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CLIMATIC WATER BALANCE AND AGRICULTURAL PRODUCTION IN THE NORTHERN PLAINS OF WEST JAVA.

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# CLIMATIC WATER BALANCE AND AGRICULTURAL PRODUCTION

# IN THE NORTHERN PLAINS OF WEST JAVA

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

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By

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Dedicated to my late parents, Sujini and Sumadi Resosudarmo, whose entire lives were dedicated to the education of their children.

ACKNOWLEDGMENTS

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ABSTRACT

Indonesia is an agricultural country which at present is concentrating much of its development funds and efforts on improving agricultural production, especially rice, to meet the growing demands for food and job opportunities for a rapidly expanding population. Irregular rainfall and inefficient management of the available water resources result in damage to rice plants and production. Good water management, i.e., the control of water for the most efficient use of limited supplies to obtain optimum crop yield, is needed. The problem of optimum water distribution can be solved only when various water balance components and the response of crops to water application are understood.

The purpose of this study is to determine the water balance of the Northern Plains of West Java, to analyze its components under the influences of local meteorological factors, and to relate water balance conditions to agricultural production.

Several empirical methods to estimate potential evapotranspiration have been tested to determine which is best suited to tropical conditions. A linear regression analysis has been performed in order to measure the relationship between global radiation and sunshine duration ($Q/Q_A = a + b\ n/N$) for Jakarta during the period 1964-1971. The predictive formula which was derived is $Q/Q_A = 0.19 + 0.38\ n/N$, with a standard error of 0.09 and a correlation coefficient of 0.69.

Potential evapotranspiration isolines and water balance diagrams for eight stations, Serang, Jakarta, Depok, Subang, Jatiwangi, Kadipaten, Cirebon and Tersanabaru are presented.

A close correspondence has been found between poor rice harvests and periods of severe water deficits in West Java during the period 1955-1975.

TABLE OF CONTENTS

LIST OF TABLES

# LIST OF FIGURES

Figure | Page

A nation that fails to plan intelligently for the development and protection of its precious waters will be condemned to wither because of its short-sightsightedness. The hard lessons of history are clear, written on the deserted sands and ruins of once proud civilization. Responsible government can not overlook the importance of water management to the nation's economy and health.

Lyndon B. Johnson

# CHAPTER I

# INTRODUCTION

## PROBLEMS AND OBJECTIVES

> To meet the growing demands of the national economy, especially in developing countries where the income very much depends on agricultural production, it is necessary to systematically increase the accuracy of hydrological calculations and of the forecasts of flow and other elements of the water regime.
>
> Krestovskey, 1962

### Problems in Indonesia

Indonesia is an agricultural country which at present is allocating much of its development funds and efforts on improving agricultural production, especially rice, to meet the growing demands for food and job opportunities for a rapidly expanding population. Until the middle of the nineteenth century, the population of Java and Madura was considered to be stable and was estimated at 4.5 million. However, in the census of 1931, the population had become 42 million, with the density of 300 per square kilometer. Within eighty years, the population had multiplied ten times. The real population explosion in Java and Madura thus took place in the beginning of the twentieth century. Based on the census data of 1961 and 1971, Indonesia had a population increase of about 2.3 percent per year during this ten year period. In 1971, the Statistical Bureau of Indonesia in a 10 year projection (1971-1981) estimated that the growth rate would remain approximately the same, although a minor decrease was anticipated because of the government implementation of family planning in Indonesia.[1]

The population density in Indonesia in 1971 was 63 per square kilometer. However, Java and Madura, which cover an area of only 7 percent of Indonesia, had 63.7 percent of the total population, with a population density of 579.7 per square kilometer, making them one of the most heavily populated areas in the world.

In many parts of tropical Asia, irregular rainfall and incorrect management of available water result in damage to rice plants. Good water management involves the control of water for most efficient use of limited supplies to obtain optimum crop yield.

Steps taken in intensification of agricultural practices in Indonesia include better techniques of land preparation, use of improved seed varieties, chemical fertilizers, insecticides, and pesticides, and the construction of irrigation and drainage systems. The development of irrigation is probably the most important one, because the success of all agricultural innovations, such as those stated above, depends very much upon exact timing and amount of water available.

The application of irrigation water, however, has not reached its maximum effectiveness. This problem of optimum water distribution can be solved only when various water balance components and the response of the crop to water application are understood. At present there is a serious lack of accurate information concerning water balance and water

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[1]Statistical Pocketbook Indonesia (Jakarta: Biro Pusat Statistik, 1972/1973), p. 18.

requirement of major rice varieties. Although a number of climatological studies in Indonesia (Van Bemmelen, 1908; Boerema, 1925, 1926; Braak, 1921, 1923, 1928; Boerema, 1933; Berlage, 1949; Schmidt and Van der Vecht, 1952; Schmidt, 1950, 1952; Schmidt and Ferguson, 1951; Wyrtki, 1956) have been published, no detailed analyses of the water balance which is essential for water resource management has been made. These studies are primarily concerned with the general circulation of the atmosphere and the distribution of climatic elements such as temperature and precipitation.

## Water Balance Fundamentals

The determination of the water balance and its components, and their relationship to agricultural processes constitute one of the fundamental scientific objectives of agricultural meteorology. The water balance represents an expression of the complex inter-relationships between inflow (precipitation) and outflow (evapotranspiration, soil storage, and runoff) of water on the land surface. From a comparison of the supply of water by precipitation, the demands of water by evapotranspiration, and the loss of water through runoff, some insight into related problems of soil moisture can be gained.

Although there is an adequate network of stations to measure precipitation there is little reliable information concerning evaporation. Precipitation is frequently measured and its magnitude is known for many localities. However, the magnitude of evapotranspiration is still a matter of controversy. Hydrologists and irrigation engineers, as well as climatologists, often disagree as to the best method of estimating evapotranspiration. Yet such estimates are necessary, as the reliable measurement of potential evapotranspiration is difficult and restricted to a very small number of stations where special research work is being carried out.

Thornthwaite (1948) published his rational climatic classification at the same time that Penman derived an empirical formula to calculate evapotranspiration from climatological data which are commonly available in most countries. Both studies excited much interest among geographers and climatologists, speeding the progress of climatology. The Thornthwaite method immediately had a widespread application, especially by geographers to define climatic regions and to identify their relationship with the distribution of edaphysical and climatological elements. The apparent success of the Thornthwaite method in several parts of the world is based mainly on the fact that the distribution of many physical elements can be related to the arbitrarily chosen points in the continuum of a comparative index which summarizes one or more climatic elements on an annual basis. However, for applications where short-period values are important, empirical formulae using mean temperature for estimating potential evapotranspiration, such as that devised by Thornthwaite, are fundamentally and practically inadequate (Chang, 1959; Pelton, King, and Tanner, 1960).

The Penman method for calculating evapotranspiration is accepted by most scientists as the best available, and is practical in many countries. Penman's approach is based on sound physical reasoning, and expresses evapotranspiration as a function of air temperature, humidity, wind, and cloudiness through combining the energy budget and the aerodynamic equation and by adopting several assumptions which eliminate the need for difficult profile measurements.

PURPOSE OF THE STUDY

This study is intended as an exploratory analysis to determine the role of moisture balance in agricultural productivity. The focus of the study is to identify those factors influencing the water balance in the study area of Indonesia, and then to indicate the significance of the moisture budget to agricultural systems found in the area. Many studies in other countries have shown the critical need for detailed knowledge of moisture budgets in agricultural planning and improvement (Raman and Srinivasamurthy, 1971; Kindsvater, 1964; Papadakis, 1966; Domros, 1974).

Because water balance calculations identify periods of moisture surplus and deficit and thus permit the determination of surplus moisture stored in the soil or lost through runoff at any time, water balance becomes the basic tool in identifying water utilization problems and applications. These calculations are also basic in assessing the economic feasibility of irrigation in a given area, for they provide information on the total volume of water needed at any time and give a definitive measure of water deficiency. Without such information, the annual cost of operating an irrigation system cannot be accurately estimated for factoring into the benefit-cost analysis needed in project planning. When compared with moisture surplus in other periods it shows irrigation needs and water availability (Mather, Pengra, Engelbrecht, 1955). The goal, then, is to develop a moisture balance model utilizing available climatological data to produce reasonable estimates of water excess, deficiency, and soil moisture storage.

While many climatological studies have tended to concentrate on general conditions over large areas, this study will help meet the need for detailed examination of water balance within smaller areas for hydrological and climatological purposes. The advantage of concentrating on a smaller region is that the area is relatively homogeneous in its environment and experiences relatively uniform atmospheric controls. Climatic water balance analysis is especially needed in areas which have excessive precipitation during one season of the year and a lack of water during another (Thornthwaite and Mather, 1955).

Most important rice producing areas of Indonesia experience monsoon climatic conditions with pronounced dry east monsoon and wet west monsoon with heavy tropical rains.

During the Dutch colonial period, the need for and the importance of improved irrigation to increase agricultural production and thus better the general welfare of the people, was recognized, and resulted in the construction of numerous local irrigation works.

With independence, the Indonesian government put even more emphasis on irrigation by including several major regional water management projects in the Five Year Plans. The scope of these projects was expanded to include flood control, drainage, and hydroelectric power.

The Jatiluhur project, which was begun during the first Five Year Plan (1956-60) and includes a multipurpose dam with related facilities on the Citarum River in West Java, was expected to provide the necessary first solid step toward the realization of a higher standard of living for West Java and through this, for all Indonesia. This project was continued in the second national plan, the Eight Year Plan Overall

National Development Program (1961-1969), which was promulgated by the National Planning Council in 1961.[2]

In the First Repelita, "Rencana Pembangunan Lima Tahun" or Five Year Development Plan (1969-1973),[3] the Citarum project was expanded to an integrated river basins management program, which includes the control and management of all river waters in the Northern Plains of West Java, such as Ciujung, Cidurian, Cisedane, Ciliwung, Citarum, Cipunegara, and Cimanuk. It was expected that with this integrated river basin system, technical irrigation for double-cropping of rice would be extended to 577,240 hectares on the coastal lowlands (see Figure 1). Technical irrigation refers to the Dutch irrigation system which uses dams, reservoirs and canals, in contrast to the traditional Indonesian irrigation system which employs natural lakes, rivers and streams.

However, results to date have been far below target projection both in terms of area to be irrigated and yield per hectare. Possible major causes for these unsatisfactory results include: miscalculation of quantity and timing of water yield caused by insufficient knowledge of the climatic water balance in the areas concerned; poor control of water in the irrigation network because of poor maintenance and seepage; and inefficient application of irrigation waters to agricultural lands, both in amount and timing, because of the lack of understanding of water

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[2] Endang T. Atmadi, INDONESIA (Jakarta: Prapanca and Wit Sidoguri Publications, 1962), p. 32.

[3] The "Orde Baru" Government under General Suharto, decided to start with the first Five Year Plan again. Orde Baru means new order or new generation.

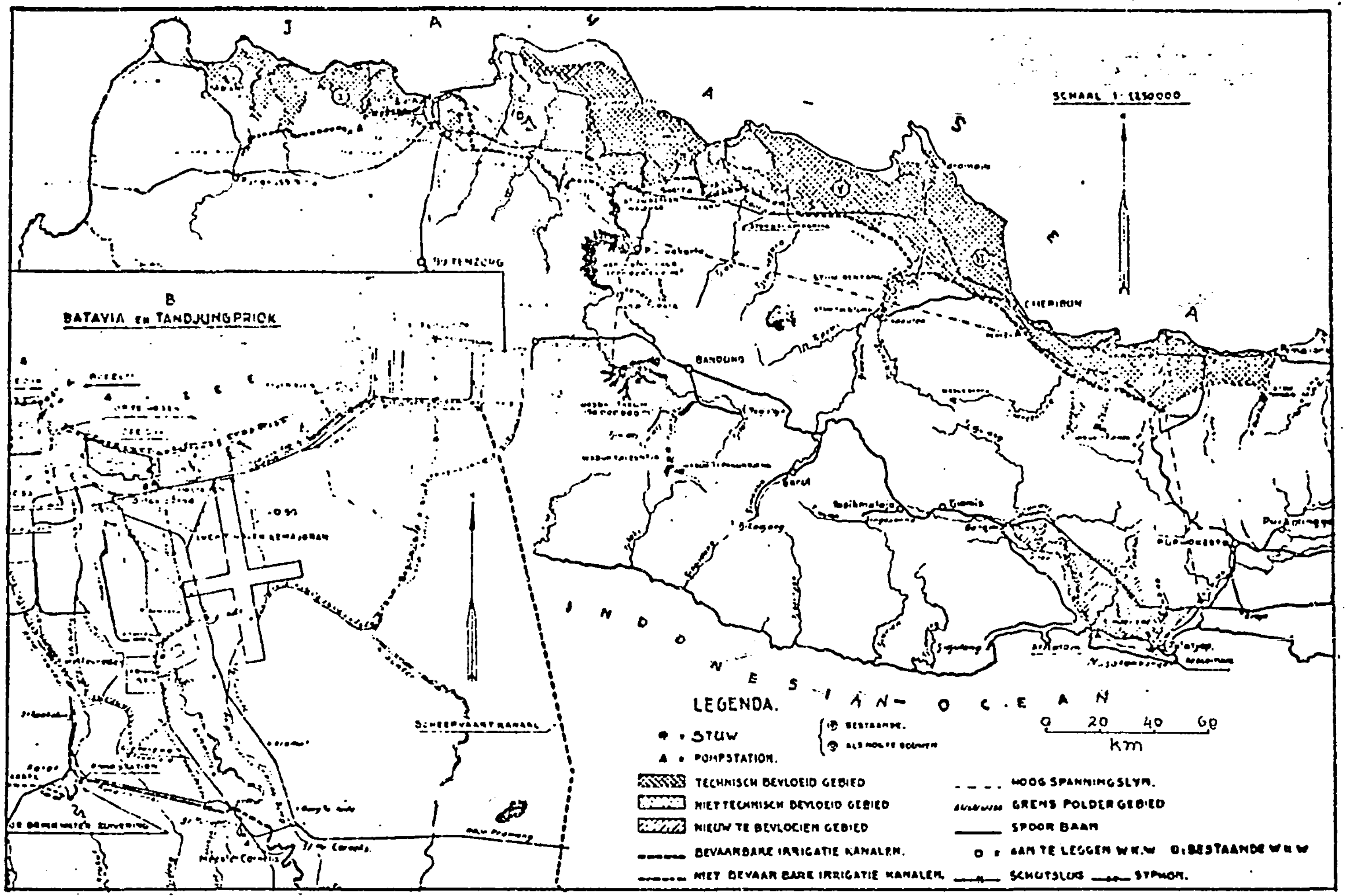


Figure 1. Federal Welfare Care, Western Part of Java.
After Van Blommestein (1949).

balance, especially the failure to properly take into account the potential evapotranspiration during the period of the dry east monsoon.

The objectives of this research are to determine the water balance of the Northern Plains of West Java and to analyze its components, and to examine the relationship of the water balance to local agricultural patterns. Several formulae will be tested to examine the accuracy of empirical methods in estimating the value of potential evapotranspiration (PE) in light of the existing local meteorological factors.

## EXPECTEL SIGNIFICANCE OF THE STUDY

Knowledge and understanding of the climatic water balance in the study area will aid planners in: prediction and control of the physical environment for better agricultural forecasting (growth and development of crops) and operational management; protection of agriculture from environmental hazards, such as floods and drought; and prediction, control, and management of agricultural pathogens and pests.

As previously indicated, this study relates to practical problems in economic development in a specific area and fills a research gap. Accurate calculation of the climatic water balance of the Northern Plains will eliminate a gap in water resource analysis and planning for this region, and will have direct application to problems of irrigation, flood control, drainage, and long term prediction of climatic conditions.

# CHAPTER II

# PHYSICAL ENVIRONMENT

## STUDY AREA

The Northern Plains of West Java[1] have been built up since the Quarternary Period by a number of river systems including, from Banten in the west to Cirebon in the east: Ciujung, Cidurian, Cisedane, Ciliwung, Citarum, Cipunegara, and Cimanuk.[2] The geographical location is between 5° 30' 22" S and 6° 20' S and between 106° 0' 30" E and 108° 40' E (see Figure 2). Administratively, it includes the areas of District Banten, Jakarta DKI, Karawang and Cirebon. Stretching east-west in the northern section of West Java from Cirebon to Serang, it has an average width of about forty kilometers, and consists mainly of alluvial sediments and of young volcanic material which originated from the volcanic complex south of the Plains. In some places where slight folding was followed by denudation, tertiary marine sediments are observed. The higher mountainous area bounding the Plains on the south is called the Bogor Zone and is a complex mountain chain with volcanoes stretching from the Jasinga area to the Pemali river, Bumiayu (van Bemmelen, 1949).

Kuyp (1938) divided the Northern Plains of West Java or the Plain of Batavia (van Bemmelen, 1949) into areas which he called the Plains and

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[1]This includes those areas below 100 meter contour line. The term Northern Plains is preferred rather than Northern Plain, since the northern coastal area consists of a series of coalescing river plains.

[2]Ci (Sundanese) means water or river.

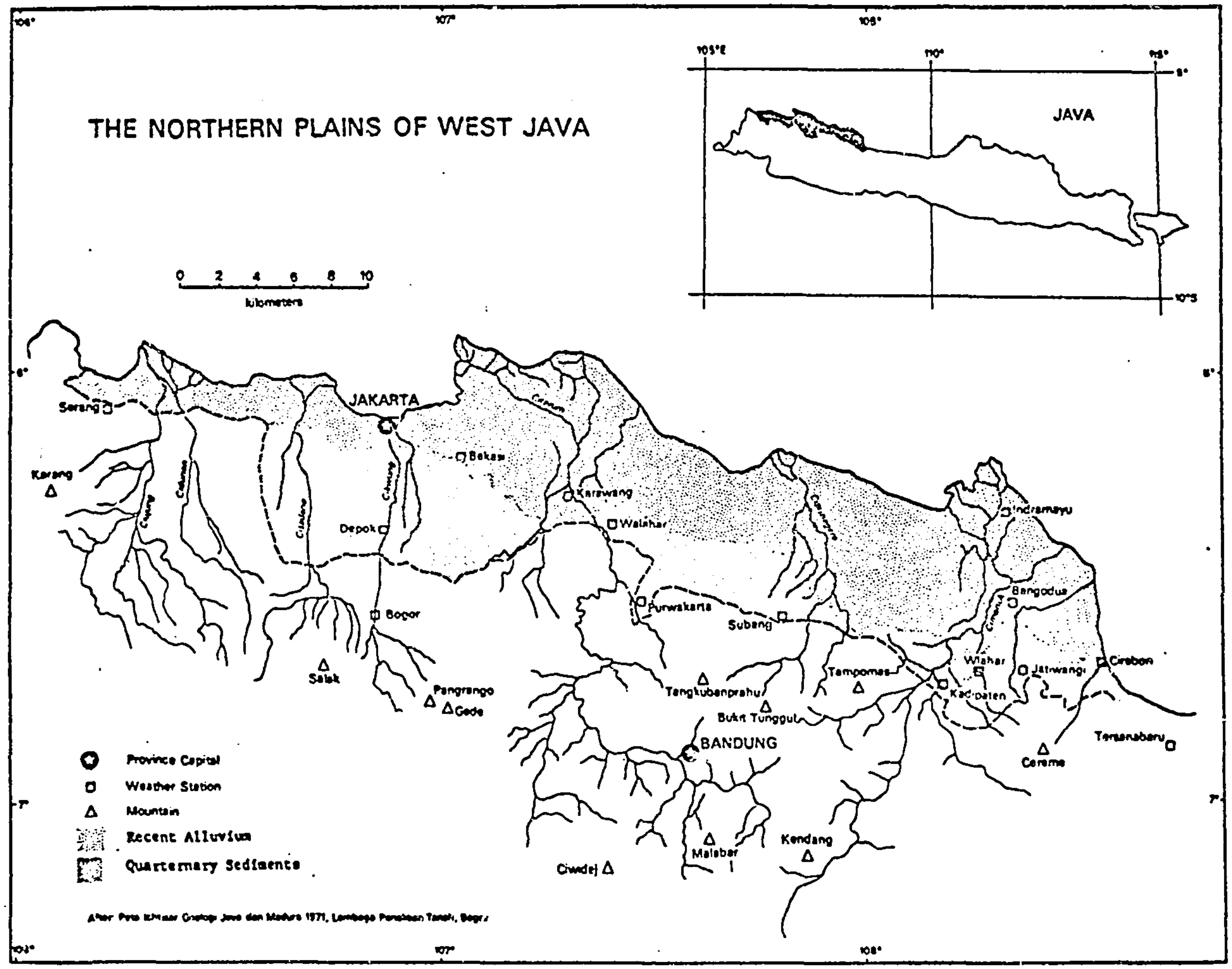


Figure 2. The Northern Plains of West Java.

the Middle Area. Although his division is based primarily on geological conditions, differences in elevation also exist between the two areas and thus slight variations in climatic elements, especially precipitation, are observed.

The Northern Plains, an area of about 600,000 hectares, has approximately 200 weather stations. For practical reasons, and in the light of the monotonous topography, only fourteen strategically located stations were chosen for investigation in the study (see Figure 2). The selection of these stations was based on their long period records and on their locations, which, it is believed, adequately represent the weather stations of the entire area. Station descriptions are as follows:

Table 1

The Particulars of the Stations in the Northern Plains

| Name: | Station Number: | Elevation: | Latitude | Longitude |
|---|---|---|---|---|
| Serang | 23 | 25 m | 6° 07' | 106° 08' |
| Jakarta | 27 | 7 m | 6° 11' | 106° 50' |
| Depok | 36 | 95 m | 6° 34' | 106° 49' |
| Bekasi | 78a | 20 m | 6° 14' | 106° 59' |
| Walahar | 101b | 25 m | 6° 23' | 107° 21' |
| Purwakarta | 117 | 82 m | 6° 25' | 107° 23' |
| Subang | 156 | 95 m | 6° 35' | 107° 46' |
| Indramayu | 10 | 10 m | 6° 20' | 108° 18' |
| Bangodua | 15 | 15 m | 6° 32' | 108° 20' |
| Kadipaten (*) | 22 | 45 m | 6° 46' | 108° 11' |
| Wlahar | 35 | 34 m | 6° 43' | 108° 14' |
| Jatiwangi (*) | 37 | 45 m | 6° 43' | 108° 17' |
| Cirebon | 62 | 0 m | 6° 42' | 108° 36' |
| Tersanabaru (*) | 88 | 5 m | 6° 59' | 108° 41' |

(*) = Sugar Plantation

Almost all of these stations have continuous rainfall records of the 30 years from 1931 to 1960, for which mean monthly and annual rainfall have been calculated (Meteorological Note No. 8 Part I, 1969). For Wlahar and Cirebon the calculation is based on twenty years observations from 1941 to 1960, and for Depok is based on eight years records from 1952 to 1959. This study makes use of all available records, the earliest dating from 1879 (see Appendix I). In almost every record of climatic elements discrepancies were found. Nevertheless, the results of this study should still have important value, because they are the best that can be done with the available data.

Since the seventeenth century, these alluvial lowlands have been known as a rice bowl for other parts of Java. However, steadily increasing population pressures induced agricultural encroachment on the steeper slopes of the watersheds of the rivers and, coupled with uncontrolled deforestation in the Japanese period and during the Revolution, resulted in increasing frequency of extremes in river flow.

In the Dutch colonial period, Indramayu rice which is considered high quality rice, and sugar from Tersanabaru were exported. Since shortly before World War II until the Japanese invasion in 1942, almost all arable lands received enough water in the rainy seasons due to the irrigation system, while in the dry seasons, only 14 percent of the arable land could be used for <u>sawah</u> or paddy field. However, from the time of the Japanese administration (1942-1945) to 1968, the condition of the irrigation system declined. The capacity of the irrigation channels dropped to 60 percent, and some could not function at all. Factors which led to the degradation of the irrigation systems include, sedimentation due to soil erosion upstream caused by uncontrolled deforestation; the lack of systematic and consistent maintenance of the irrigation works and channels, and farmers' unwareness of or unconcern for irrigation regulations.

Accelerated soil erosion upstream actually began in the mid-1900's. Based on their research in the watershed area of Cilutung, a tributary of the Cimanuk, Van Dyk and Vogelzang (1948) stated that in the years 1911 and 1912 the erosion rate in that area was 13.2 tons per hectare per year. Such a condition does not necessarily endanger the soil structure and is still within the range of permissible erosion. However, since 1917 (Van Dyk and Vogelzang, 1948), under the presure of increasing population, and as a result of irresponsible deforestation by local farmers, the soil erosion rate increased to a dangerous level. Measurements carried out in 1934/1935 revealed an increased rate of 28.9 tons per hectare per year which is equivalent to a loss of a 2.9 millimeter soil layer, and is three times faster than the rate in 1911/1912.

Soil degradation resulting from uncontrolled deforestation reached its peak during the Japanese Occupation. Millions of tons of top soil were eroded and carried away to the shallow Java Sea; many irrigation channels were destroyed. Abdurachim (1970), estimated that the watershed of Cimanuk lost about six to nine million cubic meter of top soil annually.

The effect of soil degradation in the upstream portion of the river systems not only causes problems of siltation and floods but also creates severe droughts, because most of the wet season rainfall is lost as runoff water or by floods to the sea rather than infiltrating to replenish the ground water supply and subsequently feed the streams in the drier season.

The densely populated Northern Plains are constantly under threat of flooding from the heavily charged river systems during the rainy season (see Figure 2). A single rapid rise of these rivers may destroy large tracts of ripening padi, carry away vital transportation links, and damage thousands of farmsteads and some commercial establishments. During the dry season, however, even in those areas under the present technical irrigation systems, farmers are faced with the equally serious problem of water deficit. Lack of water complicates land preparation, fertilizer application, and greatly reduces padi yield, in many cases even eliminating the possibility of a second crop of rice.

Sharp decreases of rice production occur in the dry season because of the reduction of river discharge, which sometimes lasts for about three or four weeks, or even longer. For example, from the statistical data for rice production in Tangerrang District, Jakarta, collected from 1963 to 1968, it was learned that the average yield of rice dropped from 98,763 tons in the wet season to 29,500 tons in the dry season.[3] Such disasters, and other less obvious, long-term effects such as the siltation of harbors opening upon the relatively shallow Java Sea, can only accelerate the deterioration of economic conditions.

Long-term planning of water resource use has been adopted for controlling the river systems to minimize floods, and to provide effective irrigation to the Northern Plains, thus enabling these areas to produce two crops of rice a year, or one crop of rice and two of secondary crops known as polowijo.

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[3]Jaringan Irigasi Cisedane, Feasibility Report, Hanza Engineering Company International, Consulting Engineers River Project, 1969.

Thus, the Northern Plains of West Java are chosen as the area of investigation for water balance study for several reasons:

First, the Northern Plains rate as a major agricultural area and as the rice bowl for West Java and Indonesia. Their economy at present depends almost entirely on agricultural products, and because of the lack of minerals, agriculture probably will continue to be the dominant factor in the future economy of this area. Therefore, investigation of the climatic water balance to aid in improving agricultural production has great practical significance in this area. Since the economy of the Northern Plains is dependent mainly upon rice, the unbalanced and dangerous economic condition in this area can be stabilized or diversified primarily through improvement in water management. For this, the climatic conditions, in particular the water balance, must be considered.

Second, a climatic water balance study of this area can be carried out successfully from the available climatological data. The area has a relatively efficient meteorological service with good recording technique and long-term observation periods. In addition, there also are a number of reliable private weather stations (Kadipaten, Jatiwangi, and Tersanabaru) which are partly supervised by the Institute of Meteorology and Geophysics, Jakarta. These stations are located in sugar plantations and emphasize rainfall and sunshine duration in their observations.

Finally, according to Thornthwaite and Mather (1955), climatic water balance calculation is a critical need in areas of high rainfall in one season and lack of water during another. With the occurrence of the two monsoons, opposite in wind direction and rainfall effectiveness, the Northern Plains region of West Java represents a good example of such an area. Schmidt and Ferguson (1957) divided this area into two types of climate, the C and D types. This classification is based on the proportional ratio between the average dry months and the average wet months of the year. Their system of climatic classification is considered to be an improvement of Mohr's method, which is based on three degrees of moisture for the various months of the year. A month is regarded as being *wet* when there is more than 100 millimeters precipitation during that month. The precipitation then normally exceeds the evapotranspiration. Precipitation of less than 60 millimeters per month is considered as a *dry* month. The evapotranspiration then surpasses the amount of precipitation and starts to withdraw moisture from water storage in the soil. Finally, a month with precipitation between 60 millimeters and 100 millimeters is designated as *moist*.

Schmidt and Ferguson (1957) determined the quotient Q of the average number of dry months and the average number of wet months, and presented a scheme of climatic divisions for Indonesia, as follows:

| | | | | | |
|---|---|---|---|---|---|
| A | 0 | $\leq$ | Q | $<$ | 0.143 |
| B | 0.143 | $\leq$ | Q | $<$ | 0.333 |
| C | 0.333 | $\leq$ | Q | $<$ | 0.60 |
| D | 0.60 | $\leq$ | Q | $<$ | 1.00 |
| E | 1.00 | $\leq$ | Q | $<$ | 1.67 |
| F | 1.67 | $\leq$ | Q | $<$ | 3.00 |
| G | 3.00 | $\leq$ | Q | $<$ | 7.00 |
| H | 7.00 | $\leq$ | Q | | |

This scheme can be expressed in the form of a diagram as in Figure 3.

In general, rainfall increases from the coastal lowlands in the north to the foothills of the mountainous areas in the south. Rainfall pattern differentiation is the major climatological element which causes climatic differences in this area.

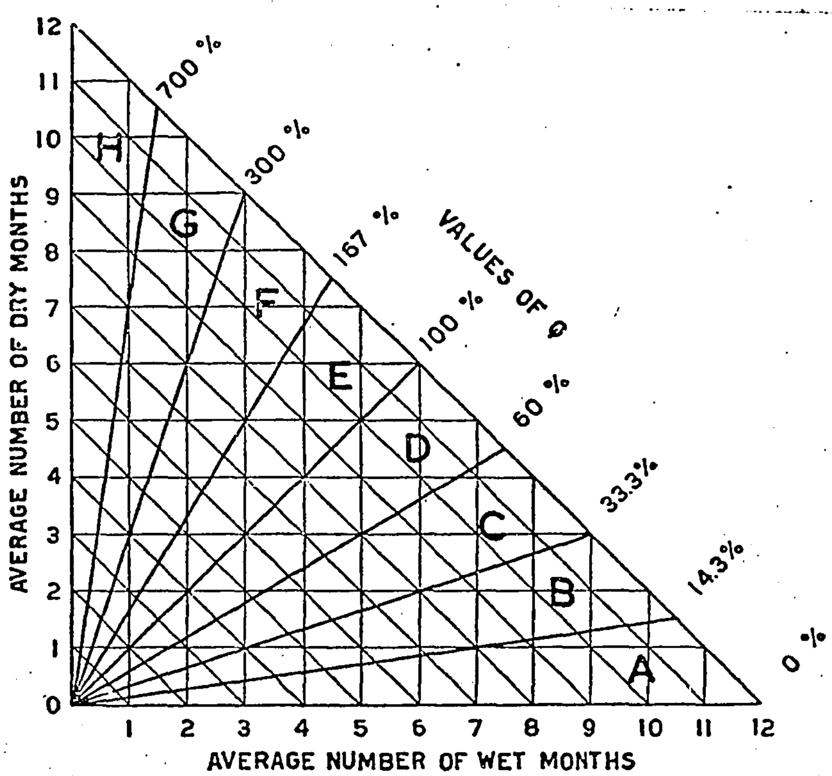


Figure 3. Diagram of Climatic Types According to Schmidt and Ferguson.

## LANDFORMS

### Physiography and Origins of Substrata

The Northern Plains of the Coastal Plain of Batavia (van Bemmelen, 1949) (see Figure 4) are about 40 kilometers wide and extend from Serang and Rangkasbitung in Banten to Cirebon. They consist largely of alluvial river deposits and lahar (mud flows) from the volcanoes in the hinterland, with occasional exposures of slightly folded marine tertiary sediments. To the south, the Northern Plains are bounded by a complex belt of hills and mountains, which extend from Banten to Pemali in Central Java. This belt is called the Bogor Zone.

The coastline steadily extends northwards, because of the deposition of silt into the Java Sea. Except in the westernmost part of Banten, where Gunung Karang produces acidic rhyolite, the deposits originating from volcanic material are in general basic, and form a level lowland ideal for agricultural practices. In some places the plain is interrupted by undulating landscapes, which are occupied by villages or ladang. From the early times this lowland was developed for agriculture, and by virtue of the gentle topography, it was used as a corridor between Jakarta and Central Java.

Kuyp (1938) divided the Northern Plains into the middle area and the coastal plain. The middle area is a transitional landscape between the coastal plain in the north and the rugged mountain chain in the south, which in turn is part of the Bogor Zone where are located several volcanic cones including Cereme, Tampomas and Kromong (see Figure 4). The middle area is about 10 to 50 meters above sea level, and forms a plateau with an undulating surface, which gently slopes to the north,

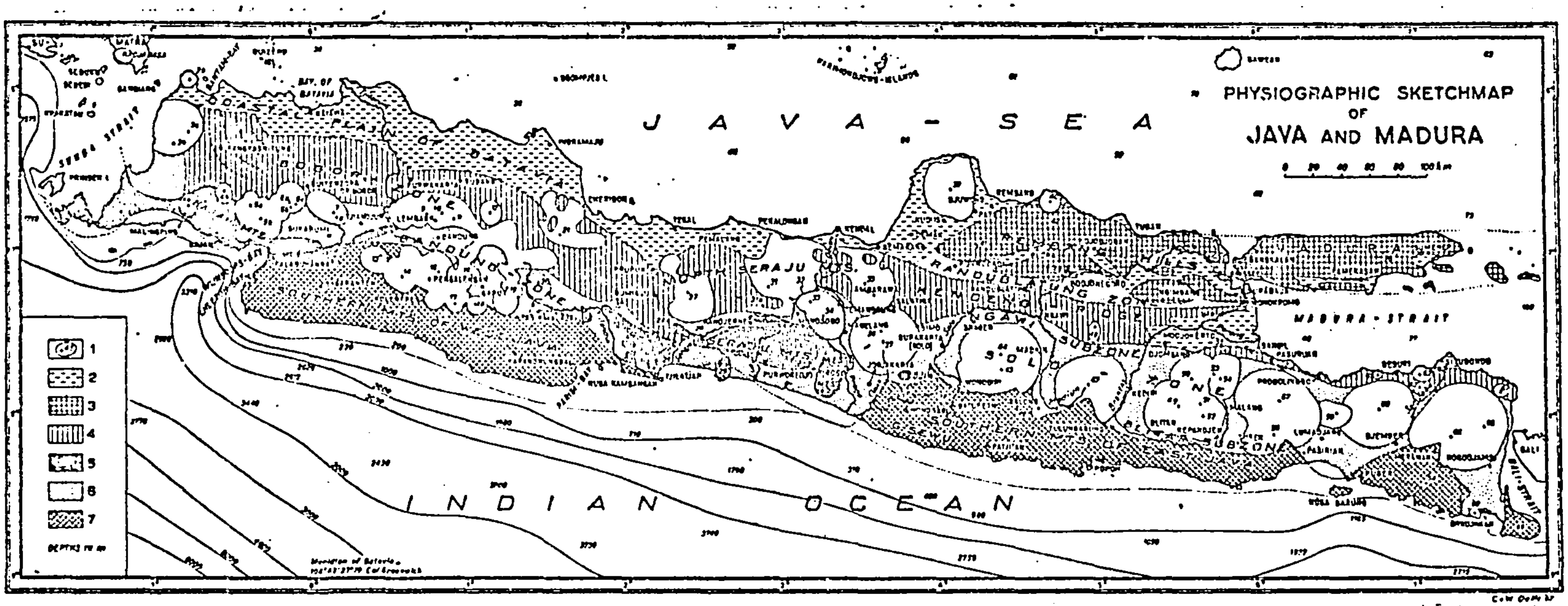


Figure 4. Physiographic Sketchmap of Java and Madura according to R. W. van Bemmelen (1949). LEGEND: 1. Quarternary volcanoes. 2. Alluvial plains of northern Java. 3. Rembang-Madura anticlinorium. 4. Bogor, North Serayu, and Kendeng anticlinorium. 5. Domes and ridges in the central depression zone. 6. Central depression zone of Java, and Randublatung Zone. 7. Southern Mountains.

interrupted only in some places by river valleys which run across from the mountains down to the Java Sea. Mud flows from the mountains form low ridges only several meters high on the broad alluvial river valleys. The low ridges provide ideal locations for villages with their associated pekarangan, while the alluvial plain supports irrigated wet rice fields.

The coastal plain is about 1 to 10 meters above the sea, and is separated from the Java Sea by young, low sand ridges which rise a little above sea level. Along the whole length of the coastal plain are found marshes or fish ponds where mainly white fish, bandeng, are cultivated.

In the Bogor Zone, south of Jakarta, a large gap is found through which volcanic materials derived from Mount Salak and Mount Gede-Pangrango, flowed and spread out in an enormous fan, to reach northwards almost to Jakarta (see Figure 5). This great fan is dissected by a system of broad and very shallow valleys, which also spread fan-wise. These valleys may have been formed immediately after the deposit of the uppermost layers. This alluvial fan provided material for the rapid growth of deltas on both sides of Jakarta, thus forming Jakarta Bay.

In the west, the peneplain of Banten (see Figure 6) slopes down under the coastal plain and is observed in some places as tertiary outcrops. The peneplain is believed to continue into the Java Sea, covered by young sediments near the coast. The entire northwestern end of Java is occupied by this undulating, monotonous peneplain. In contrast with most parts of Java the land here is infertile because upon exposure to weathering the rhyolitic Banten tuffs produce only poor soil.

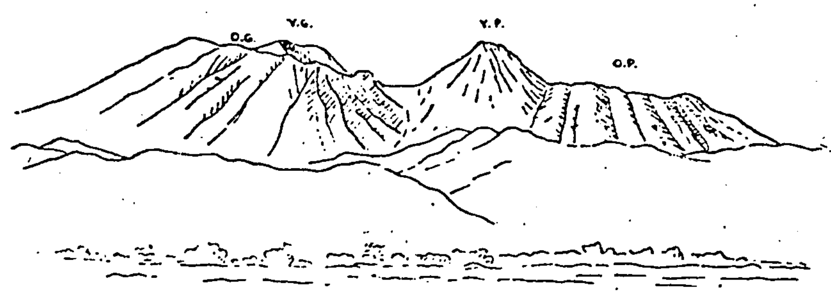


Figure 5. Gede Group from the Northeast.
After Pannekoek.

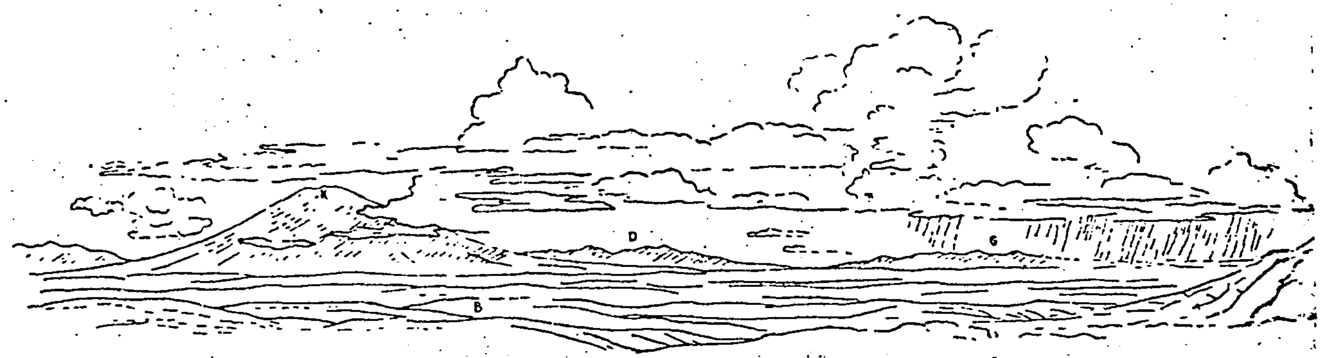


Figure 6. Banten Peneplain (B) seen from the southeast, with Karang volcano (K) and old volcanoes (D) surrounding the Danau caldera. In the right background, old Gede volcano (G) on the northernmost peninsula of Java; in the right foreground, flat-topped Cibugis andesite mass (T).

In the eastern part of the Northern Plains, the volcanic deposits of Cereme have overflowed the main part of the underlying folded rocks and have spread out freely over the coastal plain almost reaching the sea at Cirebon, where they form the eastern boundary of the plain.

The Landscape

The Northern Plains of West Java, bordered on the north by the Java Sea, consist of a series of coalescing alluvial fans and flood plains built up by river systems. Among these river systems the biggest are the Citarum and the Cimanuk Rivers, which have made the main contribution to the present north coast landform of West Java. In the west, the plains border the volcanic flows of Gunung Karang which reach almost to the coast, while in the east the border is distinctly defined by the volcanic deposits of Cereme near Cirebon. Though the whole plain is usually described as monotonously flat, lower than 100 meters above sea level, differences in relief exist (see Figure 6). The land becomes progressively more undulating and hilly towards the south, to the more rugged land at the foot of the mountain chain which stretches eastward.

In the train from Jakarta to Cirebon, a distance of some 250 kilometers, from west to east, the traveller sweeps through endless green seas of young paddy or through an expanded golden sheet of ripening paddy or through vast expanses of light brown fallow according to the season. In certain places on both sides of the track small, low hills can be observed in the middle of the sawah. These are remnants of termite mounds, which suggest that the area was formerly a forested marsh land in which termites had raised their mounds above the water level. The track runs past sugar plantations and further east, in the proximity of Cirebon, nears the coast where fish ponds or surface salt mining are found. One has the impression of travelling over an extremely flat land, indicative of its flood plain-alluvial fan origin; only the low beach ridges, river levees, and termite hills form the visible relief.

Driving by car over the same route will produce a different experience. The road is smooth asphalt-paved, running through more varied landscapes of technically irrigated sawah, of tegalan, of sugarcane, of red lands with wide shallow holes and low sheds to cover the newly baked bricks in Lemah Abang, and of villages nearly hidden by greenery on relatively higher lands. Though the general impression of the terrain is one of flatness, in some places it seems definitely to be undulating, apparently resulting from the slight folding in the Tertiary.

## Drainage Pattern

The whole Northern Plain stretching from Serang to Cirebon can be considered as one lowland unity which is potentially one integrated irrigation system. The streams, originating from the mountain complex described earlier, run through the broad plain and may easily be connected with each other by means of hydraulic construction works such as dams, waduk, and canals. The principal streams are the Ciujung, Cidurian, Cisedane, Ciliwung, Kali Bekasi, Cibeet, Citarum, Cipunegara, and the Cimanuk (see Figure 1).

In the west, from the mountainous complex in the northern part of Banten, which is geomorphologically part of the Central Zone of Java, rise the Ciujung and Cidurian Rivers, with catchment areas of 1,447 and 313 square kilometers respectively. It is expected that they will supply irrigation for 24,487 hectares of sawah, which at the present time receive their water mainly from the Ciujung. The Cidurian's discharge fluctuates heavily, resulting usually in a very low waterstand in the east monsoon which is insufficient to produce a gadu crop.

To the east the Cisedane with a catchment area of 1,215 square kilometers and the Ciliwung with a watershed of 475 square kilometers flow down over the Mount Salak-Gede fan through Bogor and Jakarta among some 60,178 hectares of sawah which would allow double-cropping of rice when water is available in both seasons. However, until recently because of the poor condition of the catchment areas resulting from the destruction of the forest system on the mountain slopes, the discharges in east monsoons have been so low that in many parts of the fields paddy planting has been impossible. The Cisedane debouches in the Java Sea, west of Jakarta forming the delta cape, Tanjungpasir.

Further to the east are the Kali Bekasi and the Citarum River. The Citarum is the third biggest river in Java after Bengawan Solo in Central and East Java and Kali Brantas in East Java. Its source is in the Ranca Gede Mountain, east of Gunung Wayang, on the highlands of Lodaya, in the volcanic mountain complex of Priangan. It flows alternately north and west through the Bandung basin, which was formerly a lake, and breaks through the border mountain chain near Saguling. Then it continues mainly northwards, meets the tributary Cisokan, and cuts again the mountain mass between Sanggabuwana and Burangrang. After receiving the tributary Cisomang, it flows through rough terrain rather sparsely populated and relatively inaccessible because it borders private plantation land, the Tegalwaru. For the third time, it slices a mountain barrier, the southern ridge of the Tegalwaru hill land, debouching onto the Northern Plains of West Java near Purwakarta. After joining with the Cikao tributary, it is dammed in Walahar to elevate its water level for irrigation purposes. Finally, after confluence with the Cibeet, it reaches the shallow Java Sea where a complex of deltas known as Tanjung Karawang, have been formed from alluvial deposits, which provide fertile soils for sawah.

Both Tanjungpasir in the west and Tanjung Karawang in the east grew relatively fast, forming Jakarta Bay in between and providing a good site for harbor development.

The Citarum River with its tributary system has a watershed area of 6,590 square kilometers including sawah fields of no less than 142,900 hectares. Dividing the Northern Plains in two almost equal west and east sections, it is the most important river system for the necessary irrigation applications. According to topographic data, the three locations in the mountain ridges where the river has broken through offer ideal conditions for building dams to create huge artificial lakes as water reservoirs. The total capacity of the three lakes is calculated above 5,000 million cubic meters. The biggest and the lowest dam was finished in 1967 and has been in operation under the Otorita Citarum[4] since May 1970 (see Figure 7).

The lowland areas presently under direct influence of the Citarum system consist of 142,900 hectares of sawah. However, when all the irrigation construction works including dams, water reservoirs, canals, and water pumps are completed in the integrated river basins of the

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[4]Otorita Citarum--Citarum River Authority.

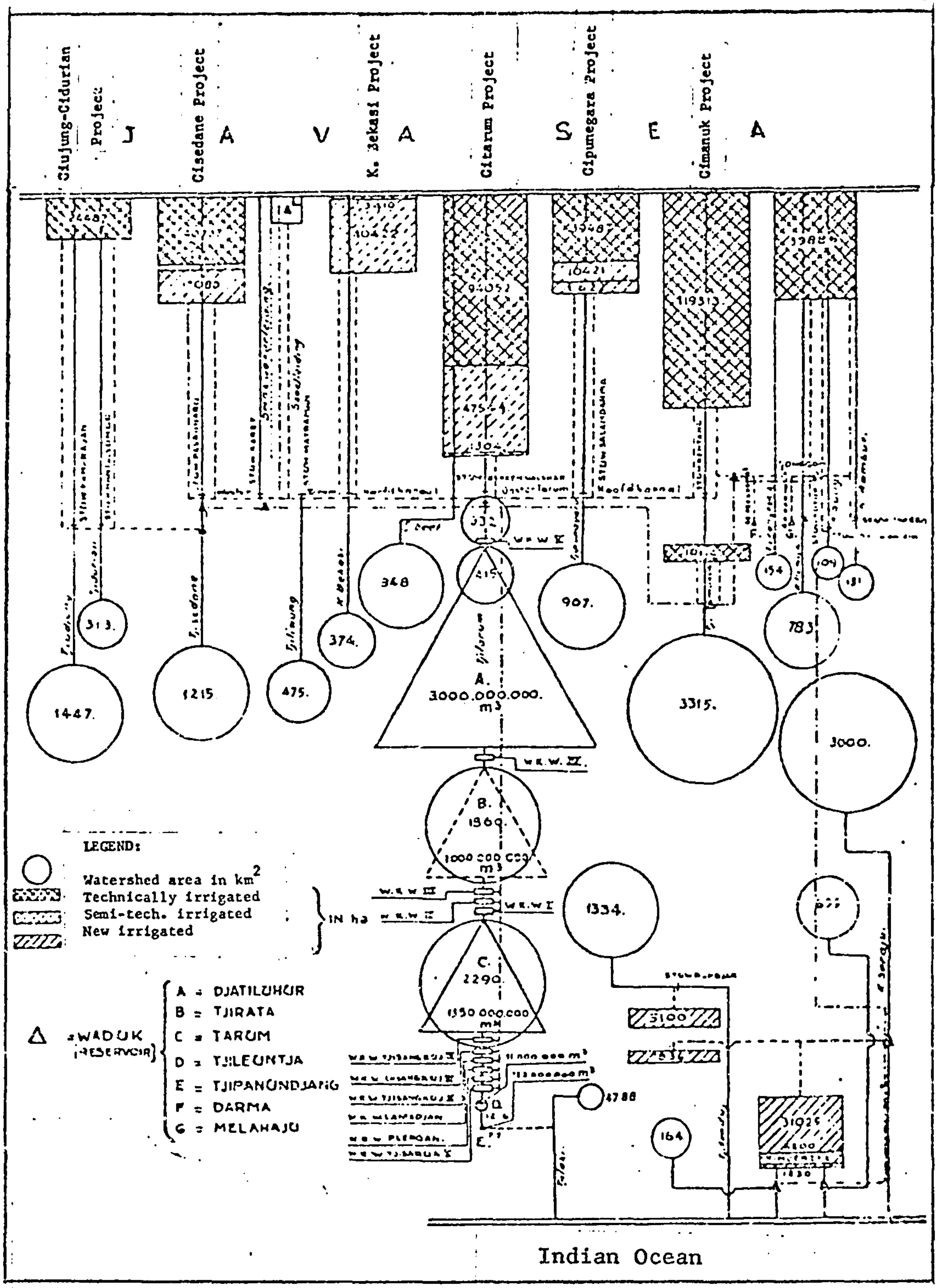


Figure 7. Irrigation Scheme in the Northern Plains of West Java. After van Blommestein (1949).

Northern Plains, the Citarum will be not only a water source for the sawah in its basin, but also is planned to alleviate the water shortages of the paddy fields in other river systems in the dry season, to provide the necessary water for industrial and harbor cities such as Jakarta and Cirebon, and to flush out the wastes of the big cities, especially Jakarta, to the sea.

To the east again lies the Cipunegara with a catchment area of 907 square kilometers. About 56,530 hectares of sawah are dependent on the water discharge of this river, but since it has large fluctuations not many rice crops can be expected from this area in the east monsoon.

The easternmost river in the Northern Plains of West Java is the Cimanuk which, with a watershed area of 3,315 square kilometers, forms the second biggest river in West Java. It rises on Mount Mandalagiri in the Southern Zone of Java in Garut, runs in a northeast direction through the Garut basin, and continues to the north through the rough mountainous area of the Central Zone of West Java. Descending near Pakumbahan to the Northern Plains of West Java, the Cimanuk leaves the rugged country behind, and reaches the shallow Java Sea to form a huge delta, the tanjung of Indramayu.

As the result of the long dry season typical of the Cirebon area, the east monsoon discharges of the main river, the Cimanuk, are very low, while the west monsoon discharges frequently arrive very late. This river system potentially has water resource capacity to irrigate about 139,427 hectares of sawah enabling double-cropping of rice or rotating of one season of rice and two seasons of polowijo.

SOILS

The geological map of Java and Madura, drawn by the Soil Research Institute of Bogor at a scale of 1:1 000 000 in 1971, shows that all the soils of the Plain of Batavia or the Northern Plains of West Java consist of alluvial deposits in the northern section with an average width of about 25 kilometers, stretching from Jakarta to Cirebon, and of about 10 kilometers between Jakarta and Banten. The southern part of the plains is described by Van Bemmelen (1949) as consisting of young volcanic material of quarternary age, brought down by rivers from the mountain areas to the south. Soepraptohardjo (1957) related the soil types in Indonesia to climatic conditions and included, for instance, Regur soils and Red Yellow Mediterranean soils in Tropical Rainforest Climate with marked dry season. In his Provisional Schematic Soil Map of Indonesia, he maintained that the whole area of the Northern Plains of West Java belongs in the soil category of Latosol and Red Yellow Podsolic Soils, built up by alluvial sedimentation (see Figure 8).

Many soils in the Tropics, including Indonesia, are red, brown, or yellow. They used to be given a variety of designations including Laterite-, Lateritic-, ferralitic-, fersiallitic-, ferral-, ferre-soil, latosol, Red and Yellow Podsolic-Red Mediterranean Soils (Mohr, Baren and Schuylenborgh, 1972), which resulted in confusion in tropical soil science terminology. Mohr, *et al*. suggested that the confusion was mainly based on the fact that many red soils are very old. Much can have occurred after uplift, or possibly accumulation of foreign material after a landslide, or there may have been a change in climatic conditions. All these factors complicate the mode of formation and the composition of

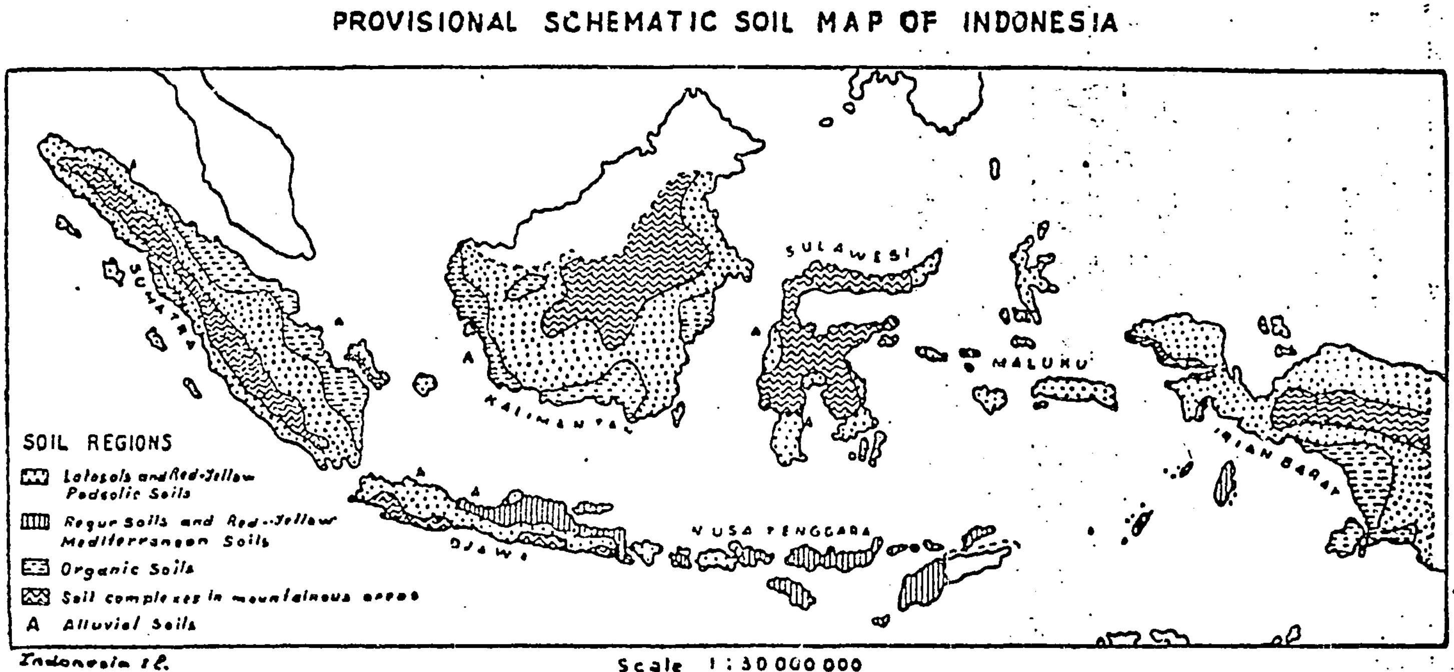


Figure 8. Provisional Schematic Soil Map of Indonesia. After M. Soepraptohardjo (1957).

the profile. Another cause of confusion was attributed to geologists who, being interested in raw materials for metallurgy, classified all formations rich in iron and aluminum as laterite.

Pendleton (1947) and Aubert (1954) have abandoned the use of the terms laterite, lateritic and laterization.[5] The United States Survey Staff has abandoned the terms ferrallitic, fersiallitic, latosol, etc., and proposed the name Oxisols for many of the red soils (7th Approximation Approach, 1960; Supplement 1967), and for some of the lateritic-, Red and Yellow Podsolic, and Mediterranean soils, Ultisols and Alfisols. Further, the dark grey and black soils of the tropics, which have received many names in the past including Black Cotton Soils, Regurs, Dark Clay, Grumusols etc., have been classified in the 7th Approximation as Vertisols, while the pale and white-colored soils, predominantly Podzols, as the Spodosols.

The Land Classification and Water Requirement Survey (starting in 1971) on the Rentang irrigation system in the lowland of the Cimanuk river, covering an area of about 91,000 hectares, reported that there are four great soil groups in the surveyed area, namely: (1) Alluvial soils, (2) Regosol, (3) Grumusol, and (4) Red Yellow Mediterranean Soils. These groups of soils will fall in the categories of Entisols, Vertisols, and Alfisols according to the 7th Approximation Approach.

Considering that almost the same conditions have contributed to soil formation throughout the Northern Plains of West Java, the conclusion can

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[5]Because these terms are still widely used in Indonesia, they will be used in this dissertation. The newer terminology is presented here for comparative purposes.

be drawn that the results of the soil survey in Rentang are representative of the whole plain in terms of soil types.

An important characteristic of the soils is swelling when wet and shrinking when dry up to 100 centimeters of depth, due to the presence of large amounts of montmorillonitic clay. In general, soil fertility is low, with contents varying from low to very low phosphorus, and medium to high potassium. Soil pH ranges from 5.0 to 7.0, but most of the soils have a pH lower than 5.5. All the soils are susceptible to erosion.

Zonal Soil

In the tropics, under abundant rainfall and high temperatures, weathering forces work faster and carry their influence to greater extremes. The coordinated weathering processes may result in a unique product of soil type, known as laterite.

Soluble bases in lateritic soils, such as calcium, magnesium, potassium, and sodium, are rapidly released and are subject to removal by leaching. In a low acidity condition, solubility of silica is encouraged, while that of iron, aluminum, and manganese is retarded. As weathering proceeds, a red or yellow soil material, high in sesquioxides and low in silica results. During laterization, oxidation and hydration of iron and aluminum occur intensively above the water table, giving a final product of red and yellow hydroxide clays containing no calcium or carbonate. In places where wet and dry seasons alternate, chemical activities also alternate between eluviation and precipitation of soluble bases.

Under flooded conditions, the concentration of iron ions in the soil may increase because of reduction to a toxic level. The level of iron in the soil solution is largely determined by the level of soil pH and the presence of readily decomposable organic matter. High iron concentration is associated with low pH and high organic matter content in the soil solution. When soils have a high phosphorus absorption coefficient, and especially when they are high in active aluminum, phosphorus deficiency tends to develop. If such soils have a large amount of organic matter, the iron content in the soil solution can be very high so that rice plants suffer from both phosphorus deficiency and iron toxicity. These disorders occur on soils formed from the early stages of laterization of basic rocks.

Iron concentrations are indicative of some translocation of the sesquioxides. In some places, between Karawang and Jakarta such as Lemah Abang, where drainage is restricted, soft deposits occur near the water table. The farmers cut them out in conveniently sized blocks, which harden when dry, for building material. After the subsoil layer is exposed long enough, the farmers can plant rice which usually produces a better crop. The hydroxide clays, as a result of intense laterization and thorough leaching processes, are very low in exchangeable bases. In general, they are extremely deficient in available nutrients. There is a disadvantage in the use of superphosphate because of this high content of sesquioxides. The iron and aluminum tend to render the phosphates of the fertilizer insoluble and unavailable to crops. Therefore, rock phosphate which is not readily affected, can be used to advantage. Typical laterite soils are moderately or strongly acid. They respond to lime as well as to commercial fertilizers.

In Java, the provenance of the sedimentary materials is from the big rivers, originating from recent volcanic areas. The mineral composition is in general favorable except for some places in the westernmost part of Java; the natural fertility, therefore, is high if they are not too old. The soils rank among the best latosols for agricultural production. Rice and sugarcane are the most important products.

Alluvial Soil

The fertility of alluvial soils depend on the basic materials from which they are formed. Some of them are well supplied with plant nutrients and others are not. However, as a general rule, most of them along large streams are of mixed origin, and are moderately well supplied with plant nutrients. The main management problem of such soils is water control, including protection from flood, drainage, and irrigation in the dry season.

The coastal areas of the Northern Plains consist predominantly of delta soils and young river sediments. Marsh soils and coastal deposits play a very small role. The salient fact about lower or younger delta soils is the annual accretion of silt brought by floods and spread over the surface of the soil. These phenomena tend to maintain the soils in an immature but highly fertile condition, since the river silt originates from young volcanic basic material. This fact may explain why Javanese farmers formerly could produce reasonably fair rice crops for centuries without applying modern agricultural innovations.

Profile development is not observed in these young delta soils. Salinity seems fairly general in the seaward portions as most deltas.

CLIMATE

## Southeast Asia

Rainfall in Southeast Asia is determined by regional as well as local phenomena, the most important being: the movement of the equatorial low pressure belt, following the solar path; the occurrence of monsoons, created by the heating and cooling of large land masses; orographic lifting; diurnal heating of land area; and cyclone formation.

The onset of the southwest monsoon, originating in the south Indian Ocean, heralds the beginning of the rainy season in the Northern Hemisphere. The broad southwesterly stream of air flows almost continuously from May to September. The rainfall maximum generally occurs around September after the equatorial low pressure belt retreats from its most northerly position.

The northern winter high pressures over Siberia cause successive anti-cyclones, which in turn, produce a broad semi-permanent outflow of air over eastern Asia and Indonesia. Arrival of the northeast monsoon initiates the rainy season in all places exposed to the north between China and Java.

Generally, areas north of the equator have a rainy season between May and October with maxima around September. While the onset of the rainy season is gradual, its end is abrupt because of the retreat of the equatorial low pressure belt coupled with cooling of land masses. It is followed by a marked dry season.

In the equatorial zone between 10°N and the equator, a moderately heavy rainfall occurs with two peaks as the equatorial low pressure belt passes. These peaks generally occur around February and October. South of the equator, the rainy season begins about October and lasts until April or May. In these areas the arrival of the rainy season is later and quite sharply marked, depending on the proximity to the Australian continent. The dry season is more pronounced, therefore, in the eastern part of Indonesia as compared with the northwestern part, since the rain carrying monsoon winds blow from the northwest.

Cyclones occur only poleward of 7°N and 7°S, mostly during late summer and over tropical oceans. The regions commonly affected by cyclones within Southeast Asia are the northern part of the Philippines (Luzon), the eastern part of South Vietnam and the western coast of Burma.

Orographic rainfall generally occurs when hot humid air ascends over mountain peaks. Heavy convectional rainfall is often observed in the afternoon and is, for example, very common in Bogor (Indonesia) throughout the year.

Indonesia

The most popular and frequently used terms to indicate the climatic type of Indonesia are "tropical climate" and "monsoon climate." The main conditions which determine the climatic features of Indonesia are its location astride the equator, and the fact that it consists of thousands of islands situated geographically in a vast ocean between the Austral-Asiatic continents. The dominating climatic factor in Southeast Asia is the monsoon, the southwest monsoon in summer and the northeast monsoon in winter. However, compared with monsoons elsewhere in Southeast Asia, the monsoonal pattern in Indonesia is quite different, indeed almost the reverse in terms of rainfall distribution. While in other Southeast

Asian countries the summer monsoon is the rainy season, in Indonesia the summer monsoon usually brings clear weather, and is the dry season.

In light of the general circulation of the atmosphere, monsoon and tropical climates are not mutually exclusive terms, since the monsoon climate can be considered as part of the general air circulation of the lower tropical latitudes.

In January an intense anticyclone exists over central Asia. As the strongest high pressure system in the world, it dominates the airflow pattern over Asia.

Schmidt-Ten Hoopen and Schmidt (1951) stated that the precipitation in Indonesia is much influenced by the air pressure over central China. They found a certain correlation between air pressure at Hongkong and rainfall in Indonesia. The pressure at Hongkong is considered to represent that of central China, since most probably the influence of southeast China dominates that of the other areas in Asia, and because of the fact that no complete data are available for central China. The resemblance between the type of pressure at Hongkong and most of the precipitation curves for Indonesia are striking. For example, as Schmidt-Ten Hoopen and Schmidt (1951) have observed, the high pressure period at Hongkong around the year 1900 corresponds almost exactly to the maximum rainfall over Java, while the low pressure from about 1920 and 1924 coincides well with the low rainfall over Java. Obviously, during the periods of high pressure at Hongkong, the northerly air masses penetrate quickly to the south and bring heavy rains over Java. During periods of low Hongkong pressure, the Intertropical Convergence Zone hardly reaches as far as Java and the abundant west monsoon showers fall near the equator.

Schmidt-Ten Hoopen and Schmidt are of the opinion that the rather heavy floods of the past decades seem to indicate that the precipitation over Java is still abundant, although there might be some effect from deforestation.

At the same time, low pressure, with a central intensity of less than 1,004 millibars, persists over Australia, with the trough extending along latitude 10°S from the Indian Ocean to northwest Australia. A secondary trough exists over northern Sumatra and northern Sulawesi. In the upper air the axis of the subtropical anticyclone stretches along 15°N latitude at about the 700 millibar level, sloping equatorward to 10°N latitude with increasing altitude. Broad circumpolar westerlies are largely confined to the north of 20°N, while upper easterlies prevail at lower latitudes. Temperatures are highest near the equator and decrease northwards in the troposphere. The tropical tropopause is highest near the equator and slopes down towards the north. This pattern of upper wind and temperatures persists from October to May.

The air pressure over Australia also seems to be a very useful element in predicting the various seasons in Java. The precipitation in West Java shows some correlation with the pressure at Darwin. The course of the annual totals of West Java's precipitation run almost parallel with the pressure at Darwin. However, of primary importance for the circulation over Indonesia is the air pressure over Asia.

Weakening of the Mongolian anticyclone commences in March and continues until it is completely obliterated in June. The heat low over northwest Australia persists in a weakened condition. The southern hemisphere equatorial trough shifts northwards and remains close to the equator, extending from central Kalimantan to Irian. A secondary trough lies over the Indian Ocean between the equator and 10°S. Thus, during the northern hemisphere's spring, two well-defined troughs exist, one in each hemisphere. South of 10°S, moderately strong easterlies occur. This flow pattern is called the equatorial bridge by Johnson and Morth (1960). In the case of the equatorial bridge, low pressure systems oppose one another across the equator, thereby producing equatorial westerlies.[6] (See Figure 9.)

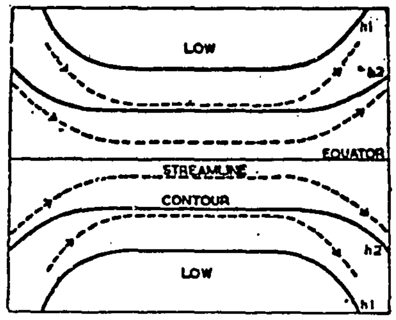


Figure 9. The Equatorial Bridge.
After Johnson and Morth (1960)

From June to September, an intense low persists over Pakistan and northwest India with an average pressure of 995 millibars. A weak secondary trough lies in the eastern Indian Ocean between the equator and 5°S, while an anticyclone dominates the northern Pacific Ocean. In the upper air, a broad belt of easterlies sweeps from the Philippines to the eastern Atlantic, with an easterly jet stream embedded in the current at about 15°N, centered over South India. Thus near the equator, high-level easterlies are found throughout the year.

By October, the Mongolian anticyclone has already developed. The equatorial trough shifts to the south, extending from southern peninsular

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[6] D. H. Johnson and H. T. Morth, "Forecasting Research in East Africa," in Tropical Meteorology in Africa, ed. D. J. Bargman (Nairobi: Munitalp Foundation, 1960), pp. 56-137.

India to the South China Sea, along 10°N latitude. The seasonal low over northwest Australia is well established and a secondary trough stretches between the equator and 10°S. In October, pressure gradients are weak in the equatorial region and stronger poleward.

Yoshino (1971) stated that the summer rainy season, Bai-u or Mai-yu, over East Asia is caused by the southerly flow originating from the easterly flow in Indonesia converging with the southwesterly flow in Southeast Asia. This means that low pressure in East Asia coincides with the dry season in Indonesia. The monsoon is not steady during the transition months of April and November. Schmidt and Van der Vecht (1952) found that there are two distinct transition periods between the wet and dry seasons in Indonesia. During the transitional season the weather is determined largely by the activity of the equatorial trough. In April and May, the equatorial trough of the southern hemisphere shifts northwards from its southernmost position and comes close to the equator. Therefore, the zone of convergence between the trade winds of the two hemispheres clashing towards the equatorial trough becomes narrower than at other times of the year and leads to convective activity. The lines of confluence fluctuate and shift position, often erratically, in tune with the strengthening and weakening of the clashing tradewind circulations.

In the spring transitional (March-April) season, the surface winds are light and showery weather associated with the activity of the equatorial trough or due to thermal convective thunderstorms is as high as fifteen per month. During the autumn transition the equatorial trough is relatively more active than in spring. Consequently this is a season of maximum rainfall in many stations. The monthly rainfall pattern shows two maxima during the transition periods and two minima during the two monsoon seasons. The higher maximum is in autumn. Thus, for Indonesia, the equatorial trough plays an important role.

The climate is significantly modified by the topography. On the high plateau, the climate is cool and bracing. The temperatures decrease at a rate of about 1°C per 100 meters. Rough terrain as an important factor in inducing thunderstorms is illustrated by the fact that Bogor, in the mountains in West Java, has recorded a very high frequency of thunderstorms and is thought to hold the world record of 322 thunderstorm days. However, recent data indicate that there are slightly less than ninety thunderstorm days a year.

In general, almost everywhere in Indonesia, the driest period covers the months of July, August, and September, the so-called east monsoon. This is a relatively dry season as this area comes under a dry and divergent wind regime in the lower troposphere.

Climate of Java

On the whole, the year can be divided into two main wind regimes, the west monsoon and the east monsoon, with two short intervening periods (April-May and October). Although generally termed west and east monsoons, the prevailing windflow comes from a northwesterly direction during the wet season from December to March (Braak, 1921), while the southeast windflow occurs from July to September during the dry season. The distinction between the dry season and wet season is most pronounced in East Java and parts of central Java which are practically dry during several months. The distinction is less in west Java, though still easily recognized.

In the following two months, October and November, the rainfall gradually increases to a high level in December. Usually, this level of rainfall is maintained during the following three months of January, February and March, or the West monsoon. This transition period to the wet season is called by the Javanese "labuh," which means the rain is coming.

The transition from the wet season to the real dry season, July to September, covers three months, April, May, and June. Here the slope of the rainfall curve is less steep than in the transition period after the dry season. This transition period is called by the Javanese farmers "mareng" (becoming dry).

The four distinct seasons in Indonesia identified by Schmidt and Van der Vecht are in accordance with the Javanese traditional seasonal periods: "rendeng, mareng, ketigo and labuh" (wet season, transition period to the dry season, dry season and transition period to the wet season).

Generally speaking, it is true that the dry season increases in intensity from west to the east in Java. Apparently this is due to the influence of the Australian thermal high during the winter of the southern hemisphere. Much variation in the duration of the dry season and intensity of drought are observed; in some years the driest months occur much earlier in the year than in others. These differences are of major importance for biological and agricultural studies.

During the rainy season, Java lies on the northern side of the equatorial trough developed in the southern hemisphere summer. The bulk of the precipitation and considerable weather changes result from the confluence of warm, humid low-level westerlies which occurs when air from the northern hemisphere penetrates the southern hemisphere and withdraws again. While evidence exists that the position of the Intertropical Convergence Zone affects the rate of rainfall in Jakarta, it is not possible to give the exact mean positions of the Intertropical Convergence Zone for all months of the year, as synoptic meteorology was developed in Indonesia only recently. Schmidt and Van der Vecht, however, were able to draw the positions of the line separating the northerly and southerly winds. These lines might perhaps not coincide exactly with the Intertropical Convergence Zone, but without doubt, they are of great importance in connection with the rate of rainfall.

The Intertropical Convergence Zone has many manifestations. When the opposing trade winds are weak it is very difficult to identify the location of the convergence zone as virtually no weather activity or clouds can be observed along it. With the increasing intensity in the weather activity, scattered alto-cumulus clouds gradually grow into veritable masses of cumulonimbus, possibly towering into the upper troposphere and are often associated with violent turbulence and heavy rains. Sometimes, there may be two separate convergence zones with clear weather in between. When convergence is strong, the resulting large-scale vertical motion of a highly humid and unstable air mass along the entire narrow zone produces long lines of heavy cumulo-nimbus formations causing violent thunderstorms and heavy rainfall. When the trade wind regimes are weak, the weather is generally sultry with light winds or calms and often oppressive. The local land and sea breezes then become dominant and convective activity is common in the afternoon.

From the climatological wind data taken from a publication by Boerema (1926), Schmidt-Ten Hoopen and Schmidt (1951) concluded that the Intertropical Convergence Zone in some years can penetrate far to the south and for quite a long period, while in other years it remains stationary over the Java Sea, or returns northward shortly after reaching Java. When the Intertropical Convergence Zone penetrates far to the south, heavy rains in the daytime may be expected over Java; if the Intertropical Convergence Zone remains over the island for a long time there will be many heavy rains.

For the purpose of relating the monsoons to agriculture, it is imperative to know the characteristics of the dry season. Berlage (1927) discovered that rainfall in the east monsoon depended to a considerable extent on the pressure over Java. He also tried to distinguish the difference between an early and a late dry period by considering the strength of the easterly wind during the preceding dry season, but he was not successful. De Boer (1947) investigated the possibility of forecasting the beginning and the end of the dry season in Java and Madura. He considered the dry monsoon begun at the time when the rainfall became less than 50 millimeters per ten days, and ended at a time when the rain began to exceed 50 millimeters. Schmidt and Van der Vecht (1952) introduced a new criterion for characterizing the beginning and the end of the dry season, and also to indicate the intensity of drought during the driest months for any place where rainfall data are available.

The precipitation in the transition period between the driest month and the wet season is certainly very important for agriculture. From an agricultural point of view the most meaningful effect of the rains falling in this period is that they contribute to the gradual moistening of the soil after it has more or less completely dried out during the east monsoon. The stimulating effect on plant growth of this change in soil conditions may become apparent much earlier in some years than in others. For West Java, Schmidt and Van der Vecht put the first of September as the beginning of the transition period to the wet season, since periods of continuous and severe drought after that date are very infrequent. A level of 350 millimeters rainfall is taken as a suitable criterion to indicate the end of the transition period. For the starting point of the driest period the first of July is taken. The choice of 350 millimeters criterion is based mainly on its association with rice culture. When this amount of rain has fallen after August 31, the soil generally is sufficiently moistened to allow farmers to prepare the seed beds for the wet season rice crop.

In the dry season of 1976, precipitation was below the average rainfall of the dry seasons over the ten year period from 1961 to 1970[7] while the west monsoon rainfall was normal. In the period from December 1975 to January 1976 a tropical cyclone was observed. In general, about four tropical cyclones occur in every twenty years in Indonesia. However,

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[7]Institute of Meteorology and Geophysics, Jakarta. An issue in KOMPAS, September 9, 1976.

in the beginning of 1976, seven tropical cyclones were already recorded, one of which was "Venessa" which occurred in January 20, 1976, passing over the island of Java. The cyclone drew enormous amounts of moist air from above the Pacific Ocean producing heavy rains over Java.

## AGRICULTURE

### General Pattern

Van Blommestein (1949) estimated that from the total area of Java and Madura, i.e., 13,217,400 hectares, more than 8,000,000 hectares were devoted to farming and fishery; almost 1,000,000 hectares to plantations, and 3,000,000 hectares to government forestry.

From the 8,000,000 hectares of farming and fishery, 3,400,000 hectares or about 42.7 percent, were used for sawah, and 3,000,000 hectares for dry land culture of various crops. The figures of van Blommestein may still be used but only to get an approximate idea of the present agricultural land use pattern. Since the Japanese period, Indonesia has experienced many changes in agricultural policy and activities. In some areas, such as Tegalwaru and Cirebon, the plantations have been converted to peasant agriculture. Government forests on the mountain slopes have been cut and transformed into ladang. Considering all of these changes, a conservative estimate of the area used for agriculture in Java at the present time would be not less than 85 percent of the total area. The remaining 15 percent is still covered with forest. Considering the steep mountainous topography of Java, the lack of forest cover is conducive to erosion and soil degradation. Moreover, much of the remaining forest is in bad condition. Over extensive areas of sloping terrain, where primary forests were once found, the plant cover has been changed into secondary forest, scrub, alang-alang fields or tegalan. Official statements by agricultural administrators indicated that the forest in Java in 1962 covered 23 percent of the total area. However, this number had dropped to 15 percent in 1972.[8]

Otto Sumarwoto (1976) found from Satellite ERTS photo interpretation that the forests along the watersheds of the Citarum River system cover even less than 15 percent, that is 11.8 percent of the catchment area.[9] Although it is not possible to determine quantitatively that the forest condition found in the Citarum area exists in other river catchments above the Northern Plains of West Java, the author has a strong belief that such is true at the present time.

Sutami (1972) warned that Java is in danger of becoming a desert if the current afforestation program fails.[10] He believes that the only means of preserving agricultural resources, of solving erosion and flood control problems, and problems of supply of irrigation water deficits caused by earlier clearing of forest is to ensure that 30 percent of Java's land on the mountain slopes is covered with forest.

Accurate data for agricultural patterns of the Northern Plains as a unit are not available. However, tables of land use of some major areas in the Northern Plains where irrigation systems have been constructed can be presented to provide some ideas for the general agricultural pattern of the whole area.

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[8]New York Times, March 26, 1972.

[9]KOMPAS, June 30, 1976 [10]New York Times, March 26, 1972.

The Cisedane irrigation system covers an area of 67,000 hectares, which consists of 40,133 hectares of sawah, 23,000 hectares of tegelan (secondary crops), and 3,867 hectares of grassland, forests, roads, canal systems, and villages. Table 2 shows the pattern of crop rotation in the Cisedane area. It is apparent that in the dry season, 61.6 percent of the sawah and 25 percent of the tegalan is not cultivated.

In studying sawah several important distinctions should be made: (1) sawah under technical irrigation which means enough water is available in the systems to provide water for the gadu rice crop in the east monsoon; (2) sawah with semi-technical irrigation where water is secured in the wet, west monsoon by means of irrigation, but only occasionally in the dry, east monsoon; (3) sawah which depend solely on rainfall to produce rice, the so-called sawah tadah hujan, and (4) sawah with poor drainage systems which give only very poor yields in the rainy season.

The Jatiluhur Project in the Citarum River basin covers 240,000 hectares of which 117,000 hectares are technically irrigated sawah, 101,200 hectares are semi-technically irrigated, 8,100 hectares are non-irrigated in the drainage area, and 13,700 hectares of sawah tadah hujan. Tables 3, 4 and 5 present area and production of rice fields, area and type of plantation, and forest condition in the Jatiluhur irrigation project, respectively, when the Jatiluhur Project was still under construction. Based on these three tables a rough estimate can be made of land use in the three districts of Bekasi, Karawang, and Purwakarta. In 1965, the rice fields covered 286,134 hectares, plantations 34,146 hectares, and forests 117,017 hectares. The figure for forest lands is rather high, because it includes bare lands which are located in the producing forests. Recent data for this area since the irrigation project has been completed could not be obtained.

Table 2

Crop Rotation in Cisedane Area

| Crop type | Wet season cultivated area (ha) | percent | Dry season cultivated area (ha) | percent | Total (ha) cultivated area (ha) | percent |
|---|---|---|---|---|---|---|
| Sawah: | | | | | | |
| rice | 40,759 | 100 | 15,100 | 37 | 55,859 | 137 |
| corn | - | - | 200 | 0.5 | 200 | 0.5 |
| peanuts | - | - | 250 | 0.6 | 250 | 0.6 |
| tuber | - | - | 100 | 0.2 | 100 | 0.2 |
| vegetable | - | - | 50 | 0.1 | 50 | 0.1 |
| Total | 40,759 | 100 | 15,700 | 38.4 | 56,459 | 138.4 |
| not cultivated | - | - | 25,059 | 61.6 | - | - |
| | 40,759 | 100 | 40,759 | 100 | | |
| Tegalan: | | | | | | |
| trop. vegetable | 1,130 | 5 | 2,260 | 10 | 3,390 | 15 |
| sweet potato | 3,390 | 15 | - | - | 3,390 | 15 |
| corn | 1,130 | 5 | - | - | 1,130 | 5 |
| peanuts | 1,130 | 5 | - | - | 1,130 | 5 |
| perennial | 9,030 | 40 | 9,030 | 40 | 18,060 | 80 |
| other crops | 6,770 | 30 | 5,645 | 25 | 12,415 | 55 |
| Total | 22,580 | 100 | 16,935 | 75 | 39,515 | 175 |
| not cultivated | - | | 5,645 | 25 | | |
| | 22,580 | 100 | 22,580 | 100 | | |

Source: Report of the Hanza Engineering Company International 1974. Djaringan Irigati Cisedane.

Table 3

Area and Production of Rice in the Jatiluhur Project (1961-1965)

| Year | Bekasi | | Karawang | | Purwakarta | |
|---|---|---|---|---|---|---|
| | Area (ha) | Prod. (ton) | Area (ha) | Prod. (ton) | Area (ha) | Prod. (ton) |
| 1961 | 78,598 | 263,389 | 144,658 | 422,677 | 102,325 | 357,675 |
| 1962 | 74,568 | 194,723 | 138,649 | 431,595 | 97,225 | 285,597 |
| 1963 | 60,141 | 111,979 | 116,247 | 301,829 | 93,361 | 202,041 |
| 1964 | 68,730 | 158,418 | 142,666 | 356,326 | 102,214 | 322,125 |
| 1965 | 69,404 | 183,806 | 112,798 | 478,212 | 103,932 | 317,760 |
| Ave. | 70,288 | 183,806 | 133,007 | 398,125 | 99,811 | 297,039 |

Source: Djawatan Pertanian DT II 1965 (District Agricultural Service).

Table 4

Type and Area of Plantation in the Jatiluhur Project (1965)

| | Bekasi | Karawang | Purwakarta |
|---|---|---|---|
| | ha | ha | ha |
| State Plant (P.P.N.) | - | 326 | 32,560 |
| Private Plant | - | - | 2,000 |
| People Plant | 1,010 | - | 250 |
| Total | 1,010 | 326 | 34,810 |

Source: Land Use Inspection West Java 1966.

Table 5

Forest Condition in the Jatiluhur Project
(1963-1965)

| Year | Producing Forest | Conservation Forest | Total |
|---|---|---|---|
| | ha | ha | ha |
| 1963 | 43,306.65 | 15,310 | 58,617.35 |
| 1964 | 42,203.50 | 14,113 | 56,316.50 |
| 1965 | 46,053.00 | 12,456 | 58,508.00 |

Source: Forestry Service West Java 1966. (These numbers include bare lands which are located in the producing forest.)

The Rentang irrigation project in the Cimanuk River covers an area of 91,000 hectares. Table 6 presents the percentage of lands suitable for the various categories of agricultural use.

## Agricultural Crops

The general rule in the Northern Plains is that whenever possible rice will be cultivated, preferably in *sawah* or wet paddy fields. For a Javanese farmer agriculture is rice cultivation. In places not accessible to irrigation, *sawah tadah hujan* are maintained, with rice grown during the rainy, west monsoon, and other *polowijo* (peanuts, corn, cassava, etc.) crops with lower water requirements produced in the dry, east monsoon.

Aside from the swampy coastal plains, which are either covered by marsh forests or converted into fish ponds, and slightly higher lands, which normally are occupied by villages or used for *tegalan*, paddy fields dominate the landscape in the Northern Plains of West Java.

The important parts of the Integrated Irrigation System, whereby the principal rivers, the Ciujung, Cidurian, Cisedane, Ciliwung, Citarum, Cipunegara, and Cimanuk were to be connected with each other by means of dams and canals, have been completed. Surplus water stored in the artificial lakes, especially Jatiluhur Lake, can be regulated and distributed to other places, where rice fields experience water shortages. Double-cropping is becoming the rule in the *sawah* located in the irrigation network.

Slightly elevated places are still occupied by villages, *tegalan*, and gardens. However, presently by means of water transported in buckets

Table 6

Available Land for Agriculture in the Rentang Project, by type

| Areal type | Percent | ha |
|---|---|---|
| Gross suitable for diversified crops | 93.6 | 85,176 |
| Unsuitable for crops | 6.2 | 5,642 |
| Nonirrigable on higher land | 0.2 | 182 |
| Total | 100 | 91,000 |
| Net suitable for diversified crops | 79.3 | 72,155 |

Source: Departemen Perkerjaan Umum dan Tenaga Distrik. Prosida Technical Paper Bulletin Report 1972.

suspended from bamboo shoulder carrying poles, these areas can receive additional water supply from the irrigation canals.

The swampy coastal strip is used for fish ponds, empang or tambak, where bandeng, a variety of white fish, is cultivated. In these fish ponds shrimp is a very important secondary crop.

Bowers (1973) estimated that in Karawang, 75 percent of the sawah are already double-cropped. The irrigation network is being extended continually through the digging of new tertiary canals to increase the hectarage of sawah suitable for production twice a year. The Jatiluhur and Curug Dams, with their enormous water storage capacity have allowed the extension of irrigation to other sawah belonging to other river irrigation systems which still have water shortages in the dry season.

It is expected that with the completion of the entire integrated irrigation network system, an adequate supply of water in the dry season can be secured, for the production of a gadu rice crop equal to or greater than that of wet season. Potentially, the gadu rice crop should produce higher yields than that of the wet season because of the better solar radiation conditions in the dry season. With less cloud cover, there is more incoming radiation.[11] Since there is less rain in the dry season, the water condition in the sawah can be controlled better, because the water deficit can be met by supply from reservoir storage waters through the canal systems. In addition, the frequency of pests and diseases is, as a rule, less in the dry season.

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[11]Jen-hu Chang, "Agricultural Potential of the Humid Tropics," Geographical Review, Vol. 58, No. 3, pp. 333-361.

However, in general, the *gadu* rice crop at the present time in West Java is still smaller than that of the wet season. High solar radiation appears to be associated with high yields only where water is not a limiting factor. Under these conditions plant evapotranspiration can increase in response to a high level of solar energy. But with an insufficient supply of water, high solar energy causes greater moisture stress in the plants. For areas receiving limited water in the dry season, therefore, higher yields can be expected when cloudy days are more frequent, and rainfall is above normal.

Moreover, in the Northern Plains, an assured water supply for the dry season is a relatively recent addition; the dry season rice planting is for many farmers still viewed as subsidiary cropping, *tanaman sambilan*, not as a major crop. Because of this attitude, the best agricultural practices are not applied. It often happens that the farmers only stamp the rice straw stubble into the mud with their feet and plant rice without spading or hoeing. The result, obviously is a low yield. This attitude, fortunately, is vanishing rapidly, in part the result of rice demonstration plots and the persuasions of the agricultural extension service through the farm leaders.

Local rice planted belongs to the Indica variety, which is relatively less responsive to solar radiation than the Japonica. The average time needed for the local rice, from planting to harvesting, is 125 days. New varieties introduced by the Institute of Agriculture in Bogor include wet rice varieties such as Bengawan, Sigadis, Syntha, Remaja, Jelita, Seratus Malam, Dewi-Ratih and Peta. Some of these varieties were taken to the International Rice Research Institute, crossed with other foreign rice varieties and brought back to Indonesia as high yielding rice varieties or padi unggul. Known as miracle rices, two of the first types were IR.5 and IR.8. IR.5 is the result of crossing Peta from Indonesia and Tangkai Rotan from Malaysia, while IR.8 from Peta and Dai-Geo-Woo-Gen from Taiwan. These new varieties, IR.5 and IR.8, were tried in Bogor, adapted to Indonesian conditions and given the names P.B.5 and P.B.8.[12] by the Institute of Agriculture in Bogor.

More new varieties, with higher yield, better taste and more resistance to disease have been introduced, i.e., Siampat (C 4), P.B.28, P.B.30, Pelita and Makmur. More recently, high yielding dry rice varieties (padi gogo), Cartina (from the Philippines), Gati, and Gata have also been tried. Gati and Gata can be planted in sawah as well as in ladang.

Padi unggul varieties require approximately 135 days to produce yields and are very responsive to fertilizer. Maximum yields are achieved only with a plentiful supply of water and the application of efficient fertilizers. When water is inadequate, taller and more vegetative varieties appear better able to conserve and make use of the available moisture. For the dry season a variety with shorter lifetime is selected, called padi Genjah which needs only 110 days to produce yield.

The chemical fertilizer urea has long been used by the farmers of West Java, and the agricultural extension workers continue to encourage its use. Compost and green manure are commonly and widely used. The

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[12]P.B. = Peta Baru.

quantity, however, is inadequate. Other new chemical fertilizers have been introduced including Fused Magnesium Phosphate (F.M.P.), Double Superphosphate (D.P.), and Triple Superphosphate (T.S.P.).

In the dry season, sawah tadah hujan, the unirrigated lands or tanah kering, and the sawah with semi-technical irrigation, too dry for sawah rice crops, are planted with a variety of secondary crops, known as polowijo, most commonly cassava, corn, various beans, and potatoes. Some places, having access to transportation or close to local markets, are devoted to vegetables such as cucumbers, tomatoes, chili peppers, and pecai, a kind of lettuce. These patches are normally located close to a supply of water, as along streams or irrigation canals, and water reservoirs. Water is carried suspended from a shoulder pole from the water source to the patches to irrigate the rows of vegetables.

In the coastal strips, the biggest problem is drainage. Small rivers emptying into the Java Sea have aggraded lower channels, blocking the flood waters in the rainy season, resulting in water overflowing the levees, spreading out across the lowlands, hampering rice growing. An additional obstacle for agriculture is that the ground water is saline; fresh water supply is hard to locate. In these coastal strips, empang or tambak, fish ponds for bandeng, are found, varying in size. They are separated by dikes; gates control the water levels, allowing drainage when the bandeng and udang or shrimp are to be harvested.

The most important constraints for agriculture in Indonesia are of agrometeorological origins. Almost every year, agricultural damages are reported, particularly those which are caused by floods and droughts. Crop losses created by floods and droughts are calculated at no less than those resulting from other agricultural hazards including pests and diseases such as hama sundep, tikus, walang sangit, wereng, and ulat tantra. Their disastrous effects can be far reaching and uncontrollable, not only destroying crops in sawah, but also damaging irrigation works, drainage systems, and transportation links.

In flood time, because of the unfavorable water conditions, farmers sometimes have to wait before they can start planting rice, which often results in crop failures, because the rice has to continue growing in the following dry season before it can be harvested. Also, this irregularity in the time schedule of rice planting favors the life cycle of pests and diseases.

In 1976, Java experienced an especially severe drought,[13] the effect of which was felt either directly or indirectly by all Indonesians because, first, around 70 percent of the population are farmers who suffer most, and secondly, Java is the actual rice producing island, while the other islands are in essence cash crop growers, and mainly depend on Java for food. Hence, a failure of food production on Java will affect much of the other islands' economy.

According to the meteorological records, the drought of 1976 was not as severe as that of 1972. One should expect that the devastation in 1976 should also not have caused as much suffering as in 1972. However, this is not so. Many water springs, rivers, and wells were dry for weeks. Sawah and tegalan were fallow; everywhere not a trace of moisture could be detected. The main factor responsible for this phenomenon was that the forest condition in 1976 was much poorer than that in 1972.

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[13] Kompas, September 9, 1976.

In February 1977, however, Java experienced exceptionally heavy rains, which caused high floods, even in places normally free from rising river waters during times of flood. The area around the National Monument in the center of the City in front of the Presidential Palace was flooded about one meter deep (see Figure 10). According to the Institute of Meteorology and Geophysics in Jakarta, this flood was the highest since 1892. A rain sample taken in Manggarai for ten hours indicated rainfall of 240 millimeters.[14]

## IRRIGATION

### History

The irrigation system in Java consists mainly of water reservoirs with related networks of detailed canal systems. It is, therefore, dependent on the existing river discharges, which, because of the heavy rainfall in the wet season, generally would be enough to provide the necessary water in the dry season to prevent cropping failure, provided about 30 percent of the land on the mountain slopes were covered by forest.[15] However, with degradation of the forest resulting from the encroachment of population, the hydrologic cycle becomes irregular and is not less beneficial for agriculture but even jeopardizes it.

Since before World War II, improvements in irrigation have been accomplished by the building of seven mountain reservoirs with a total capacity of 148 million cubic meters of water; five of these reservoirs were, for the main part, built for and financed by sugar plantations.

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[14] Kompas, January 20, 1977.

[15] New York Times, March 26, 1972.


Banjir Terbesar di Jakarta Sejak 1892

Figure 10. Flooded Central Section of Jakarta, the National Monument. After Kompas, 01/20/77.

There was no systematic regional development planning by which the poverty of the people could be alleviated by increasing their food production.

Van Blommestein (1949) presented the first plan for an integrated irrigation system for the Northern Plains of West Java, designed to end the yearly threat of water shortage during the east monsoon by making use of the water discharges of the existing river systems. The main water reservoirs were to be built in the Citarum. Many of the ideas presented in his design were taken into consideration by the present Indonesian government in its effort to develop the Northern Plains of West Java.

Irrigation Network

The main water source for the irrigation water supply system originates from the Jatiluhur reservoir, an artificial lake formed after a dam had been built in the Citarum River at the point where its valley narrows to about three quarters of a kilometer between walls of consolidated sandstone before debouching onto the extensive Northern Plains of West Java (see Figure 1). According to R. W. van Bemmelen (1949), local uplift during the Tertiary period rejuvenated the Citarum, allowing it to cut down its valley rapidly, though not as rapidly as the land rose, for there was a cataract before the dam was built. When completed, the dam backed up a huge lake covering an area of about 8,000 hectares and containing 3,000 million cubic meters of water which formerly would have spread out as runoff water flooding the lowlands. The stored water is designed partly to irrigate 240,000 hectares of paddy fields in the lowlands of Bekasi, Karawang, and Cikampek on the Northern Plains, areas formerly dry and bare during half of the year in the east monsoon. The irrigation project includes six diversion dams, and 144 kilometers of canals, twelve meters wide and three meters deep. The largest diversion dam, at Curug, is of primary importance in regulating the supply of water. From here the waters of the Citarum are distributed both west and east through main canals, each about twenty-two kilometers long, and a third canal distributes any water remaining to areas immediately northward. The main canal to the west extends to the Ciliwung River in the "Special Province" of Jakarta distributing irrigation water to 80,000 hectares of sawah from points along the main canals, such as at Cibeet, Ciherang, and Bekasi, where diversion dams have been constructed to allow for gravity flow.

The main canal to the east provides water to another 80,000 hectares of paddy fields through the diversion dams of Ciasem and Salam-Darma and extends further to the Cimanuk River. A third main canal ensures water to 80,000 hectares of rice fields in the northern regions. From these main canals spread secondary and tertiary canals, which intricately interlace the paddy fields, reaching areas located far from the main canals and forming a fine irrigation system network. Along the main canals, an inspection road has been built running from Jakarta to Jatiluhur and Cirebon.

Though the condition of the irrigation system is not entirely as projected, at the present time most of the irrigated sawah are no longer single-cropped; in many places, there is not only double-cropping of rice, but even the introduction of secondary crops or polowijo, such as sweet potatoes or peanuts, between the two rice crops.

The water supply from the Jatiluhur reservoir is connected to the Ciliwung near Jatinegara in Jakarta, from which point the water is then not only used for irrigation purposes but also partly to improve the water flushing system of the capital city. Still further to the west the Citarum surplus water is led to the Cisedane River. Because the Cisedane River level is higher than that of the canal, two electrical water pumps had to be built in Pasar Rebo to lift the Citarum water about seven meters to flow into the Cisedane River. This supply of water from the Citarum, needed in the dry season, ensures the double-cropping of rice in the Cisedane *sawah* of about 60,178 hectares. Finally, from the Cisedane River the water will be led further westward to the Cidurian River where it is projected to irrigate the low location *sawah* between *Kali* Angke and Cidurian, and to make the Cidurian water available for the paddy fields situated at higher levels which formerly depended solely on rainwater.

### Ciujung Irrigation System

The Ciujung irrigation network development was finished in 1918. The primary channels were projected initially to irrigate 24,000 hectares of *sawah*. However, since the beginning, the operational capacity was less than was expected, and it has experienced a steady decline until 1968, when the Government took steps to rehabilitate the irrigation system along with the implementation of the integrated irrigation system in the Northern Plains of West Java. The farmers were mobilized for the development as well as the maintenance of the irrigation network to obtain optimum results from the program.

The construction and the maintenance of the primary and secondary channels were the responsibility of the Public Works Office. The farmers, in cooperative organizations, were entrusted with the building, maintenance and operation of the tertiary canals and drainage system. With this policy, it was expected that the farmers would feel responsible for and better care for the tertiary canals and the drainage system; keeping them clean of water plants, such as enceng gondok, which hamper the water flow on one hand and speed up siltation on the other, and keeping their water buffaloes from the canals, the banks of which can be damaged badly by their trampling.

The rehabilitation of the Ciujung system was completed in 1973, but water supply from the Citarum water surplus was still needed in the dry season.

### Cisedane Irrigation System

The development of the Cisedane irrigation system started in 1930. The main diversion dam, Pasar Baru, near Tangarang, was finished in 1932, while the related canals and other irrigation works were completed just before World War II. After the War, from 1954 to 1966, the primary canal was expanded, including new secondary canals and other elements of the irrigation network system; the capacity of the Cisedane irrigation system has increased from 28,150 hectares before World War II, to about 40,000 hectares in 1966. However, based on the rainfall data compiled from 1943 to 1968, the annual rainfall in the Cisedane area varies from 968 millimeters to 2,820 millimeters, of which the average rainfall in the dry season is only 16 percent,[16] resulting in a very low river debit.

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[16]Jaringan Irigasi Cisedane. Feasibility Report. Hanza Engineering Company Internal, Consulting Engineers River Projects, 1969.

In 1968 and 1969, it was reported that the capacity of the Cisedane to water _sawah_ was only 14,400 hectares. Therefore, additional water supply from other river systems is needed and can be met by the Citarum water surplus.

Cimanuk Irrigation System

The irrigation system in the Rentang Project depends on the water source of the Cimanuk River, which is diverted by gravity flow through a diversion weir near the village Jatitujuh, in Majalengka, to irrigate _sawah_ in the districts of Indramayu, Cirebon, and Majalengka (see Figures 11 and 12). The development of the irrigation network was started in 1912 and was finished in 1916. From the Rentang dam, the Cimanuk stream is divided into two main channels, or primary canals, one of which is the Sindupraja canal flowing east to irrigate _sawah_ of about 56,000 hectares, while the other one is the Cipelang canal, flowing to the west through 35,000 hectares of _sawah_, distributing irrigation water especially needed in the dry season.

The whole Rentang Project covers an area of 91,000 hectares of technically irrigated _sawah_, 3,000 hectares of semi-technically irrigated fields and 2,000 hectares of non-technically irrigated lands.

Before World War II, and until the Japanese occupation, all of the 91,000 hectares of _sawah_ could depend regularly on the Cimanuk River for their water supply in the wet season. In the dry season, however, only 12,000 hectares of _sawah_ could be provided with water from the irrigation system.

From the time of the Japanese Occupation (1942-1945) until 1968, the Rentang irrigation condition has been declining. Only 15,000 hectares

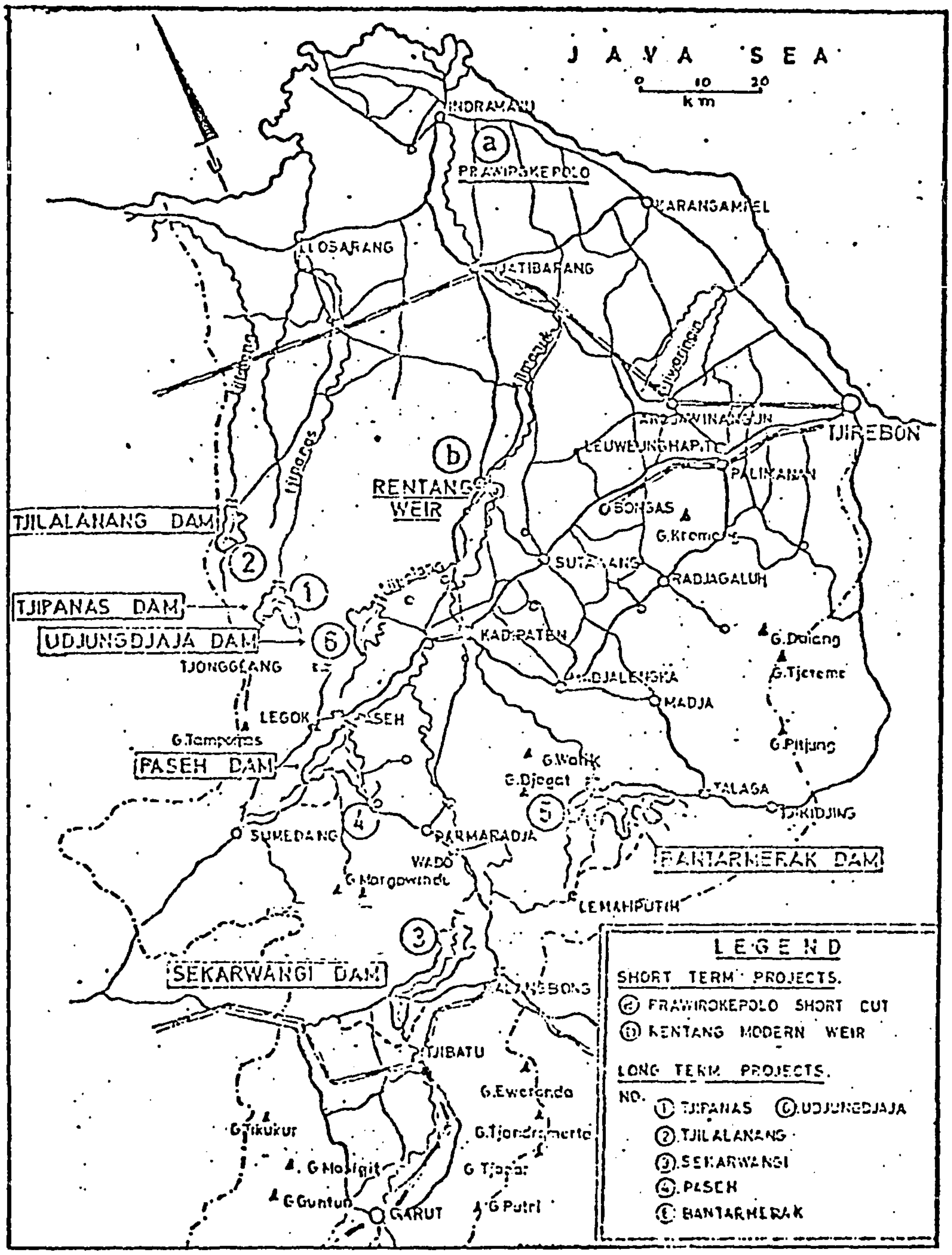



Figure 11. Cimanuk, Rentang Project.

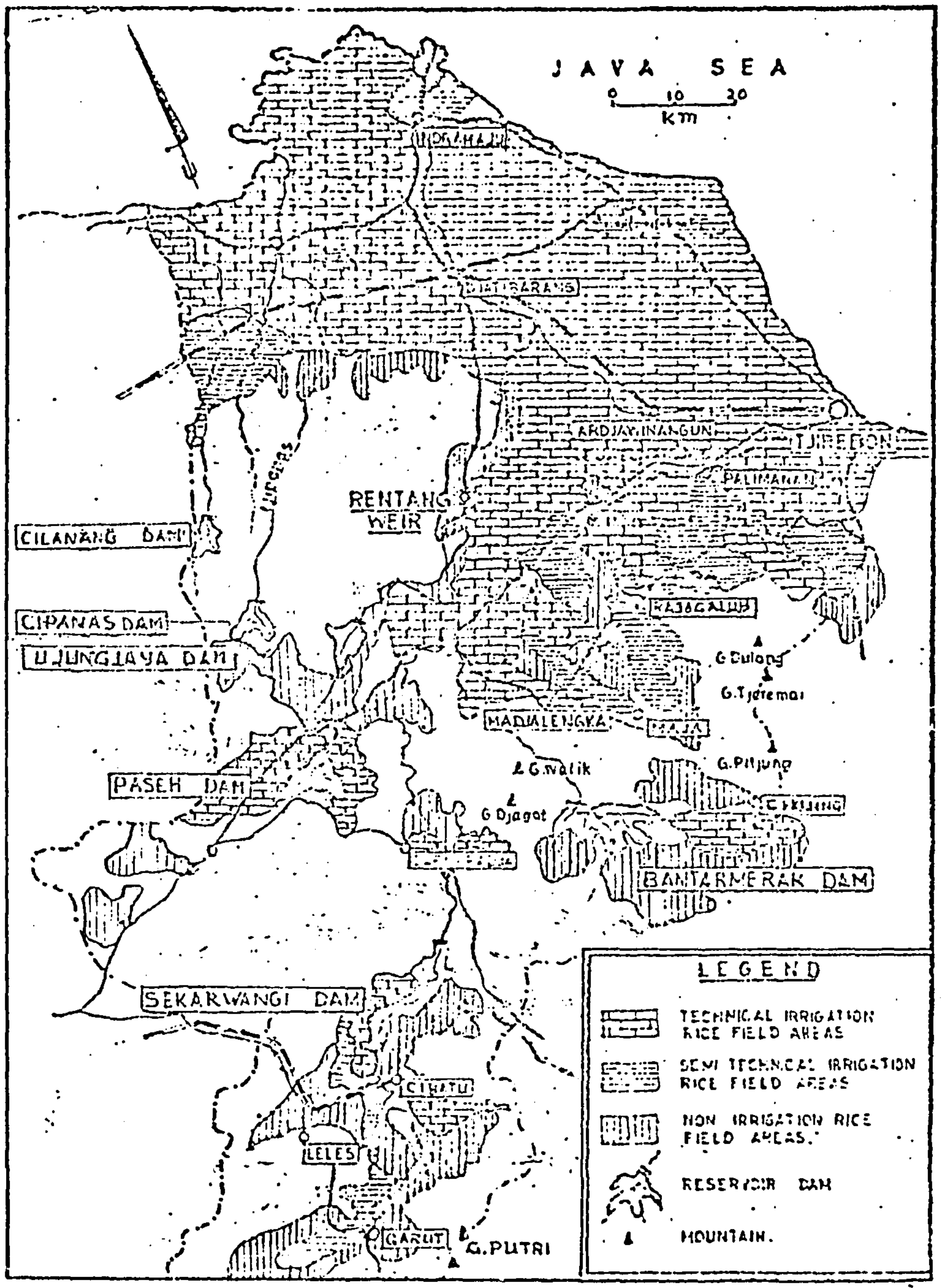



Figure 12. Cimanuk, Rentang Project, Sawah Areas.

of _sawah_ from the 91,000 formerly under technical irrigation could still receive water in the wet season from the irrigation system, while the rest became either semi-technically irrigated or _sawah tadah hujan_. Many factors were responsible for the decline of the Rentang irrigation system, among which the most important were: the soil deterioration in the area above the Rentang dam in the Cimanuk watershed, and destruction of the irrigation structures and canals.

In 1969, the rehabilitation of the Rentang irrigation system was started and it was integrated into the macro irrigation system in the Northern Plains of Java, so that when the rehabilitation was completed in 1973, the water shortage in the dry season could be supplied from the water surplus of the Citarum system.

Citarum Irrigation System

Potentially, three dams can be constructed at three sites on the Citarum River; respectively, from the source to the mouth, they are the Tarum, Cirata, and Jatiluhur Dams. The total volume of water that can be stored in the three artificial lakes which will be formed is about 5,276 million cubic meters. The _sawah_ in the Jatiluhur project cover an area of 142,900 hectares of which half is technically irrigated, and the other still to be developed by the project. However, this project includes the improvement of other smaller rivers on both sides of the Citarum such as Ciasem and Cibeet.

As far as possible the water necessary to bring the _sawah_ in the Citarum area to the status of technically irrigated will be supplied by river water from the Cibeet. Two factors make this arrangement desirable. First, flowing from higher elevations than the Cibeet, the Citarum can be tapped at higher levels and, by gravity flow, its waters distributed to other river systems which experience a deficit during the dry season. Secondly, since the Cibeet has no dam to trap the rich alluvial sediments carried in its waters, this silt will be added to the Citarum irrigation network to replenish its sawah. The Jatiluhur dam created the huge Jatiluhur lake which stores 3,000 million cubic meters of water. Much rich and fertile silt is being deposited in the lake. The former Office of Land Planning (Dienst van Landinrichting) estimated the rate of sedimentation in the Citarum River system at one millimeter per year. The lake of Jatiluhur thus receives about 4.5 million cubic meters of silt per year, for the catchment area above Jatiluhur is 4,505 square kilometers. To prevent malfunctioning of the Jatiluhur irrigation system as a result of siltation, another reservoir must be built to minimize the rate of sedimentation in the Jatiluhur lake. This will be Tarum lake above Bandung, which is planned especially for generating hydroelectric power, while Jatiluhur was intended for irrigation, even though at the present time it is also used to produce hydro-electric energy. The discharges which are released from the Jatiluhur dam fluctuate from 0 to 427 cubic meters per second during the 80 percent dry years. In the east monsoon period, the maximum water release for irrigation reaches a peak of electrical power when 380,000 horsepower can be produced.

The East Tarum canal begins at the Walahar water reservoir, runs to the east to the Cipunegara River via Salamdarma weir, and further via Rentang weir to the Cimanuk River.

The West Tarum goes from the Walahar via the Cibeet dam to Bekasi River and further west to the Ciliwung, Cisedane, Cidurian, and Ciujung rivers (see Figure 1).

# CHAPTER III

# METHODOLOGY AND SOURCE OF DATA

## HISTORICAL DEVELOPMENT OF EVAPORATION RESEARCH PRIOR TO WORLD WAR II

Dalton was the first to study the physics of evapotranspiration. He theorized at the close of the nineteenth century that evaporation was largely determined by the wind, atmospheric humidity content, and the physical characteristics of the surface.

In the early part of the twentieth century several investigators studied the physics of the evapotranspiration process. For instance, Keen (1914) found that vapor pressure within the soil was related to evaporation rate. Jefferies (1918) considered evaporation a problem of gaseous diffusion from a surface. Briggs and Shantz (1917) in Colorado correlated daily transpiration with weather conditions and used various types of atmometers and evaporation pans to compare transpiration with evaporation rate from a free water surface. Cummings (1925) used the energy balance method for estimating evaporation. He arbitrarily assigned all available energy to evaporation. However, Bowen (1926) considered that available energy might be partitioned to evaporation and sensible heat in a fixed ratio.

At the same time, in the early twentieth century several climatologists and ecologists developed the index approach to characterize the moisture regimes. The best-known example is the classical work by Köppen (1900) who related the vegetation boundaries with the ratios between the annual precipitation and temperature. Köppen considered the latter a substitute for evaporation data, which were too scanty to be used on a world basis at that time. Subsequently, Lang (1915) and de Martonne (1926) also developed an index of aridity by comparing the ratio between precipitation and temperature. Transeau was the first to suggest the use of the ratio between precipitation and evaporation to compare different climates, even though evaporation data were not available at that time. In the absence of evaporation data Meyer (1926) advocated the use of the ratio of precipitation to saturation deficit which he called the index of moisture effectiveness to study the rate of soil leaching. His work was extended to the United States by Jenny (1928) and to Australia by Prescott (1931).

The weakness of the index approach soon became apparent. For instance, Ångström (1936) pointed out that from a purely scientific point of view it is embarrassing to accept values based on a relationship between precipitation and temperatures. Such indexes do not have a common measurement unit and are thus misleading.

## REVIEW OF EVAPOTRANSPIRATION RESEARCH AFTER WORLD WAR II

Research progress in the post war years was at an unprecedented rate. Perhaps the most important first step was the clarification of the basic concept of potential evapotranspiration. This has been defined by Penman (1948) as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water."

From this definition, two useful generalizations can be made. First, when the stomata are open the potential evapotranspiration of a short green crop in the absence of advected energy closely approximates but cannot exceed the evaporation from an open water surface exposed to the same weather. Second, whenever soil moisture is adequate for favorable crop growth and in the absence of advected energy, the evapotranspiration rate of crops (except for the very few plants whose stomata are closed during the day such as pineapple) is largely independent of the type of vegetation and is determined by the weather. When the supply of water is adequate most plants cannot regulate their stomata openings while a few can. In the former case, the transpiration is controlled by the same meteorological factors which affect the evaporation from a free water surface. Even in the latter case, despite regulation of the stomatal openings, the transpiration loss is still considerably dependent on the meteorological factors.

The climatic factors are important because they determine the supply of energy and the mechanism of removal of water vapor from the evaporating surface. The latter is equal to the product of the vertical gradient of vapor pressure and the rate of mixing of air, which is in turn dependent upon the rate of change with height of wind speed.

The two basic sources of energy are net radiation and advected energy. Net radiation is the part of solar energy retained by the ground or the difference between the absorbed short-wave radiation and the effective outgoing long-wave radiation. The partition of net radiation in evapotranspiration and in heating the air, known as the Bowen ratio, varies with temperature. Therefore, in the absence of advected energy the four elements that determine the potential evapotranspiration of a vegetated surface are: radiation, temperature, wind and humidity.

Methods of measuring or estimating potential evapotranspiration fall into seven general categories: (1) lysimeter, (2) aerodynamic approach, (3) the energy budget approach, (4) empirical formulae using one or more climatic factors, (5) the use of evaporimeters, (6) the combination of (2) and (3), and (7) the use of evapotron.

In the post war years a number of expensive weighing lysimeters have been installed at such places as: Aspendale, Australia (McIlroy and D. E. Angus, 1963); Davis, California (Pruitt and Angus, 1960); Tempe, Arizona (van Bavel and Meyers, 1962); Valdai, U.S.S.R. (Popov, 1952); Wageningen, the Netherlands (Makkink, 1953); Rothamsted, England (Morris, 1959); and Sutton Bonington, United States (Hand, 1968). They provide research tools for the better understanding of the physical processes of evapotranspiration. But because of their high cost, they are not used for actual operational or regional water resources planning.

The aerodynamic approach rests on the assumption that the upward flux of water vapor can be calculated by the vertical gradient of vapor pressure and wind. The validity of this approach depends upon the proposition that (1) eddy diffusivity for momentum is the same as that for water vapor and (2) the wind profile near the ground can be accurately described by the logarithmic equation with a constant value of roughness and zero plane displacement for any given surface. Unfortunately, both these propositions are largely valid only under neutral conditions but are inaccurate under unstable conditions. Furthermore, for tall crops values of both roughness and zero plane displacement vary greatly with wind speed. Therefore, the numerous studies using the aerodynamic approach give reasonably good results only for short crops. For instance, Mukammal, *et al*. (1966) have reported that the aerodynamic method yielded results which were close to the lysimeter measurements when the corn was short, but fell to only 40 percent of the measured values at the end of the growing season.

The energy budget method makes use of the fact that in the absence of advection the net radiation is the primary source of energy for evapotranspiration. When water supply is adequate, nearly all the net radiation is used in evapotranspiration in the tropics or during the summer season in higher latitudes. However, when the temperature is low, a lower fraction of the net radiation is used in evapotranspiration as an increasingly greater proportion is used in heating the air. In 1948 Penman combined the energy budget and the aerodynamic approaches in a simplified form in order to eliminate the need for difficult profile measurements. This combination concept has been further discussed by Van Bavel (1966).

Empirical formulae are usually derived by correlating lysimeter readings with one or more meteorological elements in a given area and usually contain a constant, empirically determined. The Thornthwaite formula, based on the data in eastern and central parts of the United States, has been the basis of a well-known climatic classification and has been widely tested for studies of water balance in many parts of the world. At about the same time Blaney and Griddle derived a similar formula using the lysimeter data in the arid climate of the western United States. Their method was better known among irrigation engineers for practical day to day operation. Both formulae require only temperature and day length for their computation. Other empirical formulae include those developed by Turc and Makkink. In general, empirical formulae are accurate only when applied to a region which has more or less the same type of climate as the area from which they were derived.

Although several types of evaporimeters have been used by research workers, the U.S. Weather Bureau Class A pan is the most widely used and has been adopted by the World Meteorological Organization as the international standard. In the post war years there have been numerous studies comparing the evaporation pan data with lysimeter records, net radiation, or calculations according to the Penman, Thornthwaite and other formulae.

Only after about 1950 did research workers begin to realize the importance of advected energy. Advection is the horizontal transfer of heat in the atmosphere's lower layers. When air flows over an extensive dry area onto a moist surface, energy is supplied to the moist surface for evapotranspiration. On the other hand, when air flows over an extensive cold and moist surface onto a relatively warm surface, the evapotranspiration rate may be reduced. Several studies have indicated that in an arid climate, especially in areas affected by the subsidence of a subtropical anticyclone, the contribution of positive advected energy often exceeds 50 percent of the net radiation (Lemon, Glaser, and Satterwhite, 1957; Stern, 1967; Davenport and Hudson, 1967; McIlroy and Angus, 1964; Thompson and Boyce, 1967). Even in a subhumid climate the contribution may be as high as 20-30 percent.

It was also realized that the difference of the estimates by various methods may be partly due to the fact that some take into account the advected energy while others either ignore ir ot include a part of the effect. Therefore, the selection of the best yet most convenient method for estimating potential evapotranspiration in a given region depends in part on the strength of advection in that area.

CLIMATOLOGICAL DATA IN THE NORTHERN PLAINS OF WEST JAVA

Selection of methods for estimating potential evapotranspiration for study of regional water balance is largely dependent upon data available. The absence of lysimeter data is a major handicap because the accuracy of evaporimeter and of various formulae cannot be tested. In addition the lack of net radiation data makes it difficult, if not impossible, to use the simplified energy budget equation. It also introduces an error in the Penman equation as net radiation has to be estimated from other meteorological elements such as solar radiation, sunshine duration, cloudiness, and vapor pressure.

There are eight weather stations in the Northern Plains that record rainfall, temperature, sunshine duration and humidity. These stations are Serang, Jakarta, Depok, Subang, Jatiwangi, Kadipaten, Cirebon, and Tersanabaru. Their locations are spread out throughout the Northern Plains from west to east (see Figure 7). The locations of the eight weather stations are presented in Table 7.

Table 7

The Weather Stations in the Northern Plains of West Java

| Location | St. no. | Lat. | Long. | Elev. |
|---|---|---|---|---|
| Serang | 23 | 6°07'S | 106°08'E | 40 m |
| Jakarta | 27 | 6°11'S | 106°50'E | 8 m |
| Depok | 36 | 6°34'S | 106°49'E | 95 m |
| Subang | 156 | 6°35'S | 107°46'E | 95 m |
| Kadipaten | 22 | 6°46'S | 108°11'E | 45 m |
| Jatiwangi | 37 | 6°43'S | 108°17'E | 45 m |
| Cirebon | 62 | 6°42'S | 108°36'E | 4 m |
| Tersanabaru | 88 | 6°59'S | 108°41'E | 17 m |

Serang is located in the most western part of the study area, twelve kilometers from the small bay of Banten on the northern foot of Gunung Karang, 1,778 meters high. To the east, on the foot of the northern slopes of the Bogor Zone are respectively, Depok, Subang, and Kadipaten, while Tersanabaru lies at the eastern end of the Northern Plains.
On the north coast are Jakarta, about six kilometers from the Jakarta Bay, and Cirebon less than one kilometer from the Java Sea. Jatiwangi is between Kadipaten and Cirebon.

Jakarta has the most complete meteorological data for estimating potential evapotranspiration compared with the other stations in the Northern Plains. Its records for precipitation, temperature, humidity and wind date from 1878. Meteorologists began in 1905 measuring sunshine duration using an instrument which provided estimates every half hour of the average degree of sunshine (duration and intensity combined). The data were obtained from the sheets of two sunshine recorders, supplied with sensitive paper, viz, one of Negretti and Zamba having two slits at its sides and giving separate strips for morning and afternoon, and another instrument made at the observatory in Jakarta, which had only one slit on the top and gives one strip which is read for the interval 10:00 a.m. to 2:00 p.m.

Evaporation measurements were also initiated in 1905. Hourly observations were taken by means of an evaporimeter of the Wild's evaporation-balance type which was placed underneath, not in, the meteorological screen. However, as only eye-readings were made, the maxima were subject to observational error.

In 1931, the method of combining duration and intensity into one figure was abandoned. A twin-cylinder-recorder of Jordan's pattern was introduced. Sunshine duration was estimated from the sheets in three minute intervals. The Jordan sheets have scales of about 13 millimeters to one hour. For practical reasons they are read from 8:00 a.m. to 4:00 p.m.

Cirebon also has sunshine duration and evaporation records, but only from 1936 to 1945. Data for sunshine duration are also available in the following stations: Serang 1944-1960; Depok 1959-1961; Subang 1940-1960; Kadipaten 1937-1968; Jatiwangi 1944-1969; and Tersanabaru 1937-1968. Evaporation records are unavailable in all these stations.

Thus, of the eight stations, only two have pan evaporation and solar radiation data. Both stations, Jakarta and Cirebon, are located close to the Java Sea, and are subject to sea breeze influences. The Jakarta station especially, which is located on Jakarta Bay, receives strong negative advection from the sea breeze during the months January through March when the sea breeze is enforced by the northwest monsoon, resulting in an energy sink over the land. The Cirebon station is also located close to the sea. However, the sea breeze influence there is not strong, because it lacks the reinforcement of the monsoon wind. On the other hand, it is under the influence of the föhn type wind (Angin Kumbang) which sweeps down from the Cereme volcano bringing high advective energy to the Cirebon area during the west monsoon.

During June through October, the south wind from the Bandung and Garut Mountain basins, is forced to climb along the southwestern slope of Cereme with its temperature decreasing at a moist adiabatic rate of about 0.5 centigrade per 100 meters. However, on the other side of the mountain, the temperature increases at a dry adiabatic rate of 1.0 centigrade per 100 meters hence it becomes a föhn wind, warm and dry, for the Cirebon area.

Because of the limitations of the climatological data, potential evapotranspiration can be computed for all the stations according to the Thornthwaite, Blaney and Criddle and Penman formulae. However, pan evaporation data are available for only two of the eight stations.

COMPARISON OF SEVERAL METHODS FOR CALCULATING POTENTIAL EVAPOTRANSPIRATION AT JAKARTA AND CIREBON

Comparisons of four methods for estimating potential evapotranspiration at Jakarta and Cirebon are presented in Figures 13 and 14 (see Appendix II). At Jakarta, both the Thornthwaite and Blaney and Criddle methods show very little seasonal variation, whereas the Penman estimates show greater fluctuations with two distinct peaks in October and March coinciding with the times of maximum solar radiation intensity. It is well known that in the tropics, particularly the humid tropics, the annual temperature ranges are extremely small. Consequently, estimates of potential evapotranspiration based on temperature alone will also show small seasonal variations. Chang and Root (1975) have shown that temperature and solar radiation are not closely correlated, particularly in the tropics and in the polar regions. This explains why the Thornthwaite formula is relatively accurate in middle latitudes but introduces a large error in both the tropics and polar regions.

In the Af (rain forest) climate of the humid tropics they even found a negative correlation. The lack of correspondence between

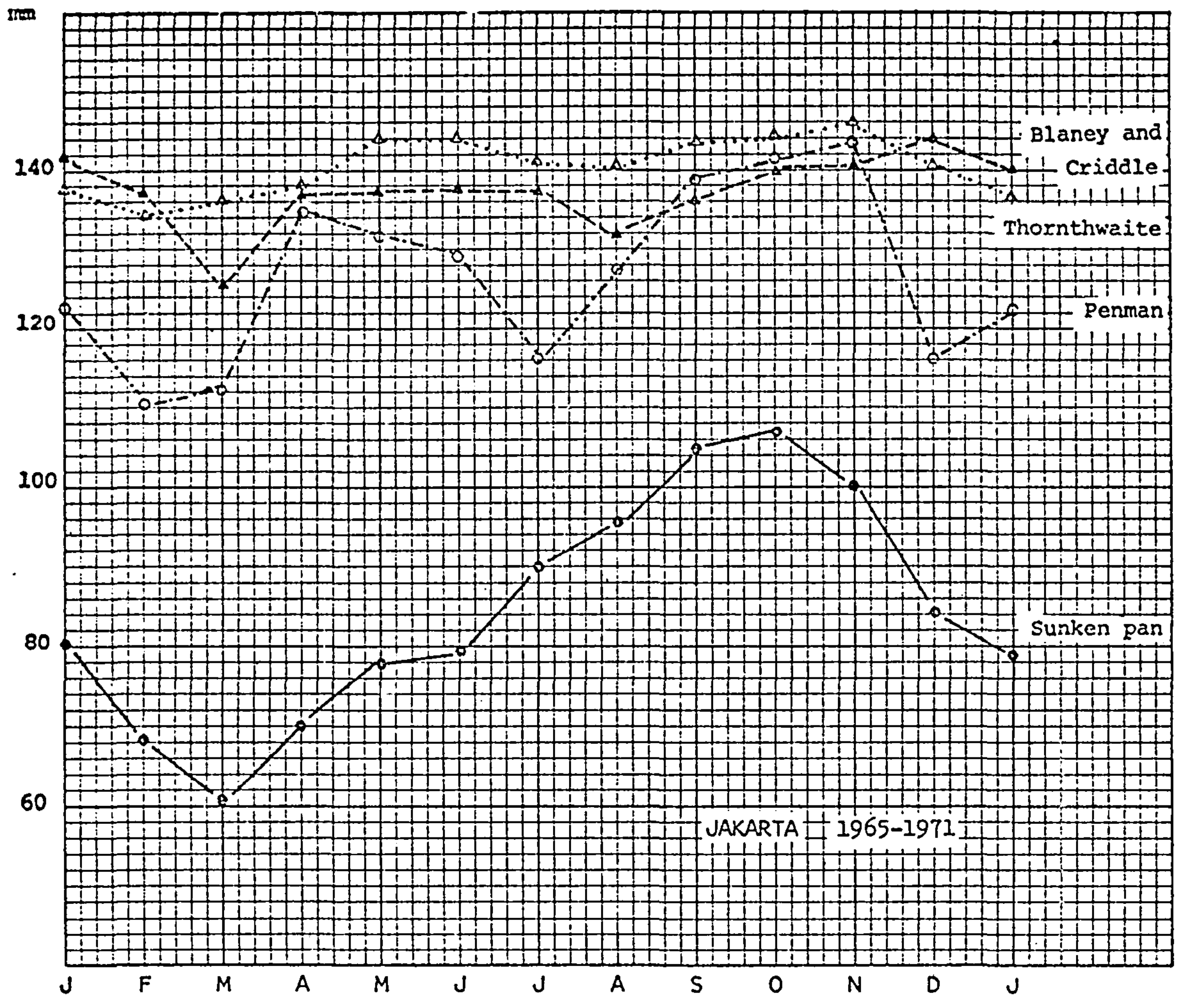



Figure 13. Potential Evapotranspiration in Jakarta, 1964-1971, According to Thornthwaite, Blaney and Criddle, Penman, and Sunken Pan Records.

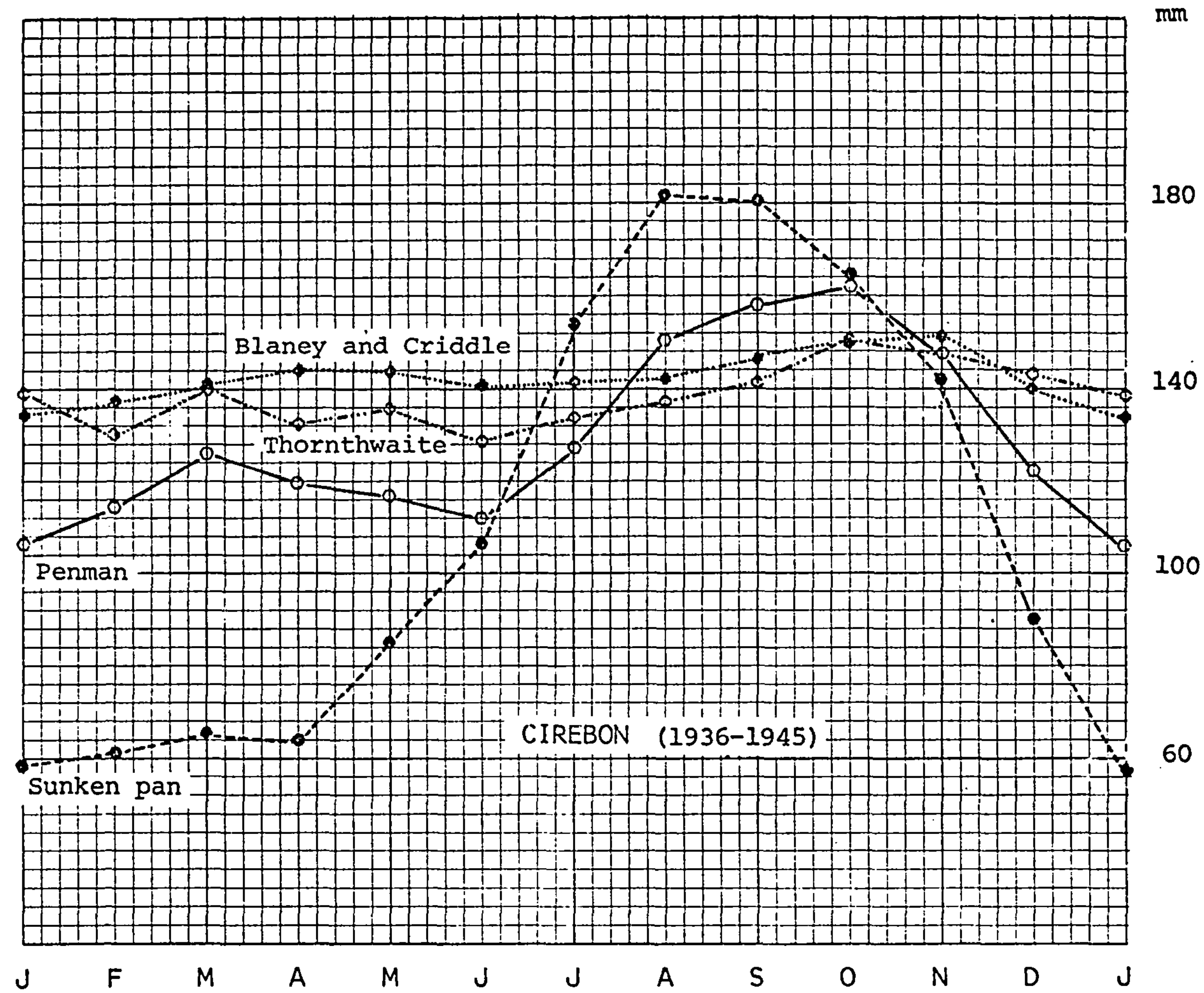



Figure 14. Potential Evapotranspiration for Cirebon, 1936-1945, According to Thornthwaite, Blaney and Criddle, Penman and Sunken Pan Records.

temperature and radiation values suggests that temperature is not a good indicator of the energy available for various physical and biological processes in the tropics, and that the Penman estimates should agree better with the seasonal trends of the potential evapotranspiration. At Cirebon the seasonal variation of the Penman values is greater than that of Jakarta, and more pronounced than both the Thornthwaite and Blaney and Criddle values.

At both Jakarta and Cirebon the Penman estimates are lower than those of either the Thornthwaite or the Blaney and Criddle. The Thornthwaite and Blaney and Criddle methods respectively produce annual potential evapotranspiration at Jakarta of 1,684.4 millimeters and 1,649.1 millimeters during the period 1964-1975, while at Cirebon 1,719.4 millimeters and 1,657.3 millimeters during the period 1936-1945. The Penman estimates in both places are more than 100 millimeters lower than those of Thornthwaite and Blaney and Criddle; however, they are higher than the pan evaporation. The differences between the annual values of pan evaporation and Penman's potential evapotranspiration are larger in Jakarta than in Cirebon. This may be caused by the cooling advective effect of the sea breeze in Jakarta, coming from the Java Sea into the Jakarta Bay and onto the land, while on the other hand, Cirebon during the dry season experiences the positive advective effect of the kumbang, or föhn type wind from the Cereme volcano. A study to test this proposition would be worthwhile in the future.

Although it cannot be said that the lower values of the Penman estimates are more accurate than those of the other two methods, since there is no way to determine absolute value without lysimeter data, almost all comparisons of Thornthwaite and Penman estimates in other parts of the world indicate that the Penman is probably more accurate (Aslyng, 1965; Bernard, 1954; Brutsaert, 1965; Chang, 1961; Cowan and Innes, 1956; Davies, 1966; Decker, 1962; Eagleman, 1967; Gilbert, 1954; Hounam, 1965; King, 1956; Ortolani, 1966; Pruitt, 1960; Ramage, 1959; Sellers, 1964; Smith, 1964; Stanhill, 1961; Thompson, 1963; van Wyk, 1953; Wallen, 1966, 1967; de Brichambaut and Wallen, 1963; Oguntoyinbo, 1965; and Dagg, 1965).

The results obtained by the Penman method were far closer to the measured values of potential evapotranspiration than the Thornthwaite method. The correlation coefficients were: Penman 0.95, Thornthwaite 0.84.

The Thornthwaite and Blaney and Criddle methods which use air temperature measurements are not at all satisfactory in the tropics. They fail to show the seasonal variations in evaporative demand that are apparent from evaporation pan records. The Penman formula is much more satisfactory.

The superiority of the Penman method is especially noticeable in the tropics where the Thornthwaite methods show large errors. This is supported by the following references: Oguntoyinbo, 1965; Dagg, 1965; Brutsaert, 1965; Cowan and Innes, 1956; and Ortolani *et al*., 1966. There are also many studies which have shown close agreement between the Penman estimates and measured potential evapotranspiration rate by lysimeter, soil moisture measuring devices or other methods in humid climates (Ahmad, 1962; Glover, 1964; McCaughey, 1968; Pereira, 1963; Ryks, 1965; Rytema, 1959; Slatyer, 1961; Stanhill, 1962, 1964; Stern, 1967; Wallis, 1963; Thompson and Boyce, 1972; de Vries and van Duin, 1953; Blore, 1966; Fitzgerald and Rickard, 1960; and Davies and McCaughey, 1968). Many of these studies were carried out in the tropics, Blore, 1966 in Kenya; Pereira, 1963 in Kenya; Ryks, 1965 in South Arabia; and Wallis, 1963 in Kenya. Therefore, it seems reasonable to use the Penman method in this study instead of the Thornthwaite or Blaney and Criddle method.

## COMPARISON BETWEEN THE PENMAN ESTIMATES AND PAN EVAPORATION

In Figures 13 and 14 the Penman estimates and pan evaporation records are presented. Jakarta and Cirebon are the only two stations where pan evaporation records are available. At both stations the evaporation pan used was the Wild pattern type sunken pan. This type of pan is not as accurate as the U.S. Bureau Class A pan for estimating potential evapotranspiration of various crops. The Class A pan is of cylindrical design ten inches deep and forty-seven and a half inches in diameter (inside diameter). It is constructed of galvanized iron or monel metal and placed on a wooden platform approximately four inches above the ground, so that air may circulate beneath the pan. On the other hand, a sunken pan is greatly affected by the moisture content and hence, temperature regime of the top soil. Furthermore, the sunken pan is more responsive to a slight change in the water level (Ventikeshwaran, Jagannathan and Ramakishran, 1959). In general, a sunken pan has a lower reading than a raised pan of the same design, sometimes by as much as 20 percent.

At both stations, the annual total of Penman estimates exceeds pan evaporation values. The annual totals of evaporation in Jakarta are, according to Penman, 1527.6 millimeters and by pan, 1014.5 millimeters. The low value recorded with the pan is apparently caused by the negative advection of the sea breeze. The latter is about two-thirds of the first which is in agreement with the Nixon and Lawless study of the coastal environment of California (Nixon and Lawless, 1968). In Cirebon the Penman estimate is 1657.3 millimeters annually and the pan total is 1351.7 millimeters. The pan evaporation is 84.6 percent of the Penman estimates. The higher percentage value for the Cirebon pan evaporation, although the station is also located on the Java Sea coast, is apparently a result of the warm and dry wind advection of the angin kumbang föhn type wind.

In Jakarta the seasonal trends of Penman values agree in general with the pan evaporation except during the period from February to June. Around February is when the sea breeze is strongest (Braak, 1929). In Cirebon, the pan evaporation values exceed the Penman estimates during the three month period July through September, when the angin kumbang föhn type wind frequently blows.

In the absence of advection the Penman estimates should closely approximate pan evaporation. Good agreement in annual totals or close correlation of monthly values has been reported by the following investigators: Stanhill, 1962, 1964; Hearn and Wood, 1964; Davies, 1965; Ryks, 1965; Cowan and Innes, 1956; Hogstrom, 1968; Chapes and Rees, 1963; and McCulloch, 1962. About half of these studies were carried out in the tropics. However, in the presence of advected energy the Penman estimates may differ greatly from the pan readings. Penman's use of one reading of temperature and humidity at the screen height makes it impossible to fully take into account the advected energy. In arid climates the Penman values may be much lower than the pan evaporation readings. Abdel-Aziz (1962), for instance, has found it necessary to add an advective term to the Penman equation in order to apply it to arid regions in the western United States.

In the arid zone of India, Krishnan and Kushwaha (1971), Sharma and Dastane (1968), and Bathkal and Dastane (1968), all found that the Class A pan evaporation is much higher than the potential evapotranspiration obtained by the Penman method. They concluded that under such conditions a pan evaporimeter might be a better indicator of the crop water needs.

In a study of evaporation rate along a seventeen kilometer transect in the Sudan Gezira, Davenport and Hudson (1967) found that as the advected energy decreased from the windward to the leeward edge of a cotton field the difference between the Penman estimates and free water evaporation also varied in accordance. Therefore, the Penman estimates, based on weather data at one site, cannot represent evapotranspiration rates at other nearby sites which are subject to different advection conditions.

In arid climates, advected energy invariably enhances evapotranspiration. On the other hand, negative advection in the form of onshore flow of relatively cold marine air may suppress evaporation. Under such conditions the Penman estimates may exceed the pan evaporation readings. Nixon and Lawless (1968) have reported a marked example of energy sink phenomenon along the coast of California. As California is paralleled by a cold ocean current during the summer months, advective cooling resulted in a much lower evapotranspiration rate along the immediate coast, but the evapotranspiration rate increased rapidly toward the interior locations. Evapotranspiration from irrigated ryegrass along the coast was equivalent to only about two-thirds of net radiation as compared to eight-tenths to nine-tenths in the absence of advection.

In the Valsetz Basin in the Coast Range of western Oregon Lowry (1959) also observed negative advection in summer. He reported that the net horizontal removal of energy caused by the relatively cool sea breeze during the midday was approximately equivalent to the vertical addition of radiation energy.

Since the evaporation rate from a pan is affected by advection and since the Penman formulae do not take into account advected energy, the ratio between the pan evaporation and the Penman estimate is a measure of the strength of advection. Fitzpatrick (1968), for instance, has constructed a map to show the geographical distribution of this ratio based on data for 143 stations in Australia. In general, the ratio increases from the humid region to the desert.

## ADVECTION ALONG THE COAST OF JAKARTA AND CIREBON

Advection is the horizontal transfer of energy in the downwind direction and is a source of energy in the form of sensible heat supplemental to the net radiation along the vertical. Only when the surface under consideration is identical in its characteristics of color, roughness, moisture availability, temperature, etc., for a sufficiently long distance upwind will non-advective conditions prevail.

The amount of advected energy depends on the wind speed as well as the contrast in sensible and latent heat between upwind and downwind surfaces.

Thus, precise determination of positive advected energy requires continuous instantaneous recording at more than one height above the surface and the integration of the results over a long period. The instruments and recorders are very expensive, and the author is not aware of any detailed study made in any part of the world.

A comparison of air temperature at Jakarta and Cirebon and the sea surface temperature off the coast would give a rough idea of the intensity of advection. Table 8 gives the mean monthly air temperatures for the two stations and the sea surface temperatures. The data are taken from the mean monthly isotherm maps of the Surface Climate of 1963 and 1964, in the Meteorological Atlas of the International Indian Ocean Expedition, which gives only generalized figures for the seas of Indonesia. However, the degree of accuracy of the sea surface values can be estimated by making comparisons with the results of sea surface temperature observations in the Java Sea, presented by Berlage (1927) in Table 9. Table 10 shows that there is close agreement for the mean monthly temperature of February and May. For August and November Berlage's results are higher.

The air temperatures from Table 11 are consistently higher than sea temperatures. However, the differences are relatively small. The mean difference is 0.7°C, with a maximum difference of 1.8°C in April and a minimum of 0.2°C in September and October. During the months of February to May the differences are above the mean, and in this period

Table 8

The Indian Ocean (Indonesia: Around Java)

| | Sea Surface Temp. ($^{o}C$) | | | Air Temp. ($^{o}C$) | | |
|---|---|---|---|---|---|---|
| Month | 1963 | 1964 | Average | 1963 | 1964 | Average |
| January | 27.0 | 28.1 | 27.6 | 27.0 | 28.8 | 27.9 |
| February | 27.0 | 27.7 | 27.4 | 28.1 | 28.5 | 28.3 |
| March | 28.2 | 27.6 | 27.9 | 29.0 | 28.5 | 28.8 |
| April | 27.8 | 28.0 | 27.9 | 29.2 | 30.1 | 29.7 |
| May | 28.3 | 27.9 | 28.1 | 28.6 | 29.1 | 28.9 |
| June | 27.7 | 27.8 | 27.8 | 28.2 | 28.8 | 28.5 |
| July | 26.5 | 27.0 | 26.8 | 27.1 | 27.0 | 27.1 |
| August | 25.9 | 26.8 | 26.4 | 26.4 | 27.7 | 27.1 |
| September | 26.0 | 26.6 | 26.3 | 25.9 | 27.1 | 26.5 |
| October | 26.9 | 27.3 | 27.1 | 27.0 | 27.5 | 27.3 |
| November | 27.4 | 27.0 | 27.2 | 27.9 | 27.8 | 27.9 |
| December | 27.8 | 27.2 | 27.5 | 28.1 | 28.4 | 28.4 |

Source: C.S. Ramage, F.R. Miller and Charmian Jefferies. 1972. The Surface Climate of 1963 and 1964. Meteorological Atlas of the International Indian Ocean Expedition, vol. I. National Science Foundation, Washington.

Table 9

Sea Surface Temperature Observation in the Java Sea

| Station Location | | Date | Depth (m) | Temperature ($^{o}$C) |
|---|---|---|---|---|
| 6°23'S | 113°58'E | April 1915 | 5 | 29.7 |
| 6°16' | 113°32' | May 1915 | 5 | 29.4 |
| 6°36' | 113°49' | February 1916 | 5 | 27.9 |
| 6°16' | 113°45' | May 1916 | 5 | 28.5 |
| 6°24' | 114°05' | February 1917 | 0 | 27.9 |
| 6°06' | 113°47' | May 1917 | 0 | 28.5 |
| 6°12' | 113°52' | August 1917 | 0 | 27.4 |
| 6°14' | 114°03' | November 1917 | 0 | 28.9 |
| 6°30' | 114°11' | February 1918 | 0 | 26.4 |
| 6°25' | 114°02' | May 1918 | 0 | 28.4 |
| 6°08' | 113°17' | August 1918 | 0 | 27.0 |
| 6°04' | 113°54' | November 1918 | 0 | 29.4 |

Source: H.P. Berlage, Jr. 1927. Monsoon Currents in the Java Sea and Its Entrances. Koninklyk Magnetisch en Meteorologisch Observatorium te Batavia, Verhandelingen No. 19.

Table 10

Surface Temperature in °C Java Sea

| Month | Berlage | Ramage |
|---|---|---|
| February | 27.5 | 27.4 |
| May | 28.5 | 28.1 |
| August | 27.2 | 26.4 |
| November | 29.2 | 27.2 |

Table 11

The Indian Ocean (Indonesia: Around Java)

| Month | Sea Surface Temperature ($^{o}C$) | Air Temperature ($^{o}C$) | Difference ($^{o}C$) |
|---|---|---|---|
| January | 27.6 | 27.9 | 0.3 |
| February | 27.4 | 28.3 | 0.9 |
| March | 27.9 | 28.8 | 0.9 |
| April | 27.9 | 29.7 | 1.8 |
| May | 28.1 | 28.9 | 0.8 |
| June | 27.8 | 28.5 | 0.7 |
| July | 26.8 | 27.1 | 0.3 |
| August | 26.4 | 27.1 | 0.7 |
| September | 26.3 | 26.5 | 0.2 |
| October | 27.1 | 27.3 | 0.2 |
| November | 27.2 | 27.9 | 0.7 |
| December | 27.5 | 28.4 | 0.9 |
| Annual | 27.3 | 28.0 | 0.7 |

the sea breeze is reinforced by the northwest monsoon. In addition, negative advection is strongest during the noon hours or early afternoon, when the sea breeze is well developed and the evapotranspiration rate is maximum. Braak (1929) observed that over the Java Sea, the west monsoon is wet and stormy. Generally, on the coast of West Java, the monsoon winds are well developed. The northwest monsoon is predominant from December to March.

The sea breeze occurs from about 10:00 a.m., becomes strongest in the afternoon at about 2:00 p.m. introducing a cooling effect on the land air temperature, and decreases rapidly in velocity after sunset.

In Table 12 the mean monthly maximum air temperatures for Jakarta are presented. It is clear that during the noon hour the temperature differences between the air and the sea temperatures are greater than at other times. The differences between the mean monthly and maximum mean monthly air temperatures in Jakarta normally are above 4°C, with an average of 4.4°C, ranging from 3.7°C in January to 4.7°C in August, September, and October. The average of the mean monthly sea surface temperature is 0.7°C lower than that of the air temperature, hence the temperature differences between the sea surface temperature and the mean maximum air temperature average about 5.1°C.

The temperature difference together with the high humidity of the air from the sea would produce negative advection and reduce the evaporation rate from the pan. However, from June to November, the pan evaporation rate is nearly the same as that of Penman estimates in Jakarta, and in Cirebon the pan evaporation even exceeds Penman's value. This may be explained by the fact that during this period the prevailing wind direction is south, southeast so that the influence of the sea

Table 12

Air Temperature ($^{o}$C)

Jakarta: 1936-1956

| Month | Mean | Mean Maximum | Difference |
|---|---|---|---|
| January | 26.2 | 29.9 | 3.7 |
| February | 26.4 | 30.2 | 3.8 |
| March | 26.9 | 31.1 | 4.2 |
| April | 27.2 | 31.8 | 4.6 |
| May | 27.4 | 31.7 | 4.3 |
| June | 27.1 | 31.4 | 4.3 |
| July | 26.8 | 31.3 | 4.5 |
| August | 27.0 | 31.7 | 4.7 |
| September | 27.4 | 32.1 | 4.7 |
| October | 27.4 | 32.1 | 4.7 |
| November | 27.0 | 31.5 | 4.5 |
| December | 26.7 | 30.9 | 4.2 |
| Annual | 27.0 | 31.3 | 4.4 |

breeze is insignificant. Also, during this period, Cirebon experiences the influence of the kumbang or föhn wind from the Cereme volcano. This kumbang wind cancels the negative advection brought in by the sea breeze, resulting in positive advection.

## THE ADVANTAGE OF EVAPORATION PAN AND THE USE OF PENMAN ESTIMATES IN LIEU OF PAN DATA

It may be concluded from the foregoing discussion that the discrepancies between the Penman estimates and pan evaporation data are partly caused by the fact that the sunken pan has a lower evaporation rate than the Class A pan placed on a wooden platform and also partly by the fact that the negative advection of cold air from the ocean reduces the observed evaporation rate from the pan.

As the effect of negative advection is strengthened by the sea breeze and is largely confined to the immediate coast, the difference between the Penman estimates and pan evaporation should be much smaller in the interior of the Northern Plains.

Numerous studies have indicated that the pan evaporation rates agree with the potential evapotranspiration measured either by lysimeters or by soil moisture sampling techniques. This is true under all conditions with different intensities of advection (Blaney and Muckel, 1955; Chang, 1961; Davies, Evans and Hazen, 1952; Gray, Levine and Kennedy, 1955; Jensen, Degman and Middleton, 1962; Jensen, Middleton and Pruitt, 1961; Hearrold, 1955; Pruitt, 1960, 1960, 1964; Pruitt and Jensen, 1955; Schleusener, Nemethey, Shull and Williams, 1961; Shaw, 1964; Thompson, Pearson and Cleasby, 1963; Pruitt and Angus, 1960, 1961;

Goldberg, Gornat and Sadan, 1967; McGillivray, 1964; Merrill, 1965; Shannon, Merrill and McGillivray, 1963; Wagner, Kono and Shannon, 1964; Nixon, McGillivray and Lawless, 1963; Stanhill, 1958, 1961, 1962, 1963; Lomas, 1964; Wilcox, 1963; Aslyng, 1965; McIlroy and Angus, 1964; Middleton, Pruitt, Grandall and Jensen, 1967; Doss, Bennett and Ashley, 1964; Stern, 1967; Aslyng, 1965; Krogman and Lutwick, 1961; Wilcox, Mason and McDougald, 1953; McIlroy and Angus, 1964; and Ramdas, 1957).

Attempts have also been made to relate the pan evaporation rate with the consumptive use for various crops. These studies are summarized in Tables 13-14. In general, the ratio between evapotranspiration and pan evaporation is very low in the early stage of the crop cycle when the canopy cover is incomplete, because the evaporation rate from the bare soil is relatively low. During the ripening period the ratio drops slightly because of crop senescence. During the mature stage when the canopy is complete and the plants are actively growing the ratio varies from 0.75 to 1.15 for various crops. The only exception is pineapple whose stomata are closed during the day.

In general, the ratio increases with height of the crops. There are two major reasons why the actual evapotranspiration rate of a tall crop may be higher than that of a short crop. First, the net radiation received by a leaf "seeing" bare soil, before the crop completely shades the ground, exceeds the net radiation received by the leaf "seeing" other green leaves below itself (Waggoner and Reifsnyder, 1961). Second, the increased turbulence, resulting from a relatively rough canopy surface, decreases the external resistance to movement of water vapor between the leaves and the air above.

Table 13

Ratios Between Potential Evapotranspiration and Evaporation from U. S. Weather Bureau Class A Pan for Various Crops

| Crop | Locality | Period | Pan Ratio | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | | Young | Mature | Ripening | Average | |
| Grass | Aspendale, Australia | 1951-61 | | | | 0.84 | McIlroy and Angus (1964) |
| Bermuda Grass | Thorsby, Alabama | Apr.-Sept. | 0.45 | 0.75 | | | Doss, Bennett, and Ashley (1964) |
| Grass | Oahu, Hawaii | 1958-59 | 0.50 | 0.80-1.00 | | 0.90 | Ekern (1959) |
| Meadow Grass | Gunnison, Colorado | May 22-Oct. 7, 1964 | | | | 1.08 | Grable, Hanks, Willhite, and Haise (1966) |
| Grass | Caesarea, Israel | June-Sept. 1959 | | | | 0.94 | Stanhill (1964) |
| Alfalfa | Thorsby, Alabama | Apr.-Sept. 1961-62 | 0.50 | 1.05 | | | Doss, Bennett, and Ashley (1964) |
| Alfalfa Brome | Ithaca, New York | June-Oct. 1953-54 | | | | 1.00 | Gray, Levine, and Kennedy (1955) |
| Alfalfa Clover | Lod, Israel | Mar. 1956-Dec. 1958 | | | | 0.82-0.98 | Lomas (1964) |
| Barley | North Logan, Utah | July-Aug. 1953 | 0.25 | 0.90 | 0.30 | | Hansen (1963) |

Table 13 (continued)

Ratios Between Potential Evapotranspiration and Evaporation from U. S. Weather Bureau Class A Pan for Various Crops

| Crop | Locality | Period | Pan Ratio | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | | Young | Mature | Ripening | Average | |
| Sorghum | Thorsby, Alabama | Apr.-Aug. | 0.30 | 1.15 | | | Doss, Bennett, and Ashley (1964) |
| Cotton | College Station, Texas | Aug. 4-5, 1954 | | 1.00 | | | Lemon, Graser, and Sattewhite (1957) |
| Cotton | Gilat, Israel | Apr.-Oct. 1959 | 0.20 | 0.85 | 0.10-0.40 | | Stanhill (1962a) |
| Corn | Ames, Iowa | June-Sept. 1959 | 0.27 | 0.90 | 0.40 | | Fritschen and Shaw (1961) |
| Sugar Cane | Chaka's Kraal, South Africa | Oct. 1959-July 1962 | | 1.00 | | | Thompson, Pearson, and Cleasby (1963) |
| Sugar Cane | Hawaii | Nov. 1958-Apr. 1959 | 0.40 | 1.10 | 0.98 | | Chang (1961) |
| Tule | California | Two Years | | | | 0.95 | Blaney (1951) |
| Pine-apple | Hawaii | 1960-62 | | 0.35 | | | Ekern (1965a) |
| Pasture | Aspendale, Australia | 1951-61 | | | | 0.84 | McIlroy and Augus (1964) |
| Alfalfa | Gilat, Israel | | | | | 1.00 | Stanhill (1961) |

Table 13 (continued)

Ratios Between Potential Evapotranspiration and Evaporation from U. S. Weather Bureau Class A Pan for Various Crops

| Crop | Locality | Period | Pan Ratio | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | | Young | Mature | Ripening | Average | |
| Corn, Grape, Peach | Prosser, Washington | 1954-62<br>1961-62 | | | | 0.8 | Middleton et al. (1967) |
| Apple | Parker, Washington | July 1-Nov. 9, 1958 | | | | 1.05 | Middleton et al. (1967) |
| Sugar Beet | Prosser, Washington | 1954-60 | | | | 0.9 | Middleton et al. (1967) |
| Soy Beans | Prosser, Washington | 1961-62 | | | | 0.9 | Middleton et al. (1967) |
| Red Beans | Prosser, Washington | 1958-61 | | | | 0.9 | Middleton et al. (1967) |
| Clover | Prosser, Washington | 1954-57 | | | | 0.9 | Middleton et al. (1967) |
| Potatoes | Prosser, Washington | 1954-55 | | | | 0.9 | Middleton, et al. (1967) |
| Wheat | Prosser, Washington | 1957 | | | | 0.9 | Middleton et al. (1967) |
| Green Peas | Washington | 3 years | | | | 1.0 | Middleton et al. (1967) |
| Raspberry | | | | | | | |
| Alfalfa | Central Washington | 7 years | | | | 0.95 | Middleton et al. (1967) |
| Peanut | | | | | | 0.9 | Goldberg et al. (1967) |

Table 14

Ratios Between Potential Evapotranspiration and Evaporation From Pans Other than the Standard U. S. Weather Bureau Type for Various Crops

| Crop | Locality | Period | Pan Ratio | | | Type of Evaporation Pan | Reference |
|---|---|---|---|---|---|---|---|
| | | | Young | Mature | Average | | |
| Grass | Aspendale, Australia | 1959-61 | | | 1.05 | Australian Evaporation Tank | McIlroy and Augus (1964) |
| Grass | Copenhagen, Denmark | 1955-64 | | | 0.90 | Sunken 12 Square Meters | Aslyns (1965b) |
| Alfalfa and Grass | Kootenay River Valley, Canada | Summer 1957-59 | | | 0.83-1.00 | Buried Four-Foot Evaporation Pan | Krogman and Lutwick (1961) |
| Lucerne | Alice Spring, Australia | Sept. 1957-Aug. 1958 | 0.40-0.60 | | 0.888 | | Jackson (1960) |
| Alfalfa | Prosser, Wash. | July 1949, 1952-54 | | 1.38 | | U.S. Department of Agriculture BPI Pan | Pruitt and Jensen (1955) |
| Timothy | Kapuskasing, Ontario, Canada | Summer 1954-58 | | | 1.24 | Buried Four-Foot Canadian Pan | Chapman and Dermine (1961) |
| Pasture | Winchmore, New Zealand | Dec. to Feb., 1955-56 | | | 0.65 | New Zealand Sunken Pan | Finkelstein (1961) |
| Rice | Murrumbidgee, Australia | Oct. 1946-Mar. 1947 | | | 1.10 | Australian Evaporation Tank | Butler and Prescott (1955) |

Table 14 (continued)

Ratios Between Potential Evapotranspiration and Evaporation from Pans Other than the Standard U. S. Weather Bureau Type for Various Crops

| Crop | Locality | Period | Pan Ratio | | | Type of Evaporation Pan | Reference |
|---|---|---|---|---|---|---|---|
| | | | Young | Mature | Average | | |
| Sugar Cane | Chaka's Kraal, Tongaat, Illovo, South Africa | Sept. 1959-Oct. 1960 | 0.35 | 1.40 | 1.09 | Sunken Symon Tank | Paarson, Cleasby, and Thompson (1961) |
| Coffee | Ruirn, Kenya | 6 years | | 0.80 | | Sunken Insulated Tank | Pereira (1957) |
| Pine, Cyprus, Bamboo | Kinal, Kenya | 1948-61 | | 0.86 | | Raised British Pan | Pereira and Hosegood (1962) |

Unfortunately, pan evaporation data in the Northern Plains are not available except for two stations. Until a network of pan evaporation stations is established, the Penman formula provides the most accurate data. The difference between Penman and pan evaporation is probably small in the interior of the Northern Plains. Furthermore, the Penman estimates can be adjusted at a time when more data such as lysimeter and pan evaporation are available.

CHAPTER IV

# POTENTIAL EVAPOTRANSPIRATION ACCORDING TO THE PENMAN FORMULA

## THE PENMAN EQUATION

The Penman formula for estimating free water evaporation and potential evapotranspiration needs:

$E_o = (\Delta Q_n + \gamma E_a)/(\Delta + \gamma)$, in which

$E_o$ = evaporation from open water surface in millimeter per day

$Q_n$ = net radiation converted to equivalent evaporation rate

$E_a$ = an aerodynamic component,

$E_a = 0.35(e_d - e_a)\ (1 + \mu_2/100)$

$e_d$ is saturation vapor pressure in millimeter of mercury at dew point temperature

$e_a$ is saturation vapor pressure in millimeter of mercury at temperature T degree centigrade

$\mu_2$ is wind velocity in miles per day at a height of two meters.

$\Delta$ = the slope of the saturation vapor pressure versus temperature curve ($de_a/dT$) at the air temperature T in millimeter per degree centigrade

$\gamma$ = the psychrometric constant.

This equation combines energy budget and aerodynamic approaches. The aerodynamic term ($E_a$) is not very important especially in the tropics where the temperatures are high throughout the year. The energy term in Penman's equation is net radiation ($Q_n$) which is closely related to global radiation. However, in the 1940's, very few weather stations measured global radiation. Therefore, Penman used sunshine duration instead, which was available at many stations. Sunshine duration and global radiation are closely related. In Indonesia, there are more stations which measure sunshine duration, thus it is possible to determine global radiation.

## RELATIONSHIP BETWEEN GLOBAL RADIATION AND SUNSHINE DURATION IN THE NORTHERN PLAINS

In the Northern Plains there is only one station, Jakarta, that records global radiation, but there are eight stations that measure duration of sunshine. Based on the simultaneous measurements of global radiation and sunshine duration at the Jakarta station for seven years, from 1965 to 1971 (see Table 15), a linear regression was derived as shown in Figure 15. The coefficient of correlation is 0.69 and the standard error is 0.09. In this equation $Q/Q_A = a + b\ n/N$, a is dependent upon the level of diffuse light which is relatively low in the tropics. The constant b is related to the attenuation of direct radiation. This equation has been used to estimate global radiation for the seven other stations in the Northern Plains: Serang, Depok, Subang, Jatiwangi, Kadipaten, Cirebon, and Tersanabaru. However, sunshine duration data available in these stations are not of the same length and of the same period. The length ranges from three years in Depok, to eleven years in Jatiwangi. Nonetheless, they are in the period between 1937 and 1969 and they are the only existing sunshine records in the Northern Plains. The results are presented in Table 16.

It is apparent that the stations in the eastern drier part of the Northern Plains receive higher global radiation (Q) than those in the western wetter part of the plains. In the wet season, in January, it

Table 15

Fractions of Global Radiation ($Q/Q_A$) and Sunshine Duration (n/N) at Jakarta for 1965-1971

Station: Jakarta  Lat.: $6^{o}11'S$  Long.: $106^{o}50'E$  Elev.: 8 m

| Year | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1965 | $Q/Q_A$ | 0.24 | 0.46 | 0.45 | 0.58 | 0.54 | 0.56 | 0.54 | 0.57 | 0.56 | 0.53 | 0.44 | 0.43 |
| | n/N | 0.31 | 0.57 | 0.48 | 0.78 | 0.71 | 0.80 | 0.75 | 0.87 | 0.89 | 0.80 | 0.62 | 0.67 |
| 1966 | $Q/Q_A$ | 0.46 | 0.47 | 0.45 | 0.55 | 0.55 | 0.57 | 0.57 | 0.57 | 0.51 | 0.49 | 0.51 | 0.44 |
| | n/N | 0.59 | 0.46 | 0.55 | 0.76 | 0.85 | 0.81 | 0.84 | 0.86 | 0.80 | 0.67 | 0.60 | 0.44 |
| 1967 | $Q/Q_A$ | 0.41 | 0.39 | 0.46 | 0.51 | 0.53 | 0.59 | 0.56 | 0.55 | 0.51 | 0.50 | 0.37 | 0.33 |
| | n/N | 0.37 | 0.31 | 0.58 | 0.69 | 0.74 | 0.92 | 0.89 | 0.91 | 0.89 | 0.76 | 0.50 | 0.39 |
| 1968 | $Q/Q_A$ | 0.37 | 0.35 | 0.44 | 0.47 | 0.44 | 0.42 | 0.35 | 0.28 | 0.39 | 0.46 | 0.24 | 0.28 |
| | n/N | 0.32 | 0.36 | 0.57 | 0.70 | 0.70 | 0.61 | 0.60 | 0.60 | 0.82 | 0.72 | 0.50 | 0.34 |
| 1969 | $Q/Q_A$ | 0.36 | 0.45 | 0.44 | 0.51 | 0.47 | 0.46 | 0.53 | 0.56 | 0.46 | 0.52 | 0.42 | 0.44 |
| | n/N | 0.59 | 0.54 | 0.63 | 0.75 | 0.74 | 0.67 | 0.85 | 0.94 | 0.73 | 0.83 | 0.52 | 0.39 |
| 1970 | $Q/Q_A$ | 0.41 | 0.42 | 0.48 | 0.43 | 0.43 | 0.42 | 0.44 | 0.41 | 0.39 | 0.35 | 0.29 | 0.27 |
| | n/N | 0.41 | 0.45 | 0.62 | 0.63 | 0.65 | 0.70 | 0.76 | 0.88 | 0.78 | 0.65 | 0.48 | 0.42 |
| 1971 | $Q/Q_A$ | 0.31 | 0.28 | 0.34 | 0.32 | 0.33 | 0.29 | 0.40 | 0.47 | 0.41 | 0.26 | 0.32 | 0.40 |
| | n/N | 0.45 | 0.37 | 0.48 | 0.75 | 0.65 | 0.66 | 0.77 | 0.82 | 0.72 | 0.56 | 0.51 | 0.58 |

Table 16

Global Radiation (Q) in the Northern Plains of West Java in ly/day at:
Serang, Depok, Subang, Kadipaten, Jatiwangi, Cirebon, and Tersanabaru

| Location: | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serang 1960-1968 | 325.8 | 375.9 | 387.5 | 338.9 | 310.0 | 312.9 | 310.8 | 359.9 | 383.4 | 411.8 | 405.0 | 370.1 |
| Depok 1959-1961 | 280.0 | 303.3 | 355.2 | 332.4 | 306.9 | 301.1 | 297.7 | 340.6 | 414.1 | 397.3 | 344.2 | 304.6 |
| Subang 1940-1960 | 296.5 | 321.4 | 346.4 | 350.3 | 307.2 | 314.0 | 299.1 | 365.1 | 390.0 | 369.4 | 343.4 | 332.9 |
| Kadipaten 1964-1968 | 324.0 | 321.4 | 349.2 | 354.6 | 323.9 | 344.4 | 343.5 | 379.6 | 421.0 | 395.5 | 382.2 | 334.8 |
| Jatiwangi 1964-1969 | 384.1 | 391.4 | 374.2 | 392.4 | 394.6 | 384.8 | 385.9 | 421.1 | 451.0 | 433.2 | 421.2 | 397.5 |
| Cirebon 1936-1957 | 342.4 | 363.0 | 405.7 | 361.1 | 357.7 | 342.4 | 348.9 | 408.0 | 446.5 | 442.2 | 428.8 | 362.6 |
| Tersanabaru 1964-1968 | 409.1 | 431.7 | 414.3 | 418.7 | 387.8 | 347.4 | 387.2 | 428.3 | 463.8 | 441.4 | 428.4 | 410.2 |
| Jakarta 1964-1975 | 330.6 | 367.0 | 375.3 | 401.2 | 361.4 | 348.8 | 364.2 | 387.5 | 392.5 | 396.9 | 346.0 | 352.7 |

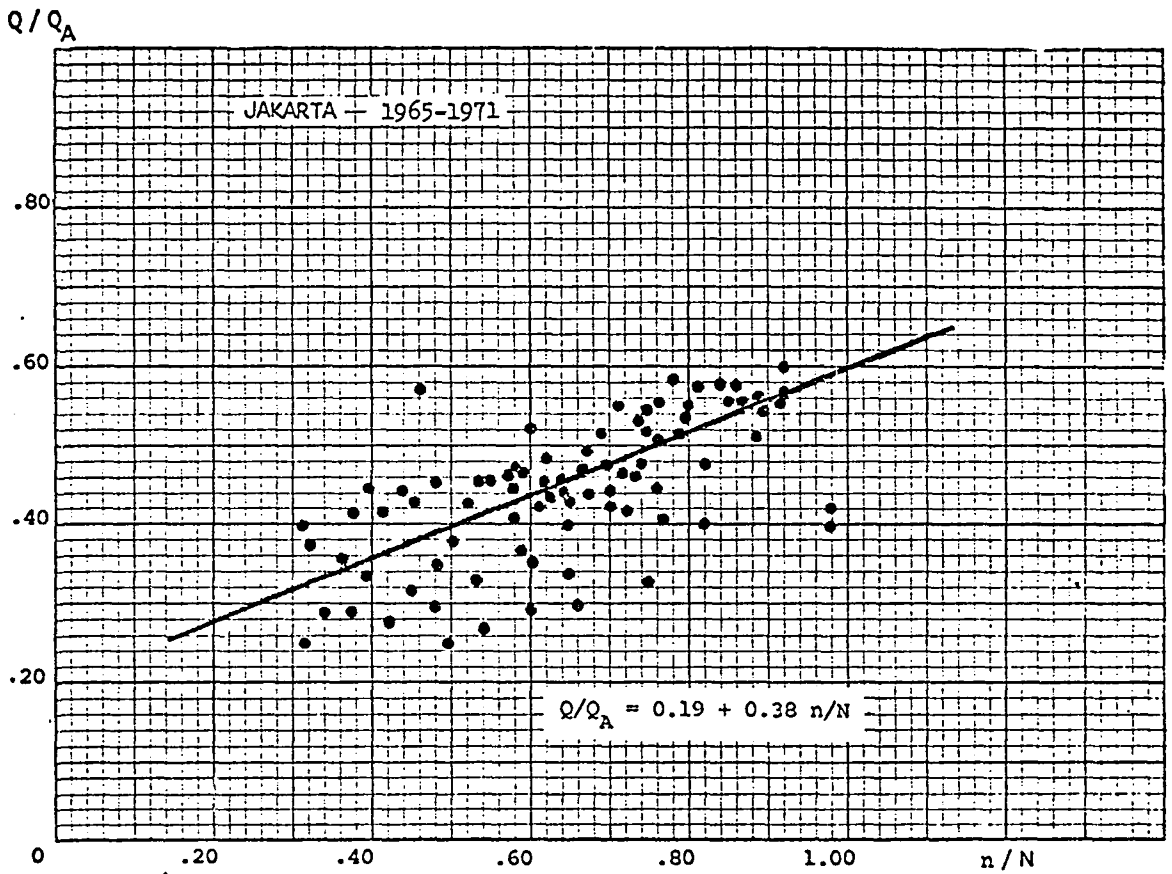



Figure 15. Linear Regression Correlation Between $Q/Q_A$ and n/N for Jakarta, 1965-1971.

ranges from 280.0 ly/day in Depok to 409.1 ly/day in Tersanabaru, a difference of 129.1 ly/day. In the dry season, however, the variation seems to be smaller. The greatest difference is found in September between 383.4 ly/day in Serang and 463.8 ly/day in Tersanabaru, or a range of 80.4 ly/day. In the western part of the plains, larger seasonal global radiations are observed. For instance, in Depok it ranges from 280.0 ly/day in the wet season, January, to 414.1 ly/day in the dry season, September, a difference of 134.1 ly/day. In the eastern part of the plains, Cirebon has the highest variation, from 342.4 ly/day in January, to 446.5 ly/day in September, a difference of 104.1 ly/day.

In addition, it seems that there is also a small variation in global radiation between locations in the coastal area and in the interior. The coastal areas receive slightly more global radiation than the interior places. This is probably related to the heavier cloudiness in the interior.

## Estimation of Net Radiation

In 1970 Chang presented a formula for estimating net radiation from global radiation instead of sunshine duration. This formula, based on actual observations of both net radiation and global radiation, at five stations, was an improvement over the Brunt formula which used only British observations. This formula reads:

$$Q_n = (1 - r)Q - \sigma T^4 \left[286.18 + 202.60\ Q/Q_A - 45.24 \sqrt{e_d} - 10.92\ Q/Q_A \sqrt{ed}\ \right]$$

where $Q_n$ = net radiation

$r$ = reflection coefficient

$\sigma$ = the Stefan Boltzman constant

$T$ = air temperature in °K

$Q_A$ = the Angot value

$e_d$ = the saturation vapor pressure in milibars at dew point temperature

This formula has been used to compute the net radiation in the Penman formula for the eight stations in the Northern Plains, Jakarta, Serang, Depok, Subang, Jatiwangi, Kadipaten, Cirebon, and Tersanabaru. The results are presented in Table 17. It shows that marked variations in net radiation exist in the Northern Plains, both in spatial as well as in seasonal values. In general, the stations in the western part, Serang, Jakarta, Depok, and Subang, receive less net radiation than stations in the eastern part, such as Kadipaten, Jatiwangi, Cirebon and Tersanabaru. It is also true that stations in the coastal areas such as Jakarta and Cirebon have higher monthly radiation values than the stations located more inland. However, the intensity of seasonal variation in the western part, where less monthly net radiation is received, is equal with that in the eastern part with higher net radiation values. In Serang, the range of variation is from 151.1 ly/day in June to 257.7 ly/day in November, thus with a difference of 106.6 ly/day, while in Cirebon, which has the largest variation among the eastern drier stations the difference is only 86.4 ly/day, with a minimum value of 209.3 ly/day in June and a maximum of 295.7 ly/day. In all stations, the highest net radiation values are found in the months September and October, except in Serang where the highest value is in

Table 17

Net Radiation (Qn) in the Northern Plains of West Java in ly/day at: Serang, Jakarta, Depok, Subang, Kadipaten, Jatiwangi, Cirebon, and Tersanabaru

| Location Period | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serang 1959-1969 | 196.5 | 228.2 | 218.1 | 199.7 | 151.7 | 151.1 | 167.0 | 203.0 | 232.7 | 249.7 | 257.7 | 220.4 |
| Jakarta 1964-1975 | 217.5 | 245.1 | 251.0 | 270.0 | 237.6 | 223.4 | 229.3 | 250.1 | 256.4 | 262.6 | 229.0 | 227.6 |
| Depok 1959-1961 | 150.9 | 169.7 | 206.2 | 191.3 | 165.7 | 159.0 | 156.2 | 188.0 | 242.9 | 234.9 | 200.6 | 167.7 |
| Subang 1940-1960 | 161.3 | 182.6 | 203.2 | 203.1 | 167.4 | 167.9 | 174.8 | 202.5 | 231.3 | 210.9 | 202.3 | 202.7 |
| Jatiwangi 1961-1967 | 215.8 | 213.8 | 229.2 | 226.0 | 197.2 | 190.4 | 177.9 | 218.4 | 235.8 | 246.3 | 231.5 | 224.2 |
| Kadipaten 1937-1968 | 194.2 | 194.7 | 222.7 | 213.6 | 188.3 | 193.1 | 190.5 | 214.3 | 242.8 | 246.0 | 231.0 | 207.1 |
| Cirebon 1936-1945 | 214.6 | 259.1 | 259.4 | 245.2 | 217.7 | 209.3 | 217.4 | 264.7 | 287.6 | 295.7 | 285.1 | 243.6 |
| Tersanabaru 1937-1968 | 237.9 | 247.2 | 256.8 | 238.9 | 209.5 | 195.0 | 198.9 | 217.9 | 259.8 | 258.8 | 245.6 | 244.4 |

November. The lowest net radiation values are in May and June. The low net radiation values during the transitional period from the rainy season to the dry season are attributed to the fact that during that period most of the daytimes are hazy. The real dry monsoon has not arrived yet. The relatively higher net radiation values in the wet west monsoon, November to March, are results of the frequent occurrence of bright sunny days between rains.

## Penman Estimates of Potential Evapotranspiration

The monthly values of Penman's potential evapotranspiration are presented in Table 18. Annual and monthly isoline maps for the months January, April, July, and October are presented in Figures 16, 17, 18, 19, and 20.

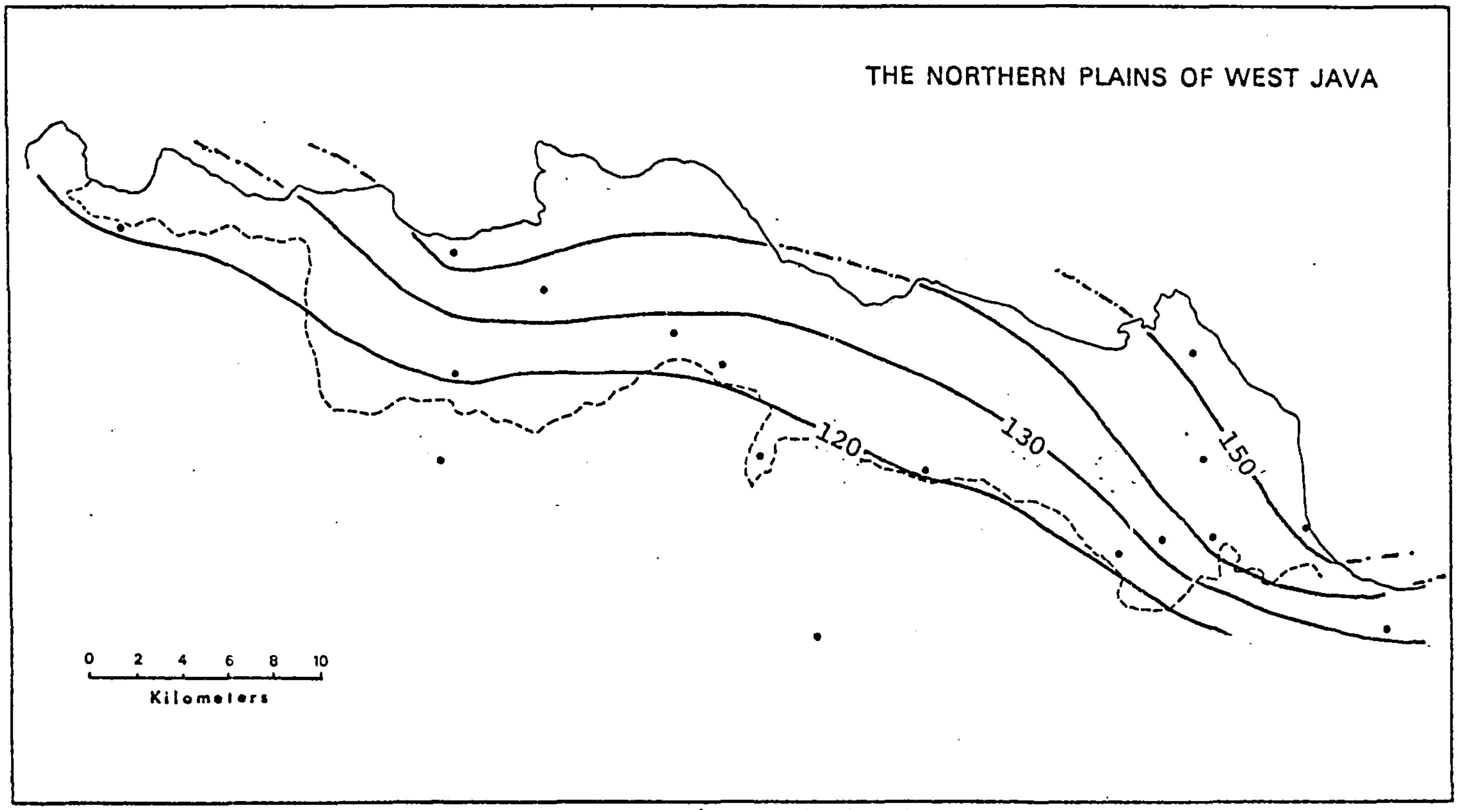
When considering the monthly and annual potential evapotranspiration values (see Appendix III), marked spatial differences are noted. Interior stations record smaller monthly and annual potential evapotranspiration compared with the coastal areas. Of all the stations Subang presents in all months the lowest potential evapotranspiration. Jakarta and Cirebon in turn have the highest values, Jakarta in the months April - July and Cirebon in months September - December. The annual totals vary from a minimum of 1214.0 millimeters in Cirebon to a maximum of 1558.5 millimeters in Subang. Differences from station to station as well as seasonal variations are in general larger in the eastern

Table 18

Potential Evapotranspiration According to Penman Method (in mm)

| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serang (1959-1969) | 99.3 | 101.9 | 110.3 | 99.8 | 95.6 | 84.3 | 96.0 | 112.9 | 123.5 | 134.0 | 125.6 | 113.9 | 1297.1 |
| Jakarta (1964-1968) | 110.3 | 113.9 | 127.9 | 139.3 | 133.0 | 124.6 | 130.4 | 141.8 | 144.7 | 154.7 | 120.7 | 116.1 | 1429.5 |
| Depok (1959-1961) | 80.3 | 79.4 | 107.3 | 93.5 | 94.5 | 90.2 | 91.0 | 107.3 | 126.3 | 133.0 | 109.0 | 102.2 | 1214.0 |
| Subang (1940-1960) | 85.1 | 82.4 | 99.8 | 99.9 | 90.5 | 90.1 | 98.2 | 116.7 | 124.4 | 123.4 | 100.9 | 104.5 | 1215.9 |
| Kadipaten (1936-1968) | 95.2 | 86.2 | 105.7 | 107.6 | 102.9 | 101.4 | 111.9 | 134.2 | 143.9 | 144.6 | 120.9 | 106.8 | 1361.3 |
| Jatiwangi (1944-1969) | 103.9 | 91.9 | 111.2 | 111.5 | 119.9 | 112.8 | 117.3 | 147.0 | 150.5 | 157.7 | 130.2 | 114.3 | 1468.2 |
| Cirebon (1936-1945) | 107.3 | 113.0 | 125.4 | 118.3 | 115.5 | 111.1 | 126.0 | 150.2 | 159.4 | 162.4 | 147.2 | 122.7 | 1558.5 |
| Tersanabaru (1937-1968) | 120.6 | 110.1 | 126.0 | 117.0 | 110.3 | 106.3 | 118.2 | 140.9 | 153.0 | 159.1 | 136.5 | 125.7 | 1370.8 |

Penman Annual Potential Evapotranspiration Isoline (cm)




Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Figure 16. Penman Annual Potential Evapotranspiration Isolines (cm).

Penman Potential Evapotranspiration Isoline: January (mm)

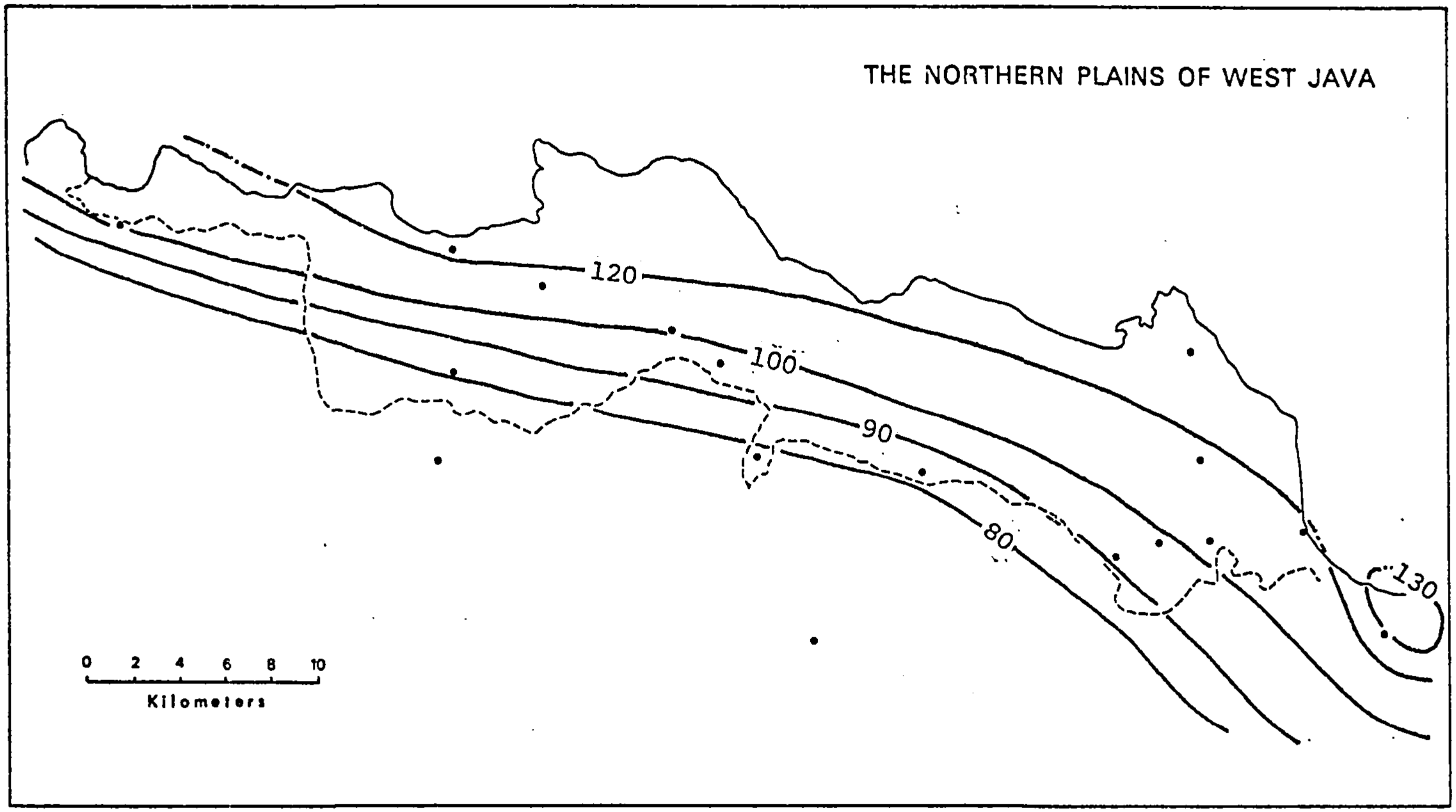
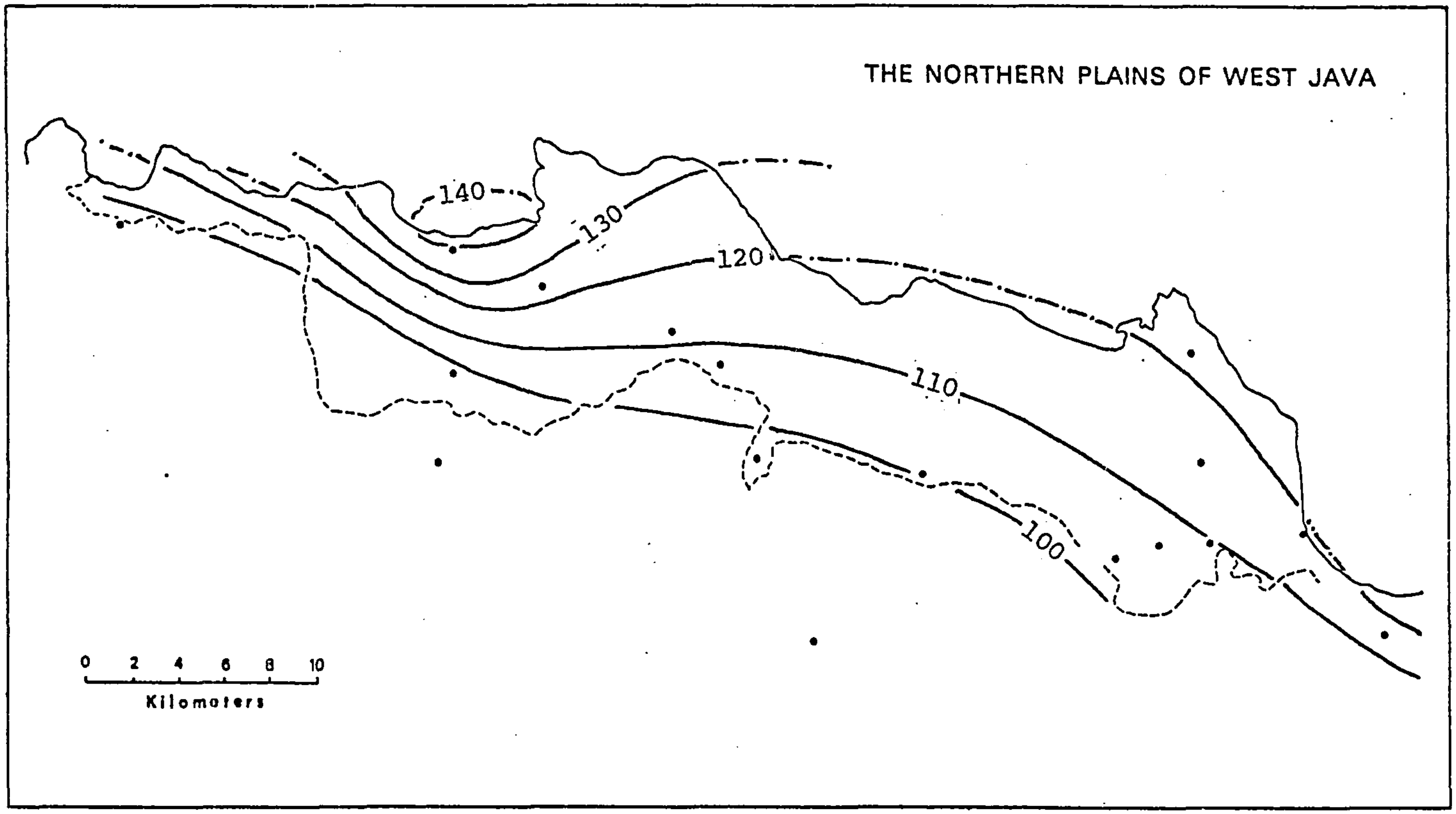



Figure 17. Penman Potential Evapotranspiration Isolines: January (mm).

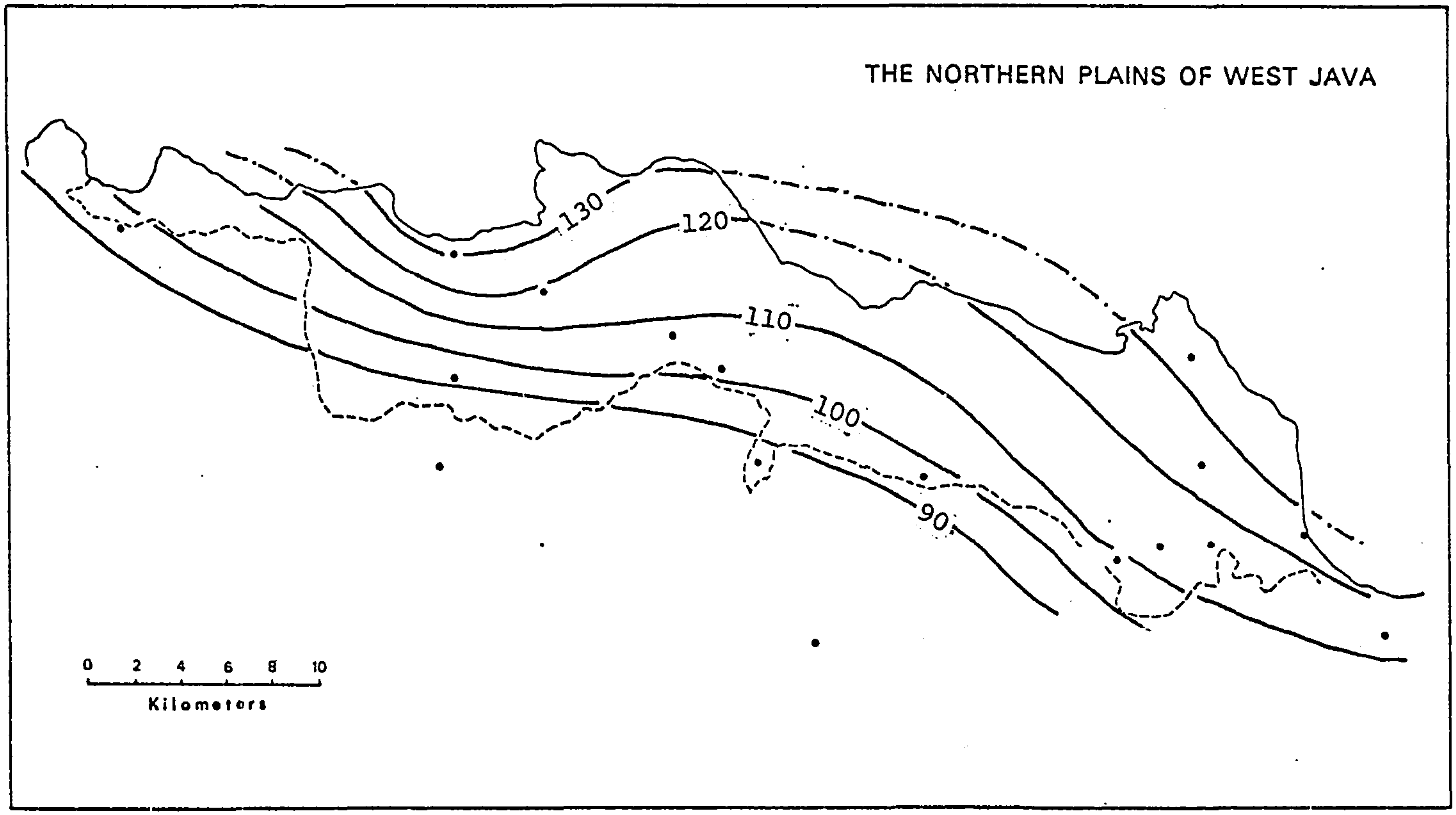
Penman Potential Evapotranspiration Isoline: April (mm)




Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Figure 18. Penman Potential Evapotranspiration Isolines: April (mm).

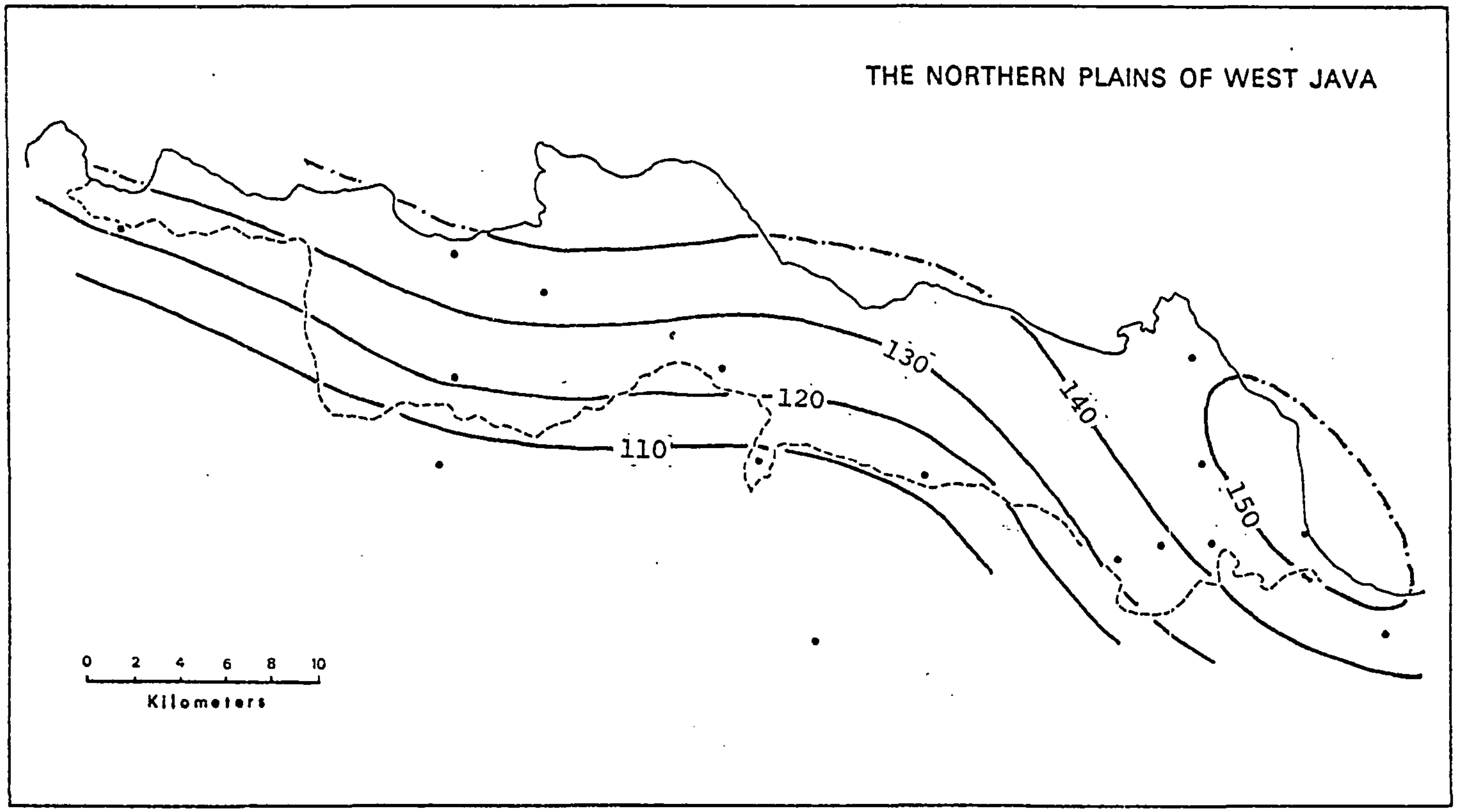
Penman Potential Evapotranspiration Isoline: July (mm)




Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Figure 19. Penman Potential Evapotranspiration Isolines: July (mm).

Penman Potential Evapotranspiration Isoline: October (mm)




Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Figure 20. Penman Potential Evapotranspiration Isolines: October (mm).

Table 19

The Variability of Mean Monthly and Annual Penman Estimate Potential Evapotranspiration Over the Period of 1964-1975

For Station: Jakarta Lat: 6°11'S Long: 106°50'E Elev: 7m

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | 111.3 | 116.6 | 89.9 | 103.5 | 123.4 | 105.9 | 130.5 | 126.5 | 108.9 | 115.0 | 123.1 | 124.9 | 1379.5 |
| 1965 | 68.5 | 129.4 | 137.3 | 165.6 | 145.4 | 141.6 | 137.9 | 168.3 | 171.9 | 184.8 | 139.2 | 135.8 | 1725.7 |
| 1966 | 140.4 | 124.0 | 142.0 | 157.5 | 138.3 | 137.7 | 148.8 | 161.8 | 154.8 | 153.4 | 149.4 | 132.9 | 1741.0 |
| 1967 | 126.2 | 106.4 | 139.2 | 138.3 | 145.4 | 139.2 | 149.7 | 165.8 | 163.8 | 169.3 | 113.7 | 96.7 | 1653.7 |
| 1968 | 105.1 | 96.3 | 131.1 | 131.7 | 112.5 | 98.7 | 85.2 | 86.8 | 123.9 | 150.3 | 78.0 | 90.5 | 1290.1 |
| 1969 | 113.5 | 127.7 | 134.1 | 140.7 | 127.7 | 114.3 | 139.2 | 162.7 | 136.8 | 172.0 | 128.4 | 135.2 | 1632.3 |
| 1970 | 126.8 | 114.5 | 151.3 | 117.9 | 113.8 | 105.0 | 119.3 | 121.8 | 122.1 | 115.9 | 83.1 | 89.0 | 1380.5 |
| 1971 | 99.5 | 73.4 | 103.2 | 92.1 | 87.7 | 74.7 | 103.8 | 134.8 | 131.7 | 88.7 | 100.3 | 124.9 | 1214.8 |
| 1972 | 85.2 | 96.9 | 105.1 | 131.1 | 124.6 | 115.5 | 125.9 | 137.3 | 150.6 | 168.3 | 135.3 | 127.7 | 1503.5 |
| 1973 | 108.5 | 99.4 | 104.2 | 123.6 | 106.0 | 98.4 | 116.2 | 133.0 | 114.5 | 144.5 | 111.0 | 103.8 | 1363.1 |
| 1974 | 101.7 | 123.2 | 137.3 | 146.4 | 129.9 | 128.7 | 134.8 | 143.5 | 140.4 | 140.4 | 124.2 | 190.3 | 1640.8 |
| 1975 | 143.8 | 114.2 | 131.7 | 137.1 | 137.0 | 135.6 | 133.3 | 134.5 | 128.1 | 121.5 | 112.8 | 117.2 | 1541.4 |
| | | | | | | | | | | | | | |
| S.D. | 19.9 | 17.6 | 20.3 | 21.9 | 17.4 | 20.8 | 19.5 | 24.3 | 20.4 | 29.1 | 22.6 | 28.7 | 185.2 |
| Mean | 107.9 | 111.4 | 125.0 | 131.7 | 123.2 | 114.5 | 126.5 | 140.2 | 138.1 | 145.7 | 116.9 | 122.9 | 1502.3 |
| Variability | 0.18 | 0.16 | 0.16 | 0.17 | 0.14 | 0.18 | 0.15 | 0.17 | 0.15 | 0.20 | 0.19 | 0.23 | 0.12 |

part of the Northern Plains. The largest seasonal variation is found at Station Jatiwangi with a minimum potential evapotranspiration in February of 91.9 millimeters and a maximum in October of 157.7 millimeters. This phenomenon is caused by the more pronounced dry season in the eastern part than in the western section. For most of the stations, on the coast as well as in the interior, similar seasonal patterns of potential evapotranspiration prevail with the months from January to July experiencing lower, and the months from August to December in many cases comparatively higher, values.

## VARIABILITY OF POTENTIAL EVAPOTRANSPIRATION

For many hydrological and agronomic studies it is necessary not only to know the mean values of potential evapotranspiration but also their variability from one year to another and the extreme values. In climatological analyses a knowledge of the variability is helpful in determining the number of years of data required for evaluating mean evaporation rates to various degrees of precision. Coefficient of variation is defined as standard deviation expressed in percentage of mean monthly values. For the Northern Plains of West Java, monthly and annual potential evapotranspiration totals for extended periods of time are available only for Jakarta. However, data for Jakarta can be taken as representative for the area as a whole. Calculated monthly and annual potential evapotranspiration totals covering a 12 year period from 1965 to 1975 for Jakarta are portrayed in Table 19. From Table 19 it can be seen that variability in potential evapotranspiration is fairly constant from month to month. The standard deviation ranges from a low of 17.4 millimeters in May to a high of 29.1 millimeters in October. The variability of potential evapotranspiration ranges from 14 percent in May to 23 percent in October with an annual variability of 12 percent.

Monthly and annual totals for the Penman estimates of potential evapotranspiration have been determined, for periods varying from seven to eleven years, at fourteen East African stations (Woodhead and Waweru, 1970). At each site these annual and monthly totals are normally distributed, with coefficients of variation of the order of 5 to 10 percent, respectively. Measurements of Class A pan evaporation made in the United States (Kohler, Hordenton and Baker, 1959) suggested a coefficient of variation of about 10 percent for annual evaporation. Values in Indonesia are slightly higher than those in Africa and the United States, but are comparable.

# CHAPTER V

# THE WATER BALANCE

## METHODS OF COMPUTATION

In the water balance computation, rainfall is balanced against potential evapotranspiration in order to estimate the moisture content in the soil as well as the water deficit and the surplus water lost either in runoff or percolation. In order to carry out this computation it is necessary to know the moisture storage capacity of the soil, which is defined as the portion of water held in the soil between the field capacity and the permanent wilting point. The quantity of moisture any soil will hold depends chiefly upon the fineness of the soil particles, the quantity of organic matter, and the root depth of the plant. The use of an erroneous moisture storage value will greatly affect daily water balance calculations, but will introduce only a much smaller error in monthly computations. Thames and Ursic (1960), for instance have shown that estimates of surface runoff from daily water balance computation is strongly affected by moisture storage capacity.

The soil moisture storage value used in this study is 100 millimeters based on the standard value adopted by the Survey Team of the Institute of Agriculture in Bogor (1971) in Rentang, the Cimanuk river area. The value is determined by the type of soil found in the area. The value may vary slightly for different types of soil and crops.

In his early studies, Thornthwaite assumed that soil moisture is equally available between field capacity and permanent wilting point. Thus the computation of water balance was simple and straightforward.

Following this procedure, the sum of actual evapotranspiration and deficit should be equal to the potential evapotranspiration, and for any specific period without irrigation, the sum of actual evapotranspiration and surplus is equal to rainfall. This principle can be used to check the accuracy of the computation.

However, in a later study, Thornthwaite adopted a different procedure in which the soil moisture depletion rate decreases with the increase of soil moisture tension. The variation of evapotranspiration rate with soil moisture is a controversial subject. Veihmeyer and Hendrickson (1955) take the view that soil moisture has virtually no influence on transpiration provided that it does not fall below the permanent wilting point. Their view is partly supported by the work of Hagan, et al. (1957). On the other hand, Thornthwaite and Mather (1955) considered that the ratio of potential to actual evapotranspiration varies linearly with the amount of available water in the rooting zone. Their views have been supported by Makkink and van Heemst (1956), Slatyer (1956), West and Perkman (1953), and Taylor (1952) (see Figure 21).

Recent studies have shown that the relationship between evapotranspiration rate and soil moisture tension is dependent upon both atmospheric and soil factors. In humid, cloudy climates where the evaporative power is low, the Veihmeyer and Hendrickson relationship is more nearly correct. On the other hand, in arid climates, the Thornthwaite and Mather model is probably more realistic. The works of Scholte Ubing (1961), Holmes and Robertson (1963), Denmead and Shaw (1962), and Closs (1958) support Thornthwaite and Mather's point of view.

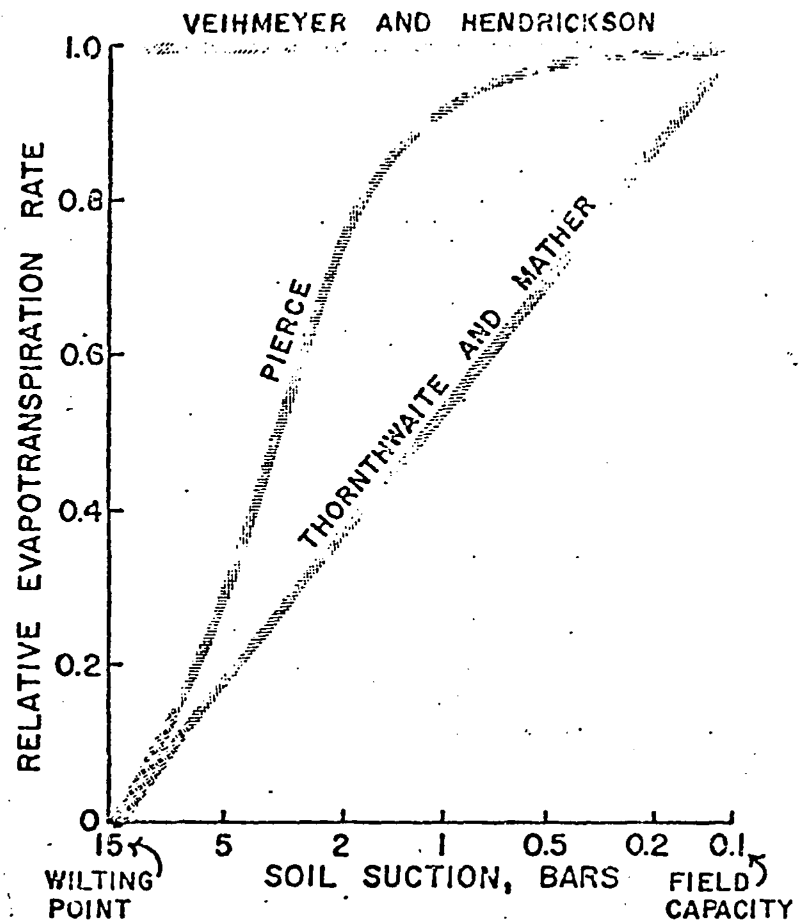



Figure 21. Soil Moisture Depletion Curves According to Thornthwaite, Veihmeyer and Hendrickson.

Penman (1968) argues that, from the standpoint of the energy budget approach, the Viehmeyer and Hendrickson concept cannot be faulted, and the evidence arrayed against it can probably all be explained by variations in depth of active soil profile and root depth. When the depth of soil is limited by a container or an impervious subsoil and the roots occupy all the soil, water should be readily available to the plants even at a relatively high soil moisture tension. On the other hand, if measurements of soil moisture profiles show significant drying below a shallow surface root zone, then it is misleading to say that the usable water is equal to the available water per unit depth multiplied by the depth of profile affected by the entire root action.

Since in Indonesia, the atmospheric condition is humid, cloudiness is high, subsoil is usually impervious, and crop roots usually do not penetrate to a great depth, the Veihmeyer and Hendrickson relationship is used in computation of water balance in this study. That is, water budget computations for this study are based on a soil moisture storage capacity of 100 millimeters, and a moisture depletion curve of the Veihmeyer and Hendrickson (1955) type where, between field capacity and permanent wilting point, evapotranspiration continues at the potential rate.

## COMPARISON OF DAILY AND MONTHLY WATER BALANCE COMPUTATIONS

Water balance can be computed either on a daily or a monthly basis. Almost all climatological water balance studies use only the monthly data, primarily because the computation of daily water balance requires voluminous daily observations which normally are not available from weather stations in most countries, and secondarily because of the tedious work required for its calculation. The difference between the daily and monthly computations is much greater in the tropics than in extra-tropical regions, as a result of very high rainfall intensity in the former. For instance, Olascoaga (1950) has shown that in some tropical stations 10 to 15 percent of the days with the highest rainfall account for 50 percent of the annual total, while 50 percent of the days with the lowest rainfall amount to only 10 percent of the annual total.

Another major factor contributing to the difference between daily and monthly water balance computation is that the total precipitation per month is not evenly distributed on a daily basis. Instead it is possible that one month will receive the majority of its rainfall in the first few days of the month while the following month receives its precipitation in the last few days of the month. On the basis of daily computations this produces a deficit condition while on the basis of monthly computations it may produce a surplus condition.

A comparison of daily and monthly water balance values for Jakarta during the period from 1964 to 1975 indicate that as the fluctuation in daily rainfall intensity increases, the correspondence between the monthly and daily water balance values decreases. When the rainfall is relatively evenly distributed, the monthly and daily surplus or deficit values are in close agreement. However, Jakarta's precipitation data for the twelve year period shows wide fluctuations in daily intensity. As a result, there are differences in daily and monthly water balance values. The daily surplus values are usually but not always slightly higher than the monthly values. (See Table 20 and Figure 22.) More important for agricultural practices, however, is the fact that, for deficits, the

Table 20

Monthly Water Balance Compared to the Daily Water Balance for Jakarta (1964-1975)

Station: Jakarta    Lat.: 6°11'S    Long.: 106°50'E    Elev.: 8 m

| | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | Daily | 50.8 | 74.5 | 60.2 | 29.0 | 34.2 | 0 | -72.8 | -36.1 | 23.7 | 40.9 | 30.8 | 0 | 235.2 |
| | Monthly | 48.3 | 54.0 | 77.9 | 8.8 | 53.4 | 0 | -76.5 | 0 | 0 | 8.4 | 10.4 | 0 | 184.7 |
| | | | | | | | | | | | | | | |
| 1965 | Daily | 510.3 | 132.7 | 175.6 | 42.8 | 0 | 5 | -30.0 | -116.5 | -52.2 | -112.4 | -6.3 | 164.8 | 743.8 |
| | Monthly | 546.9 | 135.6 | 144.8 | 16.4 | 22.6 | 0 | 0 | -106.9 | -52.2 | -112.4 | 0 | 255.0 | 849.8 |
| | | | | | | | | | | | | | | |
| 1966 | Daily | 59.5 | 145.2 | 162.8 | 13.3 | 61.4 | 54.4 | -78.1 | -108.4 | -89.2 | 28.2 | 121.8 | 52.8 | 423.7 |
| | Monthly | 80.5 | 141.2 | 161.7 | 20.1 | 61.3 | 0 | -21.7 | -108.5 | -89.2 | 18.9 | 131.1 | 23.1 | 418.5 |
| | | | | | | | | | | | | | | |
| 1967 | Daily | 300.8 | 467.8 | 164.4 | 51.9 | 18.3 | -74.2 | -107.1 | -118.6 | -137.7 | -104.7 | 74.1 | 198.7 | 733.7 |
| | Monthly | 328.1 | 468.7 | 133.8 | 79.5 | 0 | -51.0 | -107.1 | -118.6 | -137.7 | -104.7 | 70.8 | 199.9 | 761.7 |
| | | | | | | | | | | | | | | |
| 1968 | Daily | 250.5 | 305.3 | 99.7 | 48.0 | 44.3 | 120.5 | 57.2 | 98.3 | 0 | -62.3 | -7.4 | 30.7 | 984.8 |
| | Monthly | 252.6 | 305.3 | 92.2 | 46.5 | 53.3 | 106.8 | 67.8 | 98.7 | 0 | -59.6 | -6.0 | 26.8 | 984.4 |

Table 20 (continued)

Monthly Water Balance Compared to the Daily Water Balance for Jakarta (1964-1975)

Station: Jakarta Lat.: 6°11'S Long.: 106°50'E Elev.: 8 m

| | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1969 | Daily | 112.0 | 128.5 | 175.2 | 70.7 | 0 | 0 | -22.2 | -79.6 | 12.7 | 39.6 | 9.5 | 11.7 | 458.1 |
| | Monthly | 104.5 | 107.7 | 203.5 | 36.7 | 0 | 0 | 0 | -55.4 | 0 | 39.6 | 0 | 10.4 | |
| 1970 | Daily | 178.0 | 572.5 | 153.1 | 74.8 | 35.1 | 73.9 | 0 | -88.5 | -96.0 | -33.5 | 177.5 | 200.3 | 1247.2 |
| | Monthly | 183.0 | 578.3 | 154.4 | 79.3 | 34.2 | 33.2 | 0 | -46.9 | -96.0 | -3.1 | 142.7 | 204.6 | 1263.7 |
| 1971 | Daily | 144.3 | 522.8 | 202.6 | 3.2 | 32.1 | 103.5 | 32.4 | -72.4 | -97.1 | -8.1 | 53.8 | 43.8 | 960.9 |
| | Monthly | 144.3 | 522.8 | 196.4 | 0 | 9.3 | 131.5 | 0 | -35.6 | -96.4 | 0 | 40.1 | 27.0 | 939.4 |
| 1972 | Daily | 423.9 | 143.4 | 163.1 | 48.3 | 108.7 | -13.8 | -74.7 | -60.1 | -129.1 | -125.5 | -72.0 | -40.8 | 370.4 |
| | Monthly | 438.6 | 150.5 | 158.0 | 39.4 | 100.1 | 0 | -29.0 | -90.0 | -129.1 | -122.4 | -75.1 | 0 | 441.0 |
| 1973 | Daily | 202.4 | 314.8 | 273.4 | 115.9 | 120.3 | 0 | 0 | -2.4 | -28.3 | 91.8 | 0 | 183.9 | 1271.8 |
| | Monthly | 159.2 | 307.3 | 281.4 | 117.8 | 110.9 | 0 | 0 | -7.3 | 0 | 63.5 | 0 | 183.7 | 1216.5 |

Table 20 (continued)

Monthly Water Balance Compared to the Daily Water Balance for Jakarta (1964-1975)

Station: Jakarta Lat.: 6°11'S Long.: 106°50'E Elev.: 8 m

| | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1974 | Daily | 506.5 | 325.0 | 255.4 | 1.8 | 67.0 | 0 | 0 | 0 | 42.4 | 0 | -13.8 | 96.8 | 1281.1 |
| | Monthly | 506.1 | 325.6 | 245.6 | 0 | 44.3 | 7.5 | 0 | 0 | 22.3 | 0 | 30.2 | 81.7 | 1263.3 |
| | | | | | | | | | | | | | | |
| 1975 | Daily | 64.1 | 245.3 | 110.7 | 45.5 | 30.8 | 16.7 | -7.0 | -21.7 | -4.5 | 173.4 | 68.6 | 0 | 721.9 |
| | Monthly | 81.8 | 234.1 | 111.8 | 39.9 | 46.2 | 0 | 0 | 0 | 0 | 155.1 | 61.7 | 0 | 730.6 |

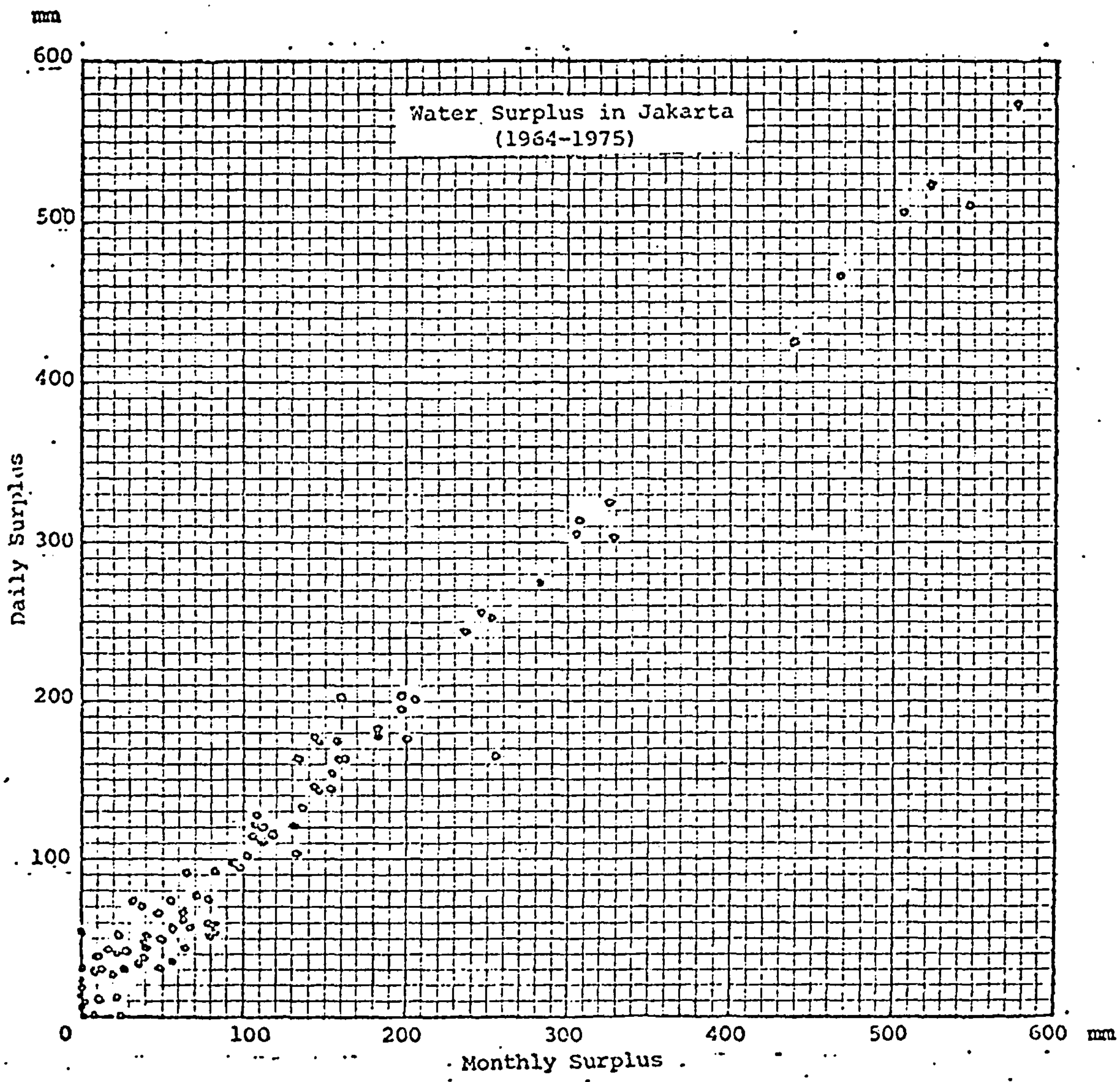



Figure 22. Water Surplus in Jakarta (1964-1975): the Monthly Against the Daily Water Balance Surplus.

daily values are nearly always higher than the monthly values, that is, the daily computations reveal a more serious deficit than the monthly computations, though both show a deficit. In fact, for the entire twelve year period, only once does the monthly water balance calculation show a distinctively greater deficit value than the daily computation (see Table 20 and Figure 23). In addition, what is critically important for the regulation of irrigation is that the daily water balance computation shows more accurately exactly when the deficit condition begins and ends.

This clearly shows that, for irrigation planning, the daily water balance computation is more effective and must be employed whenever possible. When the daily water balance data are not available, surplus and deficit values derived from monthly water balance calculations must be used with the understanding that there is a certain degree of inaccuracy. Monthly values underestimate the actual deficit. Where possible, the degree of underestimation should be calculated by applying the correlation coefficient of linear regression obtained from the comparison between daily and monthly values from a station with similar meteorological conditions.

WATER DEFICIT

Water deficit is equivalent to the volume of water necessary to prevent soil moisture from falling below the permanent wilting point. It provides useful information for long range planning of water resources development as well as for allocation of irrigation water (short period practices). Ideally, irrigation should be first applied to the area with the highest deficit. This would protect against prolonged drought in any

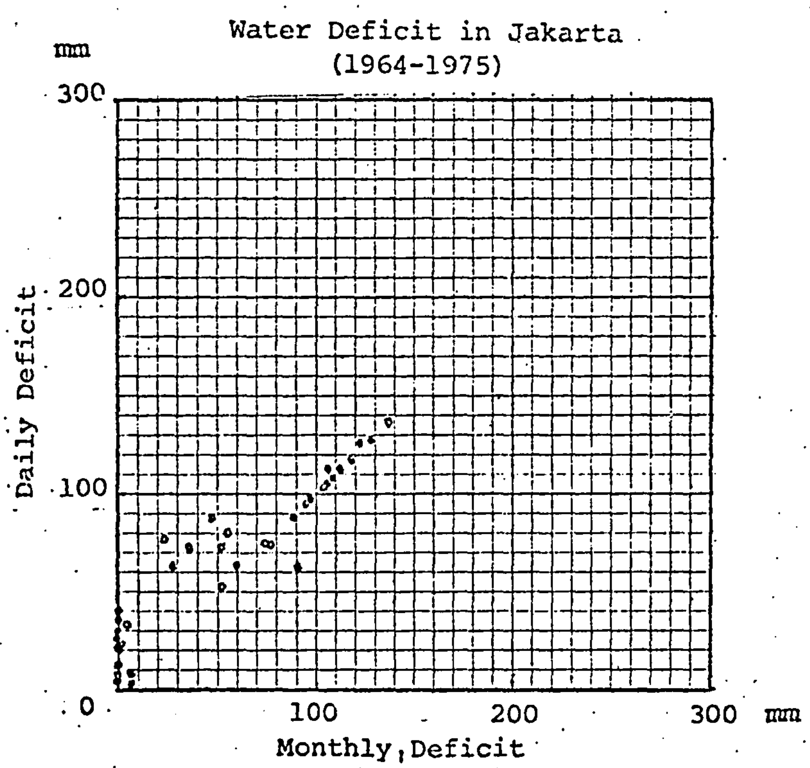



Figure 23. Water Deficit in Jakarta (1964-1975): the Monthly Against the Daily Water Balance Deficit.

area and would give the maximum yield return with the available amount of water.

Monthly water balance calculations for the eight stations located on the Northern Plains of West Java are presented in Figures 24 through 31. From these diagrams it can be shown that, across the Northern Plains, conditions range from no deficit at all in Subang, to severe deficits in Cirebon, Jatiwangi, and Tersanabaru. In general, the Northern Plains can be divided into two areas, the western part with small or no deficits, from Serang to Subang, and the eastern part with serious deficits, increasing eastward from Subang. The deficit period in the western part ranges from zero months in Subang to four months in Jakarta. However, zero deficit in Subang is most likely attributable to its more interior and higher location. The eastern portion of the Northern Plains is characterized by long and intense deficits. Jatiwangi has a deficit condition from June to mid-October, Cirebon from June to mid-November, and Tersanabaru from June to the beginning of December. In addition to long deficit periods, these stations also reveal that the deficits are more intense, especially during August when the deficit value reaches 160 millimeters in Cirebon.

These findings indicate that, in irrigation planning, the greatest stress must be placed on the eastern portions of the Northern Plains, where accurate daily water balance calculations are imperative.

Individual Stations

In Serang, starting from July, rainfall is below potential evapotranspiration, but the amount of rainfall coupled with the soil moisture storage is still enough to prevent water deficit conditions until

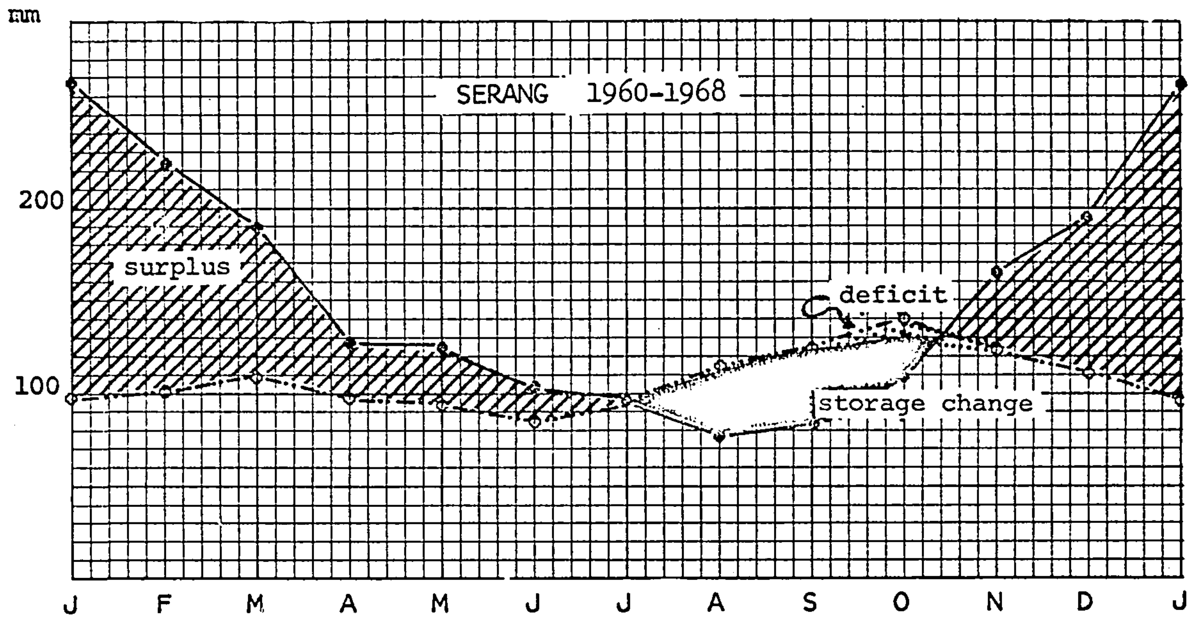



Figure 24. Monthly Water Balance for Serang (1960-1968).

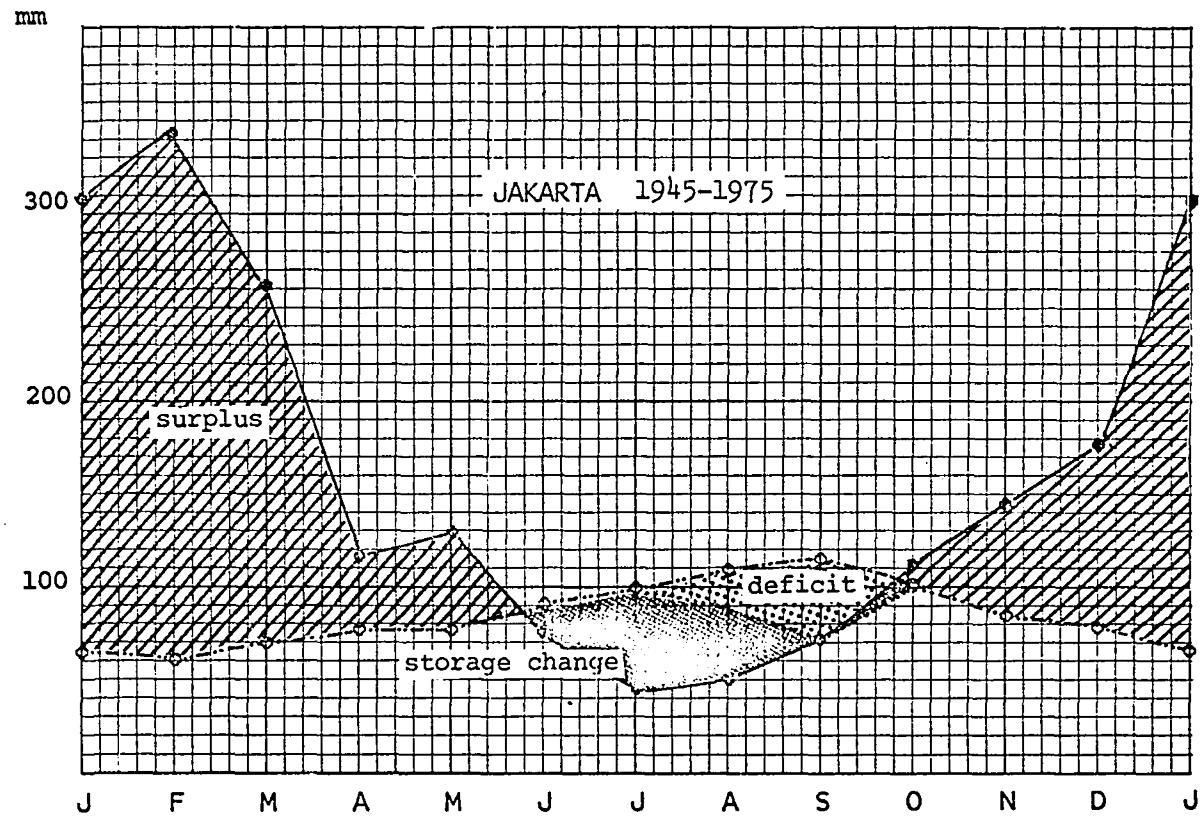



Figure 25. Monthly Water Balance for Jakarta (1945-1975).

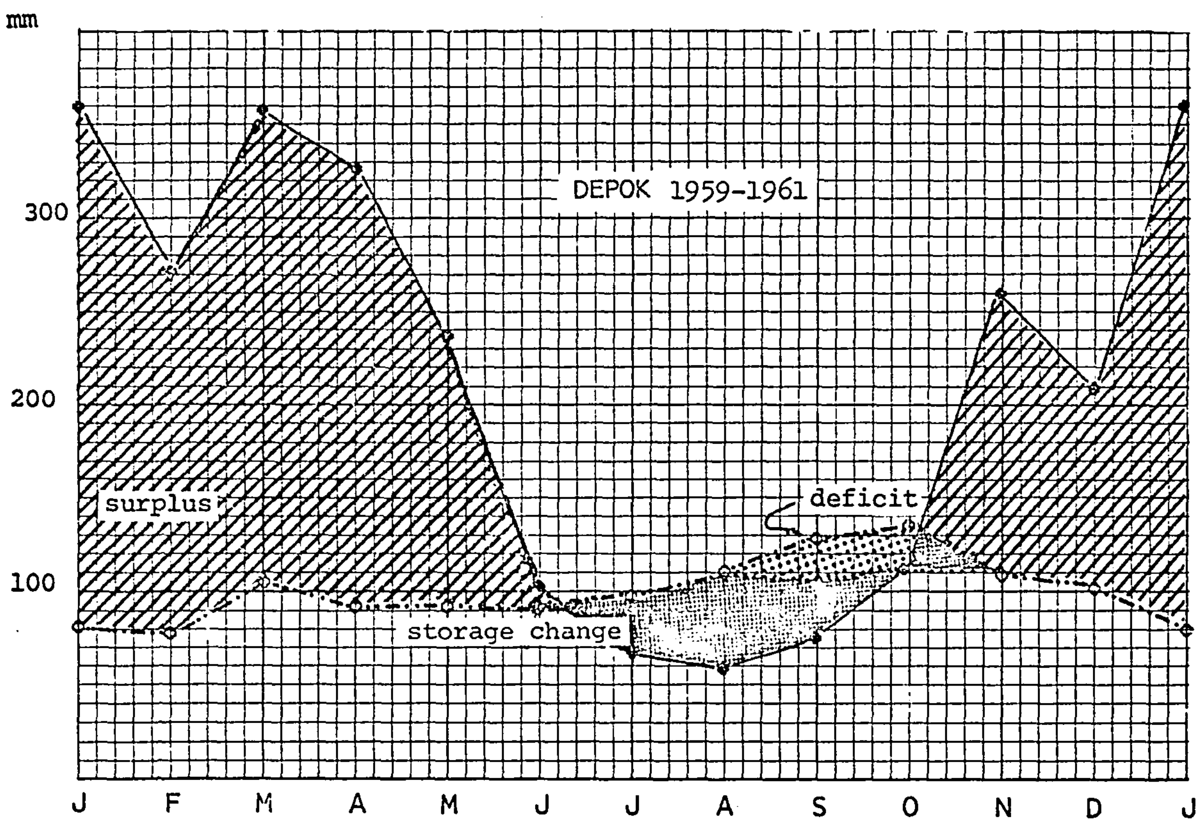



Figure 26. Monthly Water Balance for Depok (1959-1961).

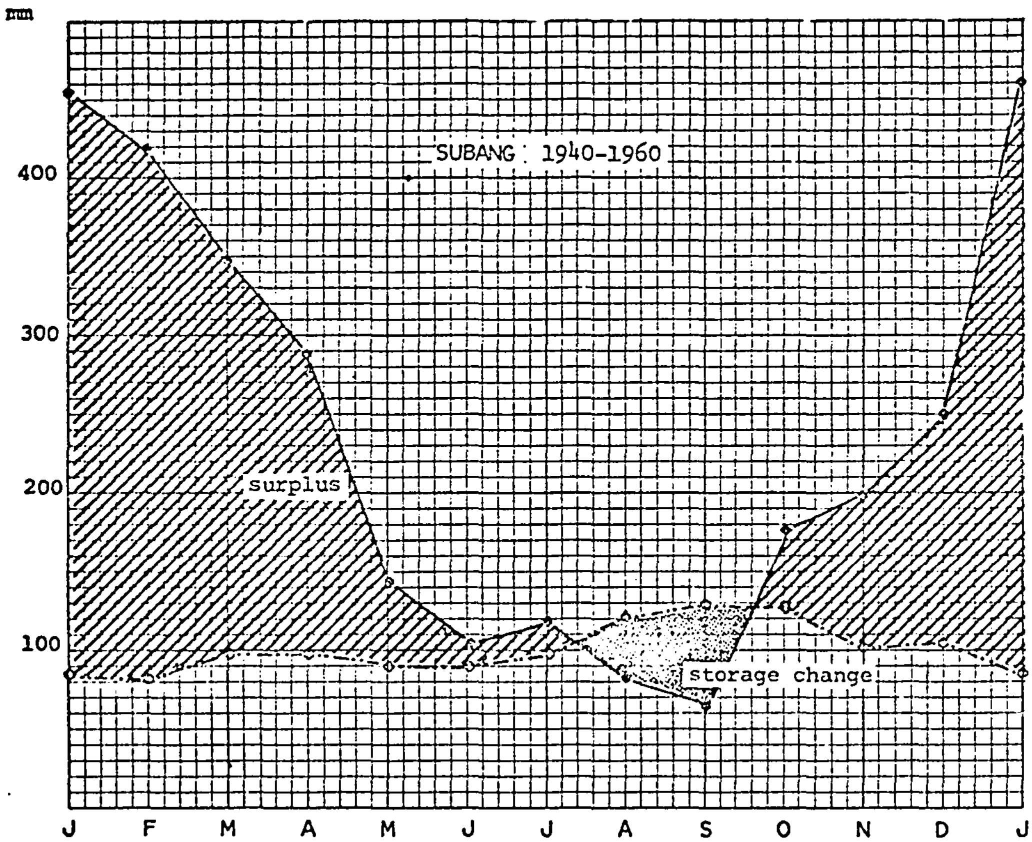



Figure 27. Monthly Water Balance for Subang (1940-1960).

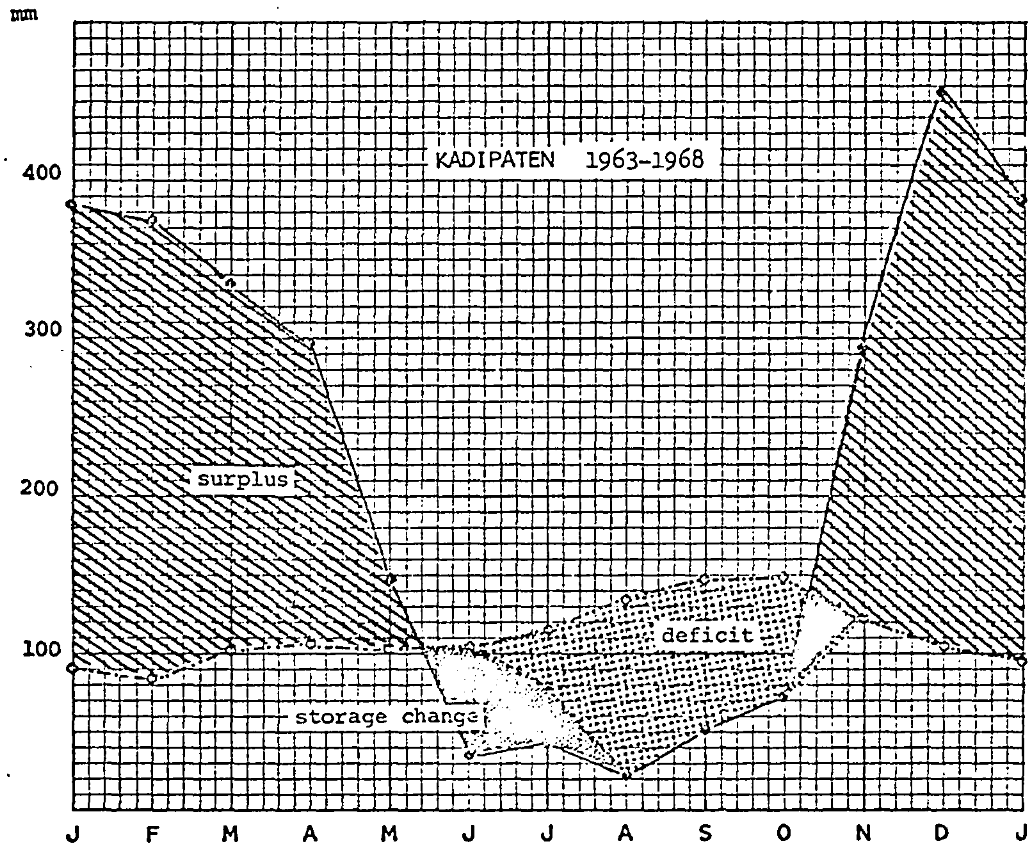



Figure 28. Monthly Water Balance for Kadipaten (1963-1968).

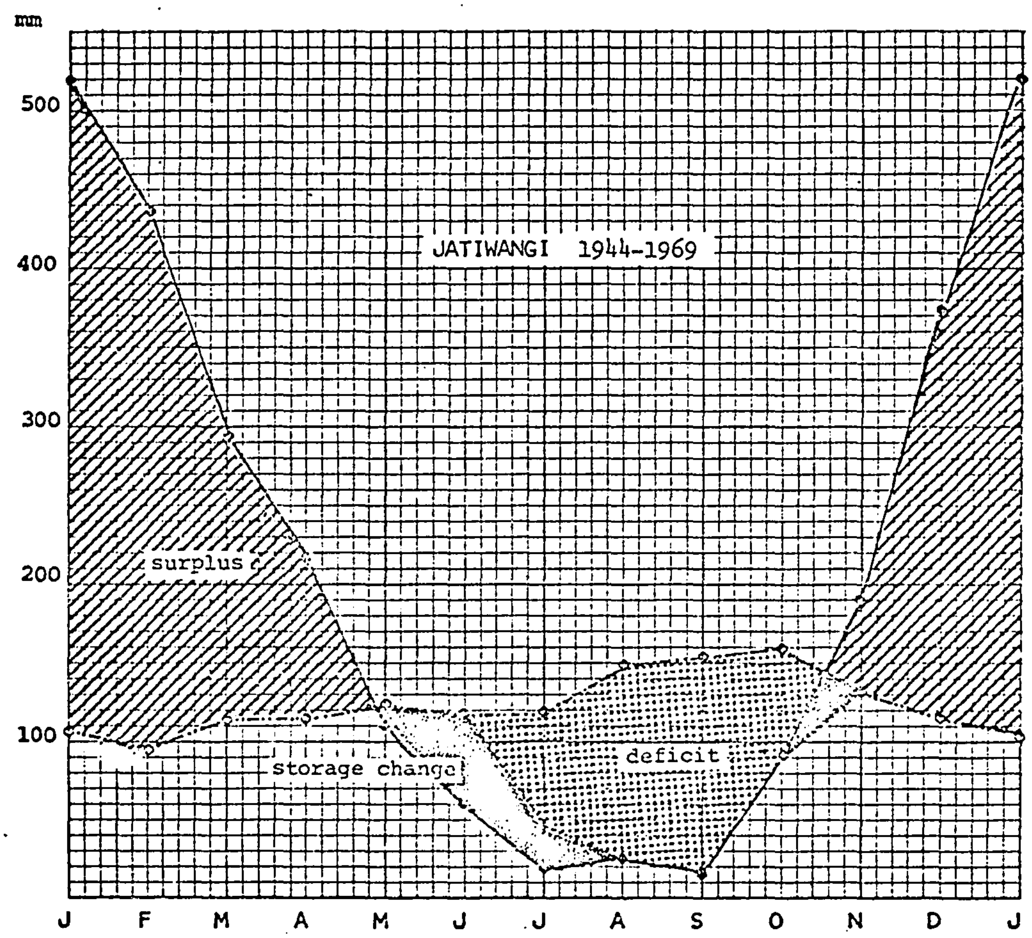



Figure 29. Monthly Water Balance for Jatiwangi (1944-1969).

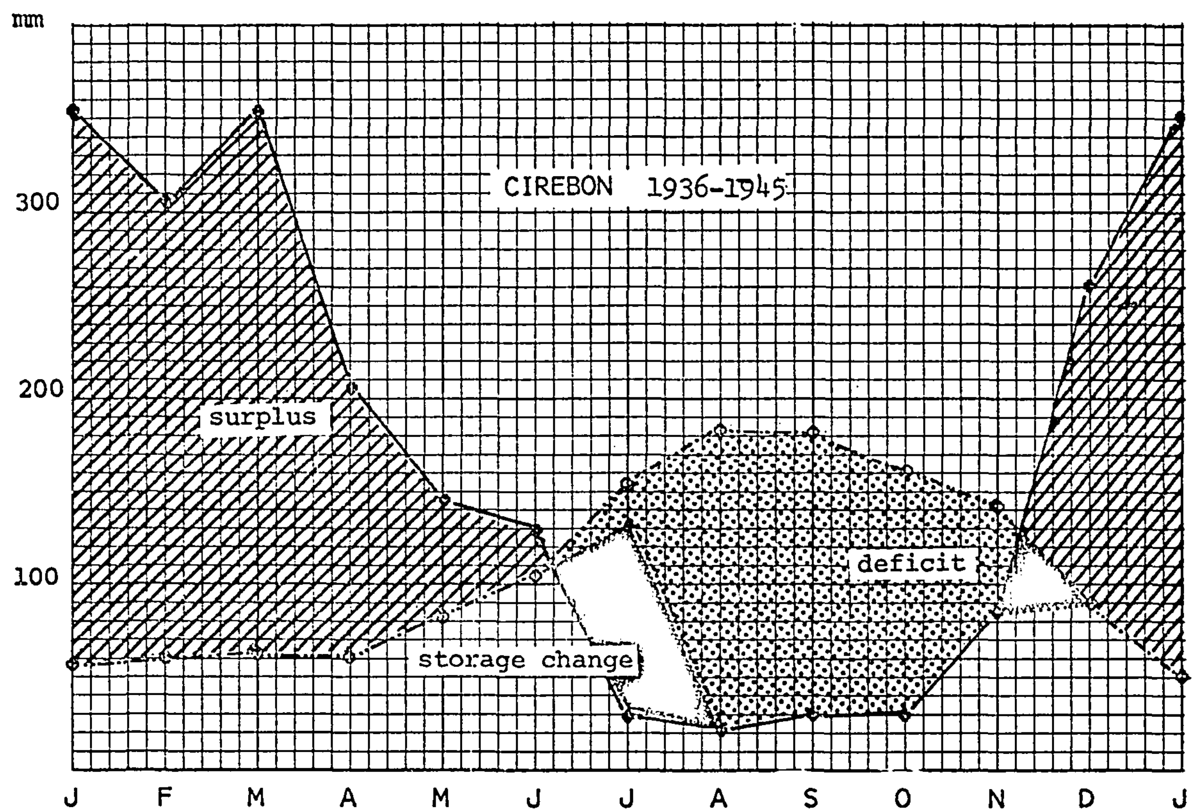



Figure 30. Monthly Water Balance for Cirebon (1936-1945).

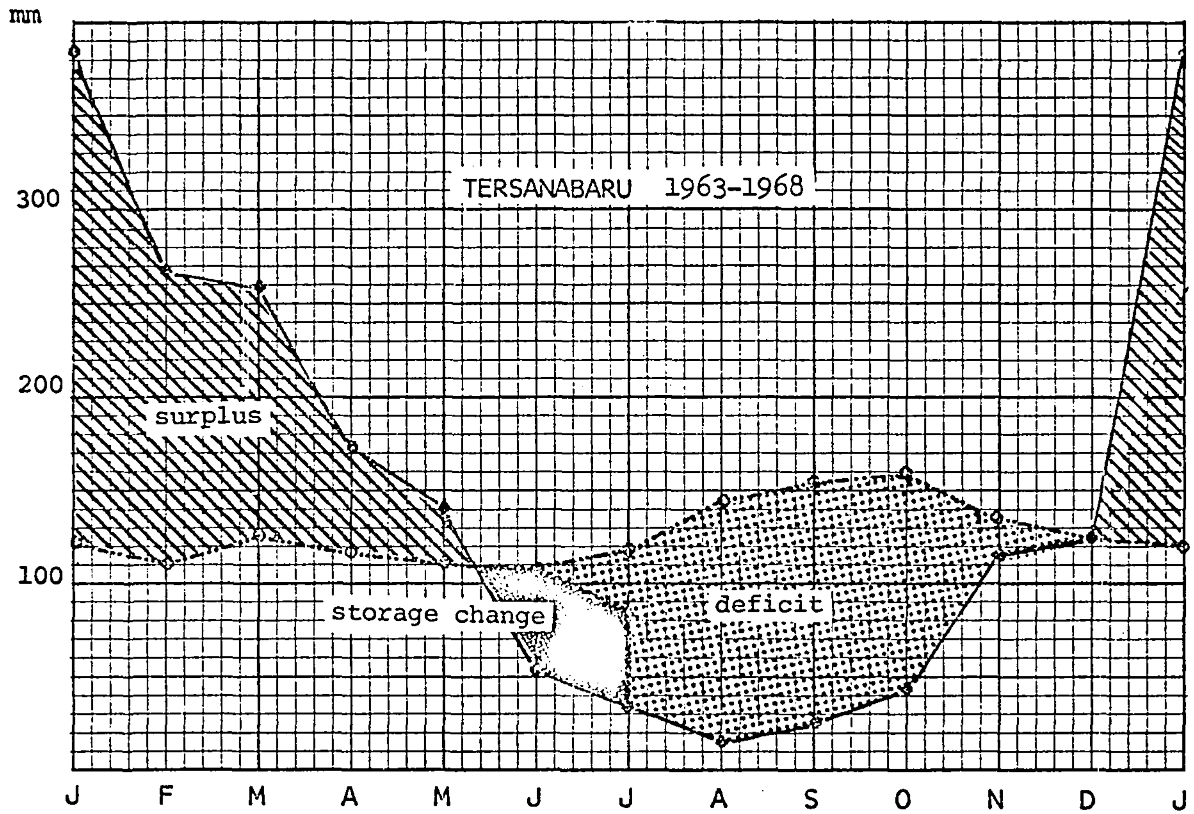



Figure 31. Monthly Water Balance for Tersanabaru (1963-1968).

September when soil moisture is completely depleted. For about one and a half months, Serang experiences deficit conditions, and then about the second week of October, rainfall normally exceeds potential evapotranspiration once again.

Beginning in June, rainfall in Jakarta is usually lower than potential evapotranspiration, thus water must be withdrawn from soil moisture storage. The real deficit starts in July and lasts to the end of September. Calm weather usually marks the onset of the wet season in this area.

Depok's heavy rains in the wet season fall off rather abruptly in June, but still provide enough moisture, together with soil storage, to prevent water deficit. From August to the beginning of October, however, a deficit condition exists. The heavy rains start again around October.

Subang occupies an exceptional position in the Northern Plains, for in the twelve year period under study, it never experienced a deficit condition on the basis of monthly water balance computations. Its dry season is very short, lasting only from mid-July to mid-September. Even in the dry season, rains still occur occasionally, and though less than the potential evapotranspiration, they are enough to keep Subang from water deficit condtions, at least on a monthly basis.

Kadipaten (see Figure 28), located in the eastern part of the Northern Plains, has a long and intense deficit, starting from June to the second week of October. This pattern of serious and long-lasting deficit conditions is characteristic of the remaining three stations to the east, Jatiwangi, Cirebon, and Tersanabaru (see Figures 29-31).

## WATER SURPLUS

Calculation of surplus during periods when the soil moisture storage capacity is full is of hydrological and pedological interest and may also be important for estimating salt or nutrient leaching from soils and the rate of soil erosion. For hydrological purposes it is important to know the probability of flooding and the potential for storing water surplus for irrigation purposes.

In general terms, the water surplus period in the western part of the Northern Plains is longer than in the east. The transition between the two monsoon seasons appears smoother, i.e., there is no sudden change in seasons in the western part. In the eastern areas, the wet season is shorter, but the rains are more intense and thus result in more frequent floods.

The surplus periods generally extend from October to June with peaks in January, except Kadipaten with a peak in December, and Jakarta with one in February. Cirebon and Depok experience second peaks in March.

### Individual Stations

The surplus months for Serang extend from mid-October to July with a peak in January amounting to 170 millimeters. Floods are common during December and January.

For Depok, too, the surplus covers nearly the same period, lasting from October to June, but there are two peaks, one in January and one in March, averaging 280 millimeters and 260 millimeters respectively. The February depression coincides with the peak surplus in Jakarta, and is apparently brought about, at least in part, by Jakarta's location north of Depok on Jakarta Bay. As a result, it catches most of the February rains, for at that time, the effects of the northwest winds are combined with those of the sea breeze.

Subang's surplus period is exceptionally long, extending from mid-September to mid-July, and in addition, the dry season receives sufficient rainfall so that, combined with soil moisture storage, a deficit condition does not develop.

Kadipaten has a surplus period from early November to mid-May. The surplus values increase rapidly from the beginning of the wet season. The peak surplus of 350 millimeters is reached early in December, drops gradually to 200 millimeters in April, and then drops again sharply at the beginning of May when rainfall becomes less than potential evapotranspiration. The occurrence of sudden heavy rains which last for days is common, resulting in frequent floods.

Jatiwangi has almost the same water balance pattern as Kadipaten with the difference being that Jatiwangi's peak is in January at 400 millimeters, and both slopes of increase and decrease in rainfall are steep. Flooding can be severe, but is generally of shorter duration.

The surplus period for Cirebon begins in early November and continues to June. The wet season often starts suddenly, after severe drought, with heavy, long-lasting rains. Two surplus peaks, reaching 300 millimeters, occur in January and March with a low depression in February. The cause of this depression is not clear, and should be the subject of research. Floods are expected to occur during the peaks in January and March.

The easternmost station, Tersanabaru, experiences a surplus from December to mid-May, with a peak in January. The increase in rainfall intensity is rapid, reaching 200 millimeters maximum and then beginning a slow decrease to the dry period.

It is evident from the analysis of the existing data that although the Northern Plains of Java in many locations experience water deficit for several months, there is sufficient surplus during the wet season to allow storage of water for irrigation.

# CHAPTER VI

# RELATIONSHIP BETWEEN WATER BALANCE AND AGRICULTURAL PRODUCTION

## VARIATION OF AGRICULTURAL PRODUCTION

Over 70 percent of the cultivated area in the Northern Plains is under rice. Crops other than rice are grown only in those areas where there is not enough water available for rice production. Intensive agricultural techniques have been applied in this area to improve rice production, including fertilizer and pesticide application, introduction of high yielding rice varieties, and the regulation of water resources. However, in terms of water management, the steps taken so far have provided irrigation water to some areas and have lessened the danger of floods, but have never been carefully and continuously correlated with the climatic water balance for optimum water management and maximum agricultural production.

If one examines the yield figures for rice production in West Java during the period of 1955-1973 (see Table 21), it is apparent that there is a trend towards increased yield. During this time, the Indonesian government was introducing the new intensive agricultural practices which contributed to this general trend of increased production. However, fluctuations are still found in the yields, and there is an indication that the depressions in yield are correlated with several drought experiences in West Java. For example, production depressions occurred in 1967 and 1972, corresponding with times of severe drought in West Java, and 1976 was, again, a dry year. Although production figures are

Table 21

Annual Rice Production
West Java *)

| | Harvested area (Ha) | | Production (ton) | | Yield rates (100 kg/ha) | |
|---|---|---|---|---|---|---|
| | Sawah | Ladang | Sawah | Ladang | Sawah | Ladang |
| 1955 | 1,872,247 | 122,520 | 4,156.324 | 142,173 | 22.20 | 11.60 |
| 1956 | 1,957,511 | 110,875 | 4,286,628 | 132,220 | 21.19 | 11.92 |
| 1957 | 1,984,819 | 126,837 | 4,292,321 | 154,976 | 21.62 | 12.22 |
| 1958 | 1,976,304 | 138,124 | 4,321,397 | 143,890 | 21.87 | 10.42 |
| 1959 | 1,986,065 | 141,762 | 4,435,916 | 174,537 | 22.33 | 12.31 |
| 1960 | 1,923,671 | 173,911 | 4,267,459 | 233,752 | 22.18 | 13.44 |
| 1961 to 1964 Average | 1,692,536 | 230,665 | 4,043,947 | 300,200 | 23.89 | 13.01 |
| 1965 | 1,393,207 | 229,110 | 3,521,267 | 309,490 | 25.27 | 13.51 |
| 1966 | 1,413,186 | 261,111 | 3,536,658 | 396,342 | 25.03 | 15.18 |
| 1967 | 1,359,690 | 216,784 | 3,335,829 | 335,839 | 24.53 | 15.49 |
| 1968 | 1,492,711 | 220,531 | 3,752,731 | 295,680 | 25.14 | 13.41 |
| 1969 | 1,531,598 | 180,504 | 4,147,165 | 273,452 | 27.08 | 15.15 |
| 1970 | 1,538,797 | 188,739 | 4,672,989 | 290,327 | 30.37 | 15.38 |
| 1971 | 1,592,035 | 195,319 | 5,980,793 | 276,771 | 37.57 | 14.17 |
| 1972 | 1,568,145 | 163,925 | 4,926,694 | 272,449 | 31.42 | 16.62 |
| 1973 | 1,715,531 | 163,045 | 6,441,377 | 251,034 | 37.55 | 15.40 |

Source: Direktoral Djendral, Biro Tanaman Prodecksi, Dep. Pertarian R.I.

*) West Java includes the provinces of West Javan and Jakarta D.K.I.

not yet available for 1976, rice prices rose, and the government was forced to import more rice.

For a more accurate analysis of the relationship between production fluctuations and drought, it is necessary to compare the water balance with yield figures for a representative area in the Northern Plains. The only station which has the requisite data is Jakarta (see Table 22). Low yields occurred during the years 1970, 1971, and 1972, and generally coincide with long period deficits in the water balance. Although there is a general correspondence between low yields and long period deficits, it must be remembered that other factors may be skewing the pattern. For example, in 1970 Jakarta experienced very low rice yields, but these were caused not only by deficit conditions, but also by serious insect infestations. For this reason, it is most unfortunate that data for water balance computation and yields are not available for corresponding periods in the other stations.

WATER REQUIREMENTS OF MAJOR CROPS

When planning for increased agricultural production through improved irrigation, it is impossible to produce a sound design without taking into account the water requirements of the crops concerned. It is generally agreed that there is much opportunity for improving agricultural production in the developing countries through reorganization of the cropping patterns to better coincide with the agro-climatic environment (Das, 1972).

In the Northern Plains of West Java, the major crop is rice, but secondary crops such as peanuts, watermelon, cassava and sweet potatoes

Table 22

Annual Rice Production in Jakarta
(kg/ha)

| Year | sawah (wet rice field) | ladang (dry rice field) |
|---|---|---|
| 1964 | 2,092 | 1,717 |
| 1965 | 2,238 | 1,809 |
| 1966 | 2,452 | 1,501 |
| 1967 | 2,248 | 1,317 |
| 1968 | 2,255 | 1,126 |
| 1969 | 2,106 | 1,492 |
| 1970 | 1,638 | 1,433 |
| 1971 | 2,135 | 1,421 |
| 1972 | 2,014 | 1,356 |

Source: Direktorat Jendral Bina Tanaman Produksi, Departemen Pertanian Republik Indonesia are also produced. Although it is obvious that the water requirements for these plants depend upon soil type and meteorological conditions, and the stage of plant development, such data are not available. The only data which can be presented are based on the findings of the Institute of Agriculture in Bogor for consumptive use in experimental plots in Rentang, located in the Cimanuk Basin.

The consumptive use (evapotranspiration from plants) for early maturing lowland rice varieties (120 to 135 days) in the growing period of November - March, is estimated at 805.06 millimeters. This is equivalent to 8,050.6 cubic meters per hectare or an average of 0.69 liter per second per hectare.

In the growing period of April - August, the consumptive use is estimated at 784.74 millimeters, which is equivalent to 7,847.4 cubic meters per hectare or an average of 0.67 liter per second per hectare.

For the late maturing varieties (150 to 165 days) in the period of November - April, the figure shows 987.46 millimeters or 9,874.6 cubic meters per hectare, or 0.69 liter per second per hectare. If cultivated from May to September, the consumptive use is 806.21 millimeters or 8,062.1 cubic meters per hectare, or 0.79 liter per second per hectare.

The irrigation requirement of early maturing lowland rice varieties, from November to March, is estimated at 821.04 millimeters or 8,210.4 cubic meters per hectare, thus an average of 0.70 liter per second per hectare (wet season).

For the growing period of April - August (dry season), the water need for irrigation is estimated at 1,057.37 millimeters or 10,573.7 cubic meters per hectare, or 0.91 liter per second per hectare.

For the late maturing lowland rice for the growing period of November - April, water needed for irrigation is calculated at 989.92 millimeters or 9,899.2 cubic meters per hectare, or 0.69 liter per second per hectare (wet season). For the period of May - September (dry season), the figure is 1,177.57 millimeters, thus 11,775.7 cubic meters per hectare, or 1.01 liters per second.

However, the irrigation requirement is based not only on consumptive use of plants, but also depends on the efficiency of water conveyance which is in turn dependent upon soil types, air humidity, canal conditions and distance. Based on calculations by the Institute of Agriculture, Bogor, from the Rentang lowland experimental plots in the Northern Plains, the water need for irrigation is 0.88 liter per second per hectare in the wet season and 1.26 liters per second per hectare in the dry season. During the soil cultivation period, even more water is needed, i.e., about 1.57 liters per second per hectare.

The consumptive use of the secondary crops, including corn, peanuts, and watermelon, in the growing period of May - July is calculated at 3.721.3 cubic meters, 3.146.3 cubic meters, and 3,217.6 cubic meters per hectare, respectively. For August - November (the second period), the consumptive use for these crops is 4,152.7 cubic meters, 3,329.8 cubic meters, and 3,443.5 cubic meters per hectare respectively.

The irrigation requirements for these crops are much less than those for rice. For the growing period of May - July (first period), the amount needed for corn, peanuts and watermelon is 2,069.8 cubic meters, 1,194.8 cubic meters, and 1,366.1 cubic meters per hectare respectively. For the second period, from August to November, the irrigation requirement for these second crops is 2,976.2 cubic meters, 2,153.3 cubic meters, and 2,267.0 cubic meters per hectare, respectively.

WATER MANAGEMENT

The success or failure of plans to increase rice production through double cropping depends heavily upon the accuracy of management in the distribution of stored water surplus. Such water management has several aspects.

First, the amount available to be stored from the water surplus must be known, and that amount had already been calculated before the design of the Integrated Irrigation System for the Northern Plains.

A second, and most important requirement, is computation of the water balance on a daily basis, thus deficit periods can be exactly defined in terms of when they begin, what their extent is, and when they end, so that irrigation water can be applied precisely when it is needed, in the amount required, and can be stopped when no longer necessary so that no water is wasted. There are two problems with this aspect of water management for the Northern Plains. First of all, those involved with the planning, construction, maintenance, and functioning of the Integrated Irrigation System are not yet aware of the need for daily water balance computations, and second, even if such computations were accepted as a requirement for efficient management, the data needed for such computations are not available from weather stations in the Northern Plains, with the exception of Jakarta. It is most important that the government take steps to insure the recording of the necessary meteorological data.

A third aspect is that the above information must be correlated with crop distribution in the Northern Plains, the consumptive use of those crops, including not only total consumptive use but also the water requirement at various stages in the growth cycle, and also with soil types, so that the percolation and seepage rates can be calculated and the soil storage capacity known.

Finally, in applying irrigation water, the canal conveyance system must be examined closely, and recommendations made for improving control of water from the tertiary and field channels so that exact amounts of water can be applied. That is, the loss during distribution through the canal system must be a known value, so that allowance can be made for it, and the design can be improved to allow maximum effectiveness.

In the matter of conveyance, studies at the International Rice Research Institute in the Philippines have shown that the major problem is getting enough water to the farther reaches of the primary distribution canals. The movement of water laterally away from the canals seems to be satisfactory even in the traditional systems of the area where the density of farm channels is low. One reason is that the *sawah* close to the canal tend to be high in elevation and to have light soil texture, while those farther away are closer to the water table and have heavier soil. As a result the farther *sawah* have a lower water requirement which compensates for their greater distance from the source of the water.

The existing and proposed irrigation networks for the Northern Plains have the capacity to store much of the yearly water surplus for distribution of irrigation to *sawah* hectarages during the dry season.

However, the real problem lies not in the building of more reservoirs, but instead with management of the stored water. The present distribution of water is not based on careful, accurate, and continuing computation of the degree and timing of the deficit periods, because, as discussed earlier in this study, the requisite data are not available.

# CHAPTER VII

## SUMMARY

Indonesia is an agricultural country. Since independence, the Government of Indonesia has been able to direct its attention to economic development and to improving the prosperity of its citizens. In the Five Year Plans, aimed at raising the standard of living, development in the economic sector has been focused on two segments, namely in the field of agriculture and industry. Between the two, the government has given priority to development in the agricultural sector rather than the industrial sector. This decision was based on the reasoning that factors involved in agricultural development were more promising at present in Indonesia than those pertinent to industrial development. Indonesia has a number of advantages, for example, soils which are relatively fertile, or if not fertile, capable of improvement. Its climate is good for agriculture, with sufficient water, and there are large numbers of farmers experienced in traditional methods.

Indonesia has two major types of agriculture, i.e., peasant agriculture and estate agriculture, producing primarily food crops and export products respectively. In considering peasant agriculture, the most important aspect is rice production, since the major food for Indonesian people in general is rice. The island of Java is the largest producer of rice, while other larger islands produce agricultural export goods. As a result, the majority of the other islands must import a part of their rice needs from Java.

The area of greatest rice production on Java is West Java, although Central and East Java also are large rice producers. West Java's major rice-producing area is located along the north coastal lowlands. In addition to this area, other rice growing regions in West Java include the Bandung basin, Garut, Sukabumi, and smaller valleys and basins scattered throughout the province. However, since early times, the area known as the rice granary for Java has been the Northern Plains of West Java. During the war between Sultan Agung of Mataram and Jan Pieterzoon Coen with his fort at Batavia, Sultan Agung used the area around Karawang on the Northern Plains as a supplier and warehouse for the vast amounts of rice needed for his warriors as they stormed the fort at Batavia.

Presently, the Government of Indonesia is striving to increase rice production in this plains area, but in actuality, the effort to improve production in the north coastal plain dates back to Dutch times. Dutch experts long searched for means of improving the standard of living for the population of the Netherlands Indies.

One such plan was outlined by the Dutch Administration, called Welvaartszorg voor Nederlandsch Indie, or welfare care for the Nederlands Indies. It was suggested that efforts which must be used by the government to improve the prosperity of the people were threefold. One was the intensification of agriculture, including irrigation, improved rice varieties, fertilizer application, improved efforts in combatting pests and insects, and improvement of agricultural techniques in rice planting. The second was the transmigration effort to move people from densely populated Java, Madura and Bali, to less densely populated lands in the outer islands. Finally, it was suggested that the industrialization should be a third goal to improve the welfare of the country. The Government of Indonesia has incorporated these three directions in its development plans.

A Dutch engineer, van Blommestein, concerned with the need to increase rice production and stimulate Indonesia's economy, proposed plans for an Integrated Irrigation System for the Northern Plains of West Java. His plan has formed the basis for the Government of Indonesia development projects in that area. Under the plan, all rivers found in the area are to be connected by canals, so that water from rivers with surplus flow can be directed to those agricultural areas whose rivers cannot supply enough to irrigate in the dry season.

The main source of water in the Northern Plains is the Citarum river, located in the central portion and cutting the plains into two approximate halves, the western portion and the eastern portion. The Citarum has a surplus of water which can be held in three reservoirs, the total capacity will be more than 5,000 million cubic meters. At present one dam, Jatiluhur, has been completed forming a reservoir with a storage capacity of 3,000 million cubic meters. Two other reservoirs called for in van Blommestein's design, Lake Tarum and Lake Cirata, were to be built at higher elevations on the Citarum. From the Jatiluhur Dam, surplus water can be channeled to the north through Curug dam. From there a primary canal, Tarum Barat, runs west to the rivers Bekasi, Ciliwung, Cisedane, Cidurian and Ciujung. In this western portion, approximately 24,000 hectares of sawah can be irrigated. Some of the water from Curug is channeled to the east through the primary canal, Tarum Timur. This canal connects with the rivers Cipunegara and Cimanuk. The area which can be irrigtated is also approximately 24,000 hectares. In addition to the two primary canals already mentioned, one more leads off to the north, Tarum Utara; this provides irrigation directly to extensive sawah lands in that area again totaling approximately 24,000 hectares.

The Integrated Irrigation System has been finished, but even during its construction, and since its completion, it has been evident that the projected target in terms of hectarage of technically irrigated sawah has not been reached. The cause may have been partially due to factors not taken into account in the original design for irrigation. Apparently, those factors considered in the original plan included, first, the total surplus of water available from the rivers to be harnessed, and second, the total amount of water needed to irrigate sawah normally not cultivated in the dry season because of water shortage. Thus, the system of irrigation is based only on the surplus of water in the rainy season which can be harnessed and channeled to meet the needs of those sawah areas which experience a deficit in the dry season. However, knowledge about the total amount of water needed, and exactly when, where and for how long it was needed, was insufficient. For such precision, it is necessary to have detailed water balance information, including not only the monthly water balance, but the daily water balance as well. Only with the daily computations can it be accurately known when a deficit period begins and irrigation water is required in a given area, how much is needed, and for what period of time.

The water balance computation, calculated on a daily basis, has never been figured for the Northern Plains. In addition, water balance calculations which were carried out to determine the extent of the dry season water deficit in the agricultural areas of the Northern Plains did not include all pertinent water balance components. The computation used at the time to calculate irrigation needs was the monthly water balance, and it did not make use of the soil storage component, so that the calculations were not as accurate as they might have been. It is understandable, if such calculations form the basis of the irrigation scheme, that the results did not reach the target. Of course, it still has provided improvements in agricultural conditions, but not at the level which might have been attained with complete calculations.

In this study the aim was to compute daily water balance and compare the results with monthly water balance for the study area, so that differences and similarities between the two could be identified, enabling these calculations to be used as a basis for more precise determination of irrigation needs.

To compute the water balance, certain meteorological and pedological data are needed. In connection with this, it was found that the data which could be collected were not very complete, and were not sufficient for computing the daily water balance directly.

Initial difficulties encountered were that meteorological stations located in the Northern Plains did not have the complete records which were needed for estimating potential evapotranspiration using empirical methods. To carry out complete water balance calculations, the components needed are rainfall totals, potential evapotranspiration, and soil moisture. In general, weather stations located on the Northern Plains have adequate records of rainfall totals, but concerning soil moisture, not enough research has been done to allow the fixing of a standard for the area. The only research on this has been carried out in the area of Rentang by the Institute of Agriculture, Bogor. Based on the soil type there, the fineness of its texture and its percolation characteristics, as well as on the major crop grown in the area, rice, and the depth of its root zone, scientists concluded that the standard for available soil moisture storage capacity in the root zone there should be 100 millimeters.

Another most difficult problem is the calculation of evapotranspiration. Indonesia does not own the kind of instrument which should be used to measure evapotranspiration. The lysimeter is the best for this purpose. However, there is not one in all Indonesia, and the only instrument which is being used in the area for that purpose is the pan evaporimeter, of which there are one in Jakarta and one in Cirebon. The results from these two stations can be used as a basis to figure the adjustment for stations which have no evapotranspiration data of their own. Because of this, the first step was to carry out a comparison between the records of the pan evaporimeter for Jakarta and Cirebon with the potential evapotranspiration obtained by empirical methods. Comparisons were made between potential evapotranspiration values obtained by the Thornthwaite, and Blaney and Criddle methods. To carry out these calculations, the only data required are temperature records. Thus, if one aims to calculate evapotranspiration for the Northern Plains of West Java, using Thornthwaite, or Blaney and Criddle, many weather stations can be used. In general, precipitation and temperature records can be obtained from almost all weather stations there. Unfortunately, it is not known which of the two methods is most accurate for tropical areas such as Indonesia. Because of this, tests must be carried out beforehand to establish which, among the empirical methods, is the most accurate to apply to environmental conditions in Indonesia. The problem is more complicated if one wishes to use the Penman method, for then additional meteorological data are needed including solar radiation (net radiation if possible), temperature, relative humidity, and wind velocity. In the Northern Plains of West Java, there is no station which has data concerning net radiation, while Jakarta is the only one that has global radiation data. Thus, using the existing data, if Penman's formula is to be used, net radiation must be calculated from global radiation for Jakarta. Global radiation for other stations lacking such data must be obtained by calculation from data concerning sunshine duration which fortunately do exist for some of these stations. Seven stations, excluding Jakarta, have sunshine duration records, but not for the same length, and periods, of time. Depok, for example, has such records for only three years while others cover up to eleven years. However, since these are the only existing data, they were used in calculations for this study. The methods used to calculate global radiation for the seven stations which lack such records was to establish the relationship between global radiation and sunshine duration. Once the correlation coefficient was known between global radiation and sunshine duration, it was possible to calculate global radiation for any station having records on sunshine duration. The formula below is used for this calculation:

$$\frac{Q}{Q_A} = a + b\ n/N$$

where Q is global radiation; $Q_A$ is the Angot value; and n/N is sunshine duration.

Jakarta has data for global radiation (Q), and Angot value ($Q_A$), and for sunshine duration (n/N), so in the equation above, the unknowns for Jakarta are the constants a and b. Using simple regression analysis, these can be calculated, and for Jakarta, for the 12-year period for which global radiation data were collected, $Q_A$ can be obtained from the Smithsonian Tables, and n/N from the Jakarta data. With these, a simple linear regression can be carried out. The results were:

$$a = 0.19$$

$$b = 0.38$$

Compared with the results of studies in other areas, the b value of Jakarta is lower than most, however, the total value of a and b is lower than any of them. This may be caused by inaccurate sunshine duration recording, or because the solar radiation is partly intercepted by air particles such as dust. The period under study was just after the explosion of Mount Agung in 1963. Dust from Agung may have been suspended by the upper air circulation for several years.

After the constants a and b were obtained for Jakarta, these constants could be used for other stations also, so that a formula was derived:

$$\frac{Q}{Q_A} = 0.19 + 0.38\ n/N$$

For these places, $Q_A$ (Angot value) can be obtained from the Smithsonian Tables, a and b constants are already known from Jakarta, n/N is sunshine duration as recorded in these stations. Thus the only remaining unknown is Q, or global radiation, which can now be calculated for the remaining stations, thus giving eight stations with global radiation for the Northern Plains of West Java. What is needed for the Penman calculation methods is not Q but Qn. Qn can be calculated from Q with relative humidity, using a formula by Chang (1970). $Qn = (1-r)Q-\sigma T^4(286.18+202.60Q/Q_A-45.24\sqrt{e_d} - 10.92\ Q/Q_A\sqrt{e_d})$ (see Table 17).

After Qn is obtained, the potential evapotranspiration for the eight stations on the Northern Plains can be computed with the Penman formula, as well as with the Blaney and Criddle, and Thornthwaite formulas. However, the results of the calculations had to be compared with pan evaporimeter readings to allow identification of the method best suited to conditions on the Northern Plains. Since pan evaporimeter readings were available only for two meteorological stations on the Northern Plains, namely Jakarta and Cirebon, potential evapotranspiration calculations using the three methods were calculated only for those two stations. The results from the three methods were then compared.

Of the three methods used, the one which gave results most closely paralleling the pan evaporimeter readings was Penman. However, the pan evaporimeter readings were lower, in general, than the Penman results, and also revealed variations from month to month. The Blaney and Criddle, and Thornthwaite, calculations showed no appreciable monthly variations, while the Penman results gave minor monthly variations. For Jakarta, in general, the readings from the pan evaporimeter represented only two-thirds of the Penman results. Thus, the Penman method clearly over-estimates free water evaporation. This may be caused by the sea breeze influence, such as occurs in the California coastal area where evapotranspiration readings are lower than those recorded for the interior. According to a study by Nixon and Lawless (1968), it reaches approximately two-thirds of the values for the interior. Jakarta may experience the same effect, since with its location on Jakarta Bay, it experiences a strong sea breeze effect during the months of February and March when the sea breeze is intensified by the winds of the northwest monsoon. This produces a depression in evapotranspiration due to the cooling effect of the sea breeze.

For Cirebon, on the other hand, the Penman formula generally gives overestimates of free water evaporation, except during the months of June to October when the Penman results underestimate the pan evaporimeter readings. In other words, the records for free water evaporation exceed the Penman values. This also occurs because of the influence of advection, but instead of the sea breeze effect, it is the land breeze, angin kumbang, or föhn wind originating from Mount Cereme. In descending from higher elevations to flow past Cirebon, the wind warms adiabatically causing higher evaporation readings.

Thus, although differences occur between the Penman results and the pan evaporimeter readings, if meteorological factors affecting local situations are carefully studied, the Penman formula is still superior to other empirical methods in computing potential evapotranspiration for a tropical area. The decision was made, then, to use Penman in calculating potential evapotranspiration for the eight meteorological stations referred to above.

The results of the Penman calculations for the eight stations were then used to construct an isoline map of potential evapotranspiration.

From the map, it is clearly seen that, in general, potential evapotranspiration is higher along the coast than in the interior, and the stations with highest potential evapotranspiration are Jakarta and Cirebon, with Jakarta having the maximum once during the year, and Cirebon also having the maximum once. This shift of higher values, however, does not alter the fact that potential evapotranspiration in the interior is lower than along the coast.

After obtaining potential evapotranspiration figures, the water balance was calculated and diagrammed. From the water balance diagrams for the various stations, the total water surplus and deficit for each station can be known. It is clear from the diagrams that the Northern Plains of West Java can be divided into a western and an eastern portion with the approximate boundary just slightly east of Subang in the north.

The western area experiences only a short deficit which is not severe. In fact, Subang does not experience a deficit at all, although there are several months which do not show a surplus either. Serang, Jakarta, and Depok experience deficits, and for Jakarta, there are several years when the deficit period is longer than the others shown in the table.

In the eastern portion of the Northern Plains, represented by the diagrams for Kadipaten, Jatiwangi, Cirebon, and Tersanabaru, all the diagrams show that when the surplus occurs, it is a heavy one, revealing high rainfall intensities. On the other hand, during the deficit months, the deficit is intense and long, reaching 200 millimeters and six to seven months, respectively, for some stations. Clearly the eastern portion experiences more frequent and severe droughts.

With this information available on the water balance, it is clear that in irrigation planning, if the danger of severe drought is to be alleviated, attention must be focused on the eastern portion of the Northern Plains. Surplus from other areas must be distributed, in a well-regulated system, to the eastern area when needed. Obviously, the western area cannot be ignored, but the drought experienced there generally is shorter and less intense, therefore the water demand is lower.

Once the variations in the water balance have been identified, it is necessary to examine crop yields from these areas to establish whether a correlation exists between agricultural production and water balance. It is known that poor harvests do coincide with times when the dry season is particularly long. However, precise calculations to identify the exact day when a deficit period begins, and ends, and its intensity for the duration of the deficit have never been undertaken. In the efficient application of irrigation waters to combat drought, these exact characteristics of the deficit period must be known.

To provide such accuracy, the most effective calculation is the daily water balance computation. When daily water balance is known for an area, the application of irrigation waters can begin precisely when needed, in the exact amount required, and continue only as long as the deficit exists. Instead, in present practice, farmers identify an area as dry when no water can be observed on the soil surface, and irrigation waters are usually applied immediately, when in actuality, no deficit exists as yet due to soil water storage. Clearly this leads to a waste of irrigation waters. This points to the need for ongoing daily water balance computation. The difficulty is that this requires daily meteorological data, which at present, are available only for Jakarta. Accordingly, for this study, the daily water balance could be calculated only for Jakarta; for the remaining stations, only the monthly water balance could be computed.

However, if the daily water balance in Jakarta is compared with the monthly water balance, the correlation can be examined. If the correlation is good, the monthly water balance calculations can be utilized in irrigation regulation until such time as the requisite data for computing daily water balance are available. If there is a correlation, even if it reveals occasional slight deviations, the monthly water balance still may be utilized, as long as the deviations are not too great, and they are examined carefully to identify possible factors explaining their occurrence. If these deviations are known, in the use of monthly water balance calculations for irrigation regulation, the inaccuracies can be carefully noted and adjustments made accordingly.

In comparing the monthly water balance with the daily water balance for Jakarta, the correspondence is good for the surplus period, although sometimes the monthly water balance is slightly higher than the daily water balance and vice versa. In comparing daily water balance and monthly water balance values over a period of twelve years, from 1964 to 1975, it is evident that the two alternate in showing surplus maxima, with the daily water balance providing the maximum slightly more frequently, although the difference is minimal between the two. However, for deficit periods, the daily water balance consistently revealed a more serious deficit than the monthly water balance; only once, for one month, in the entire 12-month period under study does the monthly water balance deficit exceed that of the daily water balance. This illustrates again the critical need for daily water balance calculations to guide irrigation applications in terms of exact timing and amounts for the deficit periods.

To enable such calculations to be utilized as soon as possible, the Government of Indonesia must begin immediately to insure that the necessary meteorological data are recorded; that is, in addition to temperature and precipitation for these stations, records of global radiation, relative humidity, and wind velocity must be kept. To enable checking of the correlation between global radiation and net radiation, it would be better if one station were equipped to measure net radiation. Once the correlation is known, global radiation for the other stations can be adjusted to provide net radiation data.

The instrument best suited to measure evapotranspiration, and thus provide a check on the degree of correspondence between the various empirical methods used to calculate potential evapotranspiration, is the lysimeter. Again, the government needs to seriously consider placing lysimeters in one or two areas to provide the means for such checking.

In this study, not only was the water balance calculated for the Northern Plains of West Java, but also the degree of relationship between water balance and agricultural production was examined. Generally speaking, a correlation can be seen between variations in agricultural yields and seasonal climatic conditions. For example, in 1967 and 1972 low yields occurred, corresponding to a long dry season in West Java. To examine the correlation more precisely, rice yields were compared with the water balance for the years when both records were available. Once more, only Jakarta had the necessary data, and so it was used as representative of the Northern Plains. From Table 22, showing rice production for the years 1964 through 1972, and from the water balance tables for the same years, an agreement can be seen between the two during low yield periods. However, it must be recognized that other factors may play significant roles in affecting yields. For example, in 1970, some rice areas in West Java suffered serious pest attacks, in particular army worms, and the rice production table reveals very low yields for that year.

Unfortunately, this correlation between water balance and agricultural production cannot be examined in detail because the data needed are simply not available. For instance, yearly statistics on second crop yields would be most helpful, but only rice yields could be obtained. For areas other than Jakarta in the Northern Plains, the years for which rice production figures are available do not correspond to the years when sufficient data are available to calculate water balance. Because of this, the relationship between water balance and rice production could not be examined in this study in a detailed and accurate manner; instead only a strong tendency for correlation can be identified. Careful research into this correlation could be carried out as soon as proper data are available. This would include all meteorological data, for a period no less than ten years, needed for daily water balance calculations; lysimeter readings for the purpose of checking the accuracy of the empirical methods; and finally, yield fluctuations for rice and other crops in the study area for a corresponding period of time. In addition, if the study is to be carried to the point where concrete suggestions for water management would be forthcoming, detailed information concerning soil types and soil moisture storage for the entire Northern

Plains is essential, rather than the situation at present where such detail is available only for the Rentang area.

Thus, with the data available to date, the study can be taken only this far. Although much more information is needed, perhaps this study can be used, not directly as a basis for irrigation planning, but instead as a guideline and initiation for further research. From this study, it is hoped, the critical need for more detailed and frequent meteorological recording, more extensive experimentation and study of those factors influencing agricultural production, and more accurate reporting of agricultural yields and conditions will be recognized and implemented.

# APPENDIX I

## RAINFALL DATA

1. Average rainfall over a period of thirty years (1931-1960) for Serang, Jakarta, Depok, Bekasi, Walahar, Purwakarta, Subang, Indramayu, Bangodua, Kadipaten, Jatiwangi, Wlahar, Cirebon, and Tersanabaru, in which in every locality is represented: mean monthly rainfall in mm, average raindays by months, average highest rainfall within 24 hours by months and absolute maximum rainfall and the time of occurrence.

2. Monthly rainfall from 1879 to 1975 for Serang, Jakarta, Depok, Purwakarta, Walahar, Subang, Indramayu, Bangodua, Wlahar, Kadipaten, Plumbon, Cirebon, Jatiwangi, and Tersanabaru. The time span where the data are available in the above mentioned individual weather stations are different. Purwakarta has the longest period of recording, 93 years from 1879 to 1974. Three stations have periods above 80 years, Indramayu 87 years from 1884 to 1975. Jakarta 86 years from 1879 to 1975, and Depok 84 years from 1879 to 1974. Bangodua and Plumbon have the shortest periods of recording, both are 14 years, Bangodua from 1959 to 1973, and Plumbon from 1945 to 1958.

3. Rainfall intensity in Jakarta for the period of 1879 to 1935, including rainfall diurnal variation hourly totals in mm and duration in minutes.

4. Rainfall distribution by 2 hours in Kosomalang, Subang, for the period 1971 to 1975.

5. Daily rainfall in Jakarta for 12 years from 1964 to 1975.

APPENDIX II. POTENTIAL EVAPOTRANSPIRATION FOR JAKARTA AND CIREBON

Mean Monthly Potential Evapotranspiration (in mm) for Jakarta over the Period of 1964 - 1975 according to Thornthwaite (TH), Blaney and Criddle (BC), Penman (P), and Sunken Pan (Ps)

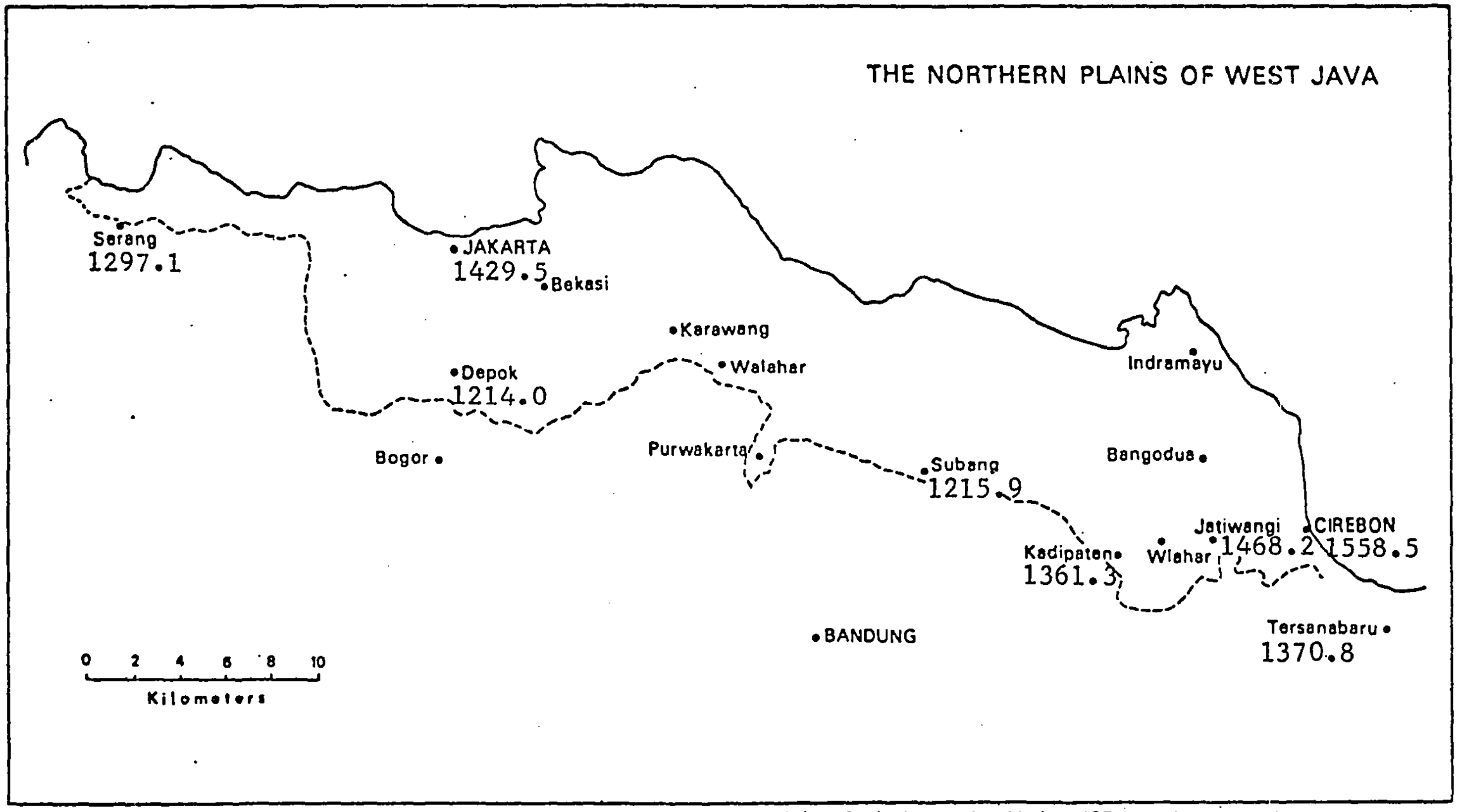
| METH. | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TH | 134.0 | 135.3 | 136.6 | 143.8 | 143.5 | 141.5 | 140.1 | 142.4 | 144.0 | 144.7 | 141.1 | 137.4 | 1684.4 |
| BC | 137.7 | 125.3 | 137.7 | 137.1 | 137.8 | 133.3 | 136.5 | 139.5 | 140.3 | 142.9 | 139.2 | 141.8 | 1649.1 |
| P | 110.1 | 112.3 | 137.0 | 132.1 | 129.8 | 116.3 | 127.0 | 139.7 | 140.7 | 143.7 | 116.5 | 122.4 | 1527.6 |
| Ps | 57.7 | 60.5 | 71.9 | 76.6 | 78.9 | 89.8 | 95.0 | 104.5 | 105.6 | 100.5 | 84.1 | 79.4 | 1014.5 |

Mean Monthly Potential Evapotranspiration (in mm) for Cirebon over the Period of 1936-1945 according to Penman (P), Thornthwaite (Th), Blaney and Criddle (BC), and Buried Pan (Pb)

| | JAN. | FEB. | MAR. | APR. | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV. | DEC. | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 107.3 | 113.0 | 125.4 | 118.3 | 115.5 | 111.1 | 126.0 | 150.2 | 157.4 | 162.4 | 147.2 | 122.7 | 1556.5 |
| Th | 135.1 | 137.7 | 141.1 | 143.7 | 143.8 | 141.2 | 141.0 | 143.7 | 147.4 | 151.8 | 151.7 | 141.2 | 1719.4 |
| BC | 138.7 | 125.4 | 140.7 | 132.2 | 136.4 | 129.3 | 132.7 | 136.2 | 142.7 | 151.8 | 147.3 | 143.8 | 1657.3 |
| Pb | 58.6 | 60.5 | 65.7 | 64.8 | 84.3 | 106.5 | 153.4 | 182.3 | 181.5 | 160.0 | 142.5 | 91.6 | 1351.7 |

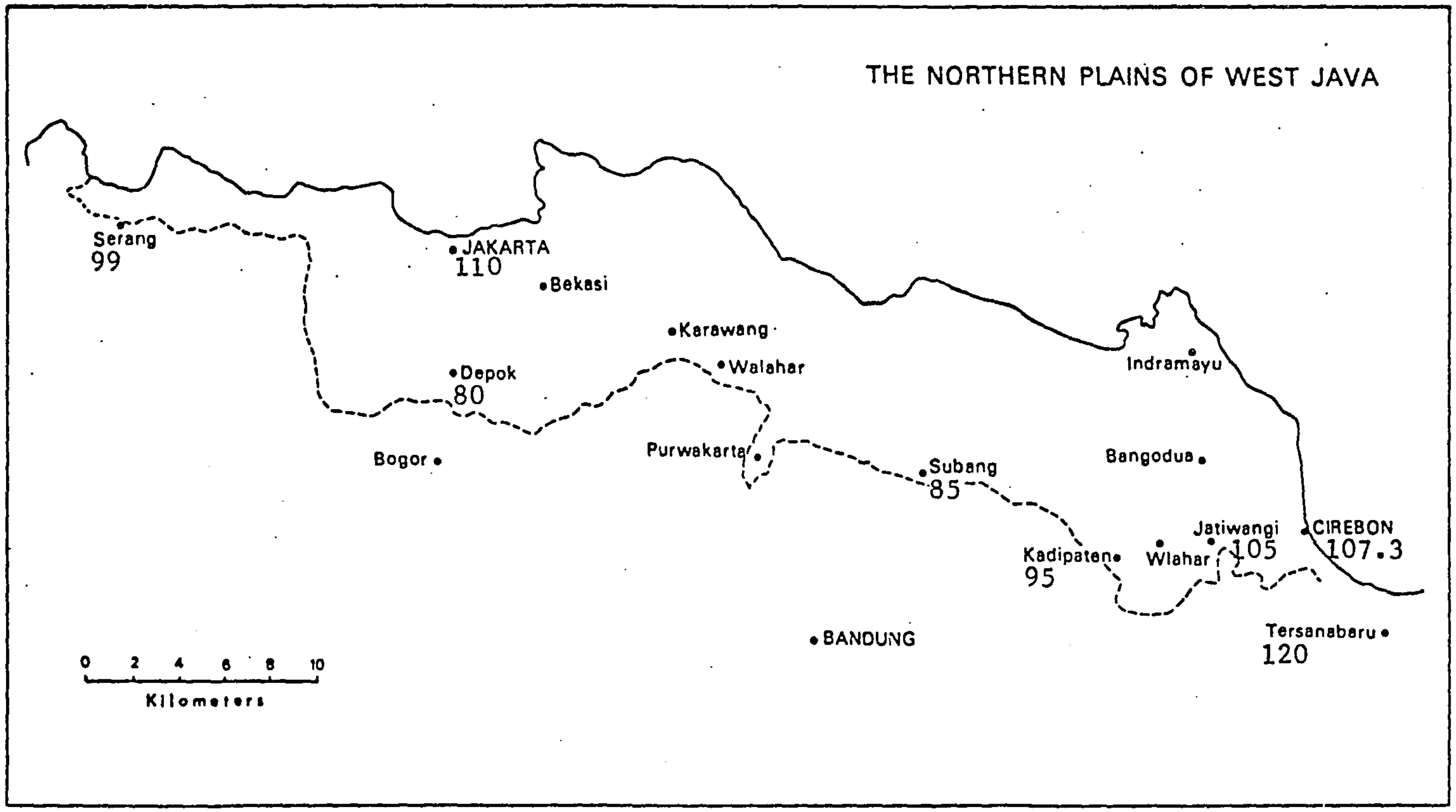
## APPENDIX III. POTENTIAL EVAPOTRANSPIRATION (PENMAN METHOD)

### Mean Annual Potential Evapotranspiration (mm)
### Penman Method,



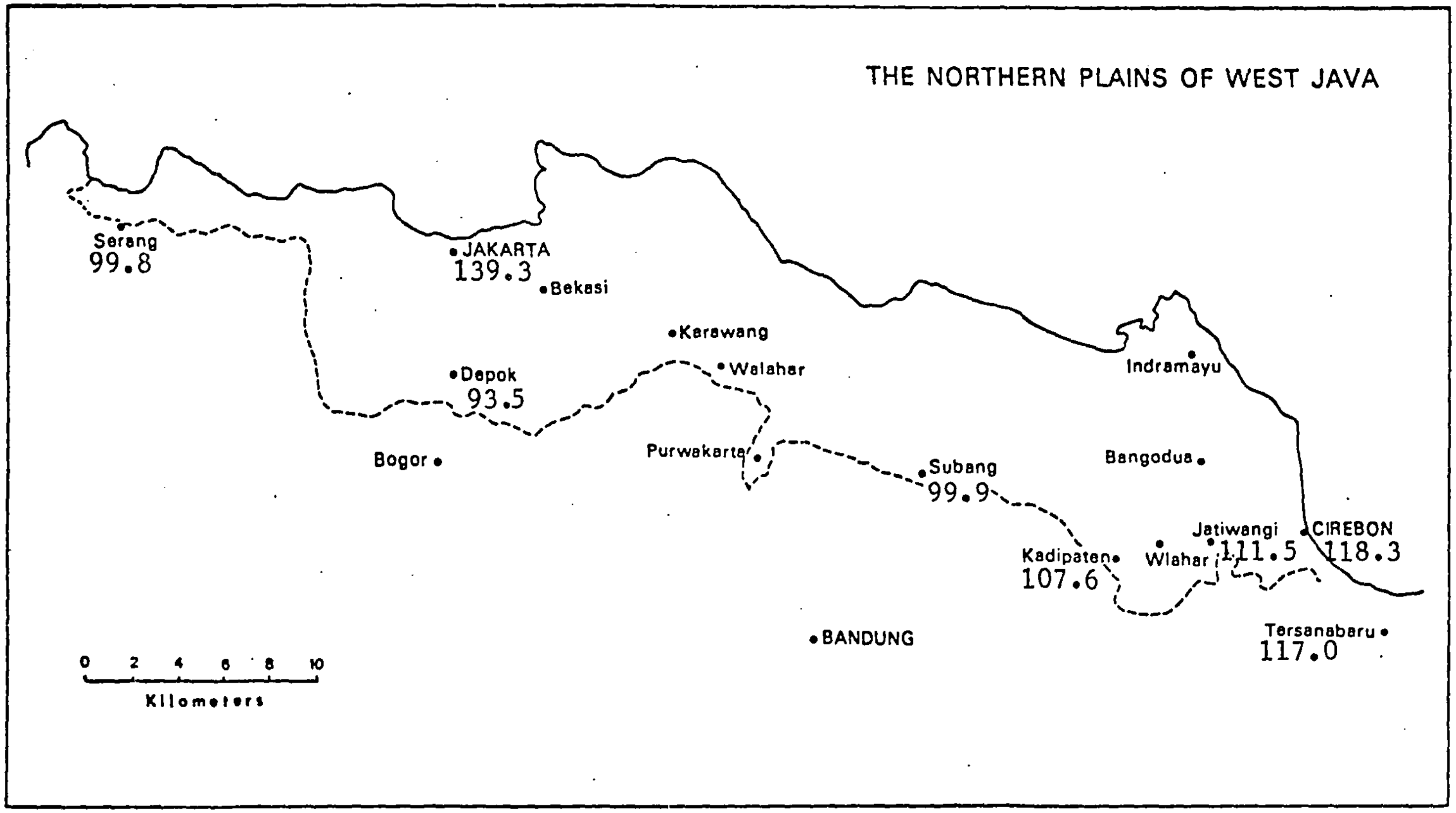

After: Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Mean Monthly Potential Evapotranspiration (mm)
Penman Method, January



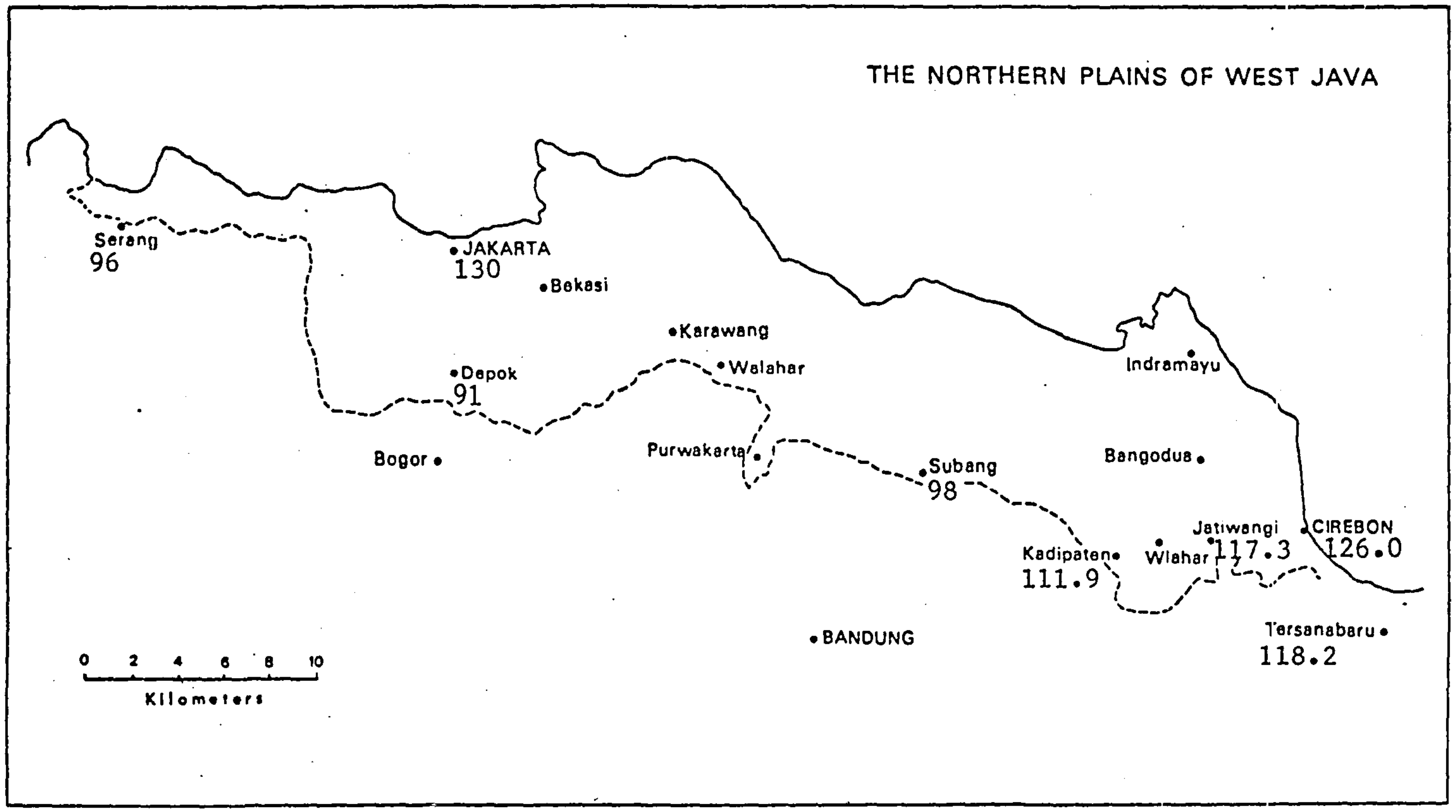

After: Peta Ikhtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Mean Monthly Potential Evapotranspiration (mm)
Penman Method, April



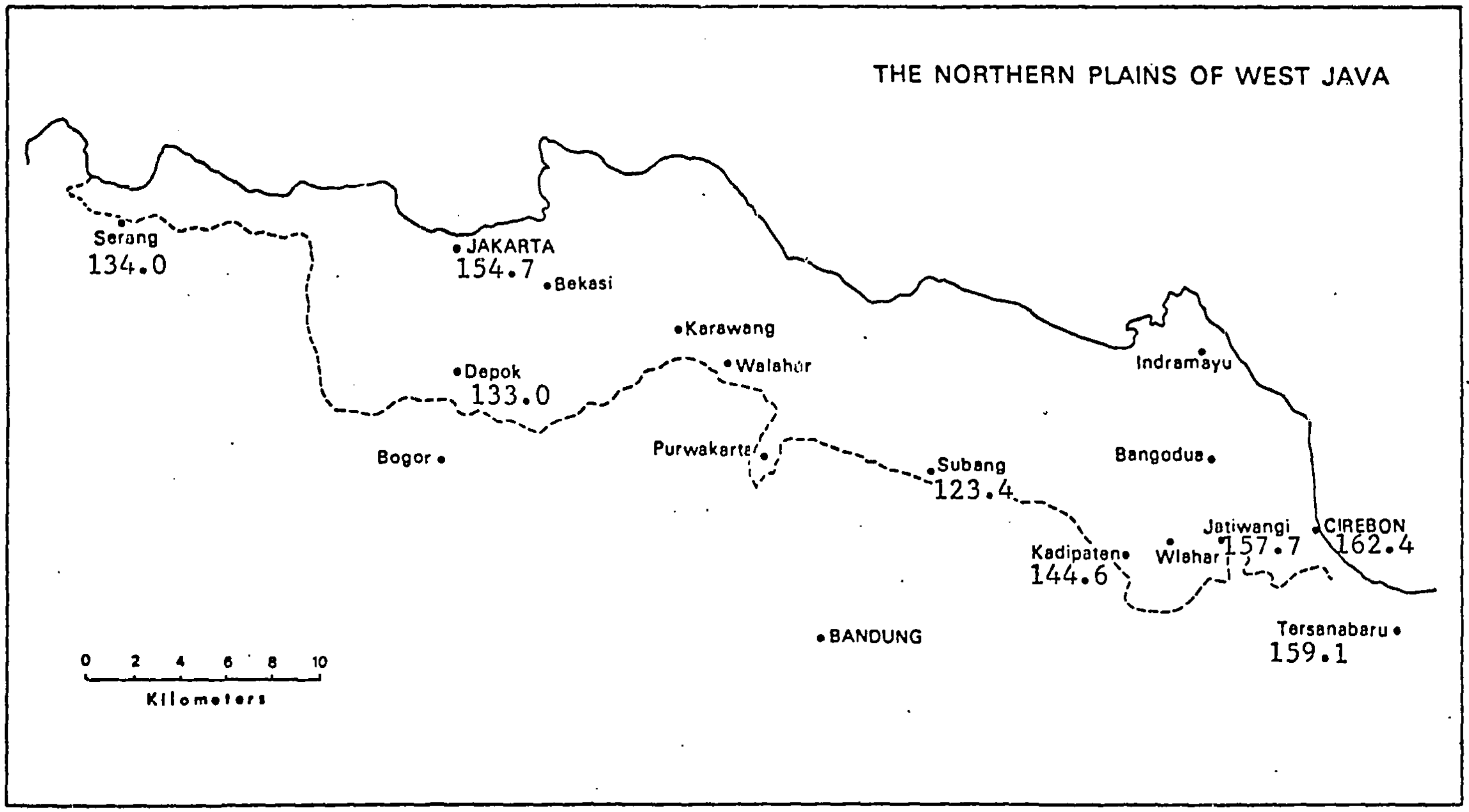

After: Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Mean Monthly Potential Evapotranspiration (mm)
Penman Method, July




After: Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

Mean Monthly Potential Evapotranspiration (mm)
Penman Method, October




After: Peta Ichtisar Geologi Java dan Madura 1971, Lembaga Penelitian Tanah, Bogor

APPENDIX IV. WATER BALANCE TABLES

TABLE:
MONTHLY WATER BALANCE COMPUTATION
FOR STATION: JAKARTA LAT: 6°11'S LONG: 106°50' ELEV: 8m.

PERIOD: 1964-1975

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 67.9 | 60.6 | 71.9 | 76.6 | 78.9 | 87.3 | 95.0 | 104.6 | 110.6 | 100.5 | 84.1 | 79.4 | 1017.4 |
| R | 305.6 | 340.4 | 259.6 | 115.2 | 127.4 | 77.3 | 44.2 | 51.0 | 69.5 | 110.2 | 140.3 | 171.9 | 1812.6 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.0 | 39.2 | 0.0 | 0.0 | 19.7 | 65.9 | 100.0 |
| AE | 67.9 | 60.6 | 71.9 | 76.6 | 78.9 | 87.3 | 95.0 | 90.2 | 69.5 | 100.5 | 84.1 | 79.4 | 961.9 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 14.4 | 41.1 | 0.0 | 0.0 | 0.0 | 55.5 |
| S | 237.7 | 279.8 | 187.7 | 38.6 | 48.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 58.4 | 850.7 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: SERANG LAT: 6°7' LONG: 106°8'E ELEV: 40m

PERIOD: 1960-1968

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 99.3 | 101.9 | 110.3 | 99.8 | 95.6 | 84.3 | 96.0 | 112.9 | 123.5 | 134.0 | 125.6 | 113.9 | 1297.1 |
| P | 262.0 | 221.0 | 187.0 | 124.0 | 121.0 | 100.0 | 93.0 | 77.0 | 83.0 | 111.0 | 161.0 | 194.0 | 1734.0 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.0 | 61.1 | 20.6 | 0.0 | 35.4 | 100.0 |
| AE | 99.3 | 101.9 | 110.3 | 99.8 | 95.6 | 84.3 | 96.0 | 112.9 | 123.5 | 131.6 | 125.6 | 113.9 | 1294.7 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 | 0.0 | 0.0 | 2.4 |
| S | 162.7 | 119.1 | 76.7 | 24.2 | 25.4 | 15.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.5 | 439.3 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: DEPOK LAT: 6°34'S LONG: 106°49'E ELEV: 95m

PERIOD: 1959-1961

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 80.3 | 79.4 | 107.3 | 93.5 | 94.5 | 90.2 | 91.0 | 107.3 | 126.3 | 133.0 | 109.0 | 102.2 | 1214.0 |
| P | 358.0 | 269.0 | 355.0 | 326.5 | 238.5 | 100.0 | 67.5 | 58.5 | 77.5 | 113.5 | 258.5 | 204.0 | 2426.5 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 76.5 | 27.7 | 0.0 | 0.0 | 100.0 | 100.0 |
| AE | 80.3 | 79.4 | 107.3 | 93.5 | 94.5 | 90.2 | 91.0 | 107.3 | 105.2 | 113.5 | 109.0 | 102.2 | 1173.4 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 21.1 | 19.5 | 0.0 | 0.0 | 40.6 |
| S | 277.7 | 189.6 | 247.7 | 233.0 | 144.0 | 9.8 | 0.0 | 0.0 | 0.0 | 0.0 | 49.5 | 101.8 | 1253.1 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: SUBANG LAT: 6°35'S LONG: 107°46'E ELEV: 95m

PERIOD: 1940-1960

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 85.1 | 82.4 | 99.8 | 99.9 | 90.5 | 90.1 | 98.2 | 116.7 | 124.4 | 123.4 | 100.9 | 104.5 | 1215.9 |
| P | 453.3 | 416.0 | 343.5 | 287.7 | 144.6 | 101.8 | 117.2 | 82.7 | 68.2 | 175.2 | 199.2 | 249.0 | 2638.4 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 66.0 | 9.8 | 61.6 | 100.0 | 100.0 |
| AE | 85.1 | 82.4 | 99.8 | 99.9 | 90.5 | 90.1 | 98.2 | 116.7 | 124.4 | 123.4 | 100.9 | 104.5 | 1215.9 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| S | 368.2 | 333.6 | 243.7 | 187.8 | 54.1 | 11.7 | 19.0 | 0.0 | 0.0 | 0.0 | 59.9 | 144.5 | 1422.5 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: TATIWANGI LAT: 6°43'S LONG: 108°17' E ELEV: 45m.

PERIOD: 1944-1969

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 103.9 | 91.9 | 111.2 | 111.5 | 119.9 | 112.8 | 117.3 | 147.0 | 150.5 | 157.7 | 130.2 | 114.3 | 1459.2 |
| P | 515.0 | 430.0 | 288.0 | 210.0 | 110.0 | 48.0 | 16.0 | 21.0 | 13.0 | 89.0 | 189.0 | 370.0 | 2299.0 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 90.1 | 25.3 | 0.0 | 0.0 | 0.0 | 0.0 | 58.8 | 100.0 |
| AE | 103.9 | 91.9 | 111.2 | 111.5 | 119.9 | 112.8 | 41.3 | 21.0 | 13.0 | 89.0 | 130.2 | 114.3 | 1060.0 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 76.0 | 126.0 | 137.5 | 68.7 | 0.0 | 0.0 | 408.2 |
| S | 411.1 | 338.1 | 176.8 | 98.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 214.5 | 1239.0 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: TERSANABARU LAT: 6°59'S LONG: 108°41'E ELEV: 17m

PERIOD: 1963-1968

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 120.6 | 110.1 | 126.0 | 117.0 | 110.3 | 106.3 | 118.2 | 140.9 | 153.0 | 159.1 | 136.5 | 125.7 | 1523.7 |
| P | 381.5 | 266.2 | 254.8 | 170.2 | 138.2 | 54.8 | 34.2 | 17.7 | 28.5 | 45.0 | 119.5 | 256.8 | 1767.4 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 48.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| AE | 120.6 | 110.1 | 126.0 | 117.0 | 110.3 | 106.3 | 82.7 | 17.7 | 28.5 | 45.0 | 119.5 | 125.7 | 1109.4 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 35.5 | 123.2 | 124.5 | 114.1 | 17.0 | 0.0 | 414.3 |
| S | 260.9 | 156.1 | 128.8 | 53.2 | 27.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 31.1 | 658.0 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: KADIPATEN LAT: 6°46'S LONG: 108°11'E ELEV: 45m

PERIOD: 1945-1968

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 95.2 | 86.2 | 105.7 | 107.6 | 102.9 | 101.4 | 111.9 | 134.2 | 143.9 | 144.6 | 120.9 | 106.8 | 1361.3 |
| P | 383.8 | 371.4 | 330.1 | 298.8 | 144.3 | 36.3 | 43.8 | 24.3 | 52.0 | 71.1 | 291.8 | 454.9 | 2502.6 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 34.9 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 100.0 |
| AE | 95.2 | 86.2 | 105.7 | 107.6 | 102.9 | 101.4 | 78.7 | 24.3 | 52.0 | 71.1 | 120.9 | 106.8 | 1052.8 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 33.2 | 109.9 | 91.9 | 73.5 | 0.0 | 0.0 | 308.5 |
| S | 288.6 | 285.2 | 224.4 | 191.2 | 41.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 70.9 | 348.1 | 1449.8 |

TABLE:

MONTHLY WATER BALANCE COMPUTATION

FOR STATION: CIREBON LAT: $6^{o}42'S$ LONG: $108^{o}36'E$ ELEV: 4m

PERIOD: 1936-1945

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 58.6 | 60.5 | 65.7 | 64.8 | 84.3 | 106.5 | 153.4 | 182.3 | 181.5 | 160.0 | 142.5 | 91.6 | 1351.7 |
| R | 350.6 | 304.2 | 353.8 | 205.8 | 145.2 | 129.0 | 35.0 | 25.0 | 36.0 | 35.0 | 89.3 | 260.0 | 1968.9 |
| St | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| AE | 58.6 | 60.5 | 65.7 | 64.8 | 84.3 | 106.5 | 135.0 | 25.0 | 36.0 | 35.0 | 89.3 | 91.6 | 852.3 |
| D | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 18.4 | 157.3 | 145.5 | 125.0 | 53.2 | 0.0 | 499.4 |
| S | 292.0 | 243.7 | 288.1 | 141.0 | 60.9 | 22.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 68.4 | 1116.6 |

APPENDIX V. PHOTOGRAPHS

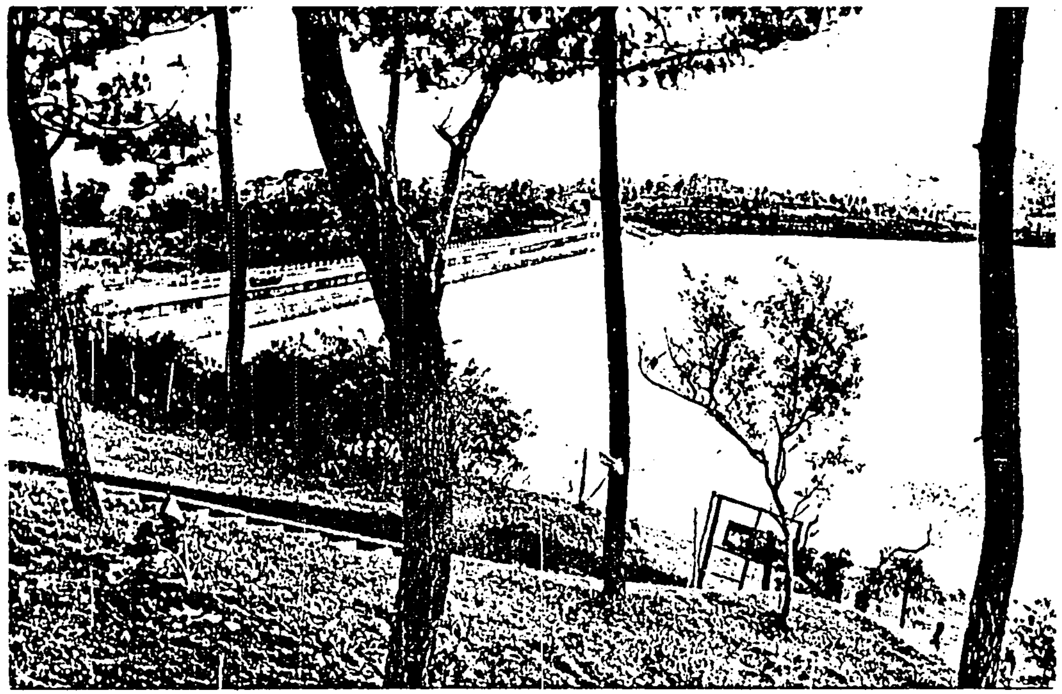


Fig. 32 Waduk Dharma Reservoir in wet season.
It is also used for recreational purposes.

Fig. 33 Waduk Dharma Reservoir in dry season. Notice the silt and stones at the bottom of the reservoir.

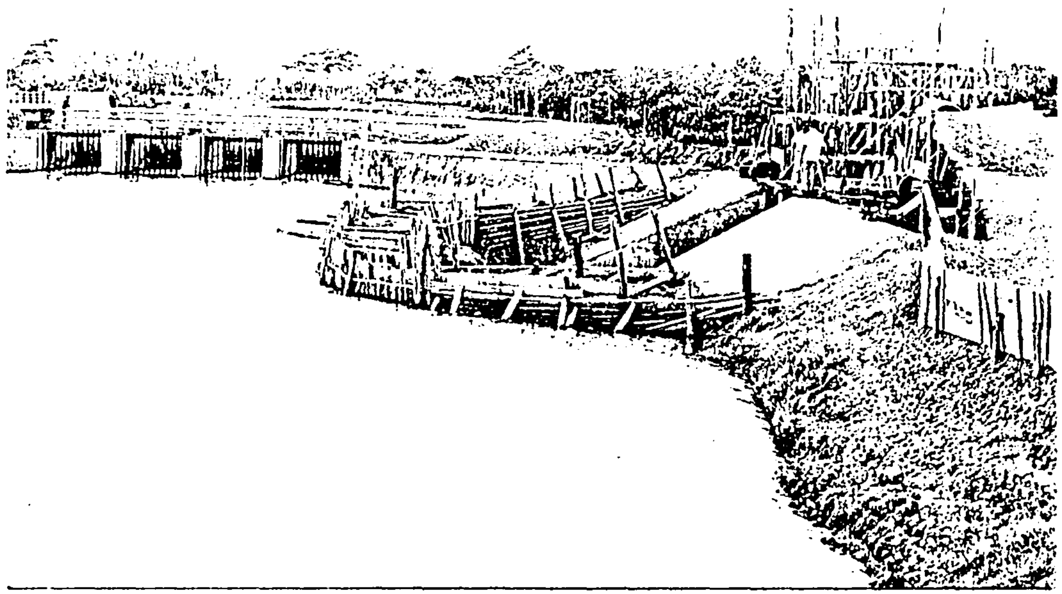


Fig. 34 Syphon under construction at Ciherang, Jatiluhur.

Fig. 35 Primary canal at West Cisedane.

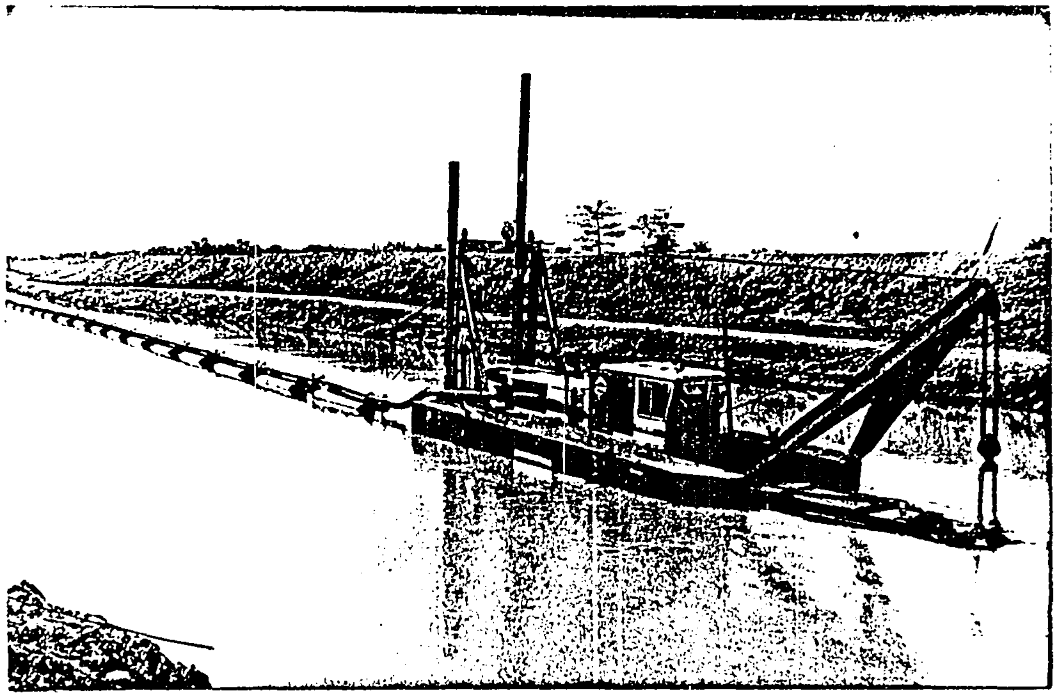


Fig. 36 Primary canal at Sindupraja. The dredging device removes sediment.

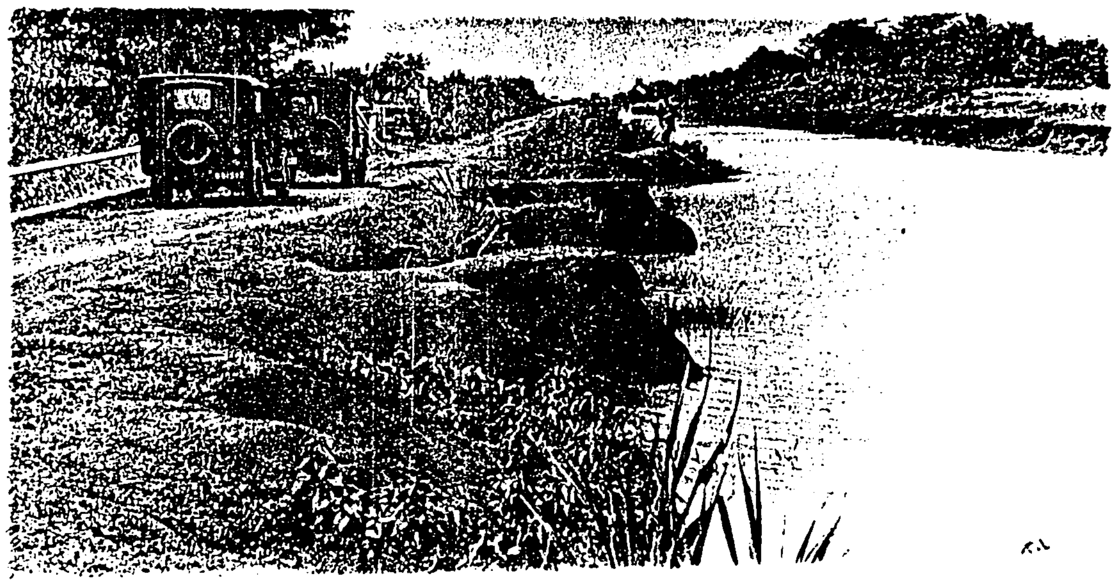


Fig. 37 Primary canal with levees damaged by water buffalo which enters the canal to bathe; always using the same place of entry.

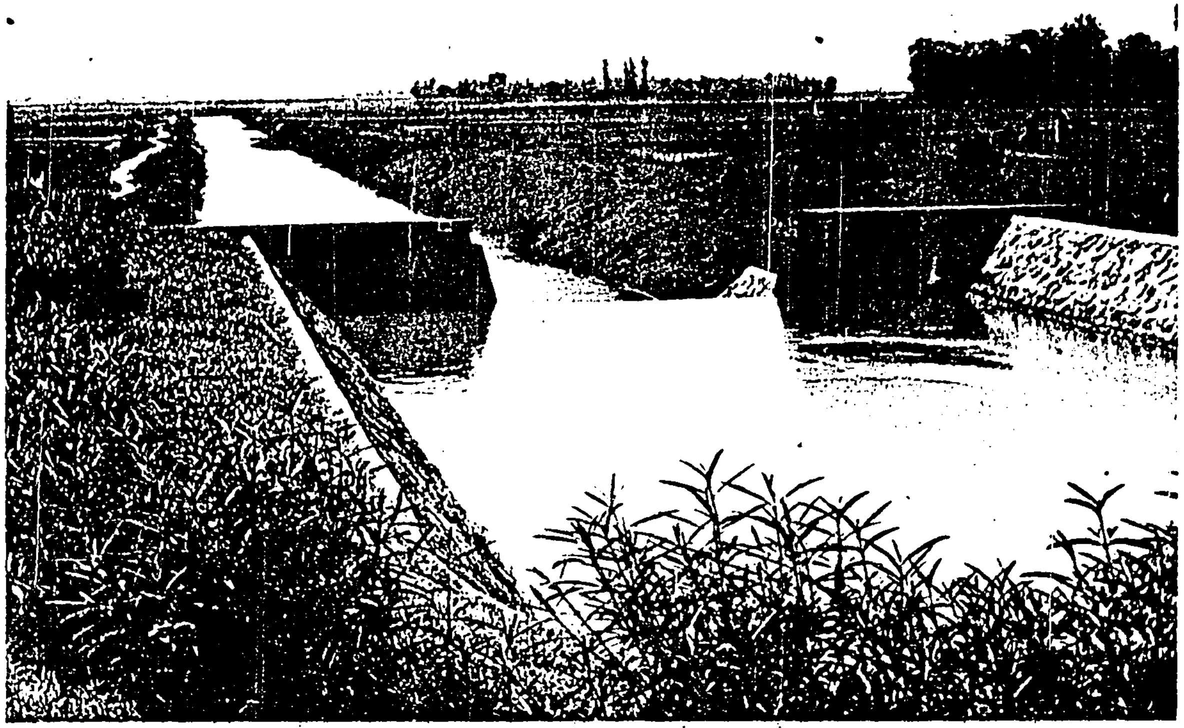


Fig. 38 Secondary canal in Telegatari, Karawang. The dikes are used as pathways through the fields. Notice that the earthen dikes are beginning to crumble in some places.

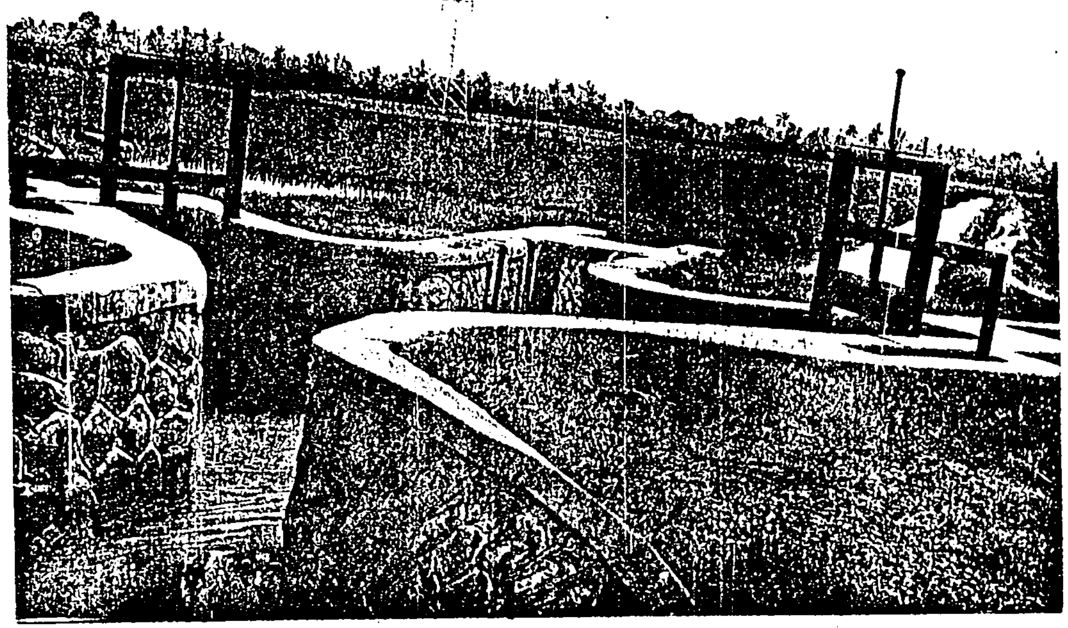


Fig. 39 Sluice to divert water to different tertiary canals at Kamujing Baru, Karawang.

Fig. 40 Sluice at tertiary canal
in Karawang.

Fig. 41 Farmers removing sediment from tertiary canal and adding it to dikes.

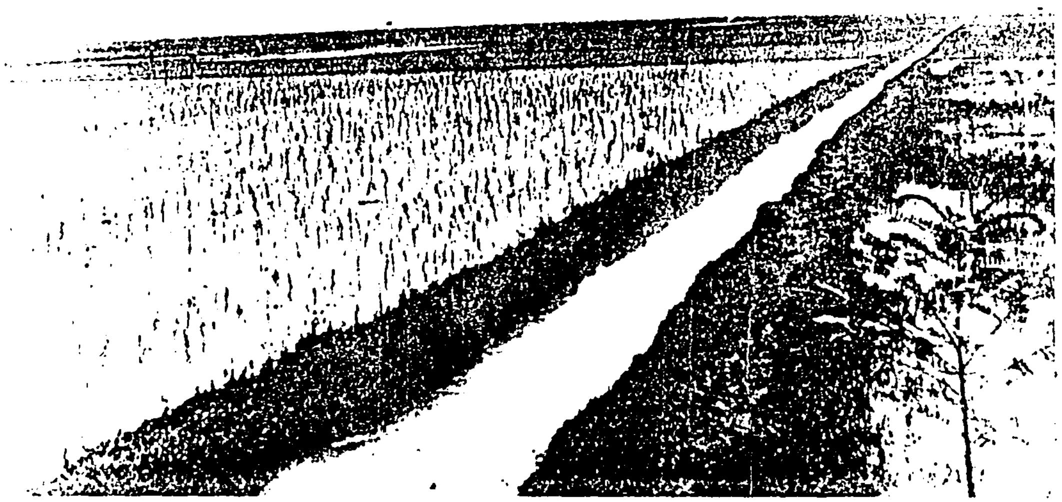


Fig. 42 Tertiary canal in Bikasi.

Fig. 43 Village shop in Kalibuaya where fertilizer and other agricultural supplies are distributed to farmers.

Fig. 44 Farmers from Kalibuaya in Telagasari, Karawang fertilizing the sawah field according to a government agricultural plan (BIMAS).

Fig. 45 Farmers spreading fertilizer over 15 day old rice plants.

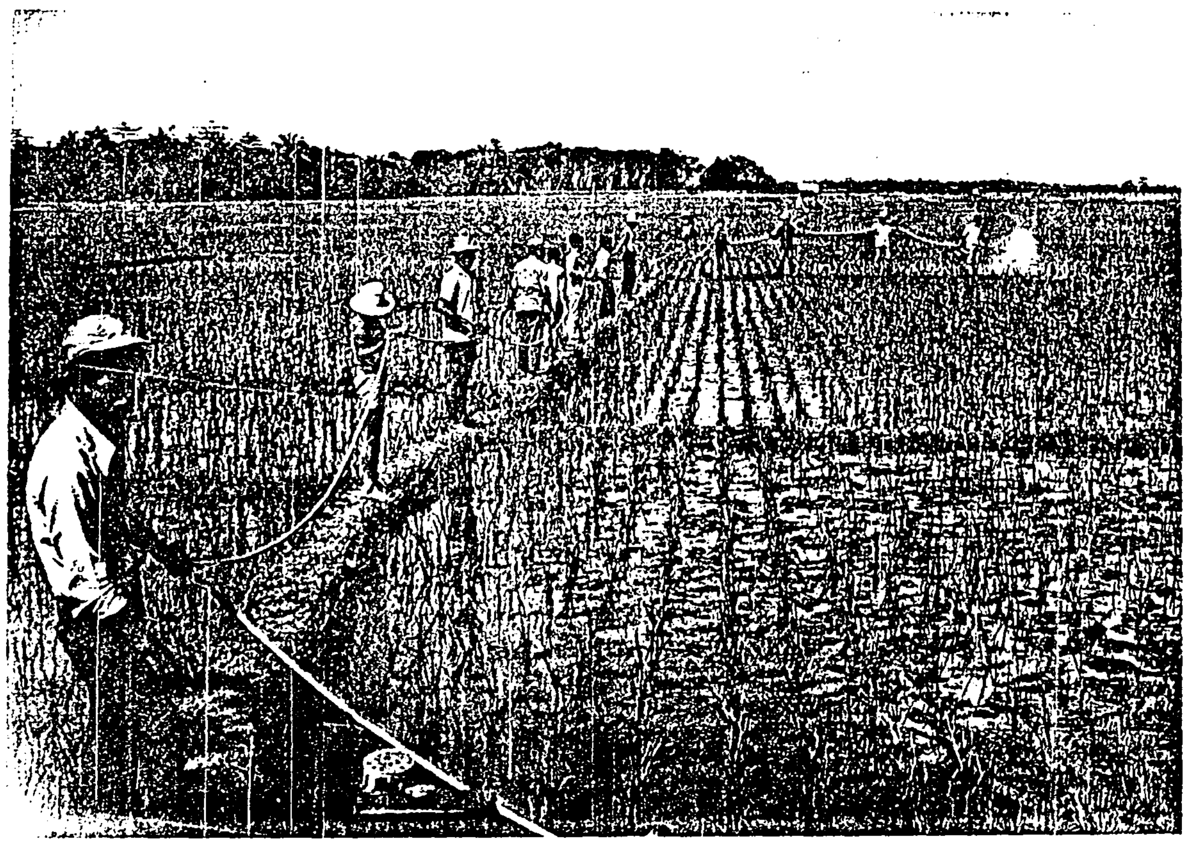


Fig. 46 Farmers' cooperative using a generator to spray young rice plants at a demonstration plot planted with a high yield variety of rice known as "Sri Mukti".

Fig. 47 Government officials visit sawah fields during harvesting.

Fig. 48 Large and small, old and young, all work in the fields at harvest time.

Fig. 49 Women harvesting dry season rice using traditional small knife (ani-ani).

Fig. 50 Men and women working cooperatively harvesting rice with the traditional small knife (ani-ani). Notice that the rice stalks have been flattened by heavy rains.

Fig. 51 Notice use of the small knife (<u>ani-ani</u>) to harvest rice

Fig. 52 Farmer happily carrying his rich yield home.

Fig. 53 Boy carrying crop of high yield variety rice. Notice the construction of the bamboo pole (pikulan).

Fig. 54 Carrying rice crop on bamboo poles (pikulan).

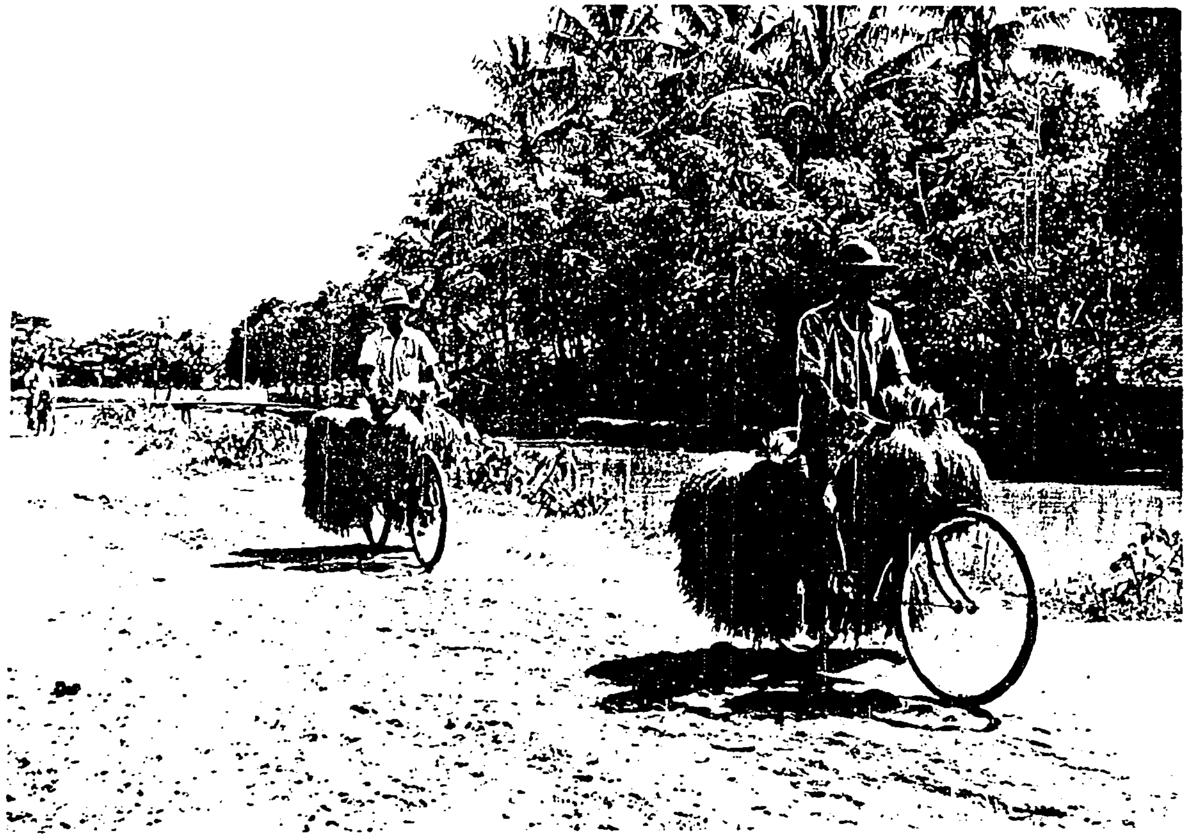


Fig. 55 Bicycles are also used to carry rice crop at harvesting time.

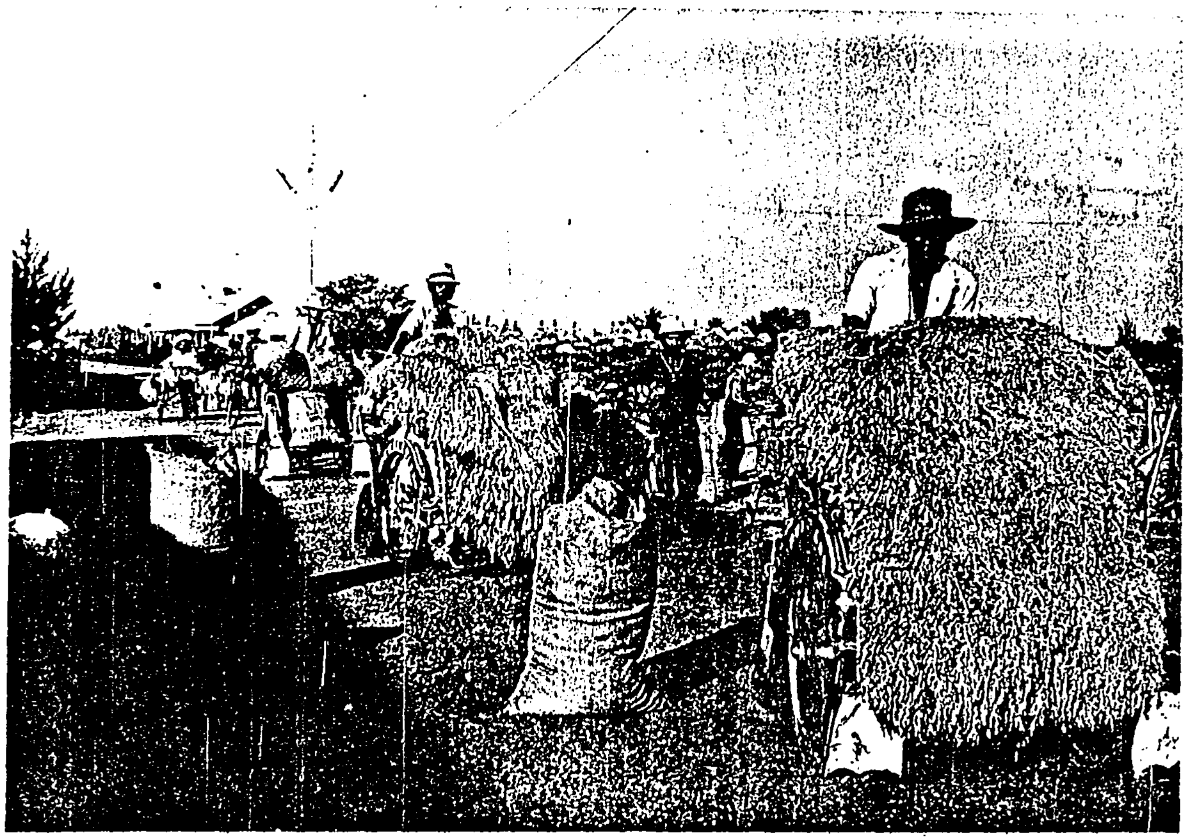


Fig. 56 Rice being transported to rice mill in becaks (three-wheeled vehicles used to carry people).

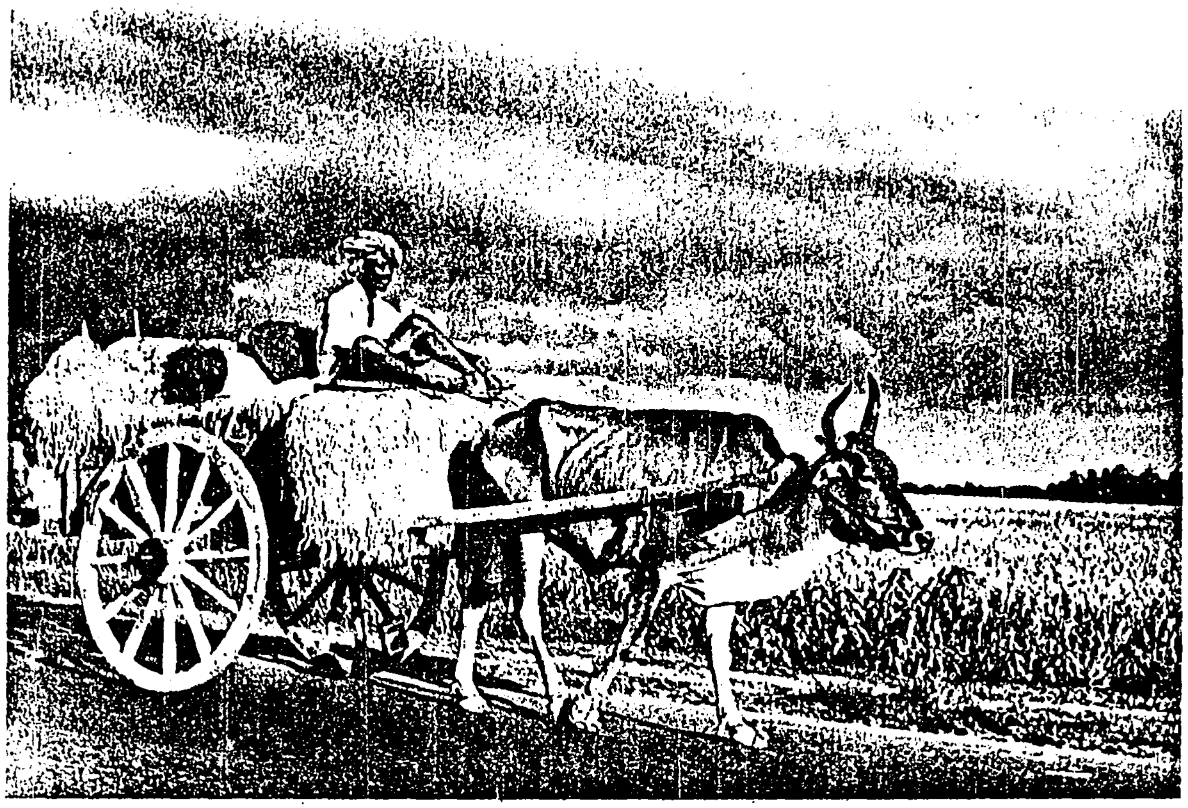


Fig. 57 Transporting the rice crop by bullock cart.

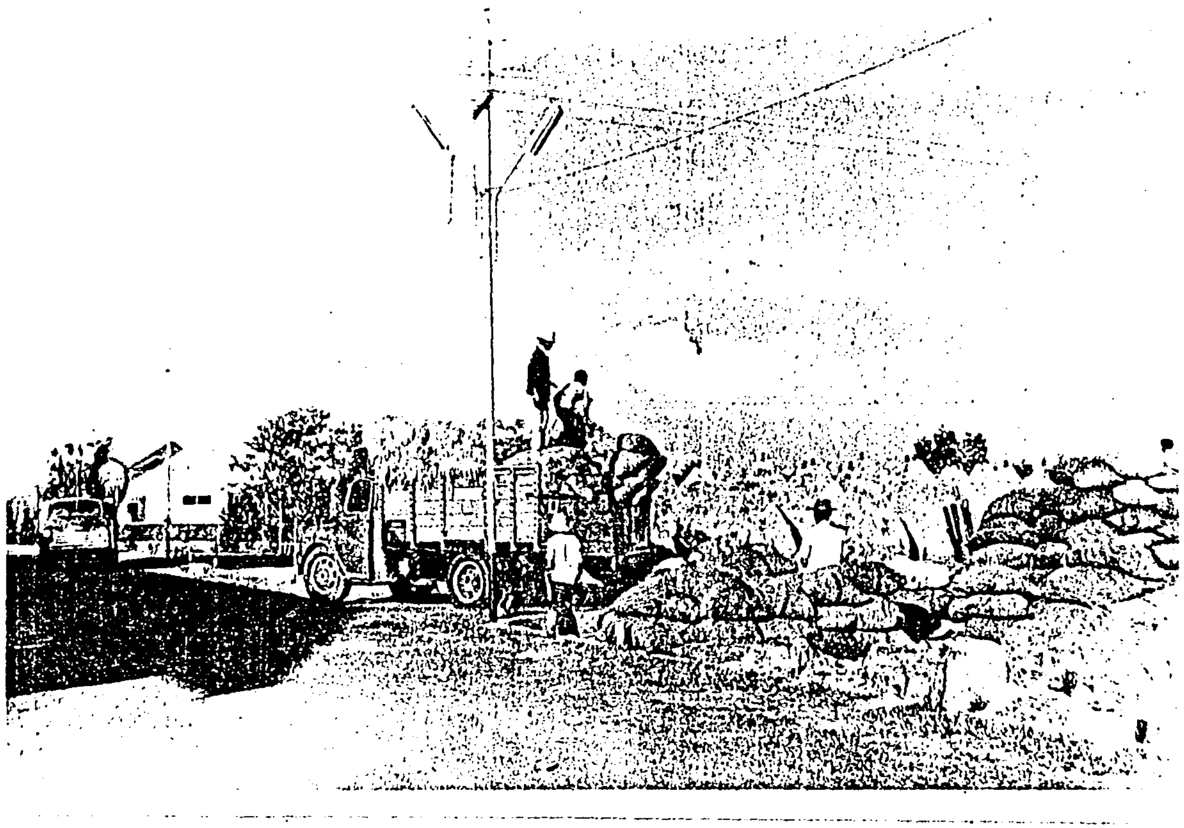


Fig. 58 Rice being transported by truck. The sacks contain grained rice.

GLOSSARY OF INDONESIAN WORDS

| | |
|---|---|
| abang (Javanese) | red |
| alang-alang | tall, tough tropical grasses, *Imperata cylindrica* |
| angin (Javanese) | wind |
| angin kumbang (Javanese) | a föhn type wind in West Java, dry and warm (higher in temperature than the local air |
| bandeng | a variety of whitefish raised in fish-ponds along the northern coast of Java |
| Bina Tanaman Produksi | Crop plant development |
| Biro Tanaman Produksi | Bureau of Crop Plants |
| ci, cai (Sundanese | water or river |
| Departemen Pakerjaan Umum dan Tenaga Listrik (P.U. & T.L.) | Department of Public Works and Electric Power |
| Departemen Pertanian | Department of Agriculture |
| Direktorat Djendral | Directorate General |
| empang | fishpond |
| enceng gondok | water hyacinth |
| gadu (Javanese) | rice crop in the dry season. Provided with sufficient water, it is usually higher yielding than that in the wet season |
| gunung (Javanese) | mountain |
| hama | pest |
| hujan | rain |
| jaringan irigasi | irrigation network |
| Jawatan Pertanian D.T. II | District Agricultural Service |
| kali (Javanese) | river |
| ketigo (Javanese) | dry season |
| labuh (Javanese) | transition period to the wet season. Literally, rain is coming |
| ladang | dry rice field depending on rain water; not permanent. Shifting agriculture |
| lahar | mud flow |
| lemah (Javanese) | soil |
| lemah abang | red soil |

| | |
|---|---|
| mareng | transition period to the dry season; lit., becoming dry |
| Orde Baru | New Order, New Generation; refers to the administration of President Suharto |
| Otorita Citarum | Citarum River Authority |
| padi genjah | fast producing rice |
| padi gogo | dry rice or unirrigated rice |
| padi ungguk | high yielding rice |
| pecai | a kind of lettuce |
| pekarangan | family gardens planted with a variety of fruits and vegetables |
| Peta Baru | name of one of the parent rice varieties used in the cross which produced PB5 (IR5) and PB8 (IR8) |
| polowijo | secondary crops; usually vegetables, corn, potatoes, cassava, peanuts, various beans, etc. |
| rendeng | wet season, rainy season |
| sawah | wet rice field |
| sawah tadah hujan | rice field solely dependent on rain water |
| sundep | small worm which attacks the roots and stems of the growing padi |
| tadah | catchment or catching implement |
| tambak | see empang; fishpond |
| tanah | soil or land |
| tanah abang | red soil, red land |
| tanah kering | dry land, dry soil |
| tanaman sambilan | subsidiary crop, not major crop |
| tanjung | cape |
| tegalan | dry land, unirrigated; usually planted with secondary crops. In the rainy season, sometimes it is planted with rice |
| tikus | mouse |
| udang | shrimp |
| ulat tantra | army worms which often attack rice plants at night |
| waduk (Javanese) | literally, stomach; used to refer to a small artificial lake |
| walang sangit | a kind of small grasshopper which attacks rice plants in the growing period |
| wereng | brown plant hopper |

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