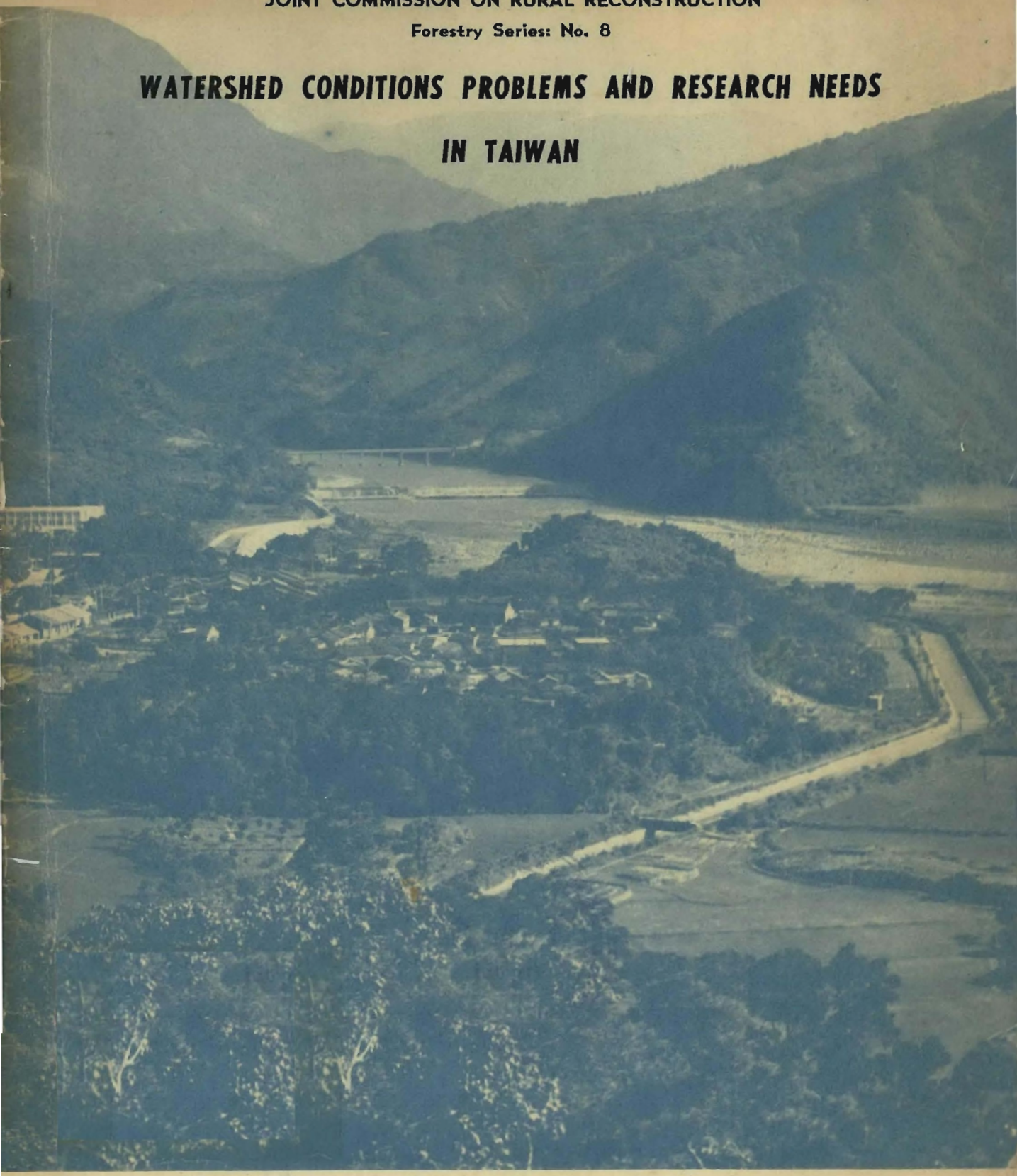
CHINESE-AMERICAN
JOINT COMMISSION ON RURAL RECONSTRUCTION
Forestry Series: No. 8

WATERSHED CONDITIONS PROBLEMS AND RESEARCH NEEDS IN TAIWAN



By
Robert E. Dils

Taipei, Taiwan, China
August 1964

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FOREWORD

Dr. Robert E. Dils, Pack Professor and Leader, Cooperative Watershed Management Unit, Colorado State University, spent two months in the summer of 1963 to study watershed management in Taiwan. During his stay in Taiwan as JCRR consultant, he made six field trips, visited ten important watersheds, gave six talks, including one in watershed seminar, and exchanged views with many technicians of related fields.

Upon completion of his duty, Dr. Dils conferred with Governor Huang Chieh of the Taiwan Provincial Government about his findings and suggestions on watershed management work in Taiwan. He also prepared the following report entitled "Watershed Conditions Problems and Research Needs in Taiwan".

We are glad to note that his recommendations have been gradually adopted and carried out by various government agencies. We appreciate not only his hard work in Taiwan but also his invaluable suggestions which will usher in a new era for our watershed management.

We are publishing Dr. Dils' report to show our appreciation and also for the benefit of those who may be interested in his findings.

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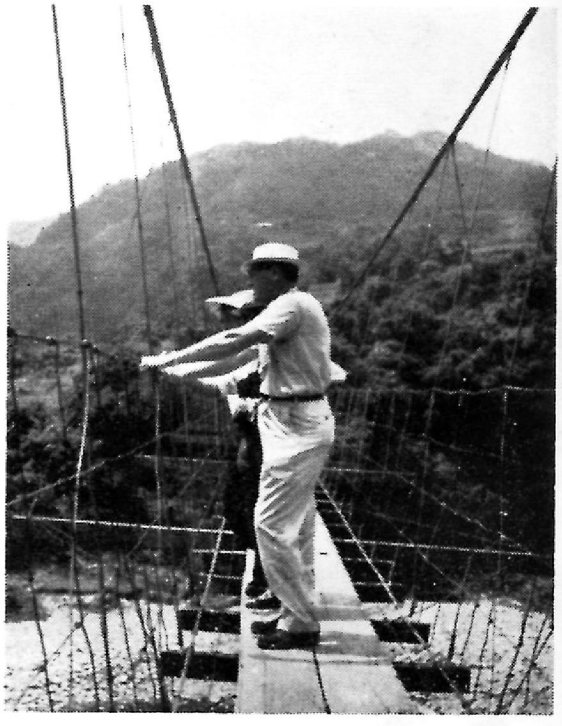
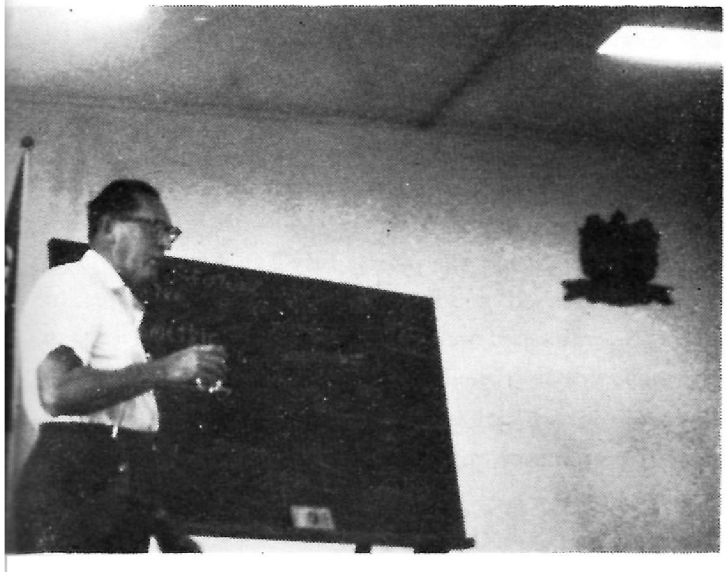
Dr. Dils conferred with Governor Huang Chieh of the Taiwan Provincial Government about his findings and suggestions on watershed management work in Taiwan.



In the field

At the watershed management seminar.



Taiwan's mountains rise to over 13,000 feet (3,900m) elevation. Due to their geologic youth, high rates and amounts of precipitation and the common occurrence of earthquakes landslides are common and geologic erosion proceeds very rapidly.

INTRODUCTION

This report summarizes the results of an assignment with AID/China as a consultant in watershed management. The investigation was conducted in cooperation with the Chinese-American Joint Commission on Rural Reconstruction during the period July 2 to August 23, 1963. The objectives of the project were to (1) assess watershed conditions and current activities in watershed management (2) to recommend future watershed management activities, and (3) to recommend a program of watershed management research in Taiwan.

Secondary objectives include recommendations for education and training and the presentation of a series of lectures at a watershed management seminar.

PHYSICAL SETTING

The island of Taiwan lies astride the Tropic of Cancer approximately 150 km southeast the coast of the China mainland between 21°45′ and 25°37′ north latitude. It is about 384 kilometers (235 miles) from north to south and 144 kilometers (88 miles) in width at the widest point. The total land area, including 77 offshore islands, principally the Pescadores, amounts to 35,760 square kilometers (13,800 square miles).

Topography

Approximately two-thirds of the island is rugged mountainous country. The Central Range of mountains runs from north to south for nearly the entire length of Taiwan. The east coast is marked by mountains rising abruptly out of the Pacific Ocean. On the west coast a level plain intervenes between the Straits of Taiwan and the Central Range. The plains or lowlands occupy about one third of the total land area. The mountains are very steep and slopes usually exceed 45 percent. In the high mountains, slopes in excess of 100 percent are common. The highest point on the island is Mt. Morrison (Yu Shan) with an elevation of 3,997 m (13,100 feet). Approximately 32 percent of the land area lies above an elevation of 1,000 meters (3,280 ft) and 37 percent lies at elevations between 100 and 1,000 meters above sea level. Most of the 19 major streams are oriented east or west and are typically short and steep.

Geology

Geologically the Island is very young. The Central Mountain Range appears to act as a hinge line. On the east coast there is some down warping and along the west side of the island, uplift. The rate of uplift has been estimated at 18 cm per hundred years. Earthquakes are common and contribute to faulting, jointing and fracturing of the bedrock. High intensity rainfall, steep topography and these tectonic disturbances contribute to very rapid rates of geologic erosion marked by frequent and numerous landslides in the high mountain country.

The six principal geologic formations are (1) Tananae schist, (2) slate formation, (3) miocene formation, composed chiefly of alternating beds of sandstone and shale, (4) pliocene yellowish brown sandstones and bluish gray shale (5) Toukoshan formation which includes largely soft sandstone and shale as well as conglomerates and (6) terrace gravel and alluvium.

Nearly all these formations are young, well faulted and fractured, soft, weak, and intensively weathered. They are often covered with an overburden of soil and soil material and concealed by vegetation. When disturbed or exposed by cultivation, road construction, or by landslides they erode rapidly.

Soils

According to Hsi and Chang (6) Taiwan soils are divided into four major zones based upon combinations of climate, relief, and parent material. They are designated as (1) Mountain stony soils (2) Red-yellow Podzolic soils, (3) Latosolic soils, and (4) Alluvial soils.

The Mountain Stony Soils are found at elevations over 1,500 meters above sea level. These soils develop typically under coniferous or mixed conifer and hardwood forest and with a humid, temperate to cool climate. Parent materials are usually sandstones, slates, shales, quartzites, andesites or schists. Small areas of gray-brown podzolic soils may occur on flat mountain tops or on high gentle slopes. Scattered areas of mountain humus soils may also be found in this zone.

The Red-yellow Podzolic Soils lie immediately below the mountain stony zone. This zone extends throughout the lower mountains up to elevations of 1,500 m. The climate here is typically humid, subtropical to tropical and native vegetation is largely hardwoods and mixed hardwoods and conifers. Parent materials are usually similar to those of the mountain stony soils. Within this zone, soil sub-groups include various intergrades among gray-brown podzolics, red-yellow podzolics and brown forest soils as well as scattered areas of mountain humus soils. In most cases the soils are shallow, stony and slightly podzolized.

The Latosolic Soils Zone extends from sea level to over 1,500 m. elevation and is closely associated with diluvial pleistocene tablelands (gravel, sand, and clay deposits) and basic volcanic rock areas. Natural vegetation was probably hardwood forest. Much of this soil zone is now in cultivation. The tableland soils are commonly red or reddish brown while those developed on volcanic materials are yellow or yellowish brown in color.

Alluvial Soils occur on flood plains, river terraces, basins and alluvial fans and are the most important agricultural soils of Taiwan. They are young soils with little or no profile development and are quite variable in their properties. Virtually all of such soils are under cultivation.

Nearly all the mountain soils are subject to serious erosion when exposed. A large percentage of the soils in the higher mountains are well protected by vegetation. In the lowlands, and to an extent, on the more level terraces, benches or tablelands, soils are generally stable. On intermediate areas the soils have been severely eroded due largely to cultivation on steep slopes. This soil loss has reduced productivity on these lands and much of the erosional debris has been deposited in reservoirs, reducing their useful life.

Climate

The climate of Taiwan varies from sub-tropical in the north to tropical in the south. The average annual precipitation is 2,500 mm (100 inches) varying from less than 1,500 mm in the south western lowlands to more than 6,000 mm at the northern tip of the island. Generally the northeast portion receives relatively uniform precipitation throughout the year whereas the southwest area usually has a dry season from October to April or May. Island-wide drought has been observed in spring and early summer sometimes creating a general shortage in water supply.

The principal feature of the Island's precipitation regime is the typhoon storm. Tropical typhoons originating in the Pacific often move westward or northwestward and hit Taiwan with a frequency of two to eight times a year bringing torrential rains and often, destructive winds. The typhoon season extends from July through September. Typhoon rainfall will commonly exceed 375 mm to 450 mm (15 to 18 inches) within a 24-hour period and is often the cause of severe flooding, landslides and attendant erosion and sedimentation damage. Local shorter storms

occur throughout the island which give rainfall intensities of 100 mm (4 inches) per hour or more several times each year. Further, the high mountain barrier thrust into the winter monsoonal air streams moving southeast from the mainland gives rise to large amounts of orographic precipitation, particularly in northern Taiwan.

Except at elevations over 1,000 meters Taiwan enjoys a year-round growing season. Summer weather is usually hot and humid and winter is mild to warm and humid. At elevations above 1,500 meters the climate becomes temperate and snow may occur in winter.

Hydrology

Taiwan is thoroughly dissected by many short, steep streams. Yen (27) indicates that there are 151 streams which flow directly to the sea. The area, channel length and slope of these streams are shown below:

Drainage Area

Drainage Area (sq. km)	Number of rivers
under 100	105
100- 500	30
500-1,000	7
1,000-2,000	5
over 2,000	4

Channel Length

Channel length (km)	Number of rivers
under 30	117
30-50	13
50-70	8
70-90	6
over 90	7

Channel Slope
(includes only larger streams)

Bed Slope	Number of rivers
1:14	18
1:14 —1:20	8
1:20 —1:40	16
1:40 —1:100	14
over1:100	5

Precipitation amounts and intensities in Taiwan are among the highest in the world as indicated in selected maximum rainfall data below:

Selected Recorded Maximum Rainfall in Taiwan (after Yen)

Duration	Rainfall in mm	Station	Date
10 min	70	Tahushan	Aug. 7, 1959
30 min	108	Tahushan	Aug. 7, 1959
60 min	176	Tahushan	Aug. 7, 1959
3 hrs	346	Tahushan	Aug. 7, 1959
7 hrs	640	Tapu	Aug. 7, 1959
18 hrs	845	Chensipo	July 31, 1956
24 hrs	1,127	Taiwu	July 19, 1934
2 days	1,671	Fenchihu (Funkiku)	July 19-20, 1913*
7 dys	2,623	Tapu	Aug. 31-Sept. 6, 1911
1 month	3,402	Taiwu	August 1922
1 year	8,507	Hooshaoliao	1912

* A world record rainfall for 2 days

Under such physiographic and meteorologic conditions extreme flood conditions are inevitable. Sheng (22) notes that 6 out of 19 major streams sometimes exhibit flows of 10,000 cubic meters per second during flood time and that some peak flows execed 22,000 cubic meters per second.

Floods are often catastrophic in Taiwan and have led to loss of life and a crippling of the economy. The August 7, 1959 flood, the largest in 60 years, was responsible for the death of more than one thousand people and directly damaged almost one-sixth of the total arable area of the island. The direct and indirect property damage was estimated at about US$100 million.

As would also be anticipated under such conditions the rivers carry tremendous loads of silt and sediment which annually reduce the amount of arable land both by erosion and deposition and often occasion high property damage (such as the complete inundation of the Tung Men Power House by sediment in 1945). Selected data from Chu (2) indicate the magnitude of the sediment problem in Taiwan.

River	Station	Drainage area (Km^2)	Average annual sediment transport (Million, M/T)	Sediment yield per unit area (M/T per Km^2)
Cho-shui Chi	Hsi-lo	2,977	57.15	19,080
	Chi-chi	2,311	59.40	25,670
	Ching-yun	1,529	21.37	13,970
	Ying-sheh	188	0.46	2,450
Wu Chi	Nan-kang	76	0.90	11,730
	Chin-liu	383	2.29	5,980
	Kan-tsu-lin	960	3.25	3,390
Ta-chia Chi	Ta-chien	526	2.23	4,240
Lang-yang Chi	Lang-yang	821	38.13	46,500
Pi-nan Chi	Lung-men	421	4.04	9,600

Based on studies of the silt trapped behind debris check dams, siltation rates from entire watersheds commonly exceed 15 to 25 mm per year, exclusive of the fine materials carried

downstream in suspension.

Since all the large urban-industrial areas are located along the larger streams and on alluvial plains, water supply appears to be adequate for these purposes, at least for several decades (with the possible exception of the Tainan area where shortages may exist during the dry season).

However, where additional irrigation water is needed to produce more paddy rice, storage reservoirs are required. Many of the reservoirs constructed for this purpose, have had their storage capacities reduced, sometimes very markedly, due to sedimentation.

Vegetation and Land Use

The distribution of land area according to major uses is indicated in table below. Approximately 55 percent of the land area is presently covered with forest vegetation. Additional areas are classified as forest lands but are presently in cultivation, grassland, or are denuded. Most of the forest land lies above an elevation of approximately 300 meters.

At the higher elevations coniferous forests predominate. The coniferous forest is comprised of five principal types: (1) cypress (Chamaecyparis taiwanensis and Chamaecyparis formosensis), (2) hemlock (Tsuga chinensis), (3) Spruce-fir (Picea morrisonicola and Abies kawakamii), (4) pine (Pinus armandi, P. taiwanensis, P. morrisonicola and P. massoniana), and (5) a mixed conifer type (which includes Libocedrus formosana, Taiwania cryptomeriodes, Cunninghamia konishii, Pseudotsuga wilsonia, Cunninghamia lanceolata, and Cryptomeria japonica).

In general the coniferous forest contains Taiwan's most valuable timber resources. Due to lack of roads a large proportion of this type is relatively inaccessible and only limited logging has taken place. Because of the very steep topography, skyline and high lead methods are usually employed. From the standpoint of watershed management these forests provide excellent watershed cover.

Land Use in Taiwan*

Land use class	Area (in 1,000 ha.)	Percent
Forested land:		
Conifers	373.0	
Conifer-hardwoods	55.3	
Hardwoods	1,427.3	
Bamboo	113.9	
Total:	1,969.5	55
Agricultural		
Paddy	559.6	
Dry-farming	445.0	
Farm woodland	38.2	
Total:	1,042.8	29
Other land		
Grassland	305.1	
Denuded, plantable	20.1	
Denuded, unplantable	117.4	
Urban and industrial	74.1	
Water area	47.0	
Total:	563.7	16
All Lands	3,576.0	100

* From Land Use Conditions in Taiwan, by E.C.H. Hsia, 1957.

The mixed conifer-hardwood forest contains a variety of conifers and hardwoods including several species of pine, Cunninghamia and Cryptomeria as well as temperate hardwoods, largely oaks (Quercus spp), Lithocarpus and Actinodaphne spp. Only about 2.8 percent of the forest area is in this type.

By far the largest portion of forest area is in hardwood forest. The hardwood forest, which covers over 72 percent of the total forested area, is composed of the tropical hardwood, the subtropical hardwood, and the temperate hardwood types which are made up of a wide variety of genera and species. A few of the more common genera are Acacia, Alnus, Machilus, Liquidambar, Ficus, Trema, Lithocarpus, Castanopsis, Cryptocarya and Quercus. The hardwood forest ranges from sea level to over 2,000 meters (6,600 feet) in the southern mountains. Unfortunately, this forest cover appears to be the least valuable economically. The trees are often poorly formed and limby and the litter they produce decomposes very rapidly under the prevailing climatic conditions resulting in a thin and often nearly bare forest floor.

Bamboo cover occurs principally within the tropical and subtropical climatic zones (from sea level to approximately 1,600 meters elevation). The bamboo type consists largely of three native species: Phyllostachys makinoi, Dendrocalamus latiflorus, and Bambusa stenostachya. Bamboo has considerable economic importance since its stems are used for a wide variety of purposes and its shoots are used for food. It also appears to have promise for watershed protection since it produces a large amount of litter, gorws in dense stands, and its root system has good soil holding features.

A reforestation program is carried out by the Forestry Bureau in cooperation with other agencies and local governments on all forest lands. Reforestation has averaged approximately 35,000 hectares per year for the past 10 years on cutover and burned areas, grass land, denuded land and on low value forest areas. Principal genera planted include Cryptomeria, Cunninghamia, Pinus, Chamaecyparis, Tectona, Acacia, Casuarina, Cassia, Cinnamomum, Swietenia, Pterocarpus and Eucalyptus. In the lowlands and along the coast Casuarina is commonly planted for windbreaks, and for sand stabilization.

Seventy-two percent of the forested land is in national ownership. The balance includes aboriginal reservations, unreserved forest land and other public and private forests. Nearly 379,300 hectares of forest land are designated as protection forest. Of this, 76,000 hectares are presently nonforested. Legally, both cultivation and timber harvesting are banned on protection forest areas. Actually much of this protection forest is subject to illegal cultivation and to timber trespass, especially for fuel wood as some of the nationally owned and county administered unreserved forest lands.

Of the total land area over 1 million hectares (29 percent) is cultivated. Approximately 560,000 hectares are in rice paddy, 445,000 hectares in dry-farming and 38,000 in farm woodland. Rice paddies will produce from one to two crops of rice annually depending upon the amount of irrigation water available and the location. Where water limits the paddy to one crop per year, such lands will also be used to produce rotational crops, commonly sweet potato, peanut, jute, soybeans and vegetables. Where water limits rice production to one crop in two or three years, sugar cane will commonly be grown between rice crops. Paddies and dryland farming in the plains area present no special problems in watershed management.

A large proportion of the 445,000 hectares classified as dry farming lies on hilly and steeply sloping mountain lands. The principal agricultural crops include tea, sugar cane, pineapple, banana, citronella, cassava, sweet potato, peanut, and citrus. Nearly all these are row crops in which a large area of soil is exposed to erosion. Increasing areas of dry farming land are being converted from both up and down and contour cropping to hillside benches and contour ditches combined with grass or concrete waterways for drainage of excess water. Where these practices have not been applied erosion is usually serious. Dry farming extends into the forest area often to elevations of 2,000 meters and on slopes of nearly 100 percent.

Abusive, illegal and shifting cultivation practices are particularly common in the dry farming areas between the lowland plains and the mountainous forests. Abusive uses include the practice of cultivating excessively steep lands in crops such as banana and cassava without applying conservation practices. Because of the tremendous pressure for agricultural land it is a common practice for farmers to illegaly clear steep forest land, both "unreserved" and national forest lands, and cultivate them. Almost invariably abusive cultivation practices are applied. Shifting cultivation applies to the practice of clearing forest land on aboriginal reservations, cropping for a few years and then abandoning the land as productivity drops. In total it is estimated that 120,000 hectares are now subjected to such practices. Of this, 27,000 hectares are scattered throughout designated national forest compartments, 33,000 hectares are in aboriginal reservations (shifting cultivation) and 60,000 hectares in "unreserved forest land" administered by the county governments with the advise of the Taiwan Forestry Bureau. In addition, other public, private and corporation lands in this zone are also subject to abusive or poor cultivation practices.

Socio-Economic Factors

The social and economic pressures for more land for all purposes in Taiwan are extremely heavy. Census figures for 1962 indicate a population of 11,547,441. This amounts to a population density of over 320 persons per square kilometer or 830 persons per square mile. On the plains areas where most of the population is concentrated, population density probably exceeds 1,000 persons per square kilometer (2,500 per square mile). Annual population increase is estimated at 3.5 percent.

The demand for more food and fiber increases with the population increase and each year significant areas of the best plains agricultural lands are lost to new construction: homes, industry, highways, military installations, and the like. Road and reservoir construction and erosion take varying amounts of hilly land out of agricultural use each year.

Small areas of "new" agricultural lands are being made available through tidal land and river flood plain reclamation efforts. Food production per hectare is being increased through the increased use of fertilizers, better soil and land management and the application of irrigation practices.

These efforts however cannot meet the demand for additional agricultural land and the pressures for the cultivation of the sensitive lower mountatins areas for such use will increase even more.

WATERSHED PROBLEMS

Problems in watershed management are generally due to (1) lack of available water supply (2) poor quality of available water (3) poor timing of streamflow (4) flooding and (5) erosion and sedimentation. All these are common to Taiwan in some degree. However, the most serious problems center around flooding, erosion and sedimentation. Due to the Island's topography, geology, and soils, the common occurrence of typhoon rainfall, earthquakes and the heavy pressure on the mountain slopes for cultivation, flooding, erosion and sedimentation conditions are extreme.

For purposes of problem discussion the Island is arbitrarilly divided into three zones designated as the (1) plains (2) intermediate and (3) mountain-forest zones. The boundaries of these zones are defined very roughly by elevation as sea level to approximately 500 meters, 500 to 1,500 meters and above 1,500 meters respectively.

Plains Zone

The plains zone or lowlands occupy nearly 10,600 sq. km. or approximately 30 percent of the land area of Taiwan. From the standpoint of watershed management there are few physical problems in this zone. A large proportion of the Island's agricultural, industrial and urban developments are centered in these lowlands.

1. *Agricultural lands.* A high proportion of these lands are in agricultural use and much of this is in rice paddy. Paddy fields are level, and, with their dikes, act as water storage reservoirs. In total they will hold large volumes of excess precipitation. Consequently, they are not subject to serious erosion and actually provide a measure of flood control. Much of the other agricultural land in this zone is relatively level to gently sloping and poses no serious erosion problem. With an increase in elevation there is usually an increase in land slope. Where conservation practices such as benching and hillside ditching with grassed or concrete waterways are employed erosion does not appear to be serious. However, cultivation of the steep slopes in this zone without benching, ditching, mulching or provisions for the drainage of runoff water appears to contribute materially to erosion and soil loss. Locally, there are areas within this zone which are eroding very rapidly such as the first low hills rising above the plain west of Taichung. Here the soil mantle is very thin or entirely absent and large gullies have formed.

2. *Urban Lands.* Urban lands include those areas occupied by cities, villages, highways, airports, military installation and industrial developments. The aggregate of land area in the plains zone now in such uses is already very substantial and is increasing rapidly. With each such new development, additional land is going out of agricultural production and these are usually the most productive agricultural lands. Often these developments too are located in the flood plains of characteristically flashy streams creating an increasing socio-economic flood hazard. Increasing the total surface of highway, rooftop and concrete effect a decrease in infiltration and storage opportunity for excess precipitation and contribute an unmeasured amount of additional flood flow and thus create higher flood peaks. Storm runoff from such areas, as well as municipal and industrial waste waters are generally of low quality as well.

3. *Reclaimed Lands.* Such areas include tidal lands, river beds and coastal sand areas that

have been or may be reclaimed for largely agricultural uses. Again they do not present an erosion problem. However, by virtue of their location they are subject to wind and salt damage and to inundation by floods. Areas of shifting sand along the coast are often stabilized by planting salt tolerant vegetation, especially Casuarina. The agencies involved are doing an excellent job in reclaiming much needed agricultural land in these areas.

Intermediate Zone

From a watershed management standpoint this zone is of primary importance. With virtually all of the plains zone occupied, it is only natural that there be increasing land use pressures up into the hilly areas and the lower mountains. While nearly all this land was originally in hardwood or mixed hardwood-conifer forest, much of it now is in agricultural use. Sheng (22) indicates that approximately 200,000 hectares of sloping land is now under cultivation, nearly all of which lies in the zone.

1. *Agriculture Lands.* Agricultural crops in this zone are essentially the same as are produced in the plains zone. Dry farming crops predominate, however, since much less of the land here is topographically suitable for paddy development.

The soil and water conserving practices being applied to agricultural lands in this area are excellent. Benching with provisions for the drainage of excess water appears to be very effective in reducing erosion and overland flow. The additional moisture made available to crops grown on benched lands combined with a conservation of fertilizer when applied also appears to effect a marked increase in crop productivity. The hillside ditches with drainage are also effective in conserving moisture and reducing erosion. Based on observations at two Tea Experiment Stations, one Horticulture Experiment Station and on privately developed pineapple lands, the mulching of row crops with rice straw is also a very effective conservation measure.

Unfortunately, on large areas of agricultural land such measures are not being applied and poor and often abusive land use practices obtain. The practice of row crop farming on steep sloping lands, often up and down hill, has been especially conductive to erosion. Soil loss has reduced productivity and contributed to additional flood flows and sediment problems.

The problem of illegal cultivation is of particular significance. Large areas of land are classified as forest land because of the topographic and cover conditions. Some of these lands are in reserved national forest compartments, some in reserved protection forest, and some in unreserved forest. Because of pressures for more land and greater food and fiber production it has been a common practice for the farmers to clear patches of this land and plant it to agricultural crops. While this practice is illegal and the Taiwan Forestry Bureau has the authority to put a stop to such practices it has been condoned due to social, economic and political pressures. Aware that they have no legal right to use such land, the "squatting" farmers have no interest in applying conservation practices or in improving the land. As a consequence, these illegally cultivated lands are being utilized for quick return cash crops—often banana, cassava and similar crops—which provide little soil protection. Erosion from such lands has very obviously been greatly accelerated. The small economic gain made through such cultivation is far more than offset by the loss of the soil resource and the downstream damage it causes.

Aboriginal reservations commonly extend from the mountain forest zone down into the intermediate zone. The shifting agriculture practiced by the aborigines poses a watershed management problem similar to that of illegal farming.

The aborigines subsist largely by farming and characteristically will clear a patch of forest, put it to agricultural use for several years, until productivity falls then abandon it and shift to another patch of forest. While legally they may follow such practices within their designated reservations, the effects are the same as that of illegal farming.

2. *Forest Lands.* As has been indicated, much of the forest land in this zone is in hardwood or mixed hardwood-conifer cover. The quality of these forests at the lower elevations appears to be poor both from the standpoint of the timber resource and for watershed protection. In part this has probably been due to past cutting in these forests for fuel and to the fact that a lot of the debris and litter is collected for fuel rather than being returned to the forest soil. Under subtropical and tropical climate conditions the litter which is left decomposes so rapidly that the forest floor is often bare. In addition to the illegal cultivation cited above, timber trespass into this area appears to be common, further reducing the cover density of the forest.

At the lower elevations bamboo has been used for reforestation purposes. This type appears to be excellent for such planting. In addition to the bamboo, Acacia is often planted for fuelwood. It appears to grow well on eroded and rocky sites. At the upper portion of this zone, China fir and Cryptomeria have been used for reforestation purposes. They too are excellent species both for timber production and watershed protection.

Mountain-Forest Zone

This zone represents by far the largest part of the land area of Taiwan. A high percentage of the total 2 million hectares of forest land lies at elevations above 1,500 meters. It is characteristically steep mountainous country and much of it is relatively inaccessible.

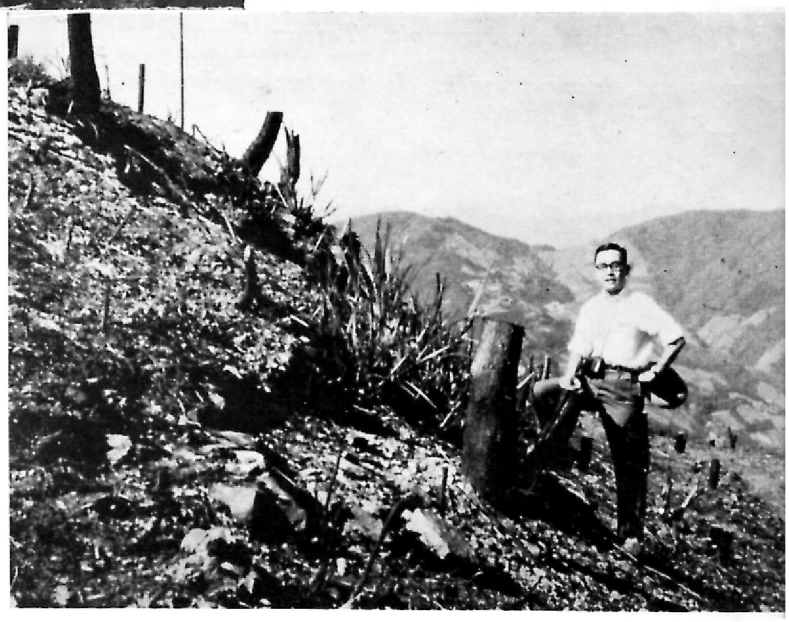
1. *Protection forests.* Approximately less than one fourth (379,300 hectares) of the national forest land is designated as protection forest, often called "water conserving protection forest" or "soil binding protection forest". These areas are usually on the steepest slopes with shallow soils. To date no cutting or management, other than protection or reforestation, has been applied to this land. In general the forest cover is good except where it has been removed or covered by landslides.

2. *Logging.* Due partly to market and economic conditions and partly to inaccessibility only small portions of the "economic" forest areas have been harvested. In some cases logging appears to proceed selectively over a period of several years so that there is no large scale exposure of bare soil. Based on limited observations it appears that the logging methods applied have not impaired watershed values. The road systems leading to the logging areas have undoubtedly caused much more damage than the logging.

Much of the forest resource in both the national forest compartments and in the protection forests appears to be mature to overmature and often decadent. Unless the harvesting program is intensified much of this resource will be lost or wasted.

3. *Landilides.* The most significant watershed problem represented in this zone is that of landslides. Massive landslides have occured on many of the basins due to topographic, geologic

Steepland cultivation, often illegal and abusive, contributes large volumes of debris to stream channels and reservoirs.



Shifting cultivation is practiced on most of the aboriginal reservations. Forests are clearcut and burned, crops grown for a few years then the patches are abandoned and new areas are cleared for cultivation. Like illegal and abusive farming practices at lower elevations such areas contribute large volumes of soil and debris to stream channels and reservoirs.

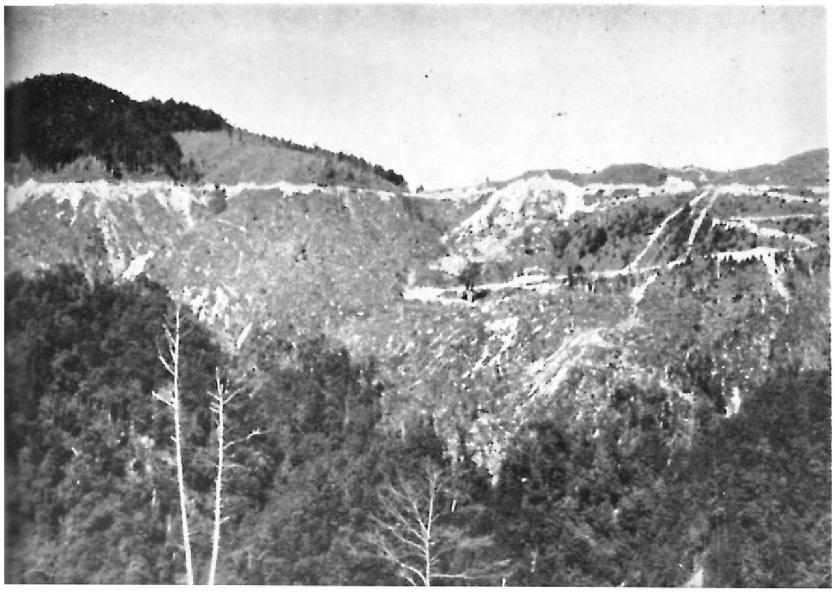
The pressure for additional cropland is so great that river beds such as this near Toulin, Yunlin County are being reclaimed. Reclamation includes land levelling, construction of diversion and protection structures and the introduction of sediment laden water to deposit soil material which is then converted to sugar cane plantation or paddy land.

The Gen-shan-pee reservoir, Tainan County, is now soil sediment laden. It has lost much of its value.

Massive landslides in the high mountains contribute much of the debris and bedload material which is rapidly clogging channels and filling reservoirs.

Sediment clogged streams are typical throughout Taiwan. Above this point almost all erosion is geologic or natural due largely to massive laudslides.

Excellent pine and cypress forests occur on the high mountain lands (elevation 2,200 meters above sea level). With conservative harvesting methods and careful road construction and maintenance this resource can be harvested without undue erosion in many areas of Taiwan.



Block clearcutting of forest near Ta-shu-shan. Note that majority of the erosion scars originate along the road.

The cross-island highway in central Taiwan caused large areas of exposed soils which are subject to heavy erosion, slumping, and sliding. During and following heavy rainfall it further contributes to flooding and downstream sedimentation.

Roads cuts and fills and other areas where sloping soil is exposed should be revegetated immediately following exposure.

and climatic conditions. The deeply weathered, soft and weak geologic materials, which in some places stand almost on end, are loosened by frequent earthquakes and when further weighted down with water following heavy typhoon rainfall, often slide several thousand feet down the mountain side. On occasion an earthquake alone may be sufficient to trigger a massive slide. The exposed slide areas are further subject to torrential rains which wash tremendous volumes of debris into the short streams from which it is carried down to the plains. The heavy debris load in the streams during high flows contributes to further erosion of the streambanks and channels.

4. *Roads.* Several cross-island highways have been constructed or are now under construction which cut across this zone. Undoubtedly road construction has caused additional landslides. Further, during and following construction there appears to be little or no effort to stabilize the road cut and fill slopes. Large areas of exposed soil are subject to heavy erosion, slumping, and sliding during and following heavy rainfall further contributing to flooding and downstream sedimentation. Natural revegetation on these exposed subsoils and soil materials appears to be slow.

5. *Mountain Farming.* At the lower portion of this zone the problems of illegal and shifting cultivation exist as described above. In addition, increasing number of retired servicemen are being given land in this area for farming. Facing the necessity of producing crops for food and for a livelihood these sloping lands are often used abusively rather than applying benching or hillside ditching practices prior to cultivation.

ASSESSMENT OF PRESENT PROGRAM

Much of the work to date whcich might be classified as watershed management activity has been done by the Taiwan Power Company, the Mountain Agricultural Resources Development Bureau, the Shihmen Local Development Commission, the Taiwan Sugar Corperation and the Taiwan Forestry Bureau, often in cooperation with the Joint Commission on Rural Reconstruction.

The work done in the Wusheh basin by the Taiwan Power Company merits particular mention. The primary purpose of their activities has been to reduce the rate of sedimentation in the Wusheh reservoir. Land use in the watershed above the reservoir included shifting agriculture on aboriginal reservations as well as steep land abusive agriculture. The majority of the watershed is in forest cover. The Company inaugurated a fire detection system, including the construction and managing of three lookout towers and a dispatching center and trained selected crews in the aboriginal villages for fire suppression work. To alleviate the problem of shifting agriculture specialized training in power pole and line maintenance was given to approximately 60 men. Following this training these men and their families were moved to lowland cities and villages and employed by the Company. In 1954 the Taiwan Power Company established a conservation work station in the watershed. The Taiwan Forestry Bureau, the Taiwan Forest Research Institute and the Joint Commission on Rural Reconstruction have cooperated with the Taiwan Power Company in this effort. An intensive extension type program was initiated to teach the residents better agricultural methods, the use of new tools, the growing of new crops, handicrafts, homemaking and the like. Reforestation was accomplished on abandoned farm lands and around the Wusheh reservoir. Benching demonstrations were made to show the farmers how they could increase their farm production. In the valley lands, paddies and irrigation water was developed. These measures have done much to reduce the land pressures in the basin and to improve the standard of living. Hopefully, they will be continued and the useful life of the Wusheh reservoir will be extended.

To provide some protection from sedimentation and to extend the life of the newly constructed Shihmen Reservoir the Shihmen Local Development Commission established a conservation work station in that watershed. Their watershed management activities have included reforestation on critical areas and around the reservoir, the improvement of agricultural lands, and the construction of check dams to hold potential sediment and debris in upstream areas.

The Mountain Agricultural Resources Development Bureau was established by the Provincial Government in 1961. In only two years they have made notable progress in bringing about soil and water conservation. Financed partly by the Provincial Government and partly through grants from the Joint Commission on Rural Reconstruction their activities have been concentrated on the critical intermediate zone. They have established numerous benchings and waterway demonstrations and constructed sabo works, especially check dams on small streams, to arrest erosion and sediment movement. As a result of their benching projects private farmers have taken an increasing interest in this activity. Technical assistance and construction materials for waterways are provided by that agency upon a farmer's request in which case the farmer provides the labor

required. Most of the check dam construction is done by the agency which employs local farmers on the projects.

The Taiwan Sugar Corporation has been active in improving, encouraging, and assisting in the improvement of sloping lands for planting to sugar. They have been active too in the reclaiming of river bed and flood plains for additional agricultural production.

Work in this area by the Taiwan Forestry Bureau has included primarily reforestation and sabo and wicker work (primarily check dams) on forest lands administered by that agency. Apparently for social, economic, and political reasons no work has been done on the illegally cultivated national forest lands.

Present watershed work in Taiwan is centered around ten projects: the Wusheh and Tachia, principally Taiwan Power Company Projects; the Shihmen Reservoir project of the Shihmen Local Development Commission; the Ah-kung-tien, Tapu, and Shuili are projects of the Mountain Agricultural Resources Development Bureau; the Wu-shan-tou, an irrigation association project; the Gen-san-pee and Lu-liao, projects of the Taiwan Sugar Corporation; and the Tabei-hu, a project of industry water supply of the Provincial Department of Reconstruction.

In addition, comprehensive watershed planning projects are currently underway for the Pa-kua-shan, Mukua Chi, Hsintien Chi and Muddy and Black Rivers for flood control, debris control, and/or marginal land development.

Watershed management activities were largely initiated by JCRR under the direction of former Commissioner Raymond H. Davis, Ira K. Landon, E. C. H. Hsia and Charles J. Krabel. More recently Messrs. C. W. Yang, T. C. Sheng, C. P. Liu and M. C. Liao of the Forestry Division of JCRR have continued and increased such activities. The Joint Commission on Rural Reconstruction and the cooperating public agencies should be commended on their excellent work in this field. Unfortunately the money and manpower that has been available has been woefully inadequate to meet the needs.

MANAGEMENT RECOMMENDATIONS

Plains Zone

Since there are no apparent major watershed problems in this zone only a few general recommendations are made.

1. The conservation work done in this area by the soil conservation field offices under the immediate supervision of the county governments should be continued.

2. The planting of farm windbreaks and of windbreaks and shelterbelts along the coast to protect farmlands from blowing sand and to aid in the reclamation of coastal sand areas should be continued.

3. The reclamation of tidal lands and river flood plains provides additional land area for agriculture. Such reclamation is very costly and the lands are still subject to inundation in major floods. This work should continue but not at the expense of improvement works in the intermediate zone which is a major problem area.

4. The development of additional irrigation water and the development of better farm crops through plant breeding should increase productivity especially in this zone. If major progress is made in this work it, hopefully, might remove some of the pressure from the upstream areas for agricultural produce.

5. The sloping land within this zone, especially those slopes on the approaches of the lower terraces, should be utilized with caution. In certain areas grass or forest cover should be the dominant use.

Intermediate Zone

A number of specific as well as general recommendations are given which if followed should alleviate or correct some of the serious watershed problems within this area.

1. The excellent work being carried out by the Mountain Agricultural Resources Development Bureau should be continued and expanded. The benching, hillside ditching, drainage and slope stabilization work (both reforestation and sabo works) should be extended to as much of the sloping agricultural lands as possible.

2. Government agencies and administrative officials should tangibly address themselves to the problem of illegal cultivation immediately. If this is not done, the problem will become infinitely worse.

   a. Based on the present marginal land survey detailed field inspections should be made on all sloping lands regardless of ownership or present classification. On the basis of this inspection those forest lands which are suitable for agriculture use with appropriate conservation measures applied should be so classified. Sloping lands now under cultivation which should not be so used even with conservation practices should be listed as forest land and reforested as soon as practical. If necessary some of the present unreserved forest land could be redesignated as national forest compartment land to compensate for the loss of forest land due to present illegal farming and potential future reclassification. This would seem especially appropriate where the consolidation of national forest lands would be brought about.

b. Those lands now under illegal cultivation and which would remain so after the reclassification should be benched or otherwise treated to reduce erosion and soil loss as soon as possible. Farmers now using such lands who are willing to improve them by applying conservation practice should be given technical assistance and materials help and a long term lease to their use (contingent upon the continued practice of conservation farming).

3. Where the treatment of long slopes is involved the establishment of a contour forested or forest and grass strips to serve as a water and soil filter strip is suggested. The width of such a strip would depend in part upon the slope and upon soil conditions. In many cases a 10-15 meter wide strip might be adequate.

4. Severely eroded areas which are not suited to benching or hillside ditching should be planted to trees or grass. Sabo or wicker work may be necessary to aid in soil stabilization. Continued effort by the Agricultural and Forest Research Institutes should be made to find species for planting that will yield economic returns as well as good soil protection. Limited observations indicate that the bamboo is an excellent species for such planting.

5. Many of the major construction projects such as the cross island highways and reservoirs, present and proposed, go through or are located in this area. Usually large areas of soil and soil material are exposed during and after construction and often are a source of serious erosion and sedimentation. It is recommended that provisions be made in construction planning and budgeting for soil stabilization measures on such areas. In most cases from 1 to 2 percent of the total construction cost applied to soil stabilization would be more than paid for through lower road maintenance costs and longer reservoir life. In the case of water storage reservoirs, land treatments should be applied in advance of reservoir filling. This fund should be appropriated as early as possible to the agencies concerned (MARDB, TFB etc.) in order to have enough time to provide watershed protection.

6. The problem of shifting agriculture on aboriginal reservations can be reduced in part by the methods applied by the Taiwan Power Company in the Wusheh watershed. Every effort should be made to retrain the people and where practical move them out of the mountains. An intensive educational and training program in farming techniques, good land use, forest management and harvesting (on aboriginal lands) and handicrafts should be initiated.

7. Where streams are already heavily laden with sediment and debris the construction of check dams in the headwater areas, along with land treatment measures, appears to be the only practical solution. It is quite likely that such debris check dams will fill in rapidly and their effectiveness will be reduced.

8. It is further suggested that the Provincial Government establish a watershed program (similar in part to the small watershed program in the U.S. PL566) on a trial basis in which the Taiwan Forestry Bureau and the Mountain Agricultural Resources Development Bureau are co-partners. On a selected watershed the recommended improvement measures would be discussed and planned in consultation with Joint Commission on Rural Reconstruction specialists in forestry and soil conservation as well as such other specialists as might be needed. The improvement works would then be accomplished by these two action agencies and their effectiveness in reducing flood flows and erosion and sediment movement assessed. If such a pilot watershed project proves successful this activity might be applied to all of Taiwan. Further, such a pilot project could

provide the basis for some of the much needed research in watershed management and watershed hydrology in Taiwan.

9. Timber trespass, particularly the theft cutting of fuel wood, is apparently common (e.g. in Puli, Nantou Hsien, Chishan, Kaohsiung Hsien and other areas). From the standpoint of national morale as well as resoures protection effective measures should be taken to halt such practices. Areas in need of thinning or timber stand improvement which are accessible to the towns and villages might be designated as free (or nominal fee charged) fuelwood cutting areas. Such cutting should be under the supervision of TFB work stations or county governments.

10. In at least one area (the Ching-mei watershed, tributary to Hsin-tien Creek) coal mine tailings are being dumped directly into the stream channel, contributing to increased sediment loads and depressing water quality. Provisions should be made for keeping such debris out of the stream.

Mountain-Forest Zone

Since the problems of illegal and shifting cultivation apply to the lower portion of this zone as well as to the intermediate zone, the recommendations above also apply. Other than these the principal problem in the high mountain forest area is that of landslides.

1. Massive landslides occur frequently throughout the mountain forest area. These are due largely to natural conditions—geology, topography, earthquakes and torrential rainfall—and cannot economically be brought under complete control. Areas which are obviously prone to landslides should not be logged or cut through by roads. On slide areas where topography and soil conditions permit, revegetation should be accomplished. Further, where accessible and practical, check dams may be constructed at the foot of slide areas to keep debris out of stream channels. Research on landslide problems is indicated below.

2. New and proposed cross-island highways as well as major timber access roads should be stabilized and provided with better drainage as soon as practical. Large areas of cut and fill slopes are exposed to torrential rainfall and road maintenance costs are very high. Some of the present road drainage facilities are improperly located, i. e. they spill runoff water directly onto bare fill slopes. In other places drainage facilities are inadequate. As noted above provisions for such stabilization should be included in project planning and budgeting. Such funds should be made available to the appropriate agencies (presumably the Taiwan Forestry Bureau and the Mountain Agricultural Resources Development Bureau) for this work.

3. Currently only a small portion of the Island's timber resource is being harvested. Large areas of mature and overmature timber in accessible as well as non-accessible areas is becoming decadent. As additional markets become available a markedly increased forest harvesting program could undoubtedly contribute much to the national economy. If judiciously accomplished little damage to the watershed should be incurred. The high lead and especially the skyline logging methods employed do not appear to be overly destructive of watershed values. Harvesting should be done on a selection or small clearcut block basis so that large areas are not exposed. Areas with very thin soils and very steep slopes, as well as obvious landslide areas should not be disturbed.

4. A little less than one fourth of the national forest land has been classified as protection

forest mostly during Japanese occupation. It was based on drainage area and vague ideas rather than on spot or sound criteria basis. Under present regulations the only management being applied is protection and the reforestation of grassed and open areas. On some of this forest area, particularly these areas with deeper and more stable soils, timber harvesting could proceed at least on a limited basis without causing undue damage. In this connection, a resurvey (preferably with up-to-date air photopraphs and supplemented by on the ground checks) of the protection forest would likely indicate that some of the present protection forest lands could legitimately be reclassified as economic forest. The present policy of no cutting on the steep slopes with shallow soils should be continued. Research on this problem is also indicated below.

5. Only very limited funds are available to conservation agencies for the application of watershed management practices. In the case of the Taiwan Forestry Bureau it is suggested that a portion of the receipts from the sale of forest products be returned directly to that agency specifically for the purpose of reforestation and soil stabilization on cutover and burned over areas, illegally cultivated lands, landslide areas, road cut and fills and road drainage.

6. In a number of areas within this zone, as well as in the intermediate zone, the Government has been resettling retired servicemen. Forest or grasslands are cleared and put to agricultural use. These settlers are requested or encouraged to apply conservation practices especially benching and hillside ditching to these lands. However, due to the necessity of making a living crops are often put in without first improving the land. Such improvements should be required and the requirement enforced. Such action may necessitate a short-term subsidy to the veterans until these improvements are made. Again, continued use of this land should be contingent upon the application of sound conservation farming practices.

7. As rapidly as practical the lower quality hardwood forest should be converted to the better quality hardwoods and to coniferous types. At the lower portion of this zone both the Chinese fir and Cryptomeria appear to be excellent species for timber and for watershed protection.

RESEARCH NEEDS AND RECOMMENDATIONS

Limited research in soil and water conservation has been and is being conducted by the Universities and by the Taiwan Agricultural and Forestry Research Institutes. Examples of such research include the runoff plots studies being conducted at the Tea Experiment Stations and the precipitation interception study conducted by Chung Hsing University. In addition, some basic studies have been conducted in related fields which has application in watershed management such as the hydraulic model studies on flat bottom hillside ditches by the Taiwan Sugar Experiment Station and the National Taiwan University.

Research specifically in watershed management as such has been almost entirely lacking due to a lack of research funds and facilities and of adequately trained research personnel. For fiscal year 1964 NT$500,000 ($12,500 US) have been budgeted for research in watershed management and soil conservation by the Joint Commission on Rural Reconstruction. This is the first money actually budgeted for this purpose.

The following recommendations are submitted in regard to watershed management research.

1. A major watershed problem as indicated above is that of illegal farming. Research should be initiated to measure quantitatively the effects of forest cutting and the application of conservation farming practices on soil erosion and surface runoff (flood water). The conservation practices that are most likely to be applied are benching and contour hillside ditching. Research should be designed to measure the effects of such practices applied to different slopes and different soil conditions. Various substudies or associated studies could readily be conducted on the same area such as a comparison of different bench construction methods, methods of stabilizing the terrace face or riser and fertility studies on newly established benches or ditches.

2. Considerable discussion has centered around the use of different logging methods and their effects on erosion. Field observation at Chilanshan and at Tashushan indicate that road construction creates a much greater erosion hazard than does logging by either the skyline or highlead methods. While highlead logging is more destructive than the skyline method there appeared to be little erosion due to highlead logging at the Tashushan operation following typhoon Wendy. Studies to indicate both rates and amounts of erosion due to road construction—both logging roads and the cross island highways, should be initiated. It is apparent that numerous landslides have been directly associated with road construction. Reconnaissance type erosion surveys, before and following new road construction, could be utilized to assess the affects of such construction. Similarly, such surveys could be utilized to compare erosion losses under different kinds of logging operations.

3. The need for quick stabilization of cut and fill slopes has been indicated. Since much of the soil or soil and rock material will not be surface soil, some research will be needed to determine the most efficient techniques and plant materials to use in establishing protective vegetation.

4. Large areas of forest land are currently "tied up" in what often appears to be an artificial protection forest classification. It is felt that some of this protection forest could be harvested without impairing watershed protection values. Studies to indicate the conditions under which 1) protection forests should remain strictly protection forests 2) protection forests might be

partially harvested, and 3) protection forest might be treated as any other forest compartment land should provide the basis for a much need reclassification of Taiwan's large area of such forest land.

5. A major problem at high elevations is that of the massive landslides. In most cases it is felt that these slides are geologic in nature and that control is uneconomic if even possible. However with new highways under construction and with additional forest harvesting anticipated a study of landslide conditions and causes is appropriate. A survey of geologic, topographic, soil and vegetative conditions on areas subject to many slides could provide very useful guides to future highway location and to safe logging areas. A team approach (including a geologist, soil scientist, and forester) would be necessary for such a survey, and the ultimate development of a landslide classification.

6. Taiwan is unique in its hydrologic conditions and basic studies in watershed hydrology would have considerable international interest. The establishment of a number of gaged watersheds to assess hydrologic characteristics, and which would also be used for fundamental watershed research, should be accomplished as soon as practical. There is currently widespread interest in the field of hydrology by several of the United Nations agencies. Future financial assistance for hydrologic studies might become available through the United Nations. A detailed study of water resources in Taiwan was published in 1958, Water Resources Survey Team—Kennedy Report, in which specific recommendations were made in regard to hydrologic data in Taiwan.

7. Due to the large area in forest land and the nature of the watershed problem, it is anticipated that the Taiwan Forestry Research Institute would be charged with an increase in research responsibility if the recommended research is undertaken. At present the Taiwan Forest Research Institute is under-staffed and under-financed for its present research program. It is recommended that consideration be given to a marked increase in research funds to this agency as soon as possible for forestry research as well as for any new watershed research that might be initiated.

8. Since research in watershed management involves many fields other than forestry it is further suggested that a watershed management and hydrologic research advisory committee be established to assist in the guidance of research in these fields. Such a committee should have representation from the various professional fields involved in water resources including engineering, forestry, agriculture, geology, soil science, botanical sciences, meteorology and economics.

TRAINING NEEDS

1. A major reason for the absence of a research program in watershed management in Taiwan, in addition to research funds, is the lack of a core of personnel trained both in watershed management and in research technique and methodology. If research is to be undertaken to seek solutions to the acute problems in this field it will be necessary to train a core of research workers. It is recommended that at least two people be selected each year for each of the next five years to study in U. S. and/or European universities. Personnel selected for such training should have proven ability, a genuine interest in research in this field and should be well versed in the language of the country they may elect for such training. At least several of these persons should be permitted to complete graduate degrees (2 to 3 years) and upon return to Taiwan, they should be assigned to universities where they may initiate similar specialized programs. The professional background of such persons might be in forestry, soil science, engineering, agricultural engineering or geology—preferably from several fields. In addition to formal university training an opportunity should be provided for them to visit research installations such as the Coweeta Hydrologic Laboratory, the San Dimas Experimental Forest or the Coshochton Hydrologic Laboratory in the United States or the Rothamsted Experiment Station in England.

2. It is further recommended that several technicians with mechanical ability be selected and sent abroad for specialized training and experience in the operation and maintenance of meteorologic and hydrologic instruments. Upon their return they should conduct training sessions for Taiwan personnel in this area. Many of the instruments observed were out of order or were not functioning properly (e.g. the siphon type recording precipitation gage). Construction projects and research programs require reliable and consistent data.

3. Consideration should be given by USAID to the possibility of joint programs with U. S. universities which would permit and finance research in Taiwan by selected U. S. graduate students. Under certain conditions it is anticipated that U. S. universities would accept, for thesis or dissertation research, projects which could be carried out in field studies in Taiwan. Such an exchange would be of benefit to a research program here as well as to the U. S. graduate student.

Bamboo plantation provides excellent economic returns and good soil protection. Bamboo should be considered in planning the rehabilitation of eroded sites.

Plantations of China fir (Cunninghamia lanceolata Hook) provide an additional resource and also furnish a dense ground cover for soil protection. They grow best at elevations ranging from 600 to 1,600 meters.

Casuarina is commonly planted for windbreaks, for sand stabilization, and for reclamation of the sea coast areas. Note the sand arresting fences at the newly rised beaches which will eventually be planted to casuarina.

Bench terraces with lined waterway premit the safe cultivation of sloping lands. The risers on this newly benched tea plantation will also be grassed to furnish soil protection.

Close planting, mulching, hillside ditching and lined waterways on this pineapple plantation provides an example of good soil conservation and land management practices.

Debris dams such as these provide only a stopgap measure in attempting to arrest sediment movement.

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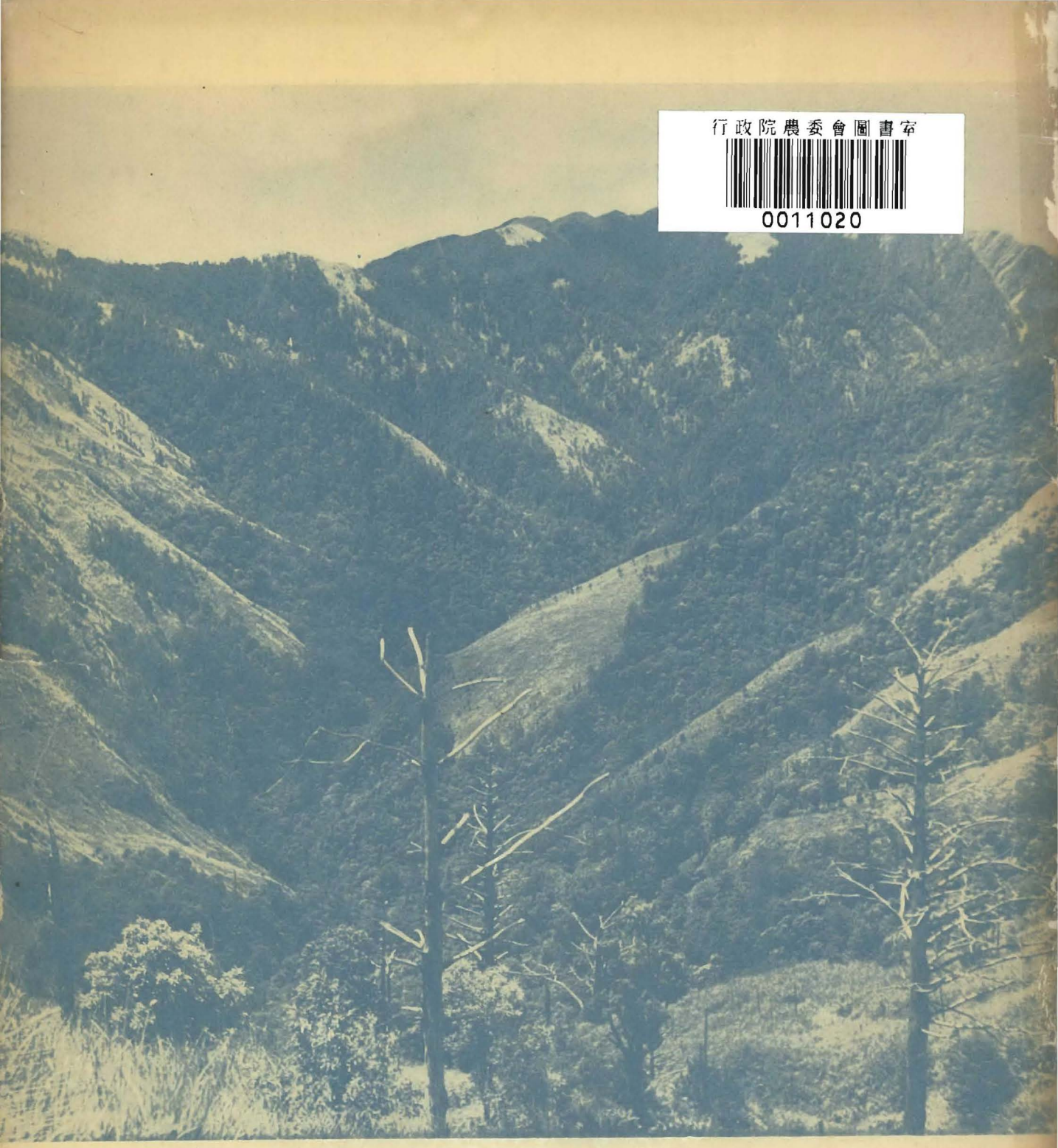

"To think of the watershed when you drink water."—Chinese Proverb