THE EFFECTS OF LAND-CLEARING ON
A SMALL WATERSHED
IN SOUTHERN GUAM

By

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UNIVERSITY OF GUAM

Water and Energy Research Institute

of the

Western Pacific

Technical Report No. 24

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Map labels:

Uracas

20° Maug

Asuncion

Agrihan

Pagan

18° Alamagan

Guguan

Sarigan

MARIANA ISLANDS

Anatahan

16° Farallon de Medinilla

PHILIPPINE
SEA

Saipan
Tinian
Aguijan

Rota

14°

PACIFIC
OCEAN

Guam

0   50

Statute Miles

145°   147°   149°

DEPARTMENT OF THE INTERIOR · OFFICE OF WATER RESEARCH AND TECHNOLOGY

THE EFFECTS OF LAND-CLEARING ON
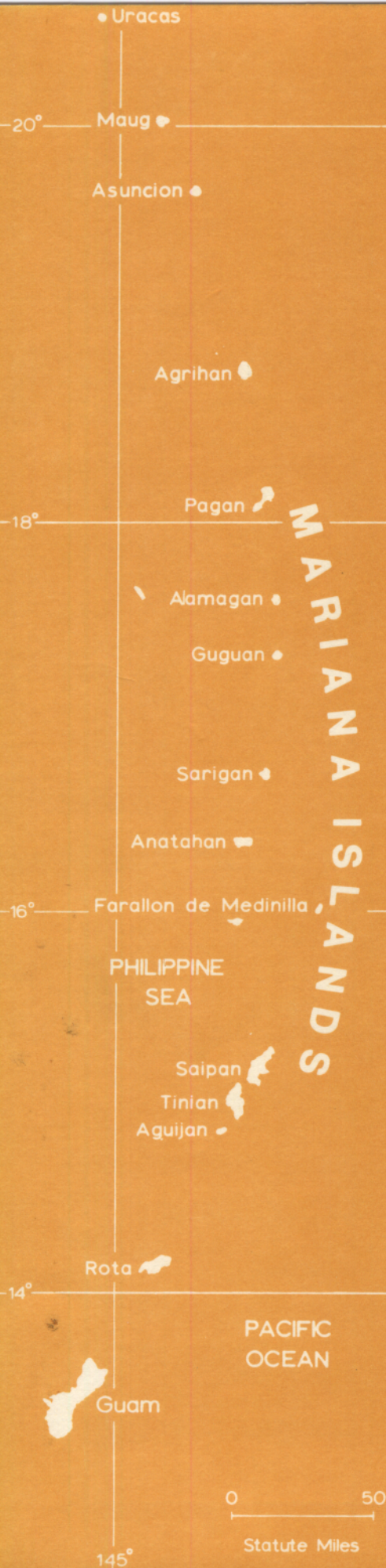A SMALL WATERSHED
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Project Completion Report

for

EFFECTS OF LANDCLEARING ON SMALL WATERSHEDS
IN SOUTHERN GUAM

ABSTRACT

Hand-clearing of a forested ecosystem in southern Guam had
significant effects on some aspects of the limnology of the river flowing
through the perturbed area compared to that of the upstream control area.
Significant differences in soil temperatures, maximum and minimum air
temperatures, water temperatures, conductivity, pH, hardness, total
phosphorus, and orthophosphate concentrations between the control and
experimental area were found, with no significant differences in
nitrate concentrations and turbidity between stations.

Mean maximum air and water temperatures of the experimental area
were 1.4° C less than that of the control area. The mean minimum water
temperature of the experimental area was 2.0° C greater than the control
area. The mean soil temperature at 0.3 m depth of the experimental area
was 0.7° C greater than that of the control area. Mean conductivity and
hardness values of the experimental area were 11.0 μmhos/cm^2 and 9.0 mg/ℓ
less than those of the control area, respectively. The pH of the water
for the experimental area was 0.22 pH unit greater than that of the
control area. Mean total phosphorus concentration of the experimental
area was 8.15 μg/ℓ less than that of the control area. The mean
orthophosphate concentration of the experimental area was 1.64 μg/ℓ less
than the control area. Nitrates and phosphates appeared to be leached
to the river in pulses with the onset of precipitation.

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INTRODUCTION

Numerous reports and studies on the effects of land-clearing (or clear-cutting) on nutrient flux, water quality, and soil erosion exist, and most of the studies have been done in the temperate zone. Such groups of studies include work done on the systems of the H. J. Andrews Experimental Forest, Oregon; Coweeta Hydrologic Laboratory, North Carolina; and Hubbard Brook Experimental Forest, New Hampshire.

Rothacher et al. (1967) used small watershed ecosystems to determine the effects of logging on stream flow and sedimentation in rivers of the Pacific northwest. Rothacher (1965) found that removal of vegetation from only 30% of a 101-ha (250 acre) watershed caused a 12-28% increase in the minimum streamflow. An 85% increase in low flow was recorded when 80% of the trees were removed from a 96-ha (237 acre) watershed. No significant increase in overland flow occurred in this study because of clearing, probably because rainfall in the Pacific northwest is generally of low intensity and does not usually lead to overland flow. Stream discharge and subsoil water flux in watersheds of the Pacific northwest have been studied. Stream discharge generally increased after logging (Rothacher, 1970; Harr et al., 1975; Harr, 1976A and 1976B) but decreased in one study (Harr and McCorison, 1979). The decrease in peak flows was attributed to a breakdown in subsurface channel networks which slowed subsurface water movement. The effects of flood-producing storms in the Pacific northwest were also studied by Dyrness (1967), Fredriksen (1971), Swanston (1974), and Brown (1976). Soil erosion occurred but was generally minimized if the soil surface was not disturbed or compacted by logging operations.

The effects of logging and logging followed by slash-burning on water temperatures have also been studied (Levno and Rothacher, 1967 and 1969; Brown et al., 1971). All studies indicated that maximum water temperatures from logged areas were greater than those from control areas. Increased water temperatures may stimulate excessive production of algae, damage potable water quality, deplete the oxygen supply for aquatic organisms and may also affect taste, color, and odor of stream water.

Water quality and nutrient budget studies were done by Fredriksen (1970, 1971, 1972, and 1975) and Fredriksen et al. (1973). These studies contain data from control and logged watersheds of the Pacific northwest. Many other small watershed studies dealing with the effects of commercial logging in the Pacific northwest are documented.

Johnson and Swank (1973) discussed calcium, magnesium, potassium, and sodium budgets from four experimental watersheds at the Coweeta Hydrologic Laboratory. Studies on the effects of clear-cutting were done by Hoover (1944), Dunford and Fletcher (1947),

Kovner (1956), and Swank and Helvey (1970); and studies on the effects of herbicides were reported by Douglass et al. (1969). The effects of converting hardwood forest to grass (Hibbert, 1969) and then to a monoculture stand of white pine (Swank and Miner, 1968) were also studied.

The Hubbard Brook ecosystem studies measured nutrient flow, water quality, and sedimentation within ecosystems under different experimental treatments. Dominant tree species and species of the herbaceous layer of the control watershed were studied by Bormann et al. (1970) and Siccama et al. (1970), respectively. Organic nutrients from leaf and branch litter and their effects on the limnology of streams were discussed in Gosz et al. (1972 and 1973), Fisher and Likens (1973), Hobbie and Likens (1973), and McDowell and Fisher (1976). Calcium, magnesium, potassium, and sodium budgets and estimates of geochemical weathering of six undisturbed watersheds were discussed in Likens et al. (1967). Likens et al. (1970) discussed the effects of clearing and herbicide treatments on calcium, magnesium, potassium, sodium, and other nutrients at Hubbard Brook. Bormann et al. (1974) reported that nutrients were initially mobilized and leaked from the soil to the stream following clear-cutting, but that erosion increased exponentially during the third year after herbicides were used to prevent plant growth. The system appeared to exercise considerable control over erodibility following clear-cutting, but this control tended to break down with time if the regrowth of vegetation was inhibited. The effect of clearing on phosphate concentrations has not been studied. Phosphate concentrations are dependent on discharge and vary considerably from year to year (Bormann and Likens, 1979). Orthophosphate and organic phosphorus budgets in an undisturbed watershed have been studied recently (Meyer, 1979 and 1980; Meyer and Likens, 1979). Phosphorus appeared to be absorbed on stream bed sediments and organic debris during times of high phosphorus concentrations in streams, and to be released during times of low concentrations.

Odum (1971) stated that nutrient cycling in the tropics is different from that in the temperate zones. A large portion of the organic matter and available nutrients is present in the soil and leaf litter in the temperate zone forest, while in tropical forests a major portion of the nutrients is stored in the extant vegetation, little leaf litter is present on the ground, and the soil is low in nutrients. Removal of vegetation in the tropics takes away the system's ability to hold and recycle nutrients.

The Amazonian tropical forest, which has a dense root system (three times as dense as that of the temperate systems), high evapotranspiration, and the ability to recycle a high percentage of the rainwater, acts as a buffer mechanism that bridges dry seasons in Brazil (Sioli, 1975). Sioli also stated that the removal of forest vegetation in the Amazon drainage system caused rainwater to run off superficially and go directly into the rivers, instead of penetrating the soil. Dry seasons could be

accentuated, leaving less water in the rivers and increasing the
possibility of major floods with the first rains of the wet season,
if enough forest vegetation were removed. Nutrient retention,
distribution, and cycling in root mats of the Amazonian tropical
forest have been studied (Stark, 1971 and 1972; Stark and Jordan,
1978; Stark and Spratt, 1978). Tropical root systems appear to
retain and recycle nutrients; this enables a large diverse forest
to grow on nutrient-poor soil.

The objective of this study was to determine the effects of
land-clearing on the limnology and aquatic ecology of a small
watershed on Guam. The findings may be of use in the future
planning and development of the land and water resources on Guam.

DESCRIPTION OF STUDY SITE

Guam is the largest and southernmost island of the Mariana
group, located at 13.5° north latitude and 145.0° east longitude.
The island (Fig. 1) is 45.0 km long and 6.4 to 12.9 km wide and
oriented in a NNE-SSW direction (Jordan, 1955).

Two primary seasons exist: wet (mid-July to mid-November) and
dry (January-April). Two secondary, transition seasons occur from
May to mid-July and mid-November through December. Precipitation
varies in the transitional seasons. Relative humidity ranges from
65-75% during the day and 85-100% at night (U.S. Dept. of Commerce,
1963).

Annual average rainfall is 225 cm; 60% falls during the wet
and 15% during the dry season. Heaviest rainfall occurs over the
southern mountains, east of the Naval Station in the area of the
Fena Valley watershed. Annual rainfalls greater than 330 cm have
been recorded in these areas. Mean air temperature is 27.2° C,
with a mean range of 26.2 to 28.0° C. The highest and lowest
temperatures recorded from Guam are 35.0° C and 13.3° C, respectively
(Jordan, 1955).

The study site is shown in Figs. 2 and 3; topographic
characteristics of the study site are presented in Table 1. The
cleared experimental area (station II) is approximately 100 m
downstream from the control (station III) area. An adjacent
watershed (stations I and IV) was also studied to determine if
differences between upstream and downstream stations existed. The
study site is classified geologically as part of the Bolanos
pyroclastic member, which consists of massive reworked tuff breccia
and volcanic conglomerate and contains fragments of the Maemong
limestone member. The upper part of the Bolanos member consists
of tuffaceous sandstone and shale embedded with minor amounts of
conglomerate. This member interfingers with the Dandan flow
member on the eastern slope of Mount Almagosa (Tracey et al., 1964).

4

PHILIPPINE SEA

N

0   4   8
KILOMETERS

PACIFIC OCEAN
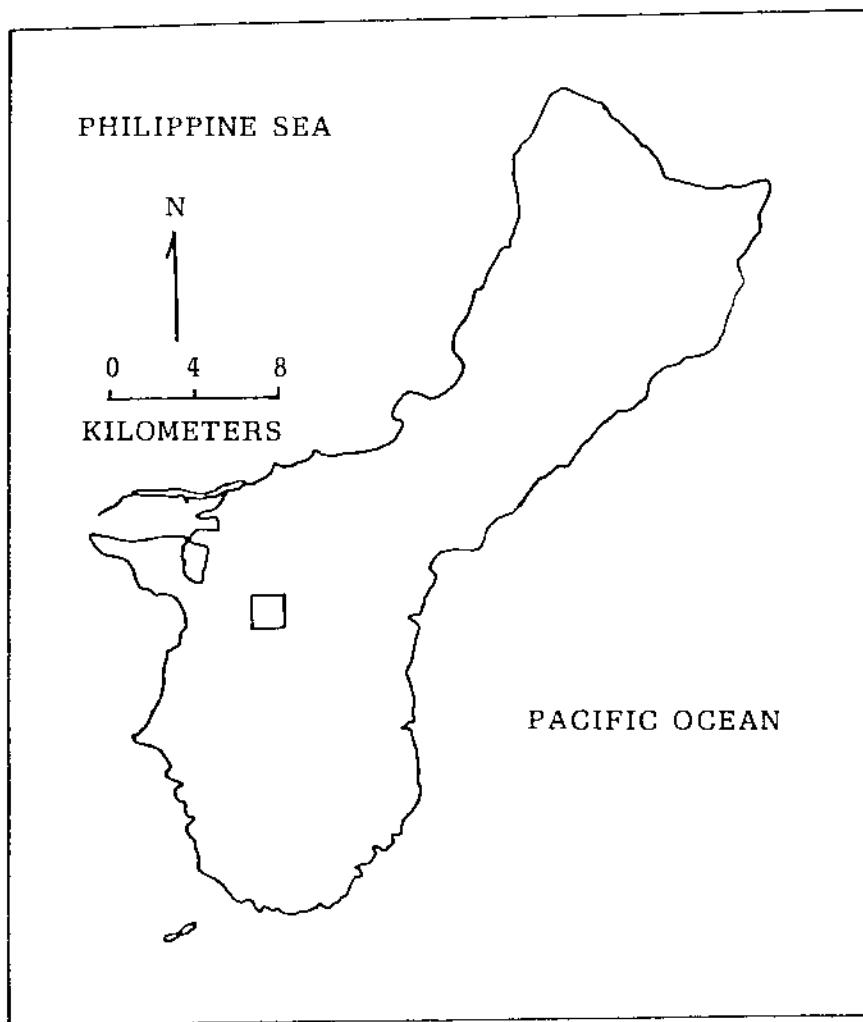
Figure 1.   Map of Guam showing area of study site;
            (outline drawing from Randall et al., 1975).

Figure 2. Map of study area with rectangle indicating the
location of the experimental watersheds (from USGS
map. Agat quadrangle, Mariana Islands – Island of
Guam. 1:24,000 series (Topographic) 1968).

Figure 3. Experimental watersheds and collecting sites
with shaded area indicating cleared area;
(outline drawing from General Planning Map
Series, Government of Guam, Uniform Mapping
System #19 of 74; contour intervals in feet).

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Streams beds of the study site have steep gradients. Black volcanic outcrops are present in rifle areas and have little or no alluvium. Pool areas are small (<1 m^2) and have sand and gravel substrates. Fine silt covers the pool area of station IV. Streams are generally less than 1.0 m wide and less than 0.5 m deep.

Table 1. Topographic characteristics of the selected study site.

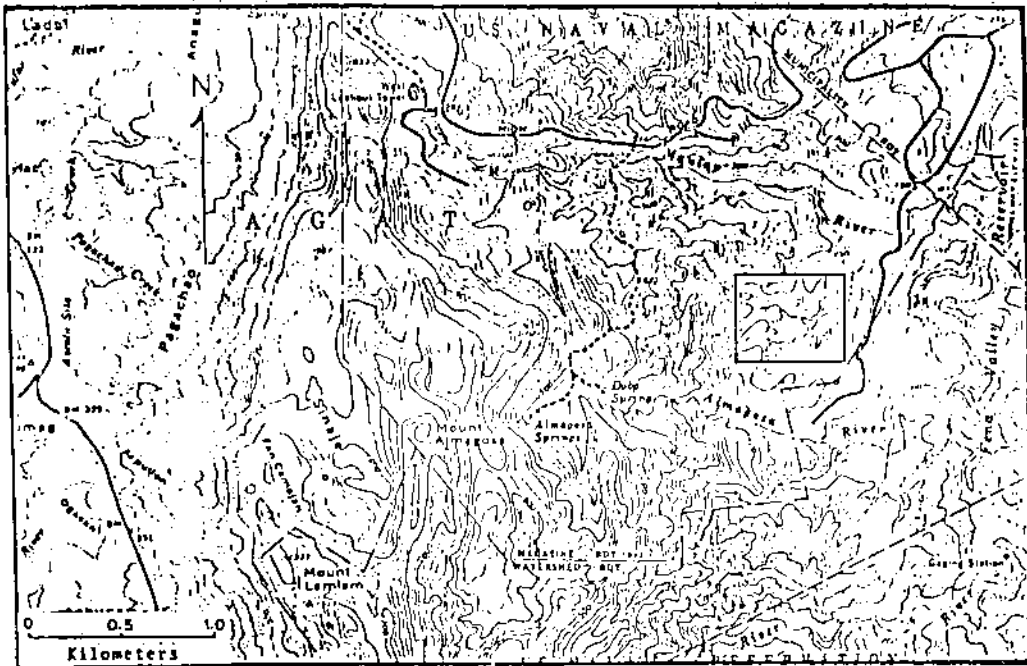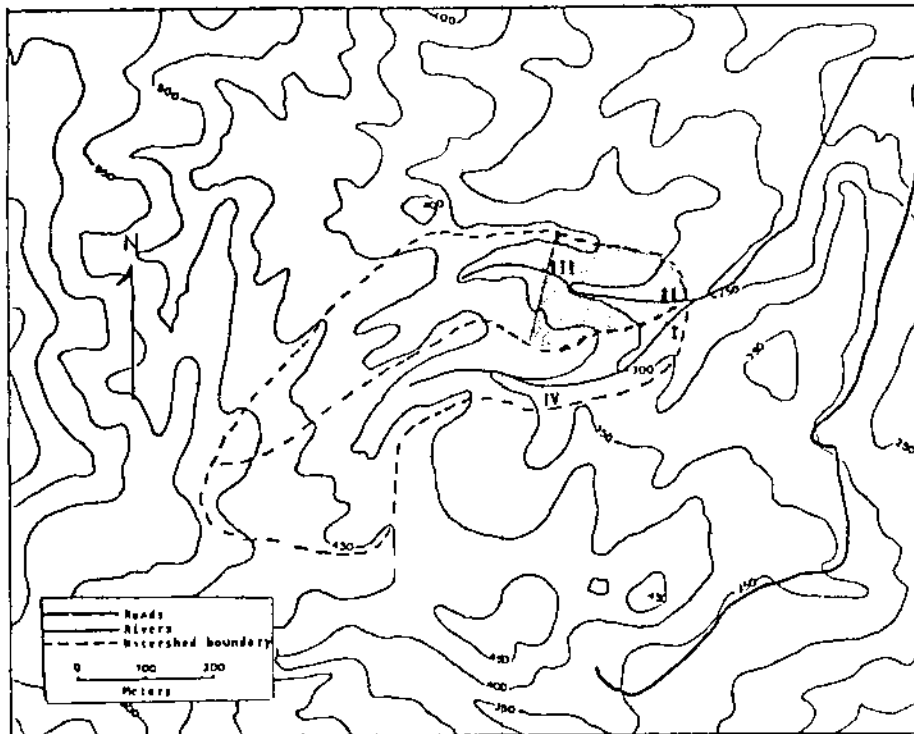|	Watershed 1	Watershed 2
Area (m^2)	89,665	91,375
Area (ha)	8.97	9.14
Aspect	ENE	ENE
Elevation (m)		
Minimum	79.2	79.2
Maximum	164.6	164.6
Drainage (m)		
Length	805	773
Elevation change	85.3	85.3
Stations	II and III	I and IV

MATERIALS AND METHODS

Vegetation was quantified with a point-quarter method before the land was cleared. The variables of species number, density, diameter and frequency can be measured more efficiently and with less bias with this method than with quadrat methods (Mueller-Dombois and Ellenberg, 1974). Only trees greater than 2 m in height were measured at breast height. A point-intercept method was used to quantify vegetation one year after the land was cleared because this method is easily adapted to measure dense herbaceous cover. Ten-meter intervals were used in both methods (Mueller-Dombois and Ellenberg, 1974). Plant species were identified according to Stone (1970), Fosberg (pers. comm.) and Raulerson (pers. comm.).

The vegetation of the study area (2.44-ha) was hand-cleared from 28 January to 2 February 1980. All plants were cut to within 0.3 m of the ground except Pandanus trees, which were cut just above the aerial roots. The limbs of felled trees were cut off and placed on the soil; no limbs extended more than 0.3 m from the soil surface. The soil was not greatly disturbed.

Water samples were collected at 2-wk intervals from four stations on two rivers and analyzed for nitrate, nitrite, ortho-phosphate, total phosphorus, pH, conductance, hardness, and turbidity. A cadmium reduction method was used to determine nitrate and nitrite values (Strickland and Parsons, 1968). "Standard Methods" (American Public Health Association, 1971) were used to determine orthophosphate and total phosphorus concentrations and hardness. A Lab-line conductivity meter, Hach model 2100A turbidity meter, and an Orion

Research Ionanlyzer model 407A pH meter were used to determine specific conductivity, turbidity, and pH, respectively. Hardness was measured as a general indicator of calcium and magnesium because an atomic absorption spectrophotometer was not available to measure them directly. Orthophosphate and nitrate samples were filtered before analysis; suspended particulate matter caused erroneous spectrophotometer readings to occur. Samples were filtered after freezing from February to September 1980 and filtered before and after freezing from October 1980 to February 1981 to determine the effects of freezing on nutrient losses.

Air and water maximum and minimum temperatures, soil temperatures at 0.3 m depth, and rainfall data were collected. All thermometers were calibrated prior to field use by comparing the temperatures of the field thermometers to a calibrated laboratory mercury thermometer. Maximum-minimum thermometers were then placed outdoors and adjusted daily until all the thermometers recorded simlar temperatures. Soil temperatures were taken from one fixed point in the control and experimental areas with special soil thermometers. All air maximum-minimum thermometers were placed 1.5 m above the soil surface and in the shade. A rain gauge was placed in each watershed and was checked every two weeks. Rainfall data collected were minimum estimates of rainfall because no correction for evaporation was made. A paired-comparisons test was used to statistically analyze the data (Sokal and Rohlf, 1969).

RESULTS AND DISCUSSION

Vegetation

The vegetation of southern Guam is dominated by the limestone forest, savanna, and ravine forest (Fosberg, 1960; Stone, 1970); the latter two dominate the vegetation surrounding the study area. Fires, which occur often in the savanna, can destroy the ravine forest. Savanna vegetation replaces the ravine forest vegetation after perturbations (Stone, 1970), which suggests that the ravine forest is the climax vegetation type.

The vegetation was hand-cleared and not bulldozed or burned because useful results could be obtained with minimal disturbance. No herbicides were used to prevent the regrowth of vegetation because stream water from the study area flowed into the Fena Lake Reservoir, which supplies potable water to the military bases and to part of the civilian community.

Ravine forest species dominated the vegetation prior to the land-clearing (Stone, 1970). According to data presented in Table 2, Pandanus tectorius was the dominate tree of the experimental watershed; Areca catechu, the betel nut, was the next most important. Areca had an importance value slightly greater than Pandanus dubius, another abundant tree. Areca had a lower relative dominance the P. dubius. However, the relative density and frequency of Areca made this species more important than P. dubius. Other species along the transects were also common ravine forest species.

Table 2. Vegetation analysis of the experimental watershed before clearing.

Species	Relative Density	Relative Dominance	Relative Frequency	Importance Value	Rank
Pandanus tectorius Park.	41.25	53.43	32.65	127.33	1
Areca catechu L.	17.50	7.43	18.37	43.30	2
Pandanus dubius Spreng.	13.75	12.27	8.16	34.18	3
Cycas circinalis L.	7.50	6.13	12.24	25.87	4
Ficus tinctoria G. Forst.	7.50	4.42	8.16	20.08	5
Morinda citrifolia L.	6.25	2.99	10.20	19.44	6
Mangifera sp.	1.25	9.28	2.04	12.57	7
Hibiscus tiliaceus L.	2.50	0.60	4.08	7.18	8
Glochidion marianum Muell.-Arg.	1.25	2.08	2.04	5.37	9
Medinella rosea Gaud.	1.25	0.94	2.04	4.23	10

Table 3. Vegetational data collected one year after clearing.

Species	% cover
Hyptis capitata	52%
Miscanthus floridulus	38%
Phragmites karka	5%
Bare soil	5%

Data from transects taken one year after the land-clearing are presented in Table 3. Hyptis capitata and Miscanthus floridulus were the dominant species of the disturbed site. Hyptis was the first species to grow back after the clearing. Miscanthus also grew back rapidly. Hyptis was found at 52% and Miscanthus at 38% of the transect points studies. Other species began to grow in the disturbed area towards the end of the study period. Bare soil accounted for less than 5% of the points, which indicated that the vegetation grows back rapidly after hand-clearing in this part of Guam. Phragmites karka will grow where standing water is present year-round. Species found in the disturbed watershed are common to the savanna ecosystem, which suggests that hand-clearing also sets back succession.

Soil Temperature

Increased soil temperatures will cause an increase in the biotic and chemical reactions occurring within the soil and will result in increases in decomposition of organic materials, mineralization, and nitrification (Bormann and Likens, 1979).

The mean soil temperatures at 0.3 m depth of the control and experimental areas were 25.9° C (range=23.9-26.7° C) and 26.6° C (range=25.6-27.8° C), respectively. A highly significant difference ($P < 0.001$) between the soil temperatures was found between the experimental and control areas at depth of 0.3 m. Soil temperatures throughout the study period did not differ significantly ($P > 0.05$) in the control and experimental areas. Temperatures were highest in the experimental area during May and June and were as much as 2.8° C greater than the temperature of the control area on the same date.

An increase in the rate of decomposition will decrease the depth of the forest litter. Increased run-off and erosion may result if the litter layer is significantly reduced because liter prevents raindrop erosion and overland flow from occurring. An increase in the amount of soluble nutrients in the soil will result from increased decomposition and nitrification. A combined increase in the soluble nutrients available, mineralization, and nitrification within the soil will cause important nutrients to be lost from the disturbed ecosystem.

Soil temperatures of the cleared area may decrease as successional vegetation continues to grow and shade the soil. Temperatures of the experimental area probably will not be as low as those of the control area until ravine forest tree species dominate the vegetation.

Air Temperature and Rainfall

The presence of vegetation appears to minimize diurnal fluctuations in temperature. Canopy species absorb heat during the day and retain warmer understory air at night and thereby

limit thermal fluctuations (Smith, 1974). Precipitation reduces thermal stratification in terrestrial ecosystems by absorbing heat from warmer areas and releasing heat to cooler areas (Smith, 1974).

Air temperature and rainfall data are presented in Figs. 4 and 5. The mean maximum air temperature of the control and experimental area was 32.0° C (range=28.9-35.6° C) and 33.4° C (range=29.4-35-6° C), respectively. The mean minimum air temperature of the control and experimental area was 21.4° C (range=18.9-22.8° C) and 21.0° C (range=17.8-22.2° C), respectively. There were significant differences in the maximum and minimum temperatures between the experimental and control areas ($P<0.001$ and $P<0.025$, respectively). A significant difference ($P<0.001$) in seasonal variation of minimum temperatures was recorded, but there was no significant difference ($P>0.05$) in seasonal maximal temperature. Air temperatures collected from stations of the control watershed show no significant difference ($P>0.05$) between the stations.

Maximum temperatures of the experimental area were almost always greater than those of the upstream control area. The maximum temperature of the control area was greater than the experimental area during the period from 26 November to 11 December because the thermometer was exposed to direct sunlight. Maximum temperatures of the experimental and control areas were occasionally the same during the wet season; this may be caused by rain and overcast conditions. The minimum temperatures of the experimental area were the same or less than the minimum temperatures of the control area. The presence of vegetation appeared to minimize air temperature fluctuations in a forested watershed on Guam. Annual fluctuations in temperature were small, with high temperatures generally occurring during June-August (wet season) and low temperatures occurring during January-March (dry season).

Water Temperature

Water temperature affects the chemical and biological reactions occurring in streams (Smith, 1974). Increased water temperature may limit organisms living in a stream (Smith, 1974) and also increase nutrient losses from the stream (Bormann and Likens, 1979).

Maximum and minimum water temperatures from the experimental and control areas are presented in Fig. 6. The mean maximum water temperatures from the control and experimental areas were 26.0° C (range=23.0-27.8° C) and 31.9° C (range=29.0-33.0° C), respectively. The average minimum water temperatures from the control and experimental areas were 21.7° C (range=21.0-25.6° C) and 23.7° C (range=21.0-25.0° C), respectively. Water temperatures were similar to those recorded from the Geus and Umatac Rivers (25.0-31.5° C; Neubauer, 1978), Fena Lake and tributaries to Fena Lake (26.0-29.0° C; Kennedy Engineers, 1974).

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Figure 4. Maximum and minimum air temperature readings from
21 February 1980 to 6 February 1981 at two-week
sampling intervals. • = experimental area, X =
control area.

Figure 5. Rainfall from 21 February 1980 to 6 February 1981 at
two-week sampling intervals. • = experimental area,
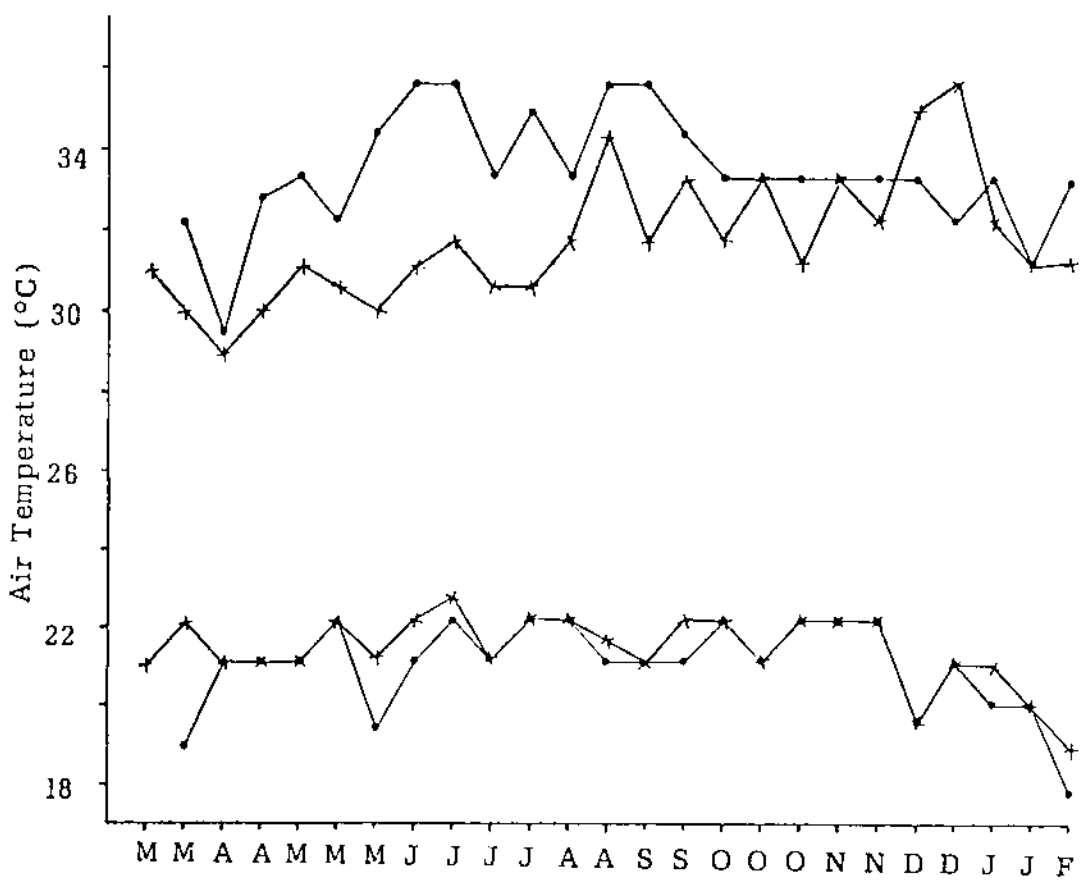X = control area.

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Figure 6. Maximum and minimum water temperature readings from 21 February 1980 to 6 February 1981 at two-week sampling intervals. • = experimental area, X = control area.
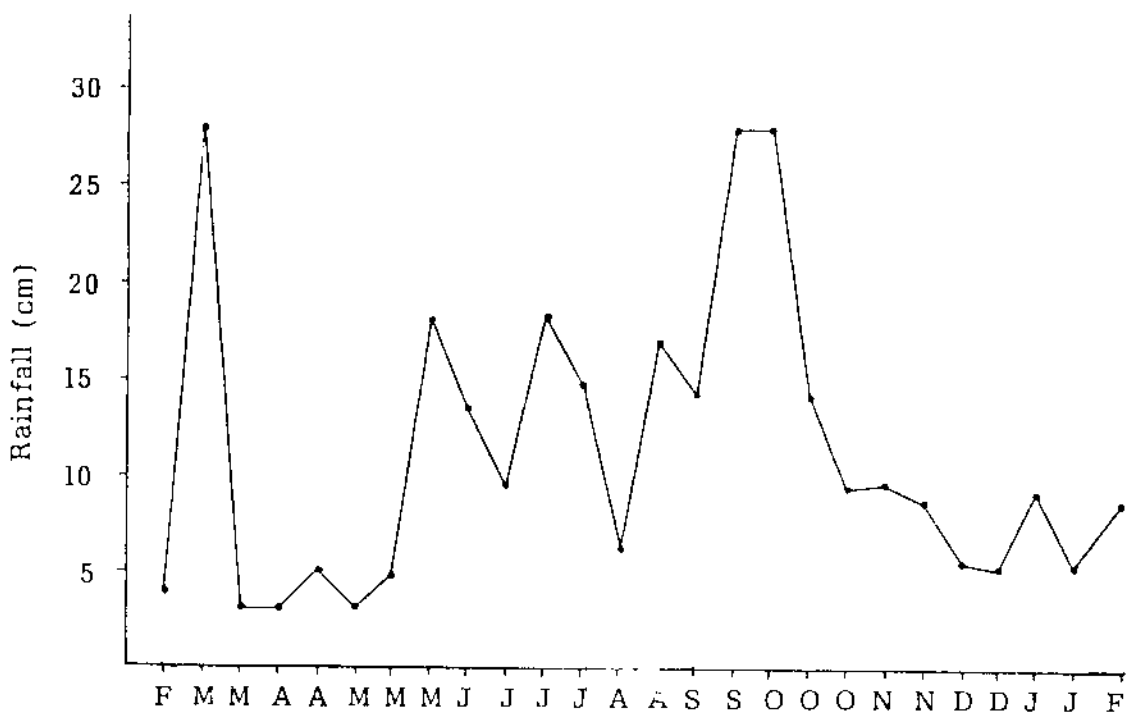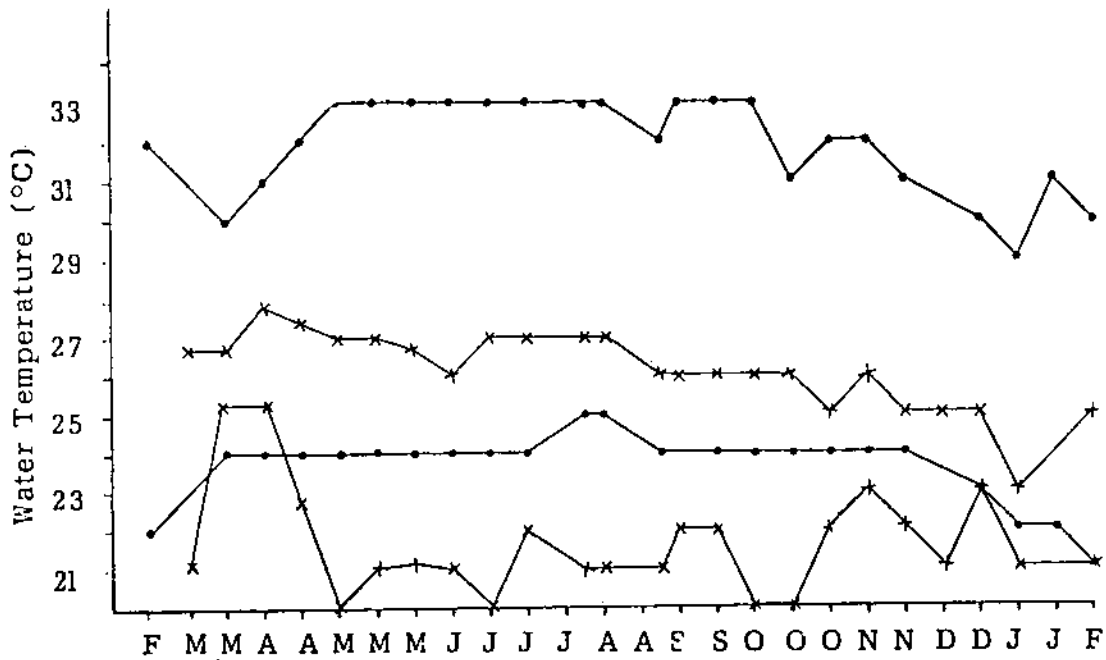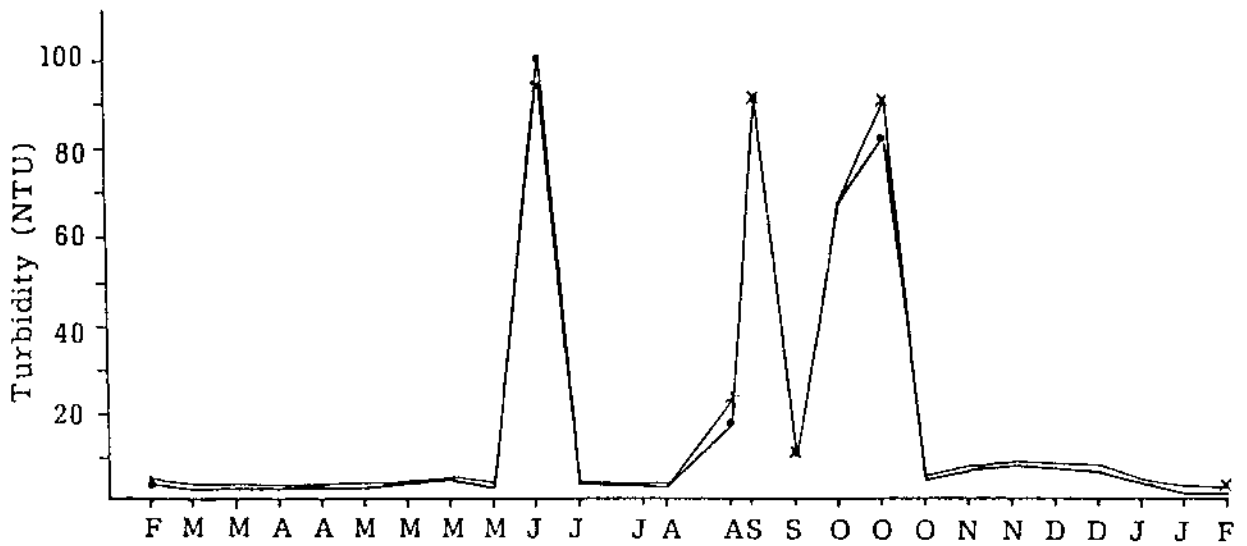

Figure 7. Turbidity readings from 21 February 1980 to 6 February 1981 at two-week sampling intervals. • = experimental area, X = control area.

There were significant difference (P<0.001) in the maximum and minimum temperatures between the experimental and control areas. No significant differences (P>0.05) in seasonal minimum temperatures were found, with a significant difference (P<0.001) in seasonal maximum temperatures at the control and experimental stations.

Shade removal, not increased air or soil temperature, was responsible for large temperature changes observed in other land-clearing studies (Brown, 1969; Brown et al., 1971; Burton and Likens, 1973). The differences in maximum temperatures between control and experimental areas were greater than the differences in minimum temperatures between areas (Macan, 1958). Macan (1958) also found that highest temperatures occurred when the sun shone strongly after rain and not during dry spells when the water was low. Water entering the river during low flows was presumably derived from cooler, lower soil layers. High humidity, which prevented cooling of surface water, and water from warmer surface soil layers, may have caused increased maximum temperatures following rain storms. Warmer waters from cleared watersheds cooled quickly downstream from the cleared site where vegetation shaded the stream (Macan, 1958; Burton and Likens, 1973). Increased water temperatures caused by land-clearing increased rat s of organic decomposition and resulted in faster flushing of materials from the system (Burton and Likens, 1973). Other adverse effects of increased stream temperature were change in taste, odor, and color of the water and a depletion of dissolved oxygen (Brown et al., 1971). These factors probably strongly influenced the organisms living in the river.

Increased maximum temperatures downstream from the cleared area probably resulted from canopy removal, which allowed river water to absorb more solar radiation. Highest water temperatures from the experimental area occurred during the wet season and lowest water temperatures were recorded during low flows of the dry season. The differences in maximum temperatures between control and experimental areas are greater than the differences in minimum temperatures between areas. Maximum temperatures of the experimental area were always greater than the maximum temperatures of the upstream control; these differences were as great as 7° C. Maximum water temperatures do not fluctuate greatly and generally do not follow maximum air temperatures; high water temperatures do not always occur during times of high air temperatures.

Minimum water temperatures of the experimental area were always greater than minimum temperatures of the control area, except from 20 March-3 April 1980. A poorly calibrated replacement ther-moment was used during this period and readings may have been inaccurate. The exposed stream flows over a black volcanic rock outcrop for the entire length of the cleared area. Heat from the sun is probably absorbed by the stone during the day and radiated back to the river water at night, causing warmer minimum water temperatures to occur. A decrease in the minimum water temperatures

of the experimental area occurred during the end of the study and may reflect increased growth of vegetation which provided shade to the river water and volcanic rock stream bank and reduced the area exposed to direct sunlight.

Heated water from the experimental area probably cooled quickly downstream from the site where vegetation completely shaded the river. Land-clearing appeared to have a significant effect on water temperatures. Increased temperatures could increase the rate of decomposition of organic matter and affect or even limit the aquatic organisms of the stream.

Turbidity

Turbidity is a measurement of suspended particulate matter transported in drainage waters and is usually the result of erosion (Likens et al., 1970).

Turbidity data are presented in Fig. 7. The mean turbidity of the control and experimental area was 18.4 NTU (range=3.0-94 NTU) and 17.3 NTU (range=1.8-100 NTU), respectively. Turbidity readings were similar to those recorded from the Maulap River (2.9 NTU; Kennedy Engineers, 1974), into which the waters of the study area flow. There was no significant difference between turbidities from the experimental area and those from the upstream control area. Seasonal turbidity readings were significantly different (P<0.001).

Most erosion within an ecosystem occurred during heavy rains which caused high flow velocities in the rivers. Bormann et al. (1974) found that 52% of all particulate matter lost was lost during floods, although the floods accounted for only 3.7% of the total discharge over a 50-mo period. Likens et al. (1970) found no differences in turbidity following the cutting and herbicide treatments of vegetation at Hubbard Brook. The peak turbidity values were depressed in comparison with values for streams in undisturbed watersheds. Measurements in turbidity were considered of little value in assessing the changes in water quality of a stream of forested and deforested ecosystems. Turbidity may increase downstream from the cleared area in time as clear-cutting reduces the forest litter layer; this may increase overland flow and expose the soil surface to raindrop erosion (Bormann and Likens, 1979). However, Branson (1975) found that grasses and herbaceous plants retarded erosion more than trees did. Regrowing herbaceous vegetation inhibited erosion and overland flow. Fredriksen (1970) and Brown and Krygier (1971) found that fire or compaction of soil by machinery increased erosion and caused high sediment concentrations in streams. Likens et al. (1970) mentioned that turbidity of stream water would probably increase if the soil surface of an ecosystem were disturbed by building access roads or if fires occurred in the cleared area.

High turbidity was recorded on 26 June, 5 September, and 2 and
16 October. The highest readings occurred on 26 June probably
because heavy rains fell just prior to and during sampling and
stream flow was greatly increased; standing water on the soil surface
occurred in both experimental and control areas. The turbidity
downstream from the experimental area was slightly greater than that
of the upstream control area, and this was the only time that
turbidity of the experimental area exceeded that of the upstream
control. This probably occurred during other heavy rains but may
not have been recorded because sampling times did not coincide with
heavy rains. Three other turbidity peaks occurred, on 5 September
and 2 and 16 October, and probably reflected increased stream flow
during the middle of the rainy season. Heavy rainfalls occurred
during February and early June, but no increase in turbidity was
noted in samples taken in these months. The precipitation may have
been absorbed by unsaturated soil, which would produce little run-off.
Turbidity values from the upstream control area were almost always
greater than those from the experimental area. This may have been
caused by differences in the sampling site; the control station had
a small riffle upstream, which caused more turbulence and increased
the turbidity. The experimental area may also have a lower turbidity
because water may percolate through the soil more rapidly than in the
control forest area and dilute the materials being transported. This
may explain the relatively large differences observed between the
stations on 27 August and 16 October.

Erosion does not appear to be a major problem on Guam if the
vegetation of an ecosystem is hand-cleared and allowed to grow back.
The vegetation in this cleared area is highly susceptible to fire;
increased erosion and turbidity would be expected if the vegetation
burns.

Electrical Conductivity

Conductivity is the ability of a substance to conduct electrical
current. The conductivity of water is a measure of dissolved ions
(Hem, 1970).

Conductivity data for the control and experimental areas are
presented in Fig. 8. The mean conductivity of the water of the
control and experimental areas was 316 μmhos/cm^2 at 25° C (range=
100-400 μmhos/cm^2) and was 305 μmhos/cm^2 at 25° C (range=100-400
μmhos/cm^2), respectively. Conductivity readings were similar to
those from the Maulap River (307 μmhos; Kennedy Engineers, 1974),
into which the waters of the study area flow. The conductivities
of the control and experimental areas were significantly different
(P<0.05), but no significant difference (P>0.05) between the
conductivities of the stations of the control watershed was found.
A significant difference (P<0.001) in conductivity between the
sampling dates was found at all stations. The fact that there was
no significant difference between the conductivity of stations I and
IV suggests that the difference in conductivity between the control
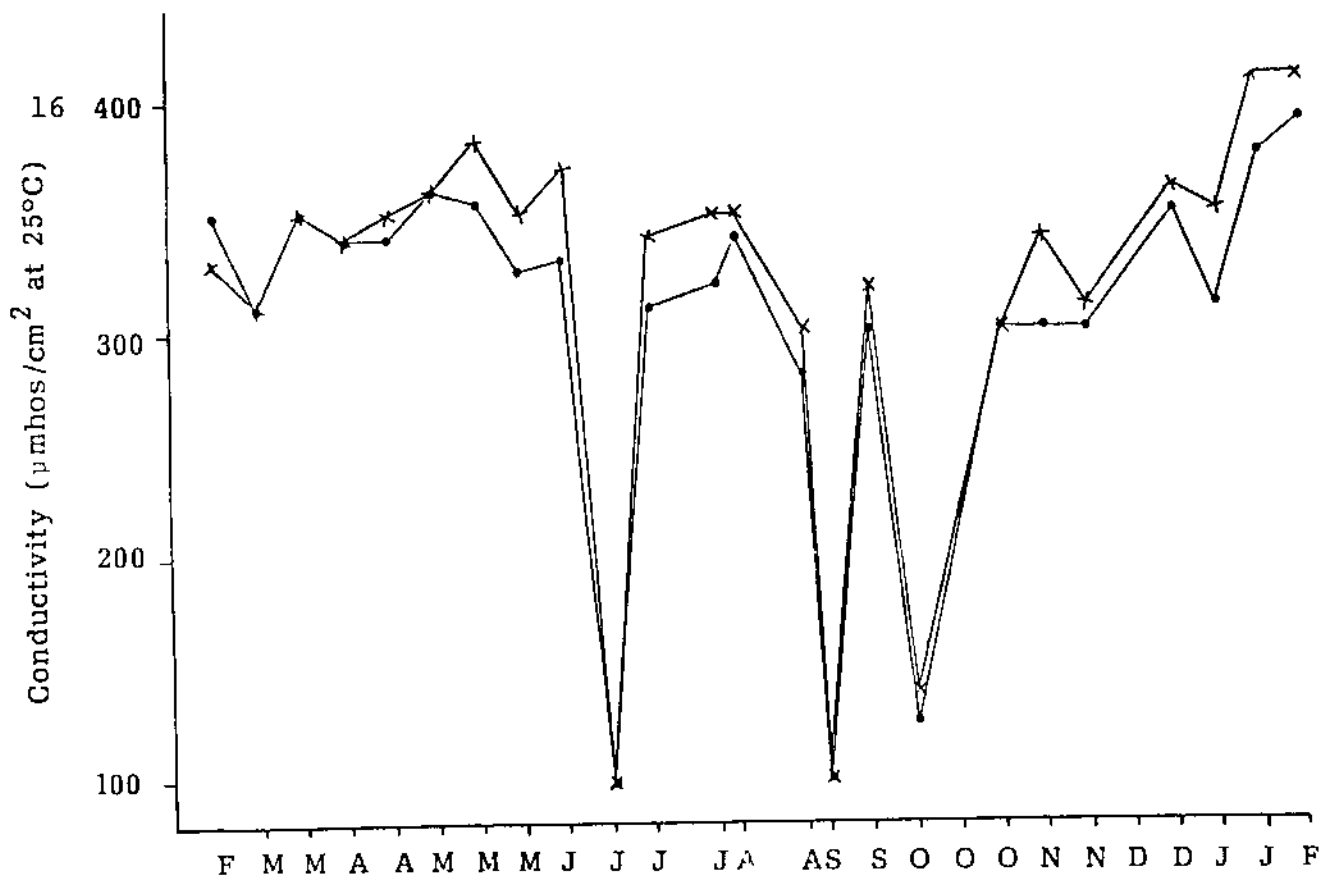and experimental areas was a result of the clearing.

Figure 8. Conductivity readings from 21 February 1980 to 6 February 1981
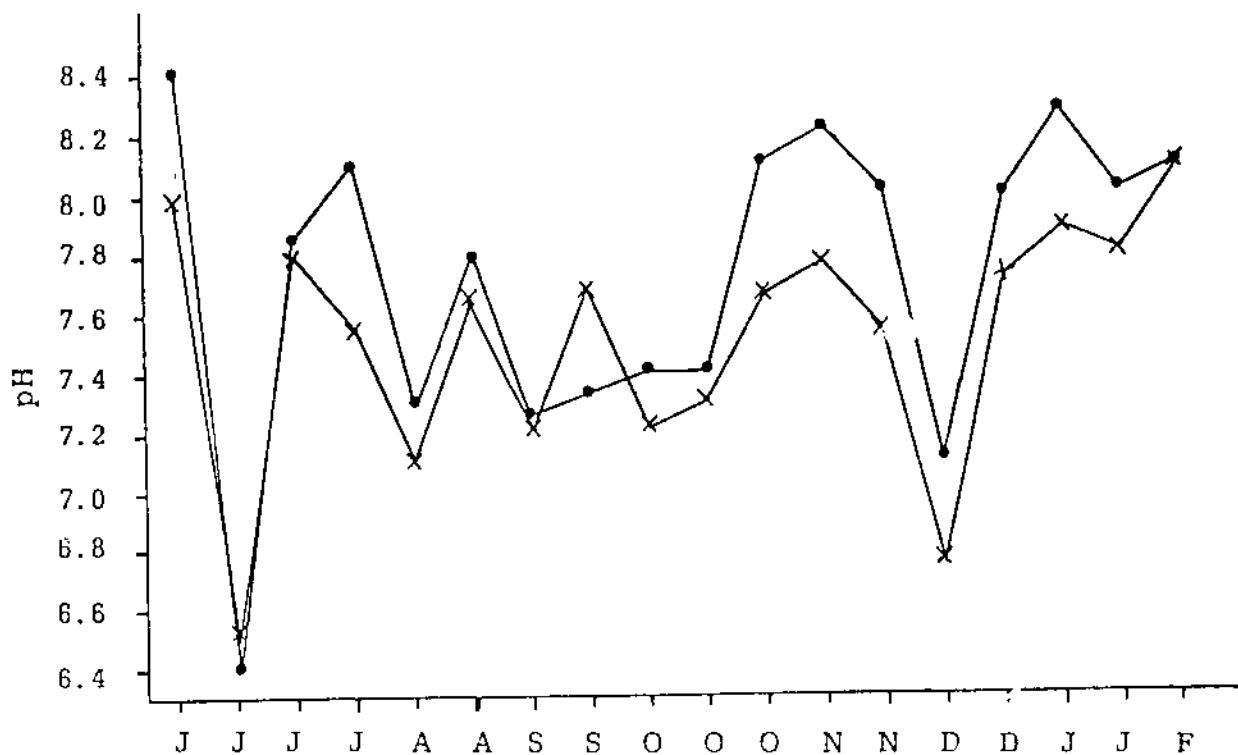at two-week sampling intervals. •= experimental area,
X = control area.

Figure 9. pH readings from 11 June 1980 to 6 February 1981 at two-week
sampling intervals. •= experimental area, X = control area.

Likens et al. (1970) found the conductivity of an undisturbed watershed changed very little on a daily or seasonal basis and the conductivity of a disturbed watershed was quite variable and approximately three to eight times greater than the control. These results were from a temperate study in which the regrowth of vegetation was inhibited by herbicidal treatments. Rates of decay were rapid and the uptake of ions by vegetation developing after cutting was also increased in areas with warm, moist climates (Marks and Bormann, 1972). Tropical systems have mechanisms for storage of essential elements in long-lived roots and stems and have mycorrhizal linkages between decomposing organic matter and roots (Farnworth and Golley, 1974; Stark and Jordan, 1978).

Conductivities from the cleared area were equal to or consistently lower than those from the control area. The recorded conductivity of the experimental area was greater than the control area only once, immediately after the land had been cleared (21 February 1980). This probably occurred because of a decrease in the ion uptake of vegetation and increased decomposition of leaf litter caused by increased soil temperatures; the conductivity was slightly depressed for the remainder of the study period. Absorption of ions by the exchange system may also account for the depressed conductivity readings from the experimental area. An increase in run-off from the experimental area caused by clearing could cause the dilution of ion concentrations from the upstream control area (Bormann and Likens, 1979). The differences between the experimental and control area conductivities became most noticeable during the end of the wet season (November and December 1980) and beginning of the dry season (January and February 1981).

A significant difference in seasonal fluctuations of conductivity was found at both experimental and control area stations. Conductivity was greatly reduced during times of heavy rains (26 June, 5 September, and 2 October) but increased rapidly to the mean conductivity value following rain storms.

pH

The pH of a water sample is a measure of the concentration of H^+ ions (Hem, 1970). Streams which have a high pH generally support more abundant aquatic life than streams with acid waters, which are generally low in nutrients (Smith, 1974).

The pH data are presented in Fig. 9 and were collected only during the second half of the study because field pH meters were not available before 11 June 1980. The mean pH values of the control and experimental area were 7.5 (range 6.5-8.1) and 7.7 (range=6.4-8.4), respectively. These values are similar to those recorded from the Maulap, Almagosa, and Imong Rivers which drain

the surrounding valley (7.7-7.9; Kennedy Engineers, 1974). There was a significant difference (P<0.001) between the pH of the water of the control and experimental areas and no significant difference (P>0.05) in pH of the water of the stations of the adjacent control watershed. A significant difference (P<0.001) among sampling dates was found at all stations. The recorded pH of the experimental area was generally greater than that of the upstream control.

Likens et al. (1970) found a decrease (5.1 to 4.3) in stream water pH when forest vegetation was cut and left in place, while the pH of control watersheds remained unchanged. The decrease in pH did not occur until the middle of the growing season, (six months after the land was cleared), and remained lower than the pH of control watersheds for the next 23 months. Nitrification increased rapidly in cleared watersheds. The oxidation of ammonium ions to nitrate causes H^+ ions to be released to the soil; reduced pH caused cations such as Ca^{++}, Mg^{++}, Na^+, and K^+ to be dissolved and quickly leached from the soil exchange sites (Bormann and Likens, 1979).

The pH of the water from the experimental area was expected to be low because of increased nitrification and the production of organic acids by decomposing vegetation. However, the pH of the experimental area was generally higher than that of the control (Fig. 9). Neutralization of H^+ ions by limestone (Tracey et al., 1964) or aluminum hydroxides (Johnson, 1979) present in the soil may account for the increased pH values recorded downstream from the cleared area. The pH of the experimental area was less than that of the control only twice, on 26 June and 19 September, when rains fell prior to and during sampling; H^+ ions were probably washed from the soil by the precipitation.

<div align="center">Hardness</div>

Hardness is a measure of alkaline earth cations, more specifically a measure of Ca^{++} and Mg^{++} ions in the water. Although water hardness is dependent primarily on the concentration of calcium and magnesium, hardness determination has very limited value in geochemical studies (Hem, 1970).

Hardness data for the experimental and control areas are presented in Fig. 10. The mean hardness values of the control and experimental area waters were 144 mg/ℓ (range=43-184 mg/ℓ) and 135 mg/ℓ (range=36-172 mg/ℓ), respectively. Hardness readings were similar to those recorded from the Maulap River (140 mg/ℓ; Kennedy Engineers, 1974), into which the waters of the study area flow. A highly significant difference (P<0.001) between the hardness of the control and experimental areas, and significant differences (P<0.05 and P<0.001, respectively) between stations of the control watershed and between sampling dates at all stations, were found.
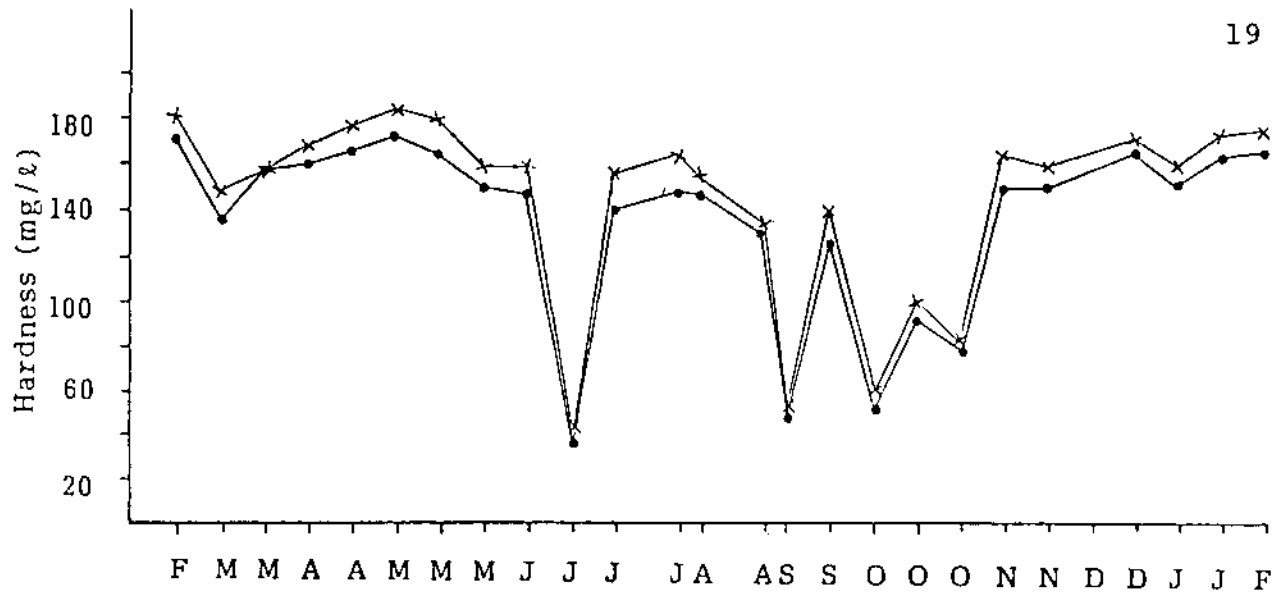
Figure 10. Hardness readings from 21 February 1980 to 6 February 1981 at two-week sampling intervals. •= experimental area, X = control area.
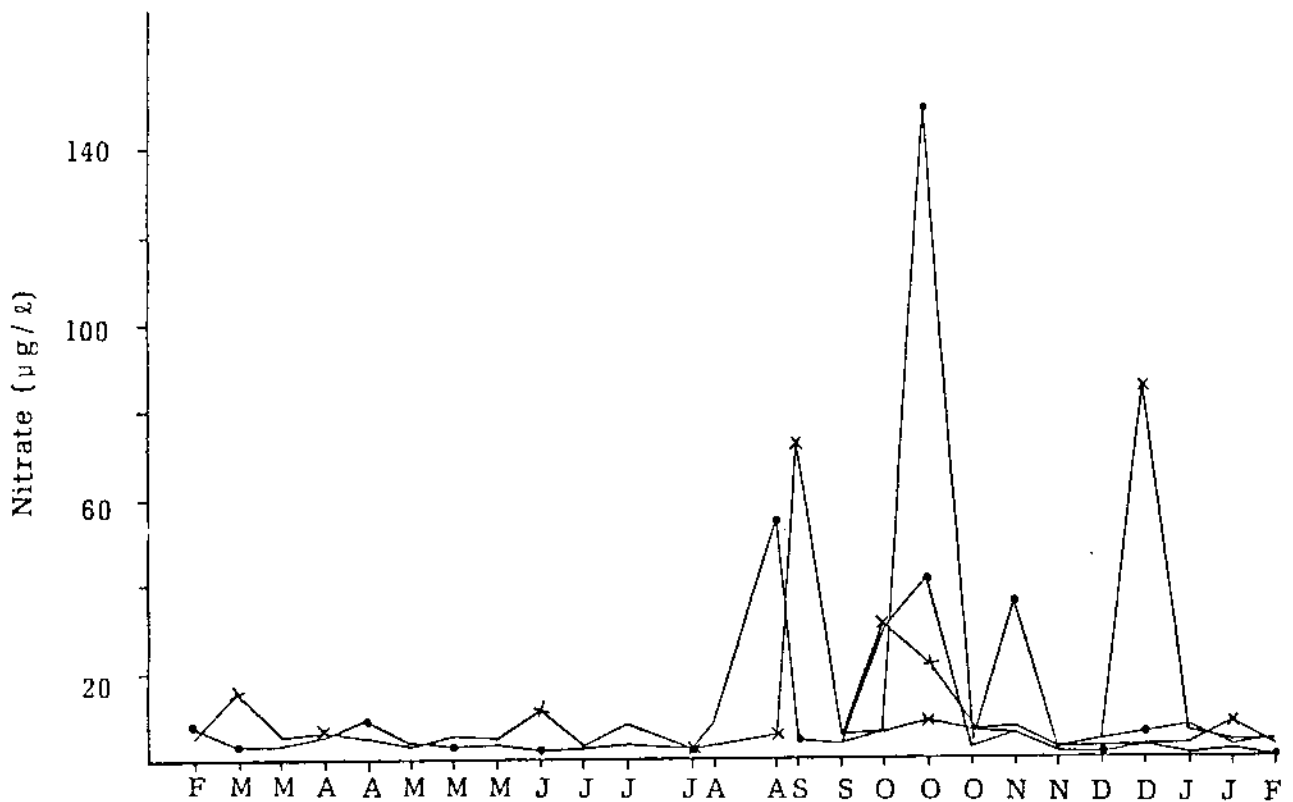

Figure 11. Nitrate concentrations from 21 February 1980 to 6 February 1981 at two-week sampling intervals. Concentrations for filtered before freezing (FBF) and filtered after freezing (FAF) from 2 October 1980 to 6 February 1981 are presented. •= experimental, X = control.

Johnson and Needham (1966) found that the ionic composition of stream water in California was not affected by a forest fire. Cations presumably were leached into the soil and were absorbed on the exchange complex rather than washed directly into the stream because the soil was acidic. Tropical systems also have mechanisms for storage of essential elements in roots and stems as well as mycorrhizal linkages between decomposing organic matter matter and roots (Stark, 1972; Farnworth and Golley, 1974; Stark and Jordan, 1978).

The hardness values obtained from station I of the control watershed were almost always slightly greater than those recorded from the upstream station IV. The reverse occurred in the experimental watershed; upstream control area values were almost always greater than those from the downstream experimental values. The increased hardness values observed at station I may be caused by the presence of a limestone outcrop (Tracey et al., 1964) or by the secretion of calcium from roots of Phragmites karka which was growing in the river between the stations (Likens et al., 1977). Hardness values for the downstream experimental area were slightly less than and once equal to the values from the upstream control area. This may be caused by a rapid increase in the uptake of calcium and magnesium by the vegetation growing back in the cleared area. Precipitation and ground water may percolate through the soil of the perturbed site more rapidly than in the control area and dilute the materials being transported in the river.

The disturbed ecosystem appeared to retain Ca^{++} and Mg^{++} ions during the first year after clearing. Calcium, magnesium and other cations lost from cut vegetation may have been held in the biological entities of the soil by storage mechanisms and not released to the river.

Nitrates

Living organisms require nitrogen for growth and development. Most plants can utilize nitrogen only in a fixed form, such as nitrites and nitrates. Nitrates leached from the soil are an important source of nitrogen for aquatic communities (Smith, 1974).

Nitrate data are presented in Fig. 11. The mean nitrate concentrations of the waters from the control and experimental areas were .009 mg/ℓ (range=.002-.073 mg/ℓ) and .013 mg/ℓ (range= .001-.148 mg/ℓ), respectively. The nitrate values were similar to those recorded from the Almagosa River (.010 mg/ℓ) and lower than those recorded from the Maulap River (.200 mg/ℓ) into which the waters of the study area flow (Kennedy Engineers, 1974). No significant difference ($P > 0.05$) between the control and experimental areas and no significant difference ($P > 0.05$) between sampling dates were found. The effects of freezing on nitrate concentrations were tested between October 1980 and February 1981, by comparing replicate samples filtered before and after freezing. No significant difference

(P>0.05) between filtering before and after freezing was found although fluctuations did occur.

Temperate zone studies have generally shown an increase in stream nitrate concentrations in disturbed watersheds (Bormann et al., 1968; Fredriksen, 1971; Swank and Douglass, 1977; Vitousek et al., 1979). Nitrification also increased in a cleared watershed (Smith et al., 1968; Likens et al., 1969; Likens et al., 1970). Increased soil temperatures and increased water movement through the soil appeared to accelerate nitrate losses from the perturbed watersheds (Bormann and Likens, 1979). The loss of nitrate from watersheds and the lag time between nitrate losses from cleared and forested watersheds may be short (hours or minutes) rather than long (days or weeks). In one study (Zolan et al., 1978), an increase in nitrate from 0.002-0.012 mg/ℓ occurred only seven minutes after rain began to fall, and nitrate concentrations returned to 0.002 mg/ℓ from the peak (0.012 mg/ℓ) after another seven minutes. Similar nutrient pulses are reported from Hawaii (Chun et al., 1972; Matsushita and Young, 1973). Nutrient cycling in the tropics is different from that in the temperate zones. A large portion of the organic matter and available nutrients is present in the soil and leaf litter in the temperate zone forest while the major portion of nutrients in tropical forests is stored in the extant vegetation; little leaf litter is present on the ground and the soil is low in nutrients (Odum, 1971). The Amazonian tropical forest has a root system which is three times as dense as that of the temperate zone (Sioli, 1975). Root systems and mycorrhizal fungi appear to exercise great control over nutrient losses in the tropics (Stark and Jordan, 1978). Increased mineralization, accumulation of ammonium in soil solution and on cation exchange surfaces, nitrogen immobilization by decomposers, and drought may also inhibit losses of nitrate from the disturbed watersheds (Vitousek et al., 1979).

High concentrations of nitrate were expected during times of heavy rains (Farnworth and Golley, 1974), especially on 26 June when heavy rains fell prior to and during sampling. Nitrate values of samples collected during or after heavy rains from the control and experimental area were similar and generally low. Several peaks and fluctuations in nitrate between the control and experimental areas did occur during the rainy season. Experimental area nitrate values were generally greater than those of the control area if rain fell several hours prior to but did not fall during the day before sampling. Control area nitrate values were generally greater than those of the experimental area if rain had fallen the day before and hours prior to sampling (NOAA, 1980 and 1981). This trend suggests that nitrates are leached from the experimental area more rapidly than from the forested control area, and a lag time between nitrate losses from the cleared experimental area and a control forest area may exist, as data collected from 27 August and 5 September imply (Fig. 11). Pulses in nitrate probably occurred often during the one year study period when rains fell after even short dry periods. These pulses may not have been recorded because continuous sampling studies conducted prior to, during, and after a rain storm were not performed. Extensive root systems, regrowing

vegetation, and the dry season may have inhibited losses of nitrate from the experimental watershed.

The low nitrate values and similarity between control and experimental nitrates may suggest that the control watershed is an aggrading one rather than supporting climax vegetation. Climax ecosystems release greater amounts of nitrates to stream water than aggrading or perturbed ecosystems (Vitousek, 1977). The area may have been disturbed during or after World War II.

Total Phosphorus and Orthophosphate

Phosphorus is often a limiting element for living organisms. The main sources of phosphorus are rock and natural phosphate deposits from which the elements are released by weathering, leaching, and erosion (Smith, 1974).

Total phosphorus data are presented in Fig. 12. The mean total phosphorus concentrations of the waters from the control and experimental areas were .058 mg/ℓ (range=.024-.204 mg/ℓ) and .050 mg/ℓ (range=.020-.184 mg/ℓ), respectively. These values were greater than those recorded from the tributaries of Fena Lake (.010-.014 mg/ℓ; Kennedy Engineers, 1974). A significant difference ($P<0.05$) in total phosphorus between the experimental and control stations and no significant difference ($P>0.05$) between the stations of the control watersheds were found. A significant difference ($P<0.001$) in phosphate concentrations between sampling dates was found at all stations. That there were no significant differences between the stations of the control watershed strongly suggested that the observed difference between the upstream control and the downstream cleared area was a result of the land-clearing. Control-area phosphorus concentrations were generally greater than those of the downstream experimental area.

Hutchinson (1957) stated that only phosphate need be considered in biogeochemical studies. The net removal of phosphorus from solution has been observed as a response to point sources in disturbed ecosystems (Brink and Widell, 1967; Keup, 1968; Johnson et al., 1976). Little is known of the processes underlying phosphorus uptake in undisturbed lotic ecosystems (Meyer, 1979), especially uptake by sediments and bryophytes. Meyer (1979) found that stream sediments and organic debris played an important role in taking up phosphorus released from terrestrial ecosystems. Sediments appeared to act as a buffer system, adsorbing and releasing phosphorus when water concentrations are great and low, respectively. Elevated temperatures (Meyer, 1978) caused an increase in the buffering effect of sandy and silty sediments. Orthophosphates appeared to be adsorbed more rapidly than other phosphorus compounds and may compete for attachment sites. Sorption was greatest when fine grained sediments were suspended during times of increased flow. Sediments are not limitless sinks and are renewed periodically when they are washed out from stream beds and brought in anew from stream banks by flood waters. Forest clear-cutting, which can lead to
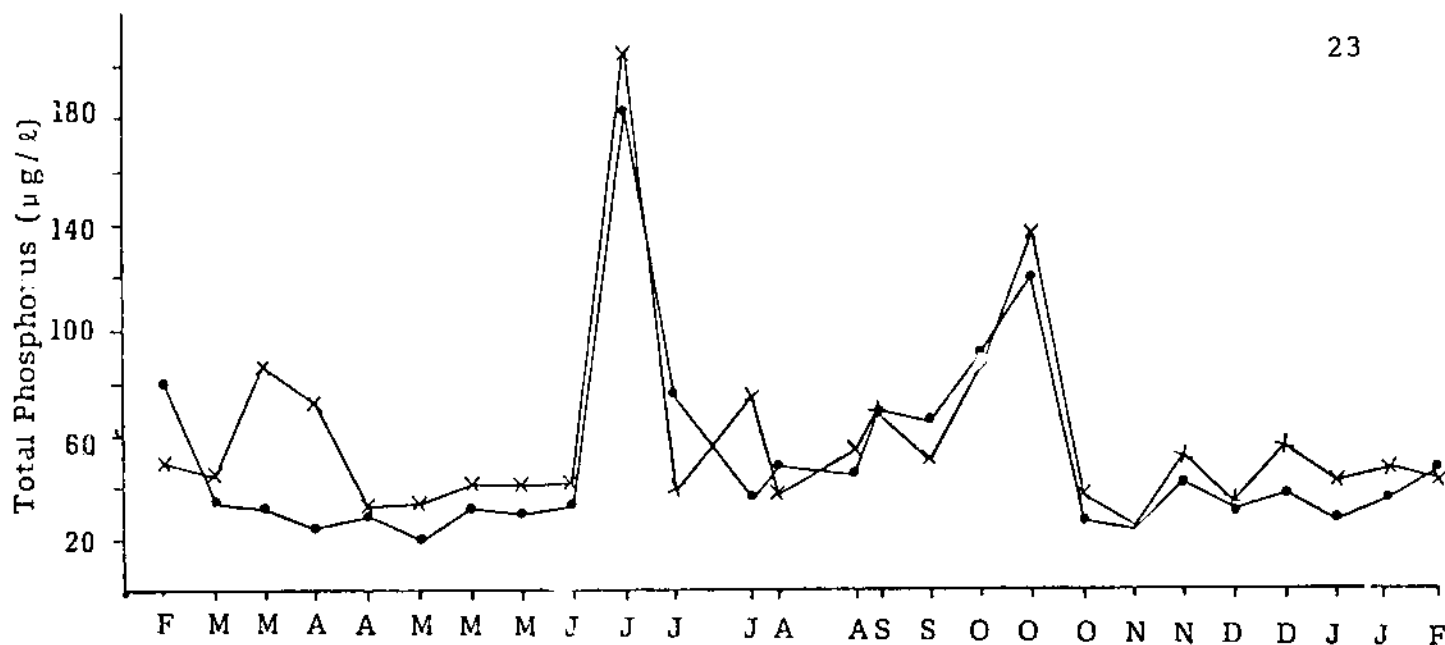
Figure 12. Total phosphorus concentrations from 21 February 1980 to 6 February 1981 at two-week sampling intervals. • = experimental area, X = control area.
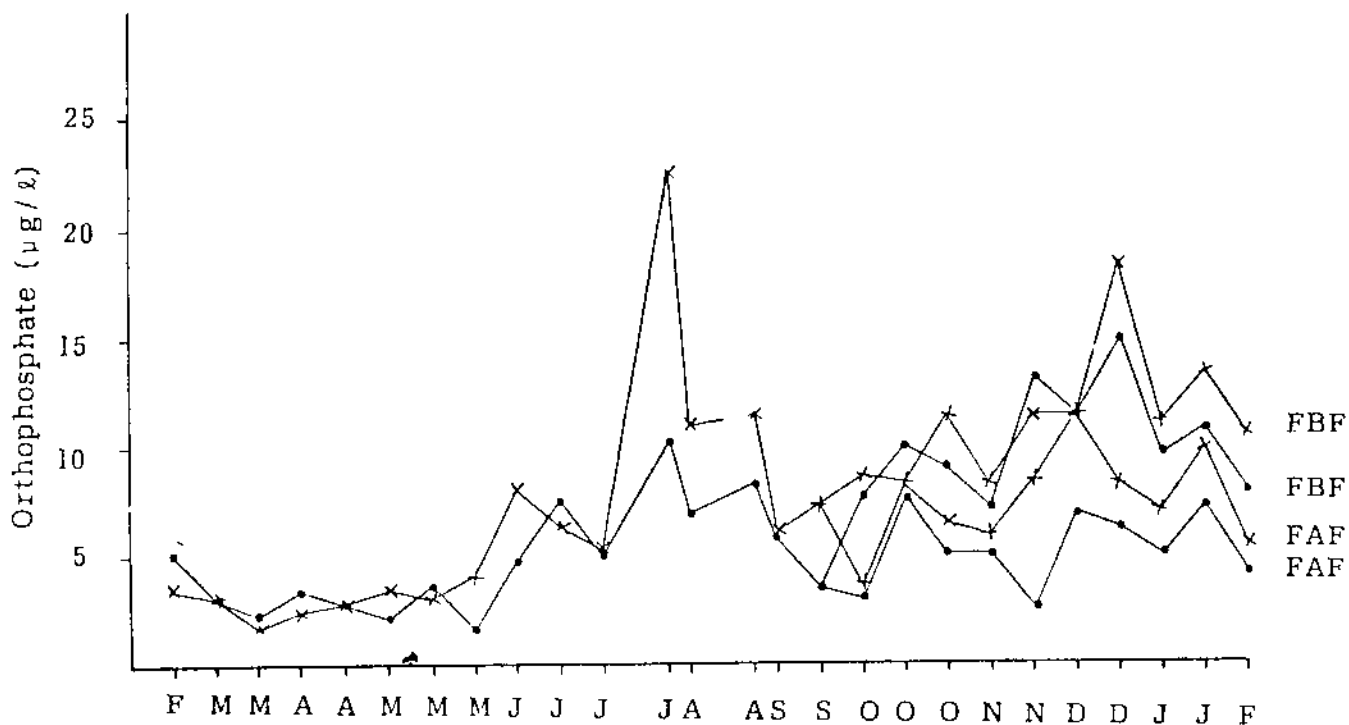

Figure 13. Orthophosphate concentrations from 21 February 1980 to 6 February 1981 at two-week sampling intervals. Concentrations for filtered before freezing (FBF) and filtered after freezing (FAF) from 2 October 1980 to 6 February 1981 are presented. • = experimental area, X = control area.

increased water flow, erosion of stream banks, and loss of organic matter in the stream bed, will reduce the buffering capacity of the stream. Phosphoɾus retention is particularly vulnerable because disturbances that increase discharge cause a greater amount of fine particulate sediment, which most actively absorbs phosphorus, to be lost from the system.

Decreased phosphorus concentrations of the experimental area were probably the result of phosphorus adsorption by stream-bed sediments. The differences between the concentrations of phosphorus in the upstream control and downstream experimental areas were most pronounced between 7 March and 18 April. Low rainfall and flow rates during the dry season probably permitted greater and longer contact between water and sediments. The effects of low flow and increased water temperatures of the experimental area probably caused increased adsorpiton of phosphate in sediments during these dates. The greatest total phosphorus concentrations were recorded during 26 June and 16 October; these were probably caused by increased flow during storms, which suspended sediment and increased phosphorus uptake. Samples collected on those dates showed high concentrations of suspended sediments (Fig. 7) and high total phosphorus readings probably reflected phosphorus adsorbed to those sediments. Turbidity was also high during 5 September but total phosphorus concentrations were not high, which is not easily explained. Experimental phosphorus concentrations were greater than those of the control area on 21 February, 5 August, 19 September, and 20 October. This may have occurred because rain falling prior to sampling leached phosphorus from the cleared area, which increased the downstream concentrations. Phosphorus appeared to be released in pulses similar to nitrate pulses. Zolan et al. (1978) found that phosphates increased from 0.0-0.079 mg/ℓ eight minutes after rain began to fall and gradually decreased to 0.031 mg/ℓ during the next seven minutes. Concentrations of 0.051 mg/ℓ were recorded 32 minutes after the peak (0.079 mg/ℓ) and 25 minutes after the rain stopped, suggesting that phosphate leaching may continue for an extended period after rain has fallen.

An attempt to correlate total phosphorus with rainfall was made and resulted in coefficients of $r=0.47$ and 0.42 for the control and experimental area, respectively. The correlations for the control and experimental were significant at 0.02 and 0.05 level, respectively.

Orthophosphate data are presented in Fig. 13. The mean orthophosphate concentrations of the waters from the control and experimental area were .008 mg/ℓ (range=.002-.022 mg/ℓ) and .006 mg/ℓ (range=.002-.015 mg/ℓ), respectively. These values were similar to those recorded from the Almagosa River, a tributary of Fena Lake (.010 mg/ℓ; Kennedy Engineers, 1974). There was a significant difference ($P<0.01$) between orthophosphate concentrations of the control and experimental areas and a highly significant difference ($P<0.001$) between sampling dates. The effects of freezing on orthophosphate concentrations were tested between October 1980 and February 1981, by comparing replicate samples filtered before and after

freezing. A significant difference between filtering before and after freezing was found at both control (P<0.005) and experimental (P<0.001) areas. Samples filtered after freezing generally showed reduced concentrations of orthophosphate compared with samples filtered before freezing. Freezing probably caused orthophosphate to be adsorbed onto sediment and organic debris particles present in the samples.

Orthophosphates accounted for 2-35% of the total phosphorus in samples collected. High concentrations of orthophosphate were found during 30 July and 24 December and did not occur during times when concentrations of total phosphorus were high. Peak orthophosphate concentrations were observed. Total phosphorus was probably high because increased rainfall and discharge caused sediments to become suspended and also caused run-off through surface soil layers, which may have greater concentrations of organic phosphate than orthophosphate. Peak orthophosphate readings were observed during times of lower flow when river waters were probably derived from lower soil surfaces which may have higher concentrations of orthophosphates.

Concentrations of orthosphosphates from the experimental area were occasionally higher than those of the control area. This condition was probably caused by more rapid leaching of orthophosphate from cleared areas than from forested control. Pulsing of orthophosphates similar to that discussed for nitrates probably occurred during the study.

GENERAL SUMMARY AND DISCUSSION

Savanna vegetation repopulated the perturbed ravine forest watershed and thus appeared to be an earlier stage of succession than the ravine forest. Fire or continued clear-cutting would set back succession and maintain savanna vegetation in the watershed.

Maximum soil temperature, air temperature, and water temperature increased because solar radiation was directly absorbed when vegetation was removed. Minimum air temperatures were slightly less in cleared areas; minimum soil temperatures were also expected to be less than those of the control area because of increased heat loss during the night. Minimum water temperatures were elevated as compared with those of the control area and were influenced by heat absorbed by river water from the volcanic rock which was heated by the sun, as well as by lack of shading from vegetation.

Turbidity does not appear to be affected by clear-cutting. Regrowing grasses and other herbaceous vegetation probably inhibited erosion. Fire, bulldozing, or herbicidal treatments of a watershed would probably increase erosion and turbidity, as would building or the construction of extensive trails in the perturbed area.

Conductivity and hardness values of the experimental area were less than those of the control area. Increased uptake of ions by regrowing vegetation or adsorption of ions by exhange surfaces,

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could account for the decrease in ion losses from the experimental
area. Herbicidal treatments, burning, or bulldozing would probably
cause ions to be lost from the perturbed area because biological
controls, which inhibit ion loss, would be destroyed. Increased
ion concentrations in the water would probably persist until
vegetation began to regrow.

Increased pH values from the experimental area were not expected.
Neutralization of H^+ ions by limestone or aluminum hydroxide in the
soil may explain the increased pH of water from the experimental
area. The pH of the experimental area was less than that of the
control area when rains fell and washed H^+ ions from the soil.

Nitrates and phosphorus fluctuated and were believed to pulse
with the onset of precipitation. A nutrient pulse may occur rapidly
and be over within half an hour after rains begin. Automatic
samplers operated prior to, during, and after a storm should be used
to measure the nutrient pulses and determine the size and length of
the pulses.

Increased temperatures and increased nutrient losses from the
land may cause algal blooms in the downstream areas. Increased
nutrient losses from large perturbed watersheds may be long-term
problems and may affect the reefs near the mouths of rivers draining
perturbed areas. Clear-cutting increases water loss and may
accentuate droughts during the dry seasons and cause flooding with
the onset of the rainy season.

ACKNOWLEDGEMENTS

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