


Fig. II-4 Air temperature in Cunha Experiment Site

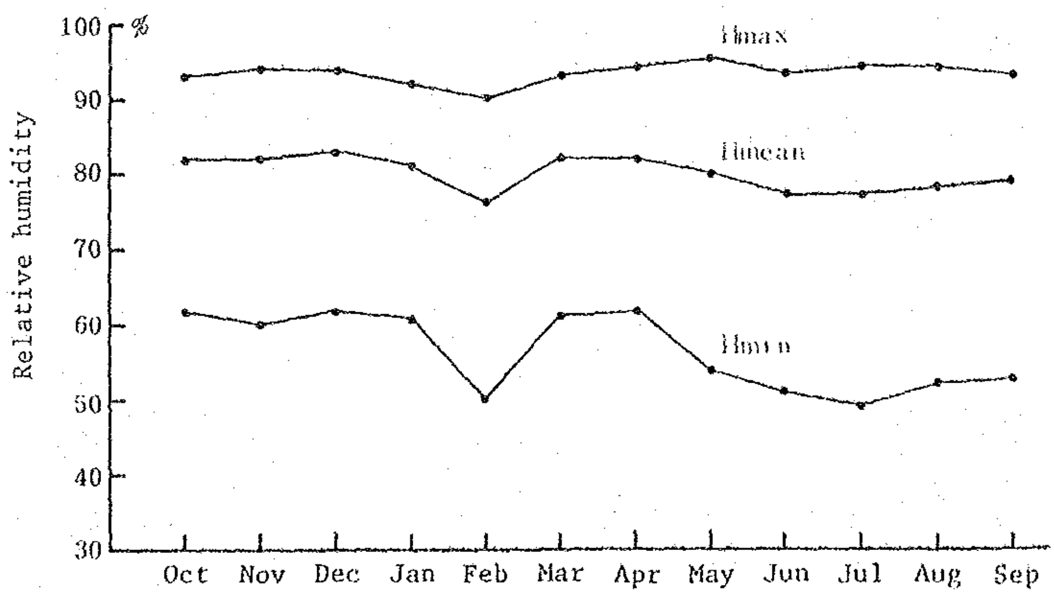


Fig. II-5 Relative humidity in Cunha Experiment Site

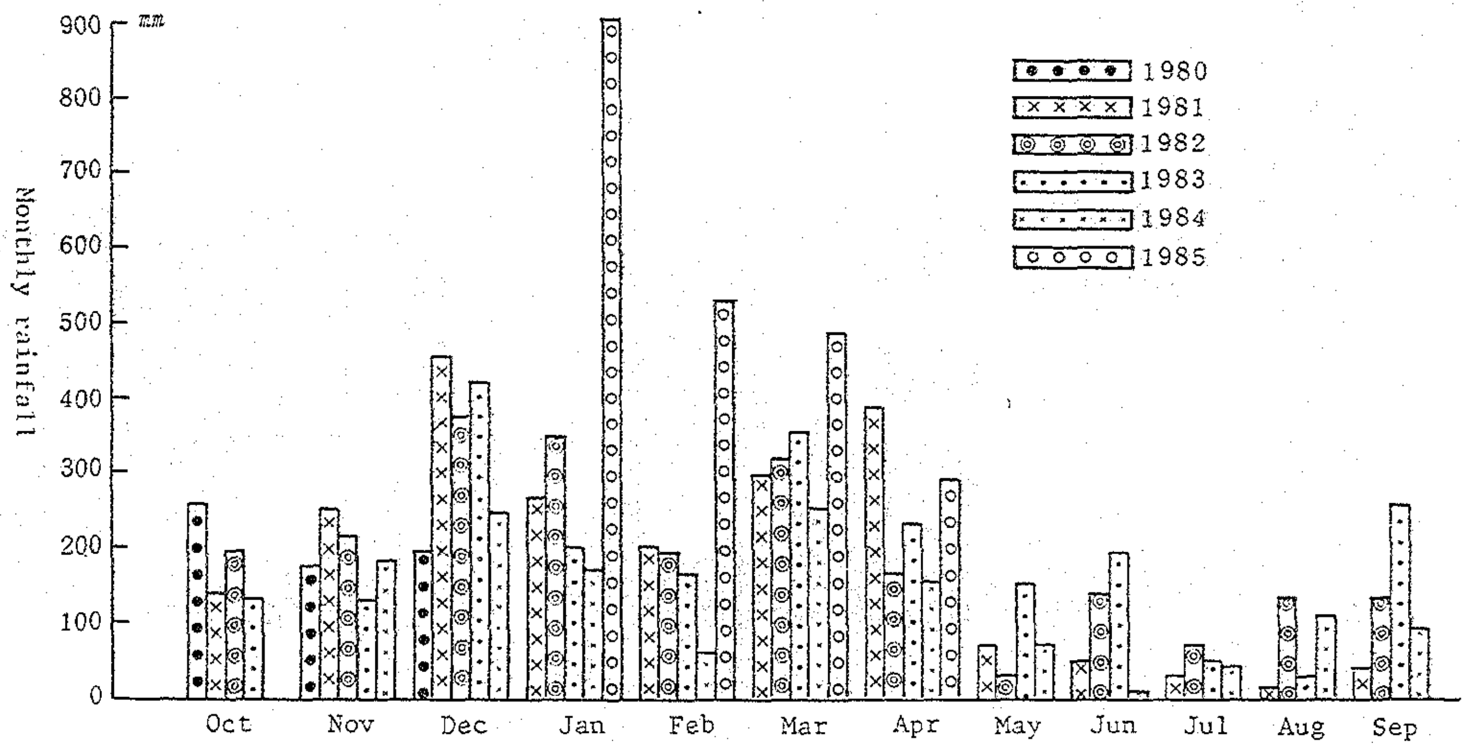


Fig. II-6 Variation of monthly rainfall in Cunha Experimental Site

(3) Power supply

It is desirable to arrange backup unit for power supply that works on the occasion power failure as is used in Assis Station.

(4) Data Processing

Data processing will be smooth by use of digitizer and personal computor.

II-2-2 Method of Studying Forest Evapotranspiration

(1) Method for Studying

Analysis of evapotranspiration is indispensable in studying water balance in forest. The evapotranspiration is estimated from meteorological data, and many methods have been proposed. We examined the heat balance method among those proposed to see if it is applicable to the forest in this district.

(1) Heat Balance Method

The radiation absorbed by a plant community is distributed as latent heat of evaporation, sensible heat, soil heat flux, etc. and the method of heat balance is based on finding the balance of the distributed heat. Estimation is generally made by Equation (1), but here modified equation (2) will be used. This is because of the ease in a long-term observation as wet bulb temperature can be used in place of water vapor pressure that is required in Equation (1).

$$\ell E = \frac{Rn - G}{1 + \beta} \qquad (1)$$

$$\ell E = (Rn - G)(1 - \frac{\gamma}{k + \gamma} \frac{\Delta T_D}{\Delta T_W}) \qquad (2)$$

where E: evapotranspiration, R_n: net radiation, G: soil heat flux, ΔT_D, ΔT_W: difference in dry bulb and wet bulb temperatures between two altitudes, l: latent heat of vaporization of water, ß: Bowen ratio, γ: dry and wet bulb constant, k: gradient of saturation vapor pressure curve

As can be seen from Equation (2), amount of net radiation, soil heat flux, dry bulb temperature and wet bulb temperature at two altitudes are required in estimating the evapotranspiration. Evapotranspiration in forest can be calculated by measuring these factors in the forest.

Photo II-1 Meteorological observation tower in Mogi Guacu state forest

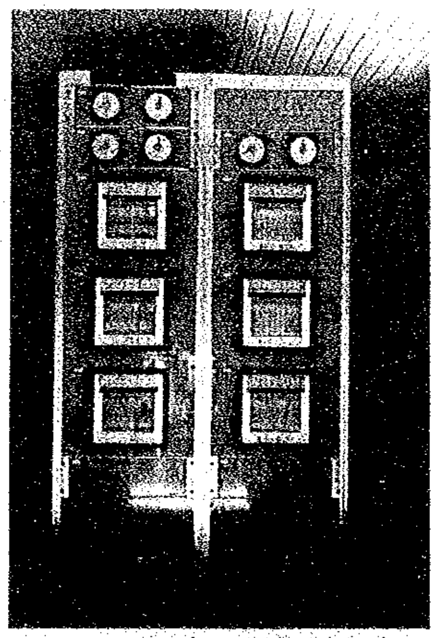
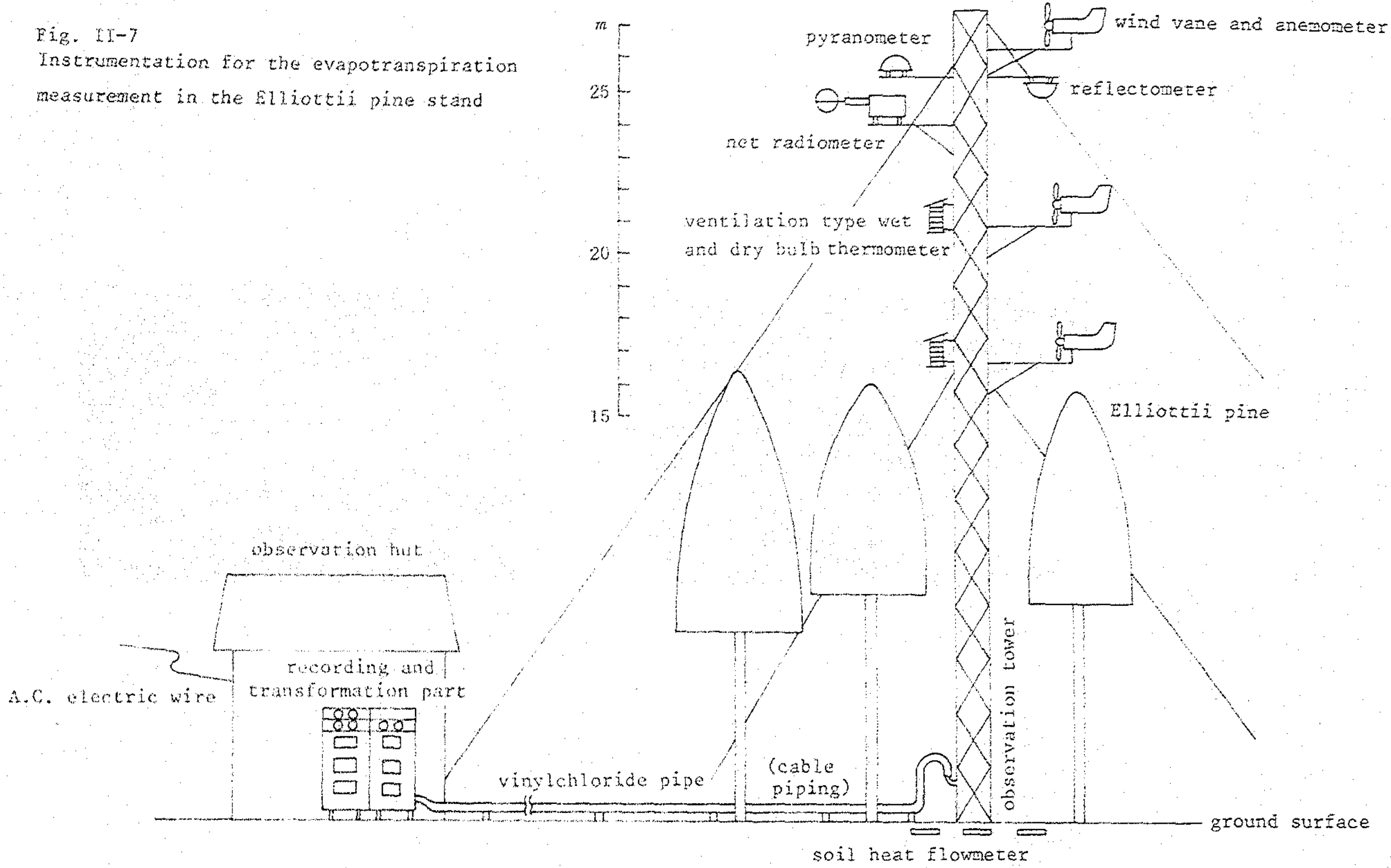


Photo II-9 Evaporation observation equipment (recording and transforming part)

Fig. II-7
Instrumentation for the evapotranspiration measurement in the Elliottii pine stand



(2) Construction and maintenance of evapotranspiration measuring equipment

Evapotranspiration measuring equipment consists of a wind vane and anemometer, pyranometer, net radiometer, soil heat flow meter, dry and wet bulb thermometer and transformation part, and recording part arranged as shown in Fig. II-7. The meteorological instruments were installed at proper heights; pyranometer, reflectometer, and net radiometer near the top of tower, dry and wet bulb thermometers near the canopy surface and 4 m higher, and wind vane and anomometers at the same heights as the thermometers and at the top of tower. Soil heat flow meters were burried about 2 cm below ground surface at three points near the tower. In the heat balance method, installation height of dry and wet bulb thermometer is a key factor; and the situation was explained based on the reports and experience so that it can be applied also to other forests.

The signal cables from various instruments were led to the observation hut through piping of vinyl chloride in order to prevent any damage of cable. In the hut 6 recorders, 18 transformers, a electric transformer, and a power source stabilizer were set on a frame and signal lines were connected. The operation was carried out under cooperation of the counterpart and technicians of Instituto Florestal, and the progress was mostly satisfactory. After assembling the unit, power source was closed, operating conditions of the unit as a whole was examined, absence of disorder was confirmed, and two-day test running was started. The values of the tests were investigated, and the routine observation was started after confirmation of the operation being normal.

For maintenance and control of the evapotranspiration easuring equipment, the following directions were given: The observation system was considered sufficient as a technician was stationed for constant guarding. The system is considered effective in reducing troubles such as missing of observation, that can take place under absence of observer.

As to inspection and maintenance of the meteorological instruments, transformers, and recorders, explanations were given mainly with the points of inspection, method, and frequency, along with the kind of frequent troubles and method of correction with reference to the cases in Japan. A manual in English was prepared with reference to the handling manual to be a guide in maintenance and control.

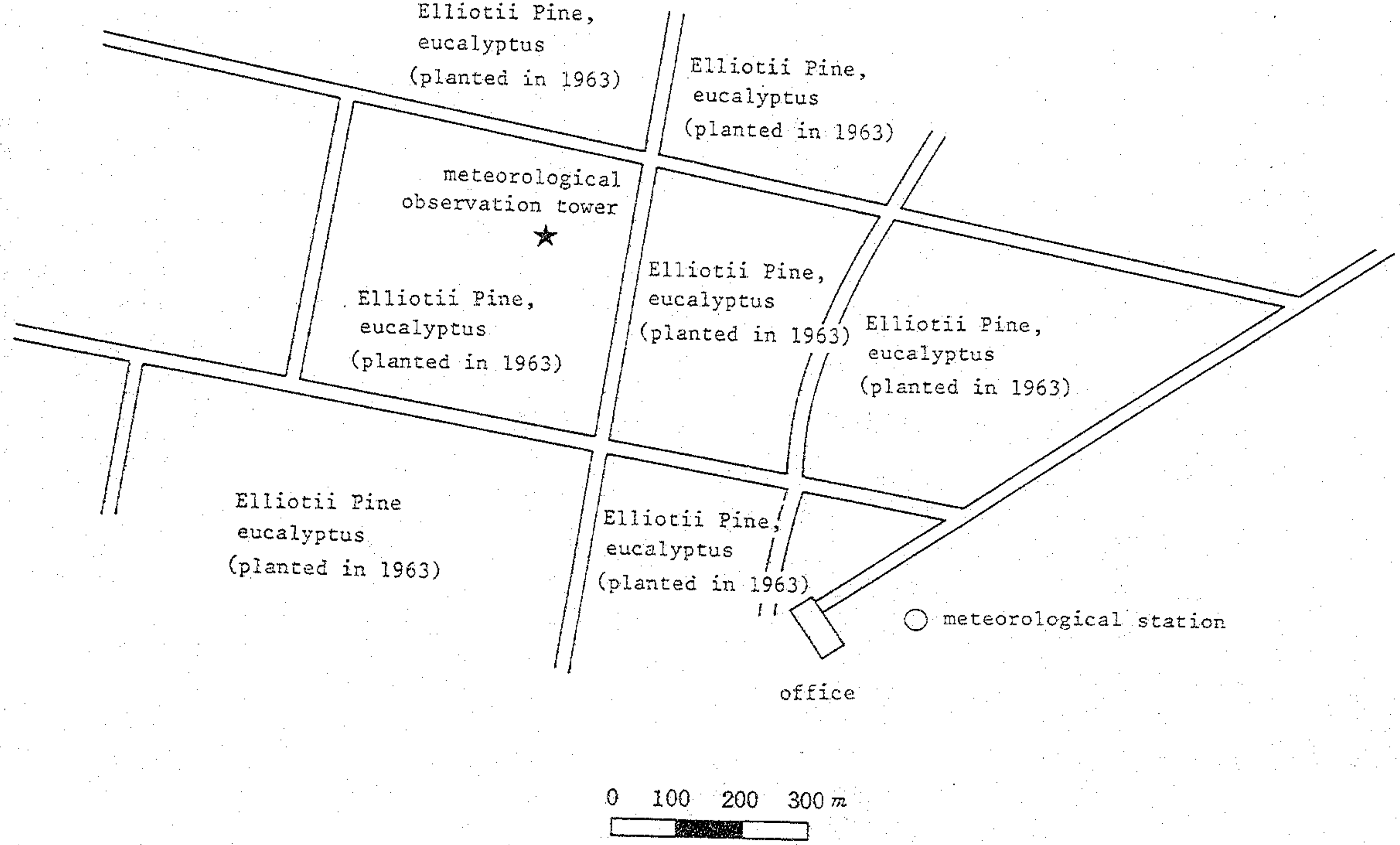


Fig. II-8 Outline of forest conditions in Mogi Guacu Experimental Forest

(3) Reading data and calculation

The recording paper for various meteorological factors was exchanged periodically for data reading and processing. Data were read for once every 1 hour to be arranged on a table, and daily total and daily average were calculated. The operation is rather troublesome, but it was useful in understanding the daily and monthly changes in meteorological factors and in judging abnormality in recording by experience.

The evapotranspiration was calculated for each of the hours and days by substitution of the meteorological data into Equation (2). The operation was started at first by manual calculation in order that the calculating equation be understood, but it was switched to calculation by a personal computor through filing. Further a main controller is operating at present in order to automate the whole process from data collection to data processing.

(2) Result of Study

The result of study was put together for the data collected during two years from November, 1982 to October, 1984. The operation is continued still at present for the meteorological data and evapotranspiration calculation is not completed for the whole period; and the result for typical days and months selected will be explained as follows:

(1) *Experimental Forest*

Tests were undertaken for Elliottii Pine forest in state forest of Mogi Guacu, that is one of the typical kinds of trees for plantation. The forest is located about 200 km to the north of São Paulo, at lat. 22°17' S., 47°09' W. and 600 m above sea level. The forest was planted in 1962, and it is of 23 of age this year. Its average tree height was 17.3 m with average diameter at breast height of 18.7 cm, average volume of 167 st/ha, and planting density of 883/ha. The soil is reddish yellow Latosol.

No.123 section of about 20 ha area were selected among activity map of Estacao Experimental de Mogi Guacu as shown in Fig.II-8. Meteorological observation tower was constructed somewhat to the northeast of the center of area, about 100 m inwards from the nearby road. Eucalyptus forest is found adjacent to the north and west, but Elliottii Pine forest of the same age in other directions. Therefore, an uniform Elliotii Pine forest is extending except to the west, and the sufficient fetch for the evapotranspiration observation is provided.

Near the forest, meteorological station of DAEE (Departmento de Aguas e Energia Electrica) is located, and meteorological conditions there are available. The meteorological data of DAEE are published periodically.

(2) Meteorological Conditions in Mogi Guacu

Meteorological conditions in Mogi Guacu will be explained roughly, referring to data reported by DAEE. According to "Effective evaporation map in São Paulo State" published in 1976, annual average of air temperature is 20.6°C, annual average of relative humidity 78.3%, annual average of wind speed 1.5 m/s, annual average of rainfall 1,175 mm, and annual average of evaporation 900 mm. According to the zoning for climate in the state of São Paulo shown in the map mentioned above, the meteorological conditions in Mogi Guacu belong to those of humid zone, and the climate can be considered to be typical one of inland district.

As to the seasonal change in meteorological conditions, for following characteristics can be found from the conditions in 1981 shown in Table II-14. The relative humidity in winter is as low as 60 - 70%, but it is as high as somewhat lower than 80% in summer. Minimum of air temperature appears in July, and maximum in February. Rainfall is very small in winter, months of less than 10 mm last to form a dry season. However, the monthly rainfall rises even to 300 mm sometimes after October to form a humid summer. On the other hand, no definite seasonal change is noticeable in sun shine hours; and it stays within the range of 150 - 250 hours/month throughout a year. In January and December in summer, sun shine hours tend to decreases owing to raining. Monthly evaporation is as small as 100 mm during May to July, but it increases to 150 mm or so in summer. The figures are measured by the evaporimeter (Class A pan). The meteorological data above for 1981 are just an example, and they are not necessarily typical for normal years.

(3) Radiation balance of Elliottii Pine Forest

Evapotranspiration is a phenomenon of water changing into vapor, and supply of heat energy is required for the change. Therefore, we must know the amount of radiation energy reaching the forest and clarify the amount of the energy that can be utilized for evapotranspiration; in other words radiation balance in the forest. Radiation balance characteristic to the Elliottii Pine forest was investigated for January and July from the various radiation data obtained on the meteorological tower as explained above.

Fig. II-9 shows the radiation balance in percent against daily amount of insolation. The calculation was made using the monthly amount. In January, 12.5% of daily insolation reaching the Elliottii Pine forest was reflected and the rest was absorbed. Of the amount absorbed, 11.2% was radiated back to the atmosphere as effective long wave radiation; and net amount of radiation available for evapotranspiration was 76.3% of the insolation. On the other hand, reflection increased by 1.4% to 13.9% in July, and the amount of absorption decreased accordingly. Effective long wave radiation also increased to 2.5 times as much as that of January, and the net radiation decreased to 57.7%, less than that of January by about 20%.

As explained above, radiation balance of Elliottii Pine forest shows a seasonal change, and the net radiation as heat source of evapotranspiration was about 20% larger in January than in July. Since there is little difference in reflection between the two months, the difference in net radiation is caused mostly by the seasonal change in effective long wave radiation, it was discussed. The values of rate of net radiation shown in Fig. 3 is similar to those reported for coniferous forests in various places in the world, showing appropriateness of the values.

(4) Relationship between net radiation and insolation

Net radiation is an indispensable factor in studying evapotranspiration, but it is not measured in routing meteorological observation and it is difficult to obtain. On the contrary, insolation can be obtained; and we can find net radiation from insolation in case relationship between the two quantities is

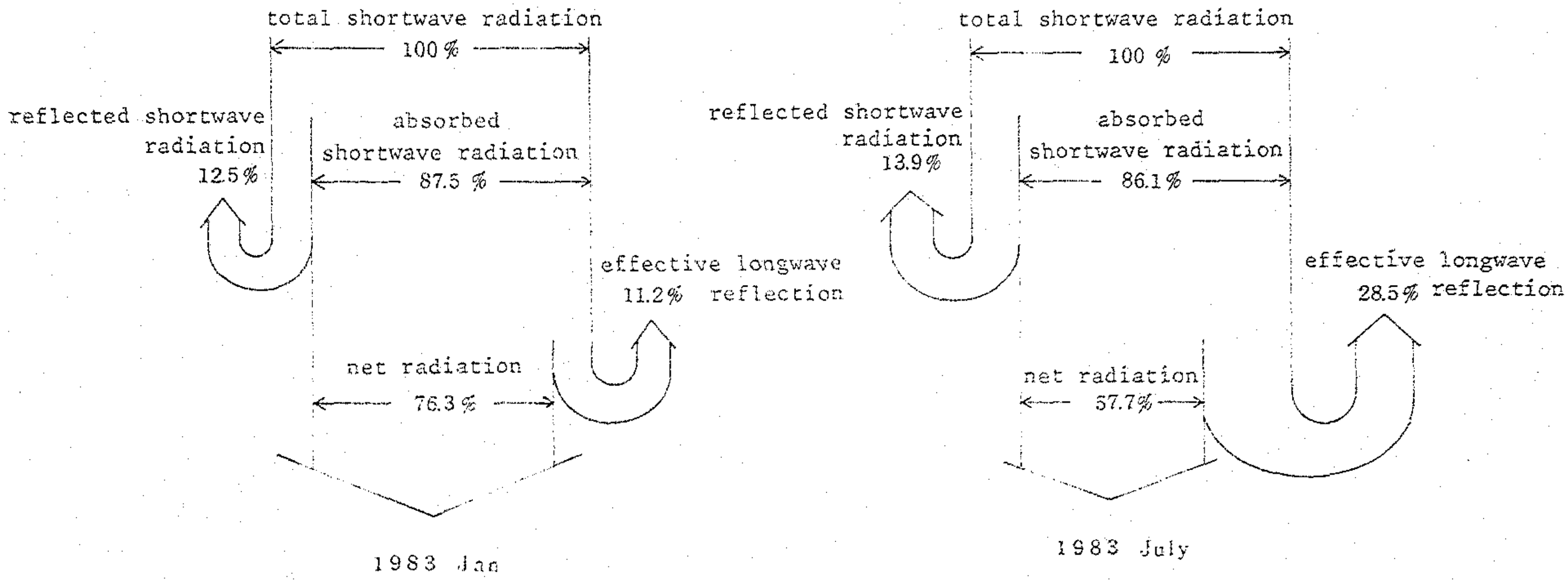


Fig. II-9 Radiation balance in Elliotii Pine Forest

Table II-14 Meteorological Conditions in Mogi Guaçu (1981)

month	Atomospheric pressure (Milib)	Relative humidity (av. %)	Atomospheric temperature (av. °C)	Maximum air temperature (av. °C)	Minimum air temperature (av. °C)	Air evaporation (mm)	Rainfall (mm)	Duration of sunshine (hr.)
1	944.7	79	23.2	29.1	19.1	117.8	290.7	154.5
2	945.5	73	24.2	31.3	18.1	152.3	69.7	211.4
3	942.7	75	23.1	30.1	18.0	148.6	121.9	214.9
4	946.4	73	20.1	28.1	14.0	118.7	66.3	237.2
5	948.6	72	18.5	27.2	11.8	93.7	8.2	239.0
6	949.2	76	15.5	23.3	8.9	62.4	88.3	166.8
7	951.6	70	14.3	23.4	7.1	86.1	5.8	213.6
8	948.3	66	18.1	27.3	9.9	120.7	4.2	203.0
9	947.2	62	21.7	30.8	13.0	165.7	13.5	180.6
10	944.8	74	20.7	27.2	15.3	134.7	295.9	178.7
11	942.0	76	23.0	29.3	17.7	141.7	171.1	191.0
12	943.8	77	22.8	28.5	18.3	150.7	193.8	146.0
average or total	946.2	72	20.4	28.0	14.3	1,493.2	1,329.4	2,336.7

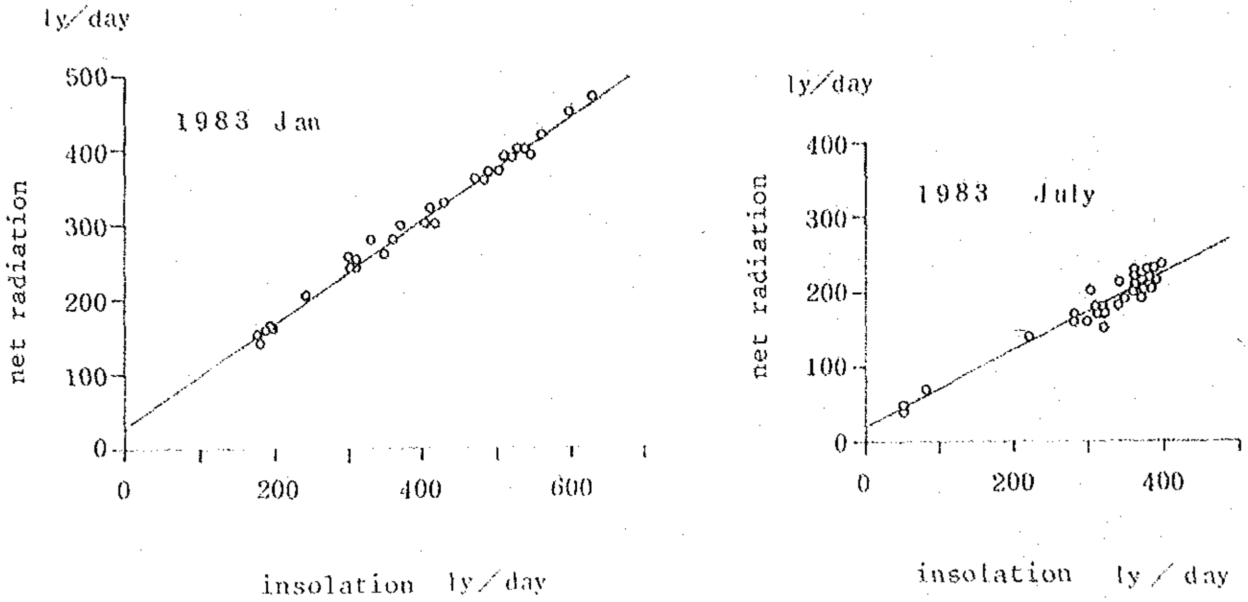


Fig. II-10 Regression relationship between net radiation and insolation

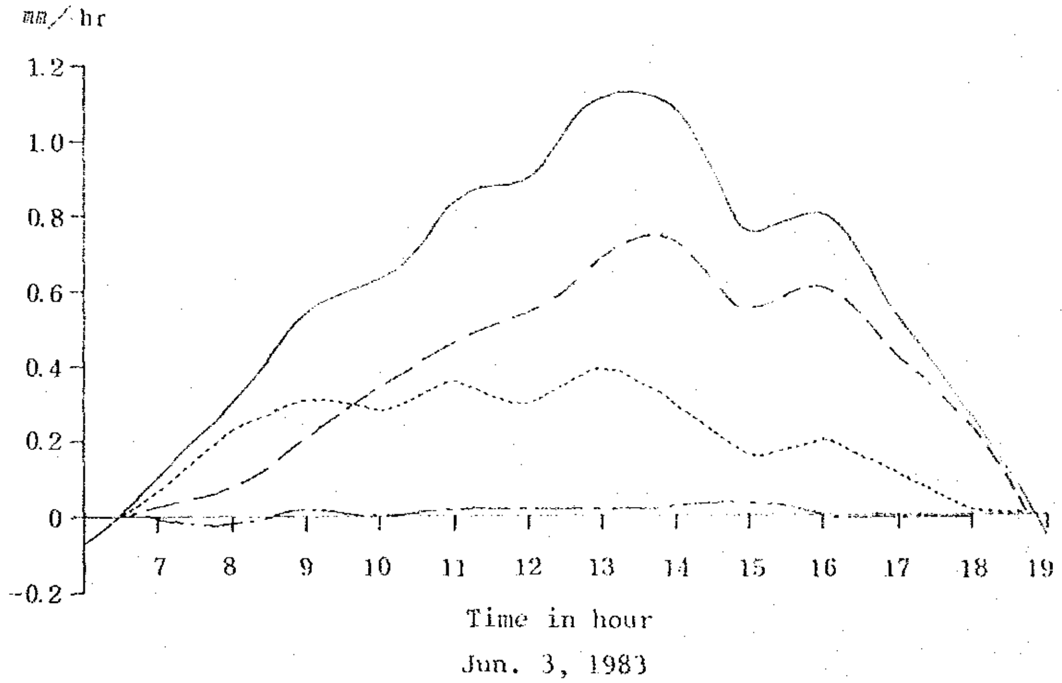


Fig. II-11 Daily change in evapotranspiration

----- evapotranspiration	——— net radiation
········ sensible heat	—·—— soil heat flow

clear. Therefore, analysis of the relationship is useful for making up for the lack of net radiation data. It is clear, however, that clarifying characteristics and structure of radiation balance in forest is important.

Fig. II-10 shows the relationship between net radiation and insolation in January and July in terms of daily amount. The regression equation and coefficient of correlation are as follows:

January: Rn = 0.69Q + 31.0 Cor. = 0.990

July : Rn = 0.51Q + 21.4 Cor. = 0.959

where Rn, Q, and Cor. are net radiation, insolation, and coefficient of correlation respectively. A high correlation is shown in both of the months, especially in January. The regression coefficient is larger for January than for July, and this agrees with the result to net radiation rate in heat balance in Fig. 3. The above result makes us think that the net radiation can be estimated from the insolation throughout a year. However, the regression coefficient seems to change by the season, as has been explained, and regression equation for each of the months or seasons can be necessary. The regression equation obtained can be applied for the same kind of trees in the inland part and under the same meteorological conditions, but further examination must be made for application under different conditions.

(5) Daily change in evapotranspiration

As a typical example of the daily change in evapotranspiration, data for a fine day on January 3, 1983 are shown in Fig. II-11. The net radiation changes from negative to positive some time after sunrise, reaches a peak about 13 o'clock, declines in the afternoon, and turns negative some time before sunset to stay negative all night. The pattern of change is the same on fine days regardless of the season, although the peak values etc. may vary. Evapotranspiration changes in a convex curve having its peak at midday when vaporization is active, in a pattern similar to that of the net radiation. Although the variation of evapotranspiration does not follow the pattern of the net radiation near sunrise and sunset, and effect of plant physiological factor and meteorological factor can be imagined, time course changes of both of the quantities

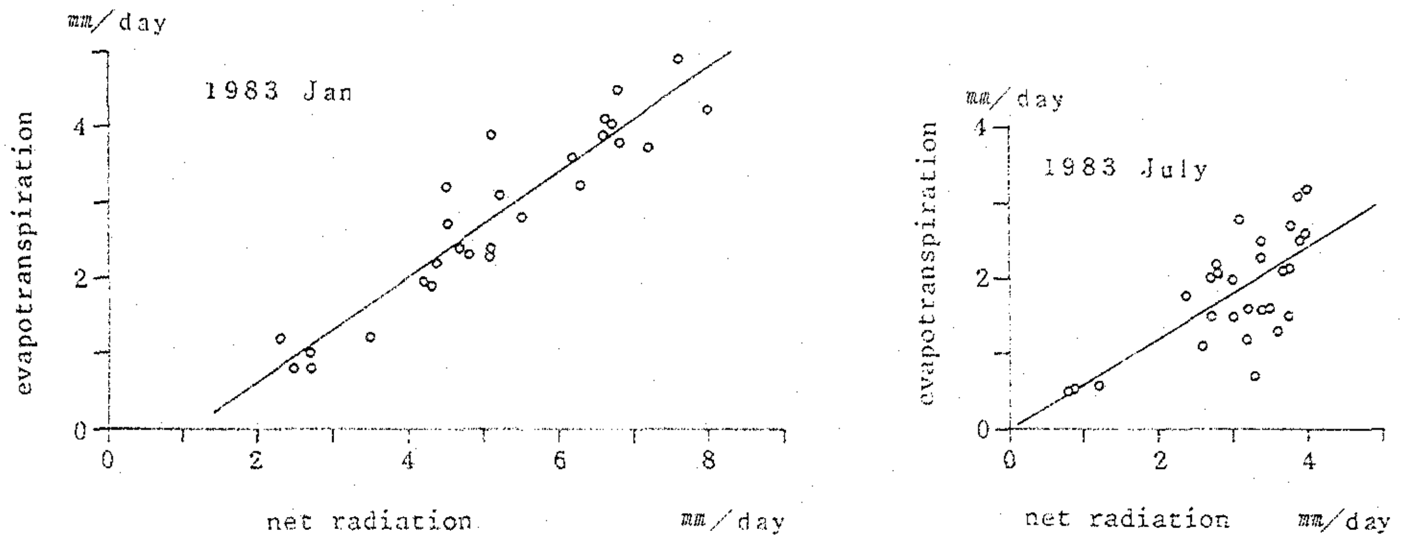


Fig. II-12 Regression relationship between evapotranspiration and net radiation are similar to each other as a whole so that the evapotranspiration can be regarded to depend strongly on the net radiation. However, the depression in evapotranspiration takes place in dry season, it is considered, owing to lack of moisture in the soil; and the time course and quantitative similarity between the two quantities is destroyed, it is anticipated. Therefore, further studies are required for the relationship between the two quantities in dry season with ample considerations for the soil moisture.

Sensible heat also shows a change in convex curve during day time, similarly to the case of the net radiation and the evapotranspiration. However, this is not so definite as in the case of the evapotranspiration for time course change; and it is of a smaller amount than the evapotranspiration in many cases, although it was often found to be larger than the evapotranspiration in early morning.

Variation in the soil heat flux was small throughout a day and night, and no definite daily change can be found. It is regarded as large as 0 mm to be plotted on the abscissa. No seasonal change was observed either. This would suggest that soil heat flux is negligible in the heat balance equation in a closed forest.

(6) Relationship between evapotranspiration and net radiation

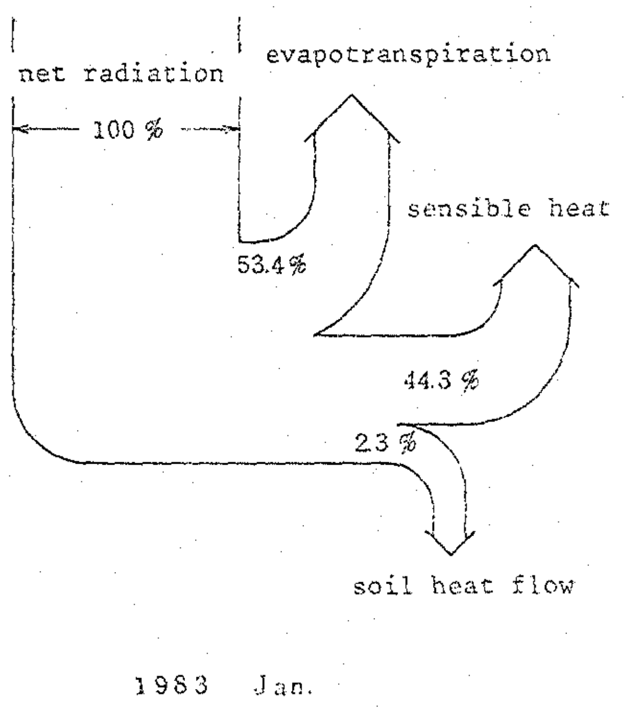
Correlation between evapotranspiration and net radiation will be examined as the latter was found to be one of the principal factors to govern the former. Fig. II-12 shows the relationship between daily evapotranspiration, as calculated by heat balance method, and daily net radiation. In January in summer, evapotranspiration may be as large as 5 mm, showing that evapotranspiration is very active. Correlation between net radiation is mostly good as shown by the following regression equation.

$$E = 0.70Rn - 0.801 \qquad Cor. = 0.934$$

where E: evapotranspiration

It is estimated that net radiation is the main factor to decide the evapotranspiration in January, and the evapotranspiration can be estimated only from the net radiation.

On the other hand, a large dispersion is noticeable in the



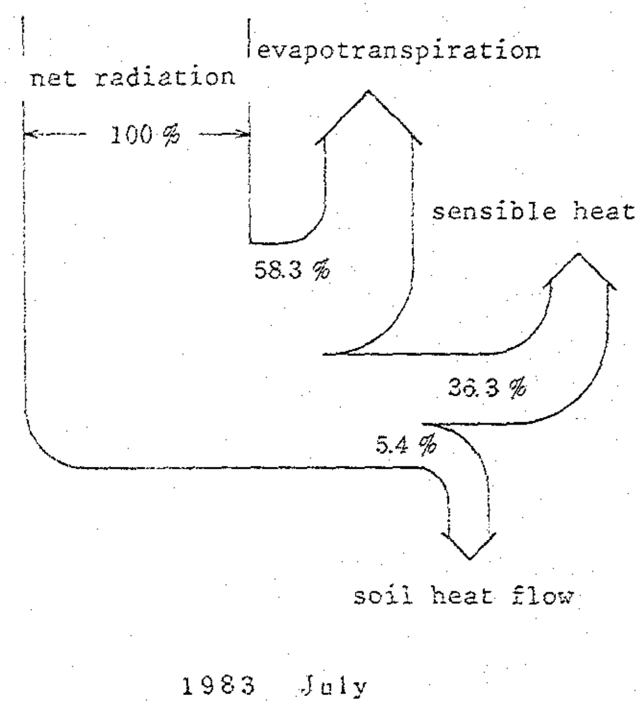


Fig. II-13 Heat balance of Elliotii pine forest figure for July, as compared with one for January; and the regression equation between the two quantities is as follows:

$$E = 0.61Rn - 0.032 \quad Cor. = 0.706$$

The equation shows that the correlation is weak end the evapotranspiration is about 60% of the net radiation. July is in the dry season when fine days last in succession, and the net radiation is concentrated in a small range of 3 - 4 mm/day, while daily evapotranspiration shows a large fluctuation in the range of 1 - 3 mm/day. The small evapotranspiration in July may mean that the evapotranspirating activity of trees is low, but the dispersion in the correlation makes us imagine that the evapotranspiration in winter is governed not only by net radiation but also by other factors such as atmospheric humidity, wind speed, soil moisture, etc. and that effect of other factors is relatively large. It seems necessary to make analysis also for other months in winter and find correlation between other factors. Therefore, it seems difficult at the moment to estimate the evapotranspiration in July accurately only from net radiation.

This kind of analysis should be continued in the future, because it is effective in finding simple methods of estimating evapotranspiration in forest.

(7) Heat balance in Elliottii Pine forest

Distribution and utilization of net radiation absorbed by Elliottii Pine forest were investigated in order to clarify the rate of evapotranspiration occupying the net radiation.

Fig. II-13 shows the heat balance in January and July. The amount of sensible heat was calculated here by subtracting evapotranspiration and soil heat flux. Energy used for photo-synthesis and respiration was neglected, for it is regarded small as compared with other heat balance terms.

In January, evapotranspiration was 53.4%, sensible heat and soil heat flux 44.3% and 2.3% respectively. In other words, a little more than a half of net radiation taken into the forest was used for evapotranspiration, the rest being changed into sensible heat. Also it was found that soil heat flux is very small in the closed forest as compared with other heat balance terms. Daily average evapotranspiration in January was 2.8 mm.

In July, evapotranspiration, sensible heat, and soil heat flux were 58.3%, 36.3%, and 5.4% respectively, showing that evapotranspiration and soil heat flux increased by about 5% and 3% respectively and sensible heat decreased accordingly. Daily average of evapotranspiration in July was 2.0mm. The large evapotranspiration even in July would mean that the activity of trees for evapotranspiration does not stop in winter as the climate is mild as shown in Table 1 for meteorological data. However, winter is the dry season, and suppression of evapotranspiration can easily take place because of the shortage of moisture in the soil. Therefore, analysis more in detail would be necessary for the rate of evapotranspiration against net radiation in winter with consideration of meteorological circumstances and soil moisture in winter to see if it compares with that of summer.

We would here simply conclude that the rate of evapotranspiration against net radiation is about the same in summer and in winter at 50 - 60 %.

(3) Problems of Studies on Forest Evapotranspiration and Future Trend

As has been explained in the beginning of the present report, it is the object of present studies to convey knowledge concerning forest evapotranspiration and method of estimating it by heat balance as one of the hydrological research. Firstly, handling, maintenance, and control of various meteorological instruments and evapotranspiration measurement equipment were well understood, it is fully judged from the fact that data were collected practically without missing and with a good accuracy for more than two years. The method of estimating evapotranspiration by heat balance and its analysis was applied to analysis of radiation balance structure and heat balance structure in Elliottii Pine forest and a part of the result obtained was already published in the Agricultural Metorological Society in Brazil, and it is steadily contributing. Analysis should naturally be advanced in the future, but the result obtained so far is sufficient as the first step.

Therefore, the object of the studies as explained at the beginning could be regarded being attained, except that the studies should be continued for a long period and advanced into further depth. The indication that follows includes the problems in this regard.

As to the meteorological instruments and equipments, they deteriorate with time and loss of accuracy and troubles cannot be avoided. Some of the instruments or their parts are difficult to repair or purchase in Brazil, and changing them into those that can be taken care of in Brazil will be necessary.

As studies for the time being, radiation balance and heat balance of Elliottii Pine forest, that have been studied partially, shall be advanced for the whole year and water consumption characteristics of Elliottii Pine forest shall be grasped.

As the direction of study in the future, similar studies shall be undertaken for natural forest and eucalyptus forest as for Elliottii Pine forest and necessary data be accumulated. Studies for eucalyptus forest is anticipated, but an early start is hoped for. Compilation of such studies will lead to clarification of water consumption, differing between forests and tree species, to its quantitative effect by forest operations, and finally to finding forests suitable for securing water resources and flood control.

Anyhow practically studies have been hardly conducted on forest evapotranspiration in the subtropical zone, and researchers should be conscious of the importance of their studies in a worldwide aspect and make the best of their efforts.

II-2-3 Studies on forest-watershed experiments

(1) Items of measurement and methods

Measurement was conducted on the following items in order to clarify the hydrologic cycle in the headwaters.

(1) Areal rainfall

In the Cunha Experimental Forest, local difference in rainfall was anticipated by the effect of sea breeze (2-3-1). Therefore, tipping bucket rain gauges (0.5 mm bucker capacity) were installed at four points in the watershed as shown in Fig. II-16 for observation. Gauges No. 1 to No.3 were installed in April, 1982 and No. 4 in November, 1982, with changing a chart every

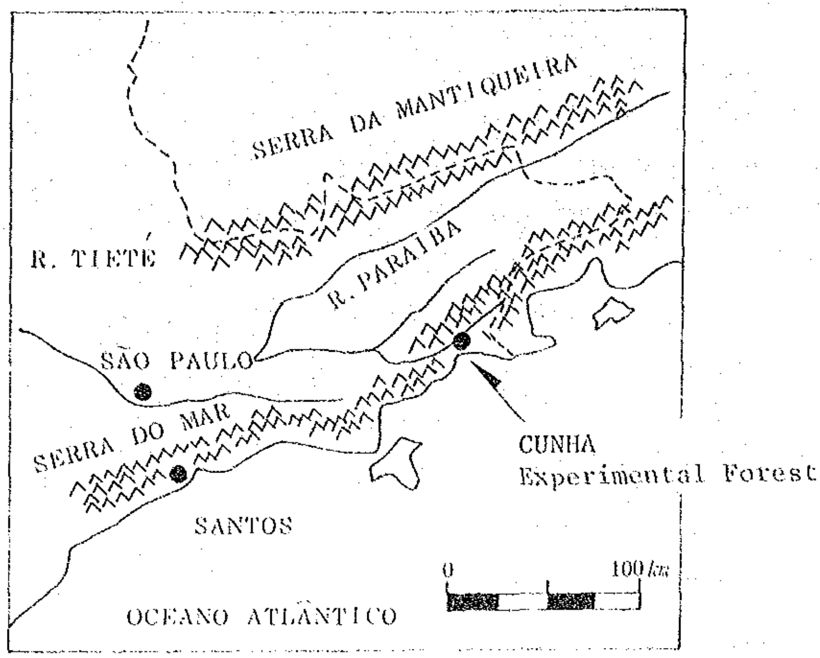


Fig. II-14 Location of CUNHA Experimental Forest

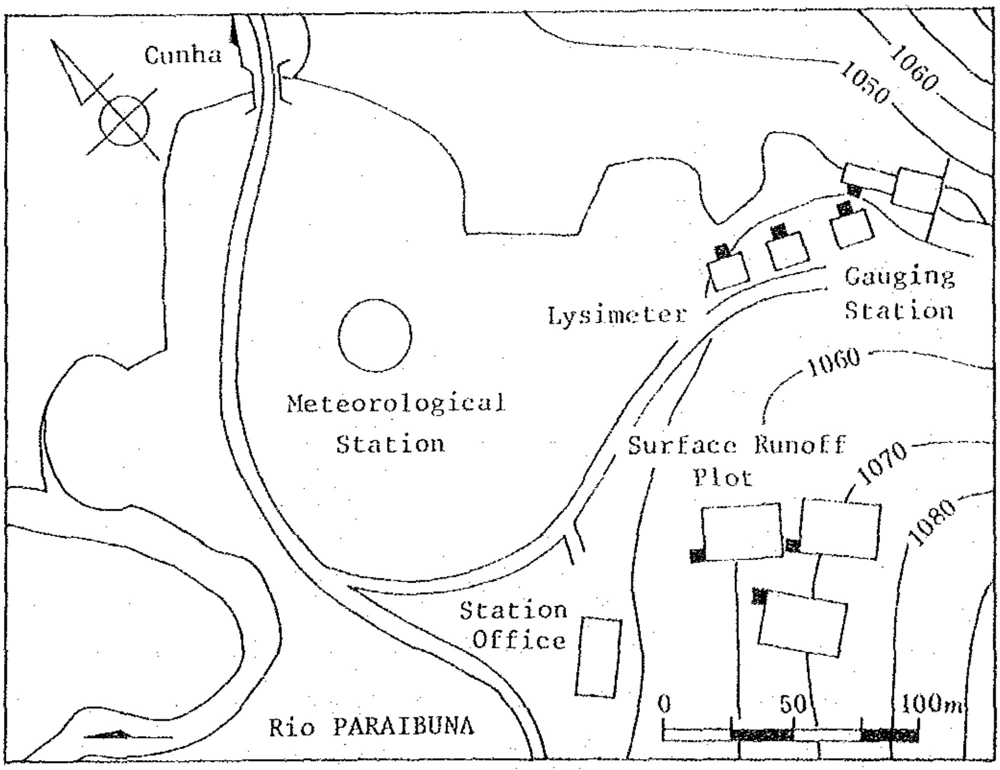


Fig. II-15 CUNHA Experimental Forest

Table II-15 Physical characteristics of D-experimental basin

Drainage area	56.04 ha
Altitude range	1048.0 - 1222.0 m
Mean altitude	1125.1 m
Mean slope	25°10'
Length of main stream	1260.0 m
Relief ratio	0.138
Mean basin width	444.8 m

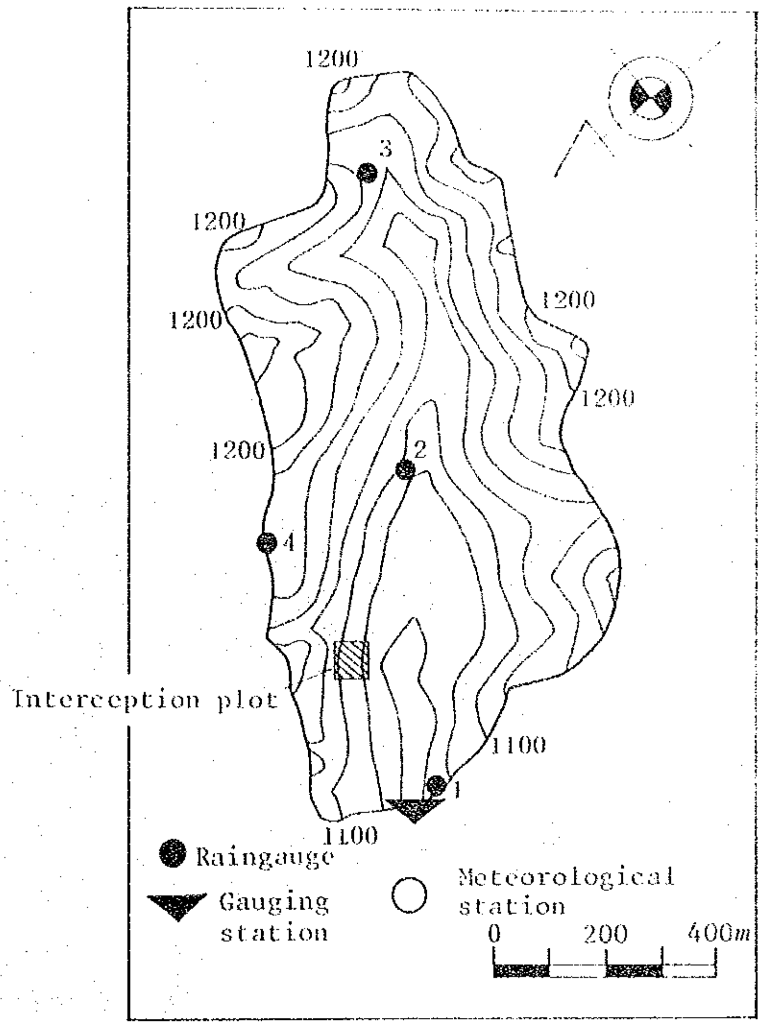


Fig. II-16 Topographic map and instrument locations at D-experimental basin.

three months and maintenance and inspection every month.

(2) Interception

In order to estimate the amount of rain interrupted by forest vegetation (interception), an experimental plot of 20 m x 20 m size was arranged on a hillside with typical forest on; and amount of rain passing through the canopy (throughfall) and amount of water running down trunks (Stemflow) were measured. The amount of throughfall was measured by arranging 16 rain gauges (throughfall gauge) of 20 cm aperture with 5 m interval. Stemflow was measured by selecting 9 trees, attaching a rubber sheet in a shape of funnel on each of the trunks, and collecting water into a polyethylene bottle of 30 liter capacity through a vinyl tube. Rainfall in a open (Gross rainfall) was measured in a neighboring plain by the same rain gauge in the plot.

The throughfall was obtained as an average from the 16 throughfall gauges in the forest, and the amount of stemflow by multiplication of the average of 9 trunks by total number of trees in the plot (65 trees) and dividing by the plot area.

(3) Stream flow measurement and run-off calculation

The gauging station is an open channel with a stilling pond of 12 x 11 x 2 m size. It is finished by mortar, and the channel

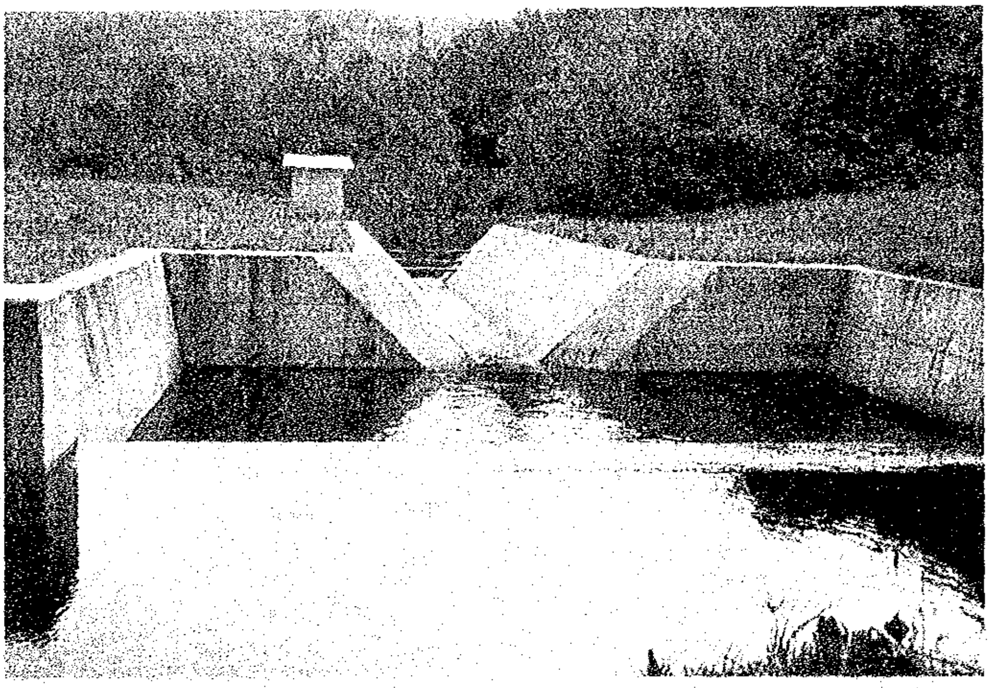


Photo II-2 Gauging station as viewed from upperstream side is 20 m long, inclined by 1%, 0.9 m wide at the bottom, and 2 m high, with an inclination of the side wall at 45° to give a cross section of trapezoid. The channel and gage house are connected by an underground pipe, and water level (stage) is measured by SUIKEN 62 stage recorder. Stream stage and rainfall are recorded on the same chart to minimize the time error.

In order to determine discharge rating curve, velocity was measured at the end of channel near the pipe by means of a small propeller current meter and Hiroi type current meter. Water depth (stage) was also measured at the point of velocity measurement by means of a scale, and discharge was calculated by the following equation.

$$Q = A \cdot V$$

where Q: discharge (liter/sec), A: cross sectional area (cm^2),
V: mean velocity (cm/sec)

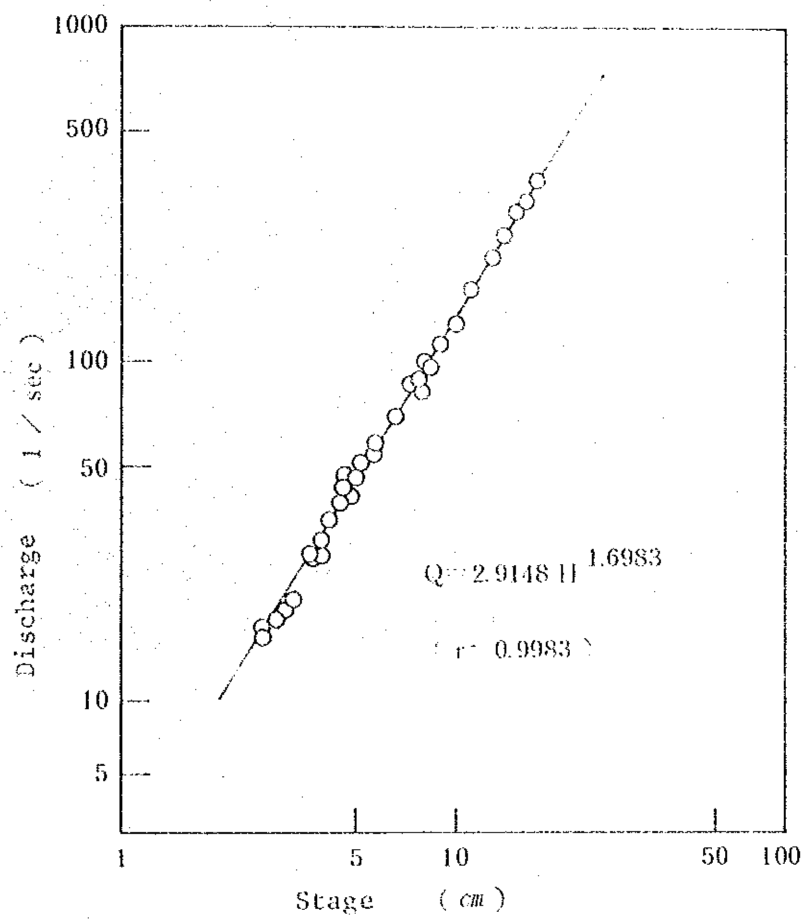


Fig. II-17 Rating curve for D-experimental basin

Fig. II-17 shows the relationships between stage and discharge, and the equation is calculated by the least-squares method.

Reading a chart and other operations are carried out in Reserva Estandual de Cunha. Calculation and data processing are carried out by FACOM 230-28 type computor in the computor room of Forestry Institute to obtain discharge (liter/sec), specific discharge (liter/sec/km²), daily run-off (mm/day), etc. The results are printed out and field in a magnetic tape at the same time.

The processes from velocity measurement to calculation of discharge are collectively reported in "Cunha Hydrology Research Project (1) On the gauging station and the discharge rating curve" in such a style that it can be used as operation manual.

(4) Surface run-off measurement

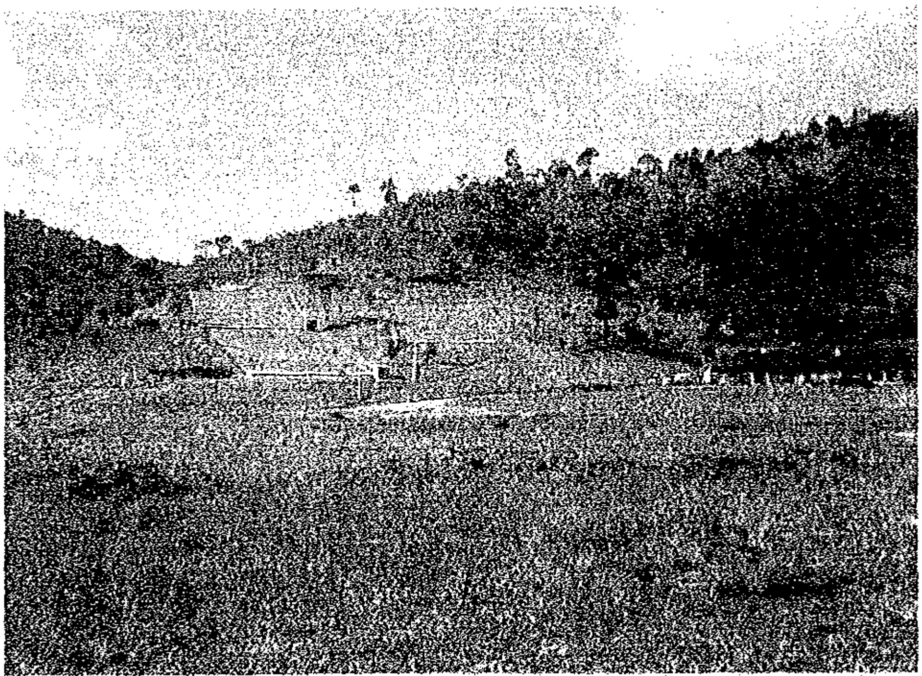


Photo II-4 Surface runoff experimental facilities (model infra undertaking at the center)

Three experimental plots were arranged for testing ground surface run-off on a balanced slope on a hillside near gauging station. The average inclination of the plot was 18° in plot A, 14.5° in plot B, and 17.5° in plot C. Each of the plot has an area of 600 m^2, with 30 m slope length and 20 m width. The upper end and both sides were sectioned by burying concrete plates of 1.2 x 1.0 m size 1.0 m deep into the ground. At the lower end, runoff water and sediment were collected by a trench of 0.8 m width, 0.8 m depth, and 2% side slope. A roof was given to the trench to shelter it from rain. The run-off water was measured by connecting tipping bucket flow meter (1000cc bucket capacity) followed by a multi-point recorder. Reading a chart was made for every one hour, and the amount of run-off was divided by the plot area to give water height (mm).

(5) Plane lysimeter

Plane lysimeter is made of concrete into a size of 10 m x 10 m square with 2 m depth. It consists of three sections of the A, B and C. Filling up lysimeter was carried out as follows: Gravels of 10 - 20 cm diameter were laid at the bottom to about 20 cm depth, and sand was placed to cover the gravel in a depth of 10 cm uniformly. The filling soil was collected at the nearby slope and laid while it is stumped. On the surface, brown black soil rich in hums was laid by 10 cm depth with consideration of seeding. Soil was supplied every time the surface subsided by natural consolidation. The total depth of soil layer including the gravel was 180 cm.

The bottom of the lysimeter was connected with the gage house by a pipe, and measurement was conducted by the same setup of instruments as surface runoff experiment. It is usual to start experiment 6 to 12 months after filling soil, and water balance in bare ground is measured at present along with calibration. In addition, A class evaporation pan was installed between plot A and plot B in order to compare evaporation from lysimeter with one from evaporation pan.

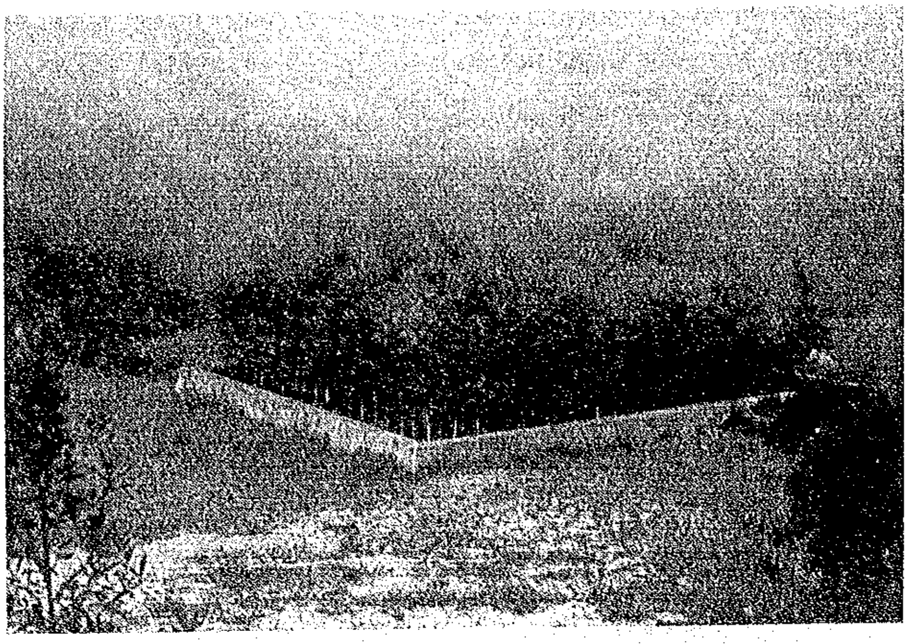


Photo II-3 Lysimeter (Eucalyptus-planted plot)
Elliott Pine-planted plot and herb-planted plot adjacent to the left

(2) Result

Before explaining the result of measurement and discussion, a simple explanation will be given on the process of runoff that is a basis of the runoff analysis.

Rain in a watershed goes through various paths until it is measured at a gauging station as a discharge. The hydrological phenomena included during the course is called collectively run-off process which can be expressed diagramatically as shown in Fig. II-18 (2.3-3). According to the source from which the runoff is derived, the runoff is classified into three components of surface runoff, subsurface runoff and groundwater runoff. Short-period change on hydrograph is brought about by direct runoff consisting of surface runoff, prompt subsurface runoff and channel rainfall. Long-period change is governed by base runoff consisting mostly of groundwater runoff. From the object of analysis, the former is called flood runoff (short-term runoff) and the latter groundwater runoff (long-term runoff).

In the case of analyzing short-term runoff, hydrograph are separated generally into direct runoff and base runoff (baseflow separation), but

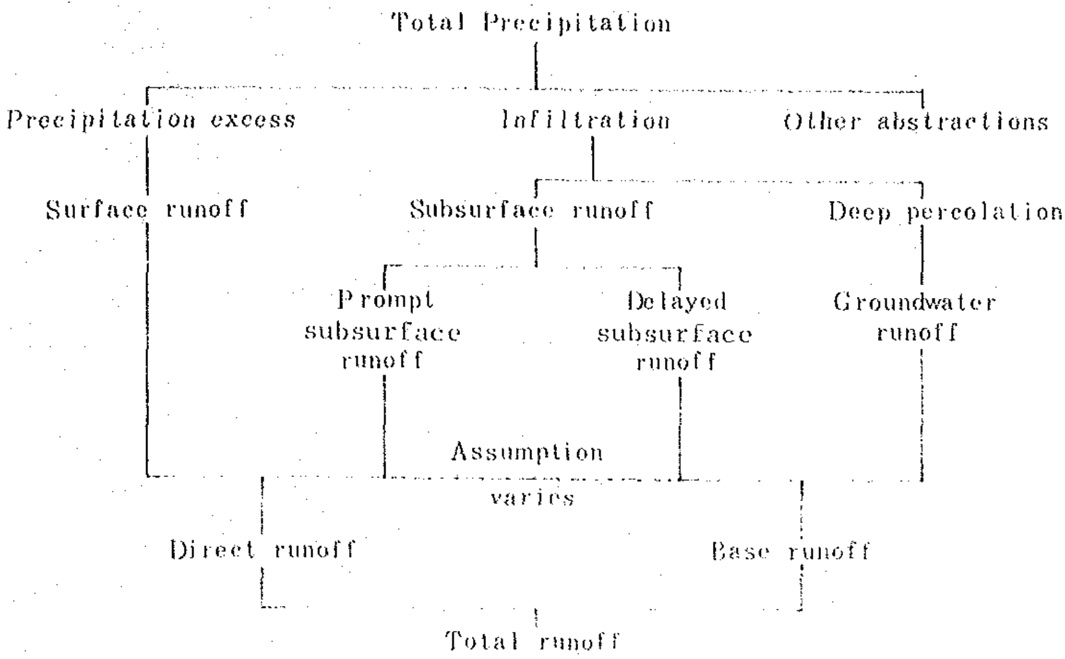


Fig. II-18 Runoff process and components
(Chow : HANDBOOK OF APPLIED HYDROLOGY, MC GRAW-HILL)

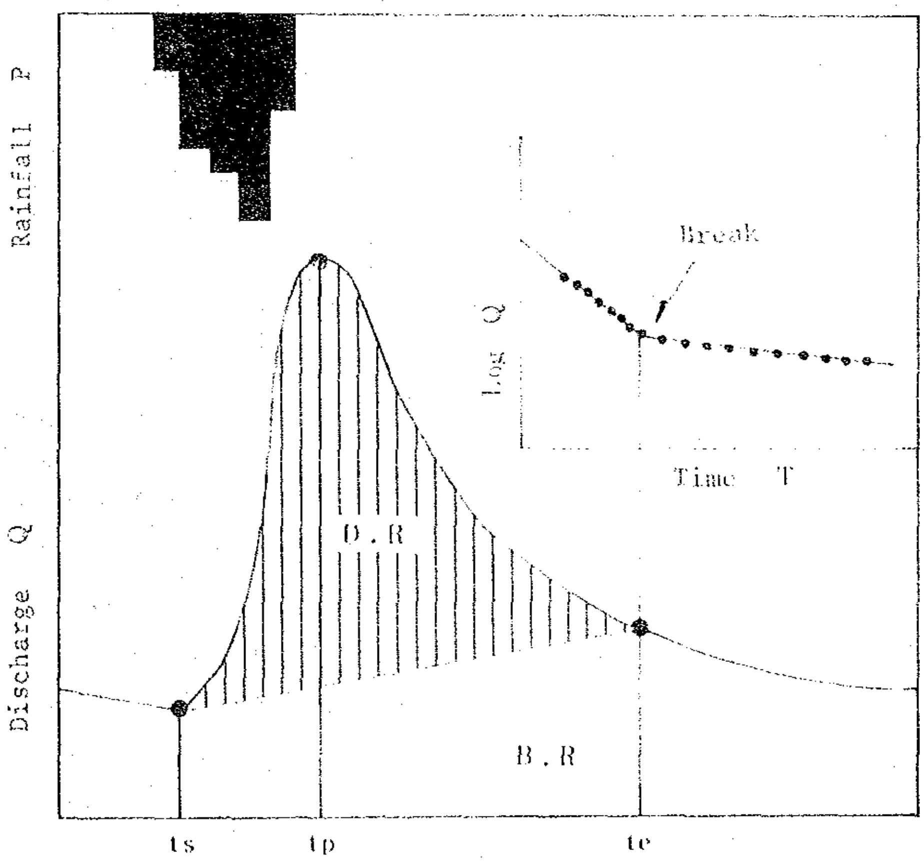


Fig. II-19 A typical hydrograph with corresponding hyetograph no established method has been known. In the present report, the base-flow separation was carried out by a method of the point of rapid change in gradient as shown in Fig. II-19.

Direct runoff (D.R.) shown by slashing is generated by Hyetograph (P) in the diagram, and the base runoff (B.R.) is brought about by sub-surface runoff and groundwater formed by a former rainfall. The ratio rainfall (P) against direct runoff is called direct runoff rate. For all of the storm hydrograph that change by a rainfall, base runoff was separated. The direct runoff separated was integrated for each of the months and years into monthly direct runoff and annual direct runoff. Monthly and annual base runoff were obtained by subtracting monthly and annual direct runoff from the monthly and annual runoff respectively. These long-term runoff are used for analysis of seasonal change in stream-flow and water balance in a watershed.

(1) Areal Rainfall in a watershed

The values of rainfall in the meteorological station (M.S.) were nearly the same as those by Rain Gauges No. 1 and No. 4, but those by Rain gauges No. 2 and No. 3 were larger in the order. Rain gauges No. 1 to No. 3 are located in the valley of watershed, and a tendency of increasing rainfall with the altitude was observed. Rain gauge No. 4 is located on a ridge of mountain, and the amount of rain captured was small, it seems, smaller values were mainly observed for heavy rain accompanied by wind. As the general relationship between the amount of rainfall and wind direction, it was found that, while southwestern wind is predominant around Watershed D, in the case of northwestern wind, rainfall of M.S. and Raingauge No. 1 was larger than that of Raingauges No. 2 and No. 3. Although annual rainfall in the experimental forest is in the region of 1,400 - 1,500 mm annual rainfall (2.3 - 3) according to the isohyetal map by DAEE, annual rainfall of 2,000 - 2,500 mm was recorded by our observation.

Areal rainfall in the watershed was obtained as arithmetical mean of values No. 1, No.2, and No.3. Regression equation for M.S. (PM) and daily areal rainfall ($\overline{P}$) is as follows:

$$\overline{P} = 1.020\ PM + 0.797 \quad (r = 0.984)$$

Correlation coefficients between areal rainfall and values by the rain gauge No.1 to No.4 were calculated at 0.991, 0.998, 0.994, and 0.995 respectively. Therefore, Rain gauge No.2 represents the areal rainfall of the watershed. It is generally accepted that the number of rain gauges needed in a experimental watershed of about 50 ha area is 2 - 3 (2.3-4) and installation of one rain gauge in the central part of the watershed in addition to one at the gauging station is considered sufficient in Watersheds A and B.

(2) Interception

The interception measurement was continued from December, 1982 to January, 1984, and 67 determinations were made. The regression equations between gross rainfall (P), throughfall (Tf), Stemflow (Sf), and interception (In) were obtained as follows:

$$Tf = 0.839P - 0.584 \quad (r = 0.999)$$
$$Sf = 0.012P - 0.044 \quad (r = 0.931)$$
$$In = 0.155P + 0.602 \quad (r = 0.952)$$

According to the result of measurement during January 11, 1983 to January 10, 1984, throughfall was 1942.0 mm (82.3%) stemflow 24.7 (1.0%), and interception 391.6 mm (16.7 %), while gross rainfall was 2,358.3 mm. Owing to the observation carried out in a natural forest, variations of throughfall gauges inside forest was large; and difference as large as 50 - 100 % against rain gauge in the open was observed for every rainfall. The total water received by each of the throughfall gauges during the period of observation was in the range of 65% to 97% versus the gross rainfall.

Usually 10 or more throughfall gauges are required to equal the accuracy of one rain gauge in the open (2.3-5). 16 rain gauges of storage type were used as throughfall gauges in the present plot, but the total area of receiving canopy passing rain was as small as 0.3% of the plot area. The values measured seems almost appropriate, judging from the reports by Paulo (2.3-6) and Ricardo (2.3-7), but it is necessary in the future experiment to install throughfall through and increase the receiving area.

(3) Short-term runoff characteristics

Fig. II-20 shows the relationship between rainfall and direct runoff rate. Although a large variation is noticeable, the following conclusion can be given. 1) Direct runoff rate is as low as 30% in any of the cases. 2) Direct runoff rate tends to increase with rainfall. 3) Direct runoff rate is higher in the rainy season than in the dry season, the difference being clear for rainfall of 30 - 40 mm or heavier. 4) For rainfall as small as 30 mm or less, direct runoff rate is about 5% in rainy as well as dry seasons in many cases. Here let us discuss about the meaning of direct runoff rate in the present watershed.

Streamflow a first order basin does not usually come from the entire surface or subsurface area but rather from an exponding and shrinking source area representing only a fraction of the total basin. The source of streamflow is usually that part nearest the perennial, intermittet and ephemeral channel, it is said (2.3-5). Survey of the present watershed revealed that marsh (humid zone) was found on both sides of the channel in 2 - 3 m width and at the bottom of the valley upstream and downstream. Measurement of the area using topographic map at the scale of 1/2,000 gave a total area of about 3 ha, which corresponds to 5.5% of the total area of the watershed. Regarding the humid zone as the source area, based on the approximate agreement of the direct runoff rate in a small flood created by rainfall of 30 mm or less with the rate of area of humid zone, the direct runoff in a small flood is generated in this humid zone, it is estimated. In the channel adjacent to Rain gauge No. 3, a stream was noticed in the rainy season but not in the dry season. Such change in source area accompanied by expansion or shrinkage of humid zone seems to reflect the difference in direct runoff rate between the rainy season and the dry season. The variation of direct runoff rate observed during small flood seems to depend largely on rainfall characteristics such as rainfall pattern, duration of rainfall, and rainfall intensity.

Runoff mechanism in the present watershed was estimated based on the results explained above. Upto rainfall of 30 to 40 mm, runoff from the humid zone or stamped ground such as working road occupies the most part of direct runoff. However, in rainfall of 50 mm or more, subsurface runoff from hill slope of seep zone

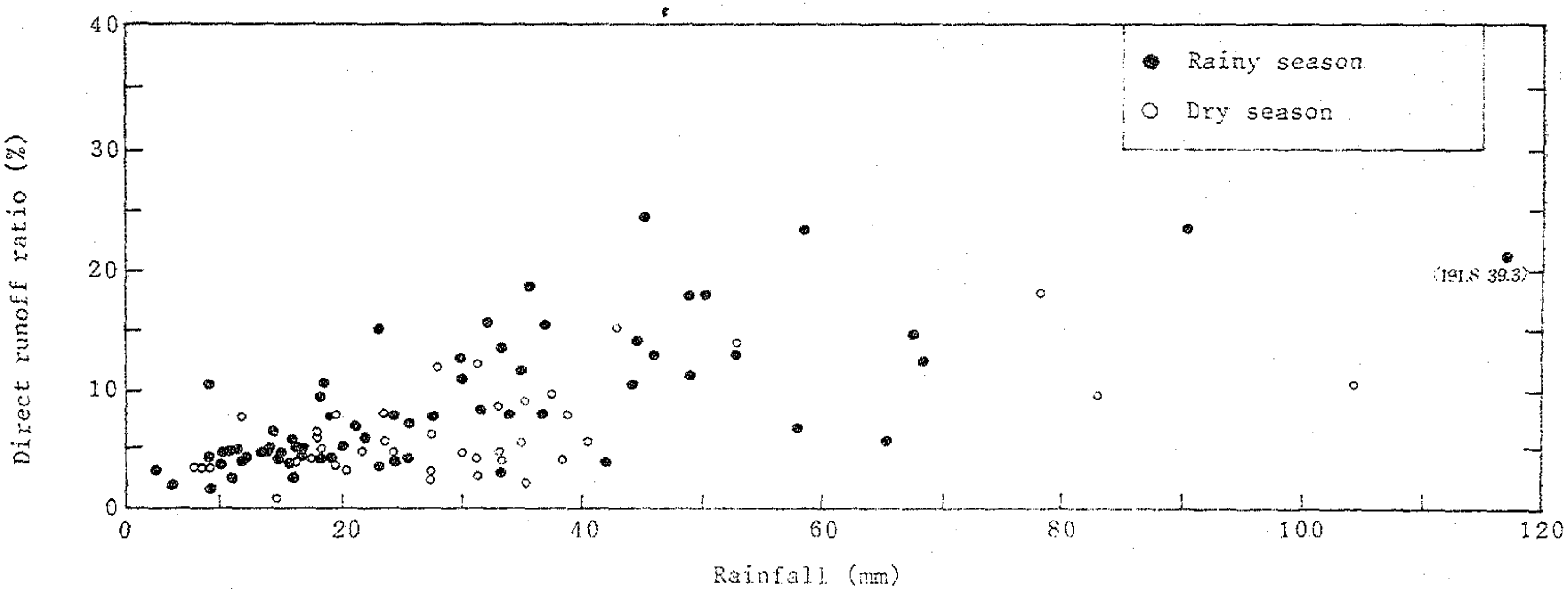


Fig. II-20 Relation between rainfall and direct runoff ratio increase with amount of rainfall, and the source area exponds at the same time. Increase of rainfall brings about generation of subsurface runoff and this brings about increase in direct runoff rate.

The largest rainfall during the period of observation was that of 191.8 mm in March 29 to 31, 1984; and the direct runoff was 39.3 mm with a direct runoff rate of 20.5 %. Although it was in the rainy season and the humid zone was expanded, 50 % or larger part of the direct runoff is considered to be come from the subsurface runoff. However, this shows that a major part of rainfall infiltrated into the soil and was stored there, with all interception by the vegetation. Therefore, it could be said that the permeability in the present watershed is high in view of the relationship between rainfall and direct runoff.

(4) Long-term runoff characteristics

Table II-16 shows the monthly rainfall and monthly runoff. General look of the result with attention to the monthly base runoff reveals that there is a variation with a year as the period, the minimum appearing in September in particular, it seems. The rate of total base runoff against the total runoff was 89.7%; and conversion of 56.2 - 177.1 mm monthly base runoff into average daily base runoff gives 1.9 - 5.9 mm. These figures are extremely stable and high as compared with those of Forestry and Forest Products Research Institute of Japan.

Watershed that is desirable in view of water resources should show a high rate of base runoff to the total runoff and a low variation in the runoff through the seasons (high uniformity in runoff). Therefore, coefficient of river regime and scanty runoff (355th day runoff) were taken up as indices of uniformity. Coefficient of river regime is the ratio of annual maximum flow to annual minimum flow and scanty runoff in defined as the runoff available within 355 days a year. Table II-17 shows an outline of the coefficient of river regime and scanty runoff in the forest experimental watersheds in Japan. The table shows that 1) Most of the coefficients of river regime lie in the order of 1,000, sometimes in that of 10,000 and that 2) scanty water runoff is 0.1 - 0.7 mm with a tendency of being the larger, the larger is the area of

Table II-16 Monthly rainfall and runoff

Month	Rainfall (mm)	Runoff Total R. (mm)	Runoff Base R. (mm)	Runoff Direct R. (mm)	Direct Rainfall ratio (%)
82.05	37.2	147.98	146.04	1.94	5.2
06	123.3	98.13	93.16	4.97	4.0
07	72.5	80.20	78.55	1.65	2.3
08	149.7	80.18	68.87	11.31	7.6
09	164.2	76.71	68.59	8.12	4.9
10	243.8	99.01	83.93	15.08	6.2
11	223.5	108.80	93.40	15.40	6.9
12	398.0	186.85	147.32	39.53	9.9
83.01	209.8	177.70	168.90	8.80	4.2
02	179.2	145.81	136.02	9.79	5.5
03	361.5	187.76	153.56	34.20	9.5
04	230.5	201.63	177.09	24.54	10.6
05	168.5	168.14	157.25	10.89	6.5
06	192.0	172.60	155.31	17.26	9.0
07	52.2	134.66	132.52	2.14	4.1
08	40.8	109.28	108.18	1.10	2.7
09	287.0	136.03	116.96	19.07	6.6
10	169.0	116.01	106.06	9.95	5.9
11	140.0	101.70	96.23	5.47	3.9
12	455.7	189.64	136.53	53.11	11.6
84.01	228.8	183.04	161.43	21.61	9.4
02	55.7	118.52	115.95	2.57	4.6
03	290.2	146.31	104.45	41.86	14.4
04	163.8	112.18	105.51	6.67	4.1
05	83.5	103.01	100.61	2.40	2.9
06	10.2	79.77	79.77	0.00	0.0
07	56.3	70.64	69.55	1.09	1.9
08	118.8	67.12	64.92	2.20	1.9
09	88.2	58.09	56.21	1.88	2.1

the watershed. Further, coefficient of river regime in H.J. Andrews Experimental Forest in Oregon, U.S.A. is reported to be 1,000 - 5,000. It is also reported that the flow may cease entirely in many first-order streams in late summer to eary fall. (2.3-8). Thus it could be said that variation in hydrological regime in a small montinous watershed is large, and that the scanty runoff is extremely small.

Examination in Reserva Estadual de Cunha in similar manners revealed that coefficient of river regime in 1983 was 101 and scanty runoff 2.74 mm, while they were 81 and 1.85 mm respectively in 1984 water year (Table II-18).

Soil survey make us suppose that forest having A-layer which is rich in humus is good for a headwater conservation and recharge improvement, owing to a high permeability of B and C layer (2.3-1). And the result of streamflow measurement also shows that the forest show abundant and stable base runoff throughout a year.

Table II-17 Low flow from forestry experimental basin in JAPAN

Name of basin	Area (ha)	Geology	Coeff. of river regime	355 days runoff
KAMABUCHI	(N38° 56′)			
No. 1	3.06	Tu	1709 ~ 60666	0.14
No. 2	2.48	Tu	928 ~ 8563	0.21
TAKARAGAWA	(N36° 51′)			
Honryu	190566	Gr & Tu	157 ~ 1974	0.69
Shozawa	117.90	Tu	224 ~ 25447	0.41
OKAYAMA	(N34° 42′)			
Minamitani	22.61	Ss & Cl	262 ~ 8216	0.12
Kitatani	17.27	Ss & Cl	946 ~ 16944	0.10
SARUKAWA	(N31° 51′)			
No. 1	6.56	Sh	229 ~ 7090	0.41
No. 2	9.17	Sh	180 ~ 4285	0.34
No. 3	8.18	Sh	185 ~ 3265	0.46

note: 1) Tu: Tuff (Neogene), Gr: Grainite, Ss: Sand stone, Cl: clay slate, Sh: shale

2) 355 days runoff shows the runoff available within 355 days a year.

Table II-18 Monthly maximum and minimum discharge

Month	Maximum discharge			Minimum discharge			Ratio
	Dis-charge (l/s)	Specific discharge (l/s/ha)	Intensity (mm/hr)	Dis-charge (l/s)	Specific discharge (l/s/ha)	Intensity (mm/hr)	
May.'82	37.5	0.669	0.25	24.5	0.437	0.16	1.53
Jun.	184.5	3.292	1.19	18.8	0.335	0.12	9.81
Jul.	61.1	1.090	0.39	13.8	0.246	0.09	4.43
Aug.	212.6	3.794	1.37	9.5	0.170	0.06	22.38
Sep.	227.2	4.054	1.46	9.5	0.170	0.06	23.92
Oct.	227.2	4.054	1.46	9.5	0.170	0.06	23.92
Nov.	761.6	13.590	4.89	16.8	0.300	0.11	45.33
Dec.	689.8	12.309	4.43	18.8	0.335	0.12	36.69
Jan.'83	110.4	1.970	0.71	30.7	0.548	0.20	3.60
Feb.	245.3	4.377	1.58	25.7	0.459	0.17	9.54
Mar.	966.9	17.254	6.21	25.7	0.459	0.17	37.62
Apr.	666.5	11.893	1.28	32.0	0.571	0.21	20.83
May.	181.8	3.244	1.17	28.1	0.501	0.18	6.47
Jun.	351.2	6.267	2.26	30.7	0.548	0.20	11.44
Jul.	44.8	0.799	0.29	24.5	0.437	0.16	1.83
Aug.	38.9	0.694	0.25	18.8	0.335	0.12	2.07
Sep.	174.5	3.141	1.12	21.0	0.375	0.13	8.31
Oct.	145.5	2.596	0.93	18.8	0.335	0.12	7.74
Nov.	70.0	1.249	0.45	18.8	0.335	0.12	3.72
Dec.	836.2	14.921	5.37	18.8	0.335	0.12	44.48
Jan.'84	652.7	11.647	4.19	28.1	0.501	0.18	23.23
Fev.	128.6	2.295	0.83	22.1	0.394	0.14	5.82
Mer.	761.6	13.590	4.89	18.8	0.335	0.12	40.51
Apr.	153.0	2.730	0.98	19.9	0.355	0.13	7.69
May.	61.1	1.090	0.39	18.8	0.335	0.12	3.25
Jun.	19.9	0.355	0.13	15.7	0.280	0.10	1.27
Jul.	34.7	0.619	0.22	13.8	0.246	0.09	2.51
Aug.	47.9	0.855	0.31	12.0	0.214	0.08	3.99
Sep.	37.5	0.669	0.24	10.3	0.184	0.07	3.64
Oct.	68.1	1.215	0.44	9.5	0.170	0.06	7.17
Nov.	61.1	1.090	0.39	10.3	0.184	0.07	5.93

Coefficient of river regime is defined as the ratio of annual maximum discharge to annual minimum discharge.
1983 water year: 101.78 1984 water year: 81.18

(5) Surface runoff measurement

Surface runoff was measured in plot A, a natural grassland, where observation was continued longer than 12 months, among three plots A, B, and C. The total rainfall from November 1, 1982 to October 31, 1983 was 2,352.0 mm and the total surface runoff was 15.12 mm with runoff rate of 0.64%. Monthly runoff rate varied in the range of 0.0% - 1.55%, depending on the rainfall conditions and moisture conditions in the experimental plot.

Table II-19 shows the result of experiment conducted in similar methods in Japan. The experiment were conducted by Forest Conservation Research Team of Forestry and Forest Products Research Institute in experimental area in Hirakasa, Iwate Pref. and Oguni, Kumamoto Pref. that are forest land and grazing land respectively. The runoff rate in the table is for a warm period in Hirakasa but for a whole year in Oguni. The runoff rate is less than 1.0 % in any of the cases, and the rate of Cunha is 2.5 - 10.0 times as large as that of Hirakasa and 1.0 - 2.5 times as large as that of Oguni. The maximum value of Oguni was about the same as that of Cunha. However, the plot in Oguni is a grazing land of 27° inclination, while in Cunha experimental plot grazing is prohibited, and the inclination is 18°. This makes us say that the runoff rate

Table II-19 Surface runoff ratio from runoff plots

No.	Area (m^2)	Ground slope (deg.)	Cover	Soil*	Soil hardness (kg/cm^2)	Surface runoff ratio (%)	Remarks
1	400	30	pasture	Bl	1.0 - 4.0	0.44-0.48	Oguni:
2	400	27	pasture	Bl	2.2 - 4.4	0.34-0.63	May, 24, '73
3	400	29	forest	Bl	1.1 - 3.0	0.24-0.34	to Mar.23,'76
4	800	Steep	pasture	Bl	4.4	0.01-0.28	Hirakasa:
5	800	Gentle	pasture	Bl	3.6	0.16-0.28	Jan.10,'72 to Nov.18,'75
6	800	Steep	forest	Bl	2.5	0.06-0.27	
7	600	18	pasture	RY	2.1 -10.0	0.67	Cunha:

*Bl: volcanic ash soil (Andosol)

RY: latosol

in Cunha is larger than Oguni. As the cause of the difference, soil conditions can be raised. That is, the soil in Oguni is a black soil (Andosoil) of volcanic ash origin and that of Cunha is red soil (latosol) being created laterilization of metamorphic rocks such as gneiss. Similarity in meteorological rainfall characteristics between Oguni and Cunha rather than Hirakasa is estimated to be one of the causes of resemblance in runoff rate.

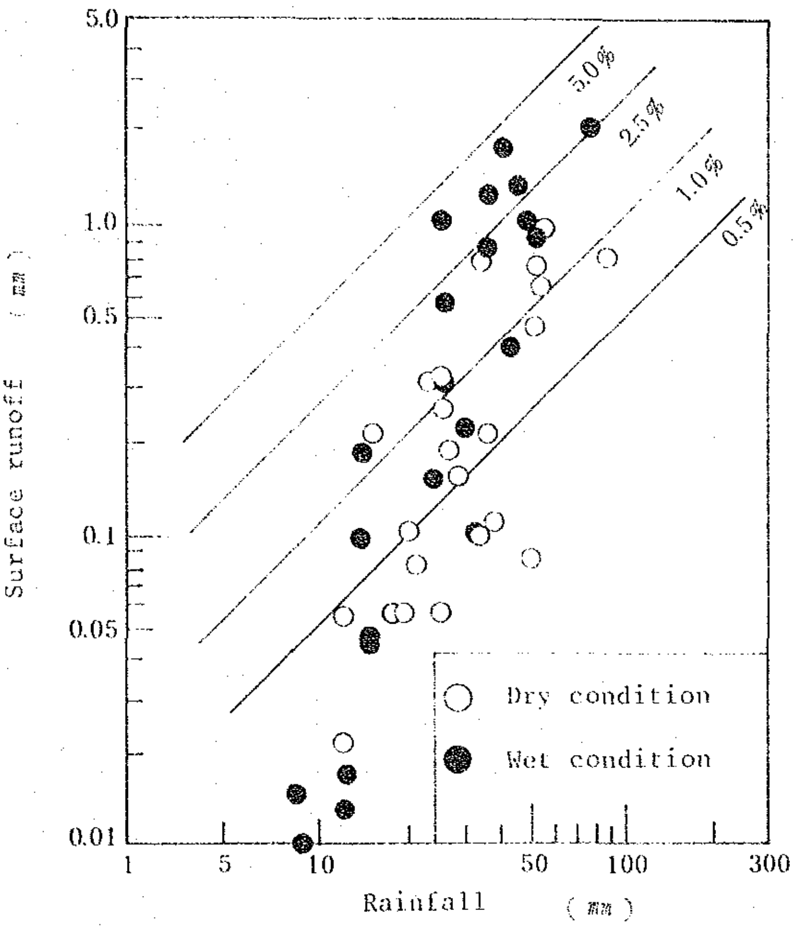


Fig. II-21 Relation between rainfall and surface runoff

Fig. II-21 shows the relationship between the amount of rainfall and surface runoff during the period of observation. Wet condition in the figure refers to the case of 30 mm or larger rainfall during three days before generation of surface runoff. Surface runoff (S_R) increases as the amount of rainfall (P) increases, and the relation between the two quantities is expressed by

$$S_R = aP^b$$

where a and b are constants. The relation was especially clear in wet conditions. Runoff rate also tended to increase with the amount of rainfall. For 30 mm rainfall or less, runoff rate was mostly 1% or less, but for more than 40 mm, 1% or larger rate and under wet conditions almost 4% rate was observed. The rainfall conditions required for generation of surface runoff were: 15 mm rainfall and 10 mm or higher maximum hourly rainfall intensity.

The coastal mountain range, on which the Cunha experimental Forest is located, is frequented in the rainy season by showers of about 50 mm/hr rainfall. Even if the ground surface is covered completely by vegetation, surface runoff is generated on inclined grazing land.

(6) Annual Water Balance

Within a certain watershed where there is no inflow of surface water and groundwater from other watersheds and no watershed leakage within a certain period, the following equation is valid.

$$P = R + E.T \pm \Delta S$$

where P: amount of rainfall, R: runoff, ET: evapotranspiration, ΔS: change in storage

Taking the hydrological period at 1 year, ΔS is equal to zero.

$$P = R + E.T$$

Water year is decided by bordering at the smallest month of river flow, that is the smallest month of storage in the watershed. Judging from the change of monthly base runoff, the water year of the Cunha Experimental Forest was decided to be from October 1 to September 30 of the next calendar year. In U.S.A., the water year is from October to September, if we are correct (2.3-8).

Water balance in 1983 water year (October 1, 1982 to September 30, 1983) and 1984 water year as obtained from Table II-16 is shown in Table II-20. Rainfall in the two years differ by 726 mm, but runoff rates are nearly the same at about 70% and evaporation was about 30% of rainfall. Annual potential evapotranspiration of the present watershed as calculated by Thornsweight Method (2.3-10) is 770 - 780 mm, and 758.5 mm evaporation in 1983 water year roughly agrees with the annual Potential evapotranspiration. However, in 1984 water year, 514.2 mm of evaporation was lower than annual potential evapotranspiration by about 250 mm. Nakano (2.3-4) assumes that although annual loses in the region of 1,700 - 1,800 mm annual rainfall (critical rainfall) is nearly constant to be equal to annual potential evapotranspiration in Japan, the critical rainfall would be larger in tropical districts. Therefore, the small annual evaporation in 1983 water year is supposed to be due to the small annual rainfall in the year. The effect on evaporation of the altitude of the Experimental Forest at more than 1,000 m and generation of thick fog by the moist air carried by sea breeze were left to be examined in the future.

Table II-21 Water balance at D-basin

Water year		Rainfall	Runoff	Evapotranspiration
1983	(mm)	2586.8	1828.3	758.5
	(%)	100.0	70.7	29.3
1984	(mm)	1860.2	1346.0	514.2
	(%)	100.0	72.4	27.6

note: Water year is from October 1 to September 30.

To sum up all of the results of various hydrological experiment obtained hitherto, rate of distribution of the annual rainfall to runoff process was obtained (Fig. II-22). 17% of the rainfall is intercepted by the vegetation, and water arriving at soil surface (Net rainfall) is 83% only. Infiltration into the soil and strage there is 75% only. The rain water straged in the soil is divided into two process. One of the process is the loss as an evaporation from soil and a transpiration from trees (13%). The other is the base runoff that rain water deeply percolated and was recharged as groundwater (62%). Direct runoff is composed, judging from the result of streamflow measurement and surface runoff measurement, mostly of surface runoff from source area and subsurface from infiltrating region, and surface runoff in the forest is extremely small.

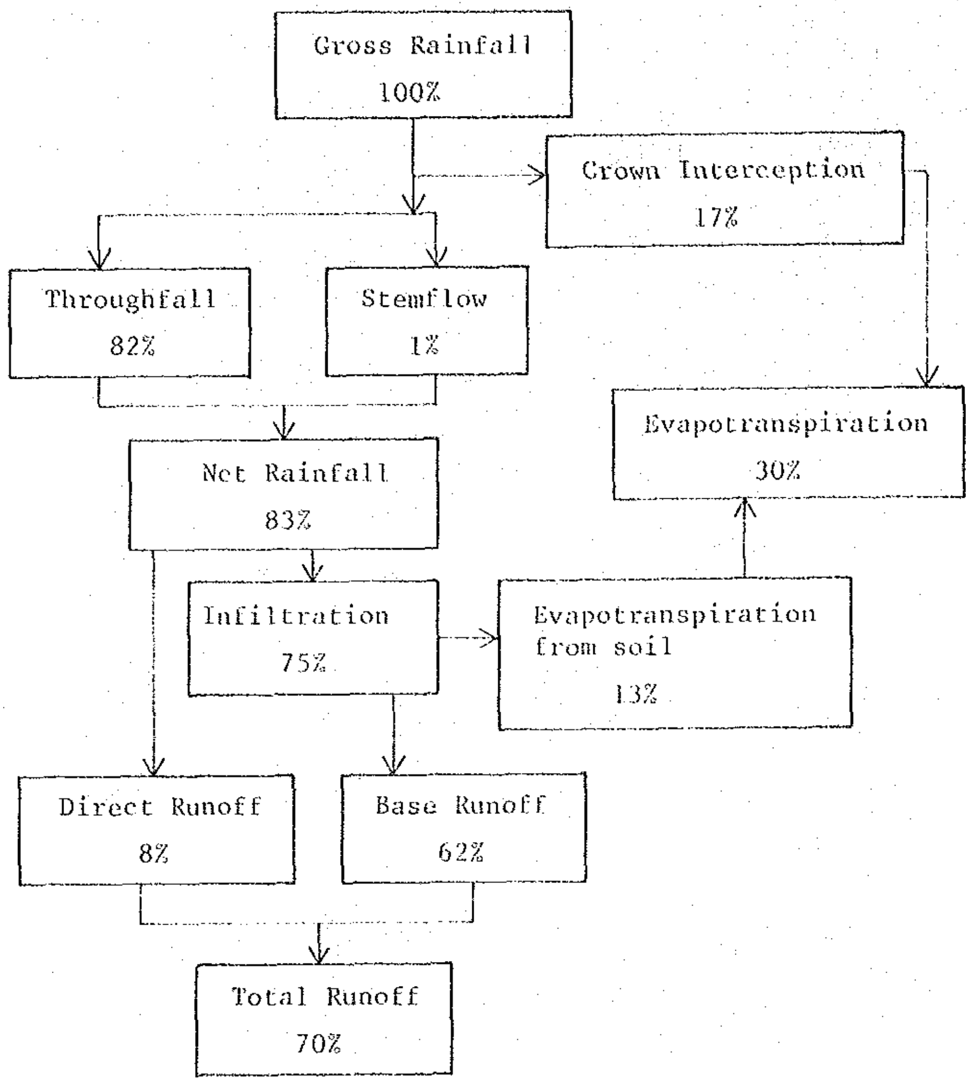


Fig. II-22 An example of runoff process at D-experimental basin.

(3) Future outlook and problem

As a result of preliminary measurements of streamflow and surface runoff, the soil of the D-watershed was found to show a high storage capacity of rain water, and base runoff shows a high uniformity. Turbidity measurement revealed that the turbidity of Rio Paraibuna is ordinary 4 to 5 PPM, which is as same levels as that of forested watershed in temperate zone (2.3-11). Therefore, positive protection and management of the natural forest widely distributed in the headwaters of Rio Paraiba is extremely important for soil and water conservation.

The future course of watershed researchs and problems are as follows:

(1) Watershed research

The result of watershed research in the past will be explained at first as follows: Increase of annual runoff is widely recognized. Summing up the report by Nakano, increase of 100 - 200 mm is observed in many of the Japanese experimental watersheds, while it is various in U.S.A. from about 50 mm in Wagon Wheel Gap to about 450 mm in Coweeta No. 17 but 100 - 200 mm in many of the places (2.3-12). Increase in base runoff is observed in a part of small rainfall belt, but most of the increase is of direct runoff. As the cause of the increase, 1) Increase of surface runoff by formation of water path as a result of disturbance on the surface owing to the logging, 2) Decrease in loses by absence of interception by the forest vegetation, etc. can be enumerated. However, the increase is reduced as regenerating plants and grow to establish forest to a certain degree, and the previous annual runoff before the cutting is restored. The time required for restoration is not the same, depending on the climate, soil conditions, etc. (2.3-4).

As typical method of watershed research, single watershed method and control watershed method can be raised. The former is characterized by comparison and examination of runoff for two periods of calibration and treatment in a watershed. The latter is characterized by experiment for two or more watersheds of resembling conditions such as topography, area, etc., and treatment such as cutting is given to the forest except one to be left untreated as control, after preceeding observation for a certain period before treatment. As the metorological conditions differ between the periods before and after treatment, the latter method excels the former. In any of the methods, 3-5 years of calibration period should be set, and hydrological characteristics in natural conditions should be grasped. As treatment of the watershed, 1) clear cutting of forest and leaving the ground in natural process thereafter, 2) clear cutting and pasturing into grazing land, etc. can be conceived. In the watershed of Rio Paraiba, grazing land is widely distributed, except forests in the headwaters and it is important to compare and examine runoff characteristics of forest land and grass land. If forest vegetation is recovered in the present experimental watershed rapidly, the method clear cutting forest and then paturizing here seems to be suitable in order to clarity the effects of forest on the soil and water conservation.

(2) Surface runoff measurement

Surface runoff measurement were conducted with an object of experiment the effect of various conditions of land utilization, as forest, grass land, or farm (bare land), on surface runoff and amount of sediment. However, soil runoff is too large on a bare land to be measured, in view of maintainance the instruments. Therefore, three ways of treatment are conceived: making a forest land by seeding, making a grass land by natural standing, and making a grass land by treatment. In the watershed of Rio Paraiba where pasturing on slope is done in many places, numberless cattle steps are formed, where bare gound is increasing. The bare ground formed by trampling soils by cows is a source of surface runoff, further to be a cause of flood. Therefore, it would be important to introduce cows artificially into one of the grass land plots and examine the relationship between the area of bare ground and surface runoff. In this case, it is necessary to change the water gauge of tipping bucket type into partial flume equipped with a precision stage recorder. In addition the instrument must be maintained and controlled frequently in order to minimize the trouble by soil runoff.

(3) Plane Lysimeter

Water balance investigation by plane lysimeter shall be conducted with emphasis on the difference in evapotranspiration between forest and grass land. Assuming a headwater forest being cultured on a pasture land, a grass land shall be taken as control and a forest as treated plot in terms of experimental plan. Three plots of experiment shall be arranged, grass land, forest 1, and forest 2, and a buffer forest shall be arranged around the lysimeter so that the external effect on the seeding can be avoided as far as possible. As the kind of trees to be planted, pines and eucalyptuses species are selected, both being the typical planted trees in Brazil; and ARUCARIA that is the native species can also be resorted to. Experimental period of three years for a plot is considered sufficient, because of the fast growing, although this can depend on the number of trees planted. The flowmeter of tipping type being used at present may not work in the case of a heavy rain, because of the too large runoff. However, for a experiment of evapotranspiration comparison between the kinds of trees, the object of the experiment will be accomplished if depression curve in the dry season is obtained.

The above is a proposal for the various hydrological experiment in the future, but something on a long-term experimental plan will be added.

The target of streamflow measurement at the moment is placed mainly on the change of runoff characteristics following conversion of the land after clear cutting into pasture land, but it would be necessary in the future to investigate the effect of afforestation in the watershed where it is utilized as pasture land for some time. An afforestion should be carried out by a careful selection of the kind of trees that is best suited for soil and water conservation by experiment of evapotranspiration covering of the ground surface, development of the root system, etc. being obtained by plain lysimeter experiment.

It is also necessary to conduct experiments at the same time on soil physics such as permeability and porosity so that they can be quantitative indices of water reservoir culturing function. The extremely high base runoff in the D-watershed is estimated to be due to the presence of a thick layer of soil following weathering bedrocks.

Therefore, investigation of porosity and determination of permeability coefficient of soil would be an important subject in view of a quantification of head water conservation and recharge improvement.

The present project accomplished 1) construction of Cunha Experimental Forest, and 2) Transformance of fundamental knowledge and technique necessary for execution of forestry hydrological experiments and arrangement of basis for full-scale tests.

Exchange of information and cooperation with University and other research institute of Sao Paulo state will be necessary for future experiment and research. It is also considered important to exchange information and interchange researchers between Forestry Institute of Sao Paulo and Forestry and Forest Products Research Institute of Japan, utilizing the friendship fostered by the present project, in order that the effect of research cooperation be maintained and enhanced.

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