SILLIMAN JOURNAL, 1987, Vol. 34, Nos. 1-4, pp. 82-107

The Climate and Hydrology of the Lake Balinsasayao Watershed, Negros Oriental, Philippines

Paul D. Heideman and Keith R. Erickson

Climate variables were recorded and a water budget calculated for the Lake Balinsasayao catchment area, 302 ha of submontane forest surrounding a 76 ha lake 14 km west of Dumaguete City on southern Negros Island. Mean annual temperature at the Lake was 22°C, 5.4° cooler than Dumaguete City. Rainfall July 1982—June 1983 was 2372mm, three times that at Dumaguete City. Monthly rainfall at Lake Balinsasayao was highly correlated with that at Dumaguete City, although annual rainfall at the lake is estemated to be about 3100 ± 300 mm, over 2.5 times that at Dumaguete City. Evaporation accounts for less than 15% of the 16,500 m^3 of water lost daily from the Lake. Since the Lake has no surface outlet, the remaining 85% must be lost through seepage. Available evidence suggests that seepage from Lake Balinsasayao is the source of the springs that join to form the Colo River. Annual evapotranspiration at the Lake was about 1700 mm, both during this study and according to data taken by others, July 1983 - June 1984. Almost 75% of total rainfall on the forest was lost through evapotranspiration during the 1982-83 study period; during the following twelve months, a wetter period, evapotranspirative losses were about 50% of total rainfall. Both annual evapotranspiration and percent runoff figures are higher than those recorded in most other studies on Southeast Asian forest catchments. The results of this study suggest that development of the Lake area as either a hydroelectric power source or a tourist resort would prove unprofitable.

Lake Balinsasayao and the surrounding primary forest (Fig. 1) have been the center of controversies regarding use. The area is currently designated as a wildlife sanctuary and also supplies clean drinking water to communities downslope, but an increasing fraction of the forest is being cleared for subsistence farming. Proposals that the area be extensively developed for tourism, as a water source for irrigation, as a geothermal power source, as a hydro-electric power source or as a protected national park have stimulated a sharp debate. The Lake Balinsasayao area has also become established as an important site for research in terrestrial ecology in Southeast Asia (Rand and Rabor, 1952; Alcala and Brown, 1969; Rabor et al, 1970; Brown and Alcala, 1970; Alcala and Alcala, 1970; Alcala and Carumbana, 1980; Heaney et al., 1981; Antone, 1983; Heaney and Peterson, 1984; Erickson and Heideman. 1984; Utzurrum, 1985; Heideman, 1987; Heideman et al., 1987). The conflicts over use of the area take place in the context of an increasing national and international search for alternatives to the destruction of rainforest, particularly due to clearing for subsistence farm plots (*kaingin*) Abregana, 1984).

Despite the fact that hydrological data are essential to any ecologically and economically sound land-and water-use program, as well as to scientific and applied field research, no such data are available for the Balinsasayao region. The climatological data available for the permanent weather station 14 km away at a lowland coastal site, Dumaguete City, are inadequate because weather patterns often vary greatly over short distances along an elevational gradient, and the climate of Dumaguete City is likely to be dissimilar in important aspects to that of the lake region, some 800 to 1200 meters higher.

There are few studies on the hydrology of forested catchment areas in Southeast Asia (see Low and Goh, 1972, and Whitmore, 1984, for reviews), or in the Philippines (Baconguis, 1980). Such studies are imperative for planning either development or conservation; given the differences between nearby locations, the paucity of hydrological studies is even more serious.

Here we present hydrological information from twelve months of climatological data taken at Lake Balinsasayao, with comments on records provided by Dr. R. Cadeliña and B. Maata (Cadeliña, 1986; Cadeliña and Maata, unpublished data) from twelve additional months. The goals of the paper are (1) to provide a description of the climate of the Lake Balinsasayao region, (2) to calculate a water budget for Lake Balinsasayao and the surrounding catchment area, and (3) to relate the climate of the lake region to the climate of southern Negros island.

Study Area

The study site is on the island of Negros, an oceanic island of 13,670 km^2 located between latitudes 9 and 11 degrees north (Fig. 1). A north-south mountain range runs along the axis of the island, including several peaks of over 1800 m in the north and central part of the range that connect via a series of low ridges with several more peaks of up to 1800 m in the south. The study area, Lake Balinsasayao and its 302 ha watershed, is situated in the southern mountains. Lake Balin sasayao and the adjacent smaller lake, Danao, are located on the eastern slope of this southern knot of mountains at elevations of 830 and 846 m, respectively (Fig. 1). No published geological description is available for the site, but two hypotheses have been proposed for the origin of the lakes. The first suggests that a volcanic cone, Mt. Guintabon (1240 m elev.), dammed two streams arising on the slopes of Mt. Guinsayawan to the west, forming the two lakes (Alcala et al., 1981) and at lower elevations creating a number of small ponds that have entirely or partially filled with silt. The second hypothesis is that the lakes are irregularly shaped crater lakes formed by explosive eruption (Wernstedt, 1953).

The two lakes are separated by a ridge only 100 meters wide at the narrowest point. The surface of Lake Danao is 16 meters higher than the surface of Lake Balinsasayao, suggesting that the dividing ridge is composed of impermeable rock (Alcala et al., 1981). The tops of the steep-sided ridges surrounding the lake range from 900 to 1200 m in elevation. Most of the slopes are between 20 and 70 degrees, with an average of approximately 40 degrees. The soils are volcanic, moderately acidic and of moderate to high fertility (Lowrie, 1983). Neither lake has a surface outlet; water loss from both is entirely due to seepage and evaporation. According to investigators at Silliman University, the lake level has dropped an average of about 200 mm per year over the past 5-10 years, and a local settler at the lake told us that the lake has dropped about three meters over the last 12 years. About two or three kilometers below Lake Balinsasayao a stream forms from a series of springs along a 300-meter length of the valley floor. We believe that the springs are fed by the seepage from the lake (see discussion and Alcala et al., 1981).

As of 1984, about 75-85% of the 302 ha area drained by Lake Balinsasayao was covered with primary mixed dipterocarp-oak-laurel forest; the remainder was second growth and recently-cleared forest planted in subsistence crops. We estimate that about 5-10% was cleared in the three year period from June 1981 to June 1984.

Climate of Negros Island

The climatic patterns on Negros are determined primarily by the two monsoons of the Asiatic mainland. The southwest monsoon from April or May through October is characterized by southwest winds that are due to low pressure systems that develop over the Asian continental land mass through summer heating of the land surface. The northeast monsoon from November through January produces northeast winds caused by air movement from the polar anticyclone centered near Lake Baikal (Ramage, 1971). During the months of February, March, and early April neither monsoon has much effect, and the climate is dominated by the prevailing northeastern trade winds. The effects of the monsoon and trade winds may, however, be strongly modified locally by the interaction of the monsoon winds with local geographic and orographic features (Lockwood, 1974; Ramage, 1971).

The monsoon winds produce the general annual climatic pattern of Negros, but the monsoon is " . . . only superficially a very orderly phenomenon" (Ramage, 1971), and minor or major changes in the timing of events, along with the occurence of severe cyclonic storms, make the actual climatic pattern of any given year unpredictable. Shifts in the position of high and low pressure systems may cause great changes in weather over large areas, as apparently occured during the first half of 1983, resulting in drought on Negros and weather that was either unusually wet or unusually dry throughout Southeast Asia and the Pacific.

In general, the monsoons bring warm, moisture-laden air to Negros, with concomitant precipitation, while the northeastern trade winds bring cooler air and less rain. In each case the moisture-laden winds rise when they encounter the mountains. As the rising air expands and cools, moisture condenses and precipitates out as rain on the windward slopes of the island. The result is frequent and often heavy rains on the coasts of the island facing the incoming monsoon winds, and lower rainfall on the opposite slopes because the air has been dried by precipitation and descent from the central mountains. Under these conditions, mountain and sea breeze circulation can still be strong enough to lead to vigorous afternoon showers on the leeward side of islands (Ramage, 1971); this greatly moderates the effects of the monsoons in some areas. In contrast, the northeast trade winds bring drier air and much less precipitation to all of Negros (Wernstedt, 1953), and this period with the transition months constitutes the dry season of February through May, only moderately dry on the northeast coast, but extremely dry on the south and west coasts

The interaction of the monsoons with the topography of southern Negros produces two different annual patterns of rainfall, one on the west and south slopes of the island (Fig. 2b), and the other on the east slope (Fig. 2a). The west and south slopes receive most rainfall from the southwest monsoon in the months of June through November, intermediate amounts of precipitation during May and December, and very little during the months of January through April (Fig. 2b). The east slope of the island is far less seasonal, receiving moderate amounts of rain from both the southwest and northwest monsoons, and lower amounts from the northeast trade winds from February through April (Fig. 2a). Thus Dumaguete City, on the east coast, experiences a mild wet season (June-January) during the monsoons, and a mild dry season (monthly rainfall one-half to one-third of wet season months) during the period dominated by the northeast trade winds. The climate of Dumaguete City is classed as "seasonal" using Schmidt and Ferguson's modification of Moh's Q index (Q=no. months < 60 mm/no. months> 100 mm X 100; see Whitmore, 1984), with a Q value of 86 (range for the class is 33 to 100).

METHODS

Data were collected each month during two to three and one-half weeks at the site of the Silliman University cabin (Fig. 1) on the north shore of the larger of the two lakes from 27 June 1982 through 20 June 1983. Rainfall and other weather records for a number of sites on Negros were also obtained from the Dumaguete City Weather Station and from printed sources (Wernstedt, 1953 and 1972; Manalo, 1966).

We took morning readings (generally between 0600 and 0800 hrs) of rainfall, relative humidity, maximum and minimum temperatures for the preceding 24 hours, and lake level. We recorded rainfall in two small raingauges (collection area 57 X 32 mm, capacity 150 mm) and one large raingauge consisting of a galvanized metal collection funnel (collection area a square 250 X 250 mm, capacity about 200 mm) which fed into a covered bucket. The two small raingauges collected from 65-100% of the amount collected over the same period by the large raingauge, varying with wind conditions and rainfall intensity. We regard the large raingauge as more accurate, as its design minimized losses due to splash and evaporation. Rainfall totals from the small gauge, when used, were adjusted according to their percentage deviation from the large gauge. The monthly rainfall totals in Table 3 and in Figure 2 are based largely on records from the large raingauge. Rainfall records from the larger raingauge provided a continuous record over the entire period, with the exception of a gap, 9-29 July 1982. The precipitation data end 10 days before the end of June 1983. We extrapolated from July rainfall in Dumaguete City (see correlation analysis below) and used records obtained at the study site by R. V. Cadeliña and B. Maata (personal commiuncation) for the last 10 days of June in order to obtain rainfall estimates for those two months. We estimate that our monthly rainfall figure for July 1982 is accurate to ± 50%, and for all other months to ± 10%. The large raingauge was moved to the ridge above the cabin (Fig. 1) each time we were absent from the site, and was tended, if necessary, by our field assistant. Because we were seldom at the site on the first day of the month, our monthly rainfall totals at Lake Balinsasayao are calculated from the second or third day of each month to the corresponding day of the following month. The Dumaguete City rainfall data, 1982-83 were similarly totalled to allow direct comparison. In order to examine the relationship between rainfall at Dumaguete City and the lake, a correlation analysis was carried out on log-transformations of the monthly rainfall totals (excluding July, the month for which we do not have complete records).

Relative humidity was calculated from temperature readings taken with a sling psychrometer. The curent temperature and the maximum and minimum temperatures for the preceding 24 hour period were recorded from two maximum-minimum thermometers kept in the shade of the cabin in the center of a small clearing. Potential evapotranspiration, the amount of water which could be lost to the atmosphere through evaporation and transpiration given the available net radiation, was estimated using the methods of Thornthwaite (1948; see also Thornthwaite and Hare, 1965) and Holdridge (1959). We calculated actual monthly and annual evapotranspiration at the study site using the measurements of precipitation and relative lake level. We noted lake levels occasionally from June to September 1982, and in October we began recording daily level to the nearest half centimeter on a marked post driven deeply into sand and gravel on the lake bottom. The surface area of the lake was obtained from Abregana (1983), and the area of the drainage basin was calculated using a polar planimeter on a photographic enlargement of a 1:50,000, 20 meter contour-interval topographic map (Philippine Coast and Geographic Survey. Ayaquitan, no. 3648 III, 1956).

RESULTS

Temperature

Mean monthly minimum, mean, and maximum temperatures for the study site and Dumaguete City are presented in Table 1. The mean annual temperature was 22.0°C at Lake Balinsasayao, 5.5°C lower than at Dumaguete City. The mean daily temperature range was 6.7°C (minimum 2°C on 3 November and 8 December and maximum 10.5°C on 18 February). In contrast, the annual range of mean monthly temperatures was only 2.5°C. Table 2 presents the 10 lowest and 10 highest temperatures we recorded and the dates upon which they occurred. The coolest temperatures were in January, February, and March, but were only 2°C below the annual mean low temperature. The highest temperatures were mostly in May-August, and were only three degrees higher than the annual high temperatue. Note that on a single day, Febuary 18, we recorded both one of the 10 coldest and one of the 10 warmest temperatures for the year. The daily, extremes of temperature were dependent more upon rain and cloudiness than time of year.

Relative Humidity

We obtained no relative humidity measurement of less than 70%; most were above 85%. Most of our readings were taken in the early morning, when relative humidity tends to be at its highest (Richards, 1952), but several readings taken around noon or early afternoon on clear days were also above 85%, and we suspect that relative humidity is generally quite high throughout the day.

Precipitation

Total rainfall for the one year period at the site was 2372 mm (Table 3). Rainfall during the following, wetter 12 months

at Lake Balinsasayao was about 3500 mm (Cadeliña, 1986; Cadeliña and Maata, unpublished data). The 1982-83 figure is certainly below the mean annual rainfall for the site, as a severe drought occurred throughout the Phiilppines during the first six months of 1983, apparently due to the shifting of the normal high and low pressure systems associated with the northeast monsoon. At Dumaguete City, rainfall during the first six months of 1983 (Table 3) was the lowest in more than 25 years. The 762 mm of precipitation recorded at Dumaguete City during the period July 1982-June 1983 was only 2/3 of the mean annual precipitation (Table 4). The lake level fell about three meters during the year (Table 3), also suggesting that rainfall was much lower than usual.

The pattern of variation of monhly rainfall over the year at Lake Balinsasayao was similar to that of Dumaguete City ($R^2 = 0.96$, $p < 0.001$, $N = 11$ months), 14 km away, although the lake area received almost three times the precipitation at Dumaguete City (Fig 2, Tables 3 & 4). We estimate mean annual rainfall for the lake area to be 3100 ± 300 mm, based on the amount of precipitation in 1982-84 and on the relationship between precipitation at the lake area and Dumaguete City. Due to the greater rainfall, the climate of the lake region from 1982 to 1984 would be classed as only "slightly seasonal," using Schmidt and Ferguson's modification of Mohr's Q,, or seasonality, index (Whitmore, 1984), with a Q value of 21 (range for the class is 14 to 33).

Catchment Water Budget

In order to obtain the daily or annual water budget of an area, the daily and annual inflow to the area and annual outflow must be calculated. By far the greatest source of water input to this montane basin is rainfall; water is lost through surface flow, subsurface flow, and evapotranspiration. Because Lake Balinsasayao has no surface outlet, losses from the lake are divided between subsurface flow and evaporation. We will first determine the daily water budget of the lake from precipitation and lake level measurements, then use those figures to determine for the forest the relative importance of flow to the lake and evapotranspiration.

Evaporation

An estimate of evaporative water loss was used to determine the relative importance of evaporation and seepage to the lake water budget. Evaporative water loss is dependent upon a number of factors including wind speed, incident solar radiation, reflectivity of the lake, relative humidity, and the magnitude of the difference between air temperature and mean water temperature. We have no direct measures of evaporation from the lake, but we can obtain an estimate of evaporative water loss from the application of a corrective factor to measurements taken by Quisumbing (1936, 1941) in a concrete fish pond at the Bureau of Science in Manila. Quisumbing found that his pans averaged about 1300 mm of evaporation annually with fairly high variation between months from 5 year monthly means of 43 - 73 mm/month from June to December, to 81 - 145 mm/month from January to May. Because evaporative water loss from pans is greater than evaporation from free bodies of water, pan-to-lake coefficients have been determined at many locations in order to estimate lake evaporation from pan evaporation measurements (water loss from pan X pan-to-lake coefficient = estimate of water loss from lake). In general, simple pan-to-lake coefficients are in the range 0.60 - 0.90; we selected a coefficient of 0.70 because the lower temperatures near the lake should result in reduced evaporation compared to lowland areas (Gale, 1972). This procedure provided estimates of daily evaporative water loss of 0.9 - 3.8 mm/day, with a mean of 2.5 mm/day. Evaporation over the 762,000 m^2 surface area of the lake can account for about 1900 cubic meters (2.5 mm/day X 762,000 m^2) of of water loss daily. The use of other reasonable pan-to-lake coefficients does not greatly alter this figure, nor does it affect the conclusions below.

Daily Water Budget

Actual daily water-loss from the lake is well above 1900 m^3. On rainless days at the end of the drought in 1983 the lake level dropped an average of 21.7 mm/day over 35 consecutive days with no measurable rainfall following a long period with almost no rainfall. During that time, all of the streams that fed the lake were dry and all springs had dried up or slowed to a trickle; we suspect that water input from subsurface springs was also negligible, as the daily rate of water-loss was constant over that period. At that rate of water-loss, about 16,500 m^3 of water was lost every day (21.7 mm/day X 762,000 m^3), and, given the volume of the lake, complete replacement of the lake water would require about three years. If about 1900 m^3 per day is evaporative water-loss, then the remaining 14,000 m^3 (88%) must escape as subsurface seepage.

Since daily water-loss from the lake is roughly constant at 16,500 m^3, determining the rainfall and change in lake level over a period of time allows calculation of the amount of water added to the lake by that amount of rainfall. Furthermore, rainfall can be partitioned into the amount entering the lake and the amount lost from the forest as evapotranspiration, assuming that groundwater stores remain constant. This assumption is probably reasonable unless the period is bounded at the beginning by a dry period and at the end by a wet period (or the reverse).

We used a 23-day period in November over which there was no net change in lake level to obtain an estimate of the amount of rain necessary per day to prevent a net change in lake level. The mean daily rainfall over that period was 10.63 mm per day. We round to obtain 10.6 mm as an estimate of the daily precipitation necessary to prevent a net change in lake level.

The 10.6 mm of rainfall required to prevent a net change in lake level can be partitioned into that entering the lake and that escaping through evapotranspiration. If 10.6 mm of precipitation is sufficient to prevent a drop in water level, and 16,500 m^3 of water is lost from the lake each day, then 10.6 mm of precipitation must provide approximately 16,500 m^3 of water to the lake. Of this 16,500 m^3, 8100 falls directly on the lake (10.6 mm X 762,000 m^2 of lake surface) and 8400 must come from run-off in some form. The area drained by the lake is 3,020,000 m^2, and 10.6 mm of precipitation deposits 32,000 m^3 of water on that area, of which 8400 m^3 drains into the lake within the day. The remaining 23,600 m^3 is lost through evaporation or retained in the soil. Some of the latter portion never reaches the soil as a significant fraction is intercepted by vegetation and evaporates directly back into the atmosphere. Kenworthy (1971) found that in lowland dipterocarp forest at Sungei Gombak in West Malaysia, more than 4.5 mm of rain was required before any moisture reached the floor; there are similar findings for dense temperate forests (Shpak, 1971). If we use 4.5 mm as an approximation for the forest in the Balinsasayao drainage basin, then about 18,700 m^3 reaches the ground, and 10,300 m^3 of the rainwater remains on vegetation and is eventually lost through evaporation and transpiration. Thus, this analysis indicates that on these steeply-sloping forested slopes, approximately 74% of the moisture received from 10.6 mm of precipitation normally escapes through evaporation and transpiration within the forest. During the periods of exceptionally heavy rain associated with typhoons, a much larger fraction of the precipitation reaches the lake; Kenworthy (1971) found that up to 99% of a very heavy rain left the forest as runoff. We lack enough data from such periods for even a rough quantitative analysis.

Annual Water Budget

Over the entire year of the study, the lake region received 2732 mm of rain, or 8,966,000 m^3 (2.372 m X 3,780,000 m^2) of water over the area of the catchment. Over the same period the lake lost 6,035,000 m^3 of water (21..7 mm drop in lake-level/day without input X 762,000 m^2 X 365 days). Our records of lake level indicate that the lake level dropped approximately three meters over that period, indicating that 2,285,000 m^3 (3.0 m X 762,000 m^3) was lost from the lake without replacement. Therefore, 5,217,000 m^3 (8,966,000 — [6,035,000 — 2,286,000]) of water was lost through evapotranspiration from the forest, assuming no net change in groundwater stores. Therefore,, total evapotranspiration from the forest over the year was 1,727 mm (5,217,000 m^3/3,020,000 m^2), or 73% of total rainfall. Evapotranspiration in the period July 1983 - June 1984 was similar. The same calculations carried out using data from Cadeliña and Maata (Cadeliña, 1986; Cadeliña and Maata, unpublished data) for that period indicate that evapotranspiration was approximately 1750 ± 150 mm, or 50% of total rainfall.

Monthly estimates of evapotranspiration for the forest around the lake are provided in Table 3. We estimate the potential error in these monthly estimates at at least ± 25%, due

to the combined errors from possible changes in groundwater reserves, in the measurement of rainfall, and in the measurement of runoff. Evapotranspiration for the months of February through May was probably underestimated because of error due to unreplaced groundwater outflow from the watershed. The total for the year may also underestimate actual evapotranspiration for the same reason, although groundwater stocks were probably replenished to a great extent by the high rainfall in June.

While actual evapotranspiration is limited by the water supply, potential evaporation is a description of how much water could be lost to the atmosphere if moisture is not limited, given the net radiation received (Thornthwaite and Hare, 1965). Although calculations of potential evapotranspiration are frequently lower than observed evapotranspiration in the tropics (e. g., Kenworthy, 1971), potential evaporation at both the lake and Dumaguete City were determined for comparative purposes. Figure 3a shows observed evapotranspiration, potential evapotranspiration (Thornthwaite and Hare, 1965), and rainfall at the lake for July 1982-June 1983, while figure 3b shows potential evapotranspiration and rainfall at Dumaguete City for the same period. Figure 3c shows mean monthly precipitation and mean monthly potential evapotranspiration at Dumaguete City. Potential evapotranspiration at the lake was considerably lower than observed evapotranspiration for most of the year, a result consistent with the general finding that the Thornthwaite method for estimating potential evapotranspiration tends to be low for many parts of the tropics.

Moisture is likely to be limiting to vegetation in the months of December through July in Dumaguete City, but was limiting to vegetation at Lake Balinsasayao only in March, April, and May in 1983. In the wetter period of July 1983 - June 1984 (Cadeliña, 1986; Cadeliña and Maata, unpublished data) moisture was either not limiting at the lake, or was limiting only for a short period in April.

Seepage from the Lake

The roughly 14,600 m^3 of water lost daily through seepage from the lake amounts to a loss of about 10.1 m^3 per minute, and it is worth speculating on the fate of this water. It is clear that the dividing ridge between the two lakes is composed of nearly impermeable rock, since the water level of Lake Danao is 16 meters higher than that of Lake Balinsasayao. The ridges and exposed bedrock along the west side of the lake appear similar to the ridge dividing the lakes, and we suspect that they may be composed of impermeable rock. In contrast, the northeastern ridge above the lake has the appearance of a dam of jumbled rock and dirt, and numerous springs flow from the opposite side a few kilometers from the lake. These springs join to form a swiftly flowing stream, the source of the Colo River. The stream is much larger than one would expect from the drainage of such a small area, and it maintained a heavy flow even during the drought in 1983, when flow rates had greatly decreased in all other streams in the area. The available evidence supports the hypothesis that Lake Balinsasayao is the source of the Colo River.

DISCUSSION

Long-term records for Dumaguete City indicate that most years have identifiable wet and dry seasons, but that the beginning and end of the wet and dry seasons vary by some months (Heideman, 1987). The amount of rain in any given month is quite variable from year to year (Fig. 3c), and the average rainy season is only about two and one-half times as wet as the dry season.

The pattern of rainfall at the lake was very similar to that of Dumaguete City, but the lake area received almost three times as much rain (Fig. 3a and 3b). The increase in rainfall at the lake is probably due mainly to the effects of orographic cooling. As a result, the dryer part of the year at the lake is shorter and milder than at Dumaguete City. This difference is exemplified by the Q or seasonality, index (Whitmore, 1984), which classes Dumaguete City as seasonal and the lake area as only slightly seasonal.

Rainfall at the study area appears to correspond to the pattern on the eastern slope of southern Negros (Dumaguete and Pamplona, Fig. 2a), with appreciable rainfall in January and February both during the drought in 1983 (Fig. 3a) and during the more normal period of July 1983 to June 1984 (Cadeliña and Maata, unpublished data). This is consistent with the location of the lake some 14 km inland on the eastern slope of the mountains. Nonetheless, the high correlation between the two locations supports our conclusion that the pattern of wetter and drier periods is the same at both sites.

Wernstedt (1953) reported monthly rainfall data from a variety of sites over the island of Negros. His data show that within the two major rainfall regimes, total rainfall may vary between sites by a factor of at least three, even though very few of his sites are the wetter upland sites. Mean annual rainfall at 51 sites on Negros varied from 1320 to 4220 mm (Manalo, 1956), and, in general increased from east to west across the island (Wernstedt, 1953). Wernstedt (1953) compiled a rainfall map of Negros placing Lake Balinsasayao in an area which receives an average annual rainfall of 2030 mm, much less than our estimate of 3100 mm. His values for upland regions depend on data from very few sites, however. There are no upland or inland data points within 20 km of the lake area.

It would be inappropriate to use the figures obtained from the daily lake water budget to calculate an estimate of the annual precipitation required to prevent a net change in lake level. The figure we would obtain, 3900 mm (10.6 mm/day X 365 days), is not meaningful because this implies an unrealistic distribution of rainfall. A significant fraction of the annual rainfall is received when typhoons bring heavy rains for periods of several days, and a high proportion of this water may become runoff (e. g., up to 99% in a catchment in Malaysia; Kenworthy, 1971). Thus, the actual precipitation required to maintain a constant lake level is probably somewhat lower than 3900 mm/year and would vary with the timing of precipitation. In fact, the lake level rose 2-3 meters from July 1983 to June 1984 when total rainfall was only 3500 mm.

The relationship between potential evapotranspiration and precipitation suggests that moisture stress on plants is common through half of the year at Dumaguete City, but is much less common at Lake Balinsasayao. During periods with high potential evapotranspiration and low precipitation, plants may need to restrict growth and reproduction due to lack of water. Moisture stress might occur at Lake Balinsasayao during short periods in many or most years. This does not necessarily imply that moisture stress will be severe, and in fact it appears that the study area receives adequate moisture for plant growth except during drought periods. This is not the case for

Dumaguete City, where mean monthly precipitation approaches or exceeds potential evapotranspiration for only five to seven months per year (Fig. 3c). It is clear that in most years the drier season at Dumaguete City will include periods of moisture deficiency that may be several months in length.

Our estimate that about 1700 mm of water (about 73% of rainfall in 1982-83, and about 50% rainfall in 1983-84) is lost annually through evapotranspiration is near the upper end of the range recorded for Southeast Asian catchments both in quantity and in percent of rainfall (Low and Goh, 1972). Our 1982 - 83 results were very similar to those of Kenworthy (1971), who reported on the water balance of a partially logged watershed of dipterocarp forest at an elevation of 300 - 500 m in West Malaysia. Kenworthy estimated that annual rainfall was 2500 mm, of which 1750 mm (70%) left the system by transpiration and by direct evaporation from the canopy. Only 100 mm (4%) was lost through surface runoff; 650 mm (26%) was lost through subsurface flow. Similar evapotranspiration estimates were obtained for two Amazonian catchments (1720 mm/year by Jordan and Heuveldop, 1981; 1500 mm/year by Leopoldo et al., 1982). In contrast, Baconguis (1980) found a lower value for annual evapotranspiration, 1035 mm (32% of annual rainfall), for a forested catchment in Luzon. The difference in value for annual evapotranspiration may be due in part to the difference in the pattern of rainfall received. The Luzon site receives 97% of annual rainfall during only seven months of the year, much of which may be intense rain during typhoons. That pattern of rainfall is conducive to higher losses to surface and subsurface runoff (see discussion above). In addition, low soil moisture may restrict evapotranspiration during the dry months. Finally, methodological differences in the calculation of evapotranspiration may account for part of the differences between the two sites. Baconguis calculated potential evapotranspiration using the Penman method (Penman, 1948). Empirical evidence suggests that both the Thornthwaite (1948) and Penman (1948) methods of estimating potential evapotranspiration may underestimate actual evapotranspiration in the tropics (e.g., Kenworthy, 1971; Jordan and Heuveldop, 1982).

The fact that the lake level has been dropping suggests that actual annual rainfall over the past years has probably been slightly lower than the long-term average. It is tempting to attribute the lowering of the lake level to the effects of the almost complete deforestation on the island. Although the catchment itself is still largely forested, virtually all of the surrounding forest has been cleared to near the tops of the ridges bounding the basin to the north, east, and south. In the temperate zone 10% or less of rainfall comes from local evaporation (Lockwood, 1974). Temperate forests have been reported to receive 3—10% more rainfall than nearby deforested areas, but this difference may be due to more efficient collection within forests due to decreased wind velocity (Shpak, 1971). The climatic significance of forest may be greater in the tropics where higher evapotranspiration can contribute more to local rainfall. There is little data available on the influence of deforestation on climates in the tropics, but in the Amazon basin 48% of annual rainfall is derived from evapotranspiration (Salati, et al., 1979). Thus, it is clear that deforestation can have a great impact on rainfall, and could have affected rainfall on southern Negros.

From these results we conclude: (1) that the lakes cannot be used as hydroelectric power source because the large daily losses through subsurface seepage cannot be prevented and (2) that circumstantial evidence suggests that local evapotranspiration may contribute substantially to rainfall on the island, with deforestation part of the cause of the drop in mean annual rainfall at Dumaguete City. We recommend that the lake area and other forested mountain areas be kept in forest as a valuable water source, and in an attempt to reduce the adverse climatic effects of deforestation. Southern Negros is fortunate in having this natural supply of clean water that is reliable even during conditions of severe drought; in a time of increasing local and national concern over water supplies, developments that might threaten the area should be considered with care.

ACKNOWLEDGMENTS

We are grateful for extensive logistical support from Dr. Angel C. Alcala and the late Dr. Luz U. Ausejo. Tuting Batal, O. J. I. Delalamon, C. Lumhod, L. Tag-at, and R. L. Thomas were of great help in the field. We thank Dr. Rowe Cadeliña and B. Maata for graciously allowing us to see their data, and for useful comments. We also benefited from discussions with Ms. Betty Abregana and the rest of the staff of the Balinsasayao Rainforest Project. P. Myers and L. R. Heaney read earlier drafts of the manuscript and provided many helpful comments.

We were privileged to be Visiting Research Associates of the Institute of Philippine Culture of Ateneo de Manila University, Manila, and Silliman University, Dumaguete City; both institutions provided invaluable support. The research was supported in part by funding from The Rackham Foundation and the Museum of Zoology of The University of Michigan, the American Society of Mammalogists, Sigma Xi, and The Explorer's Club of New York. Heideman was also supported in part by predoctoral fellowships from the National Science Foundation and the Horace H. Rackman Foundation.

LITERATURE CITED

Abregana, B. C. (ed.), 1983. Comprehensive small-scale upland agroforestry: An alternative to shifting cultivation in the Balinsasayao rainforest region, Negros Oriental, Philippines: Part II, Silliman University. 135 pp.

———. 1984. Comprehensive small-scale upland agroforestry: An alternative to shifting cultivation in the Balinsasayao rainforest region, Negros Oriental, Philippines, Silliman J. 31:3-24.

Alcala, A. C. and W. C. Brown, 1969. Notes on the food habits of three Philippine wild mammals. Silliman J. 16:91-94.

———, and E. E. Carumbana. Ecological observations on birds of southern Negros, Philippines. Silliman J. 27:197-222.

———, et al. 1981. Unpublished position paper on the use of the Twin Lakes as a hydroelectric power source Silliman University, Dumaguete City, Philippines.

Antone, M. 1983. Vegetation analysis surrounding Lake Balinsasayao-Lake Danao, Negros Oriental. I. The tree species. Unpublished M. S. thesis, University of the Philippines at Los Baños.

Baconguis, S. R. 1980. Water balance, water use, and maximum storage opportunity of a dipterocarp forest watershed in San Lorenzo, Norzagoray, Bulacan. Sylvatrop 5:73-98.

Brown, W. C. and A. C. Alcala. 1970. The zoogeography of the herpetofauna of the Philippine Islands, a fringing archipelago. Proc. Calif. Acad. Sci. 38: 105-130.

Cadeliña, R. V. 1987. Soil nutrient changes under various upland cropping systems in Negros Oriental Province. Philippines. Pp. 97-108. *in* Agroforestry in the humid tropics: Its protective and ameliorative roles to enhance productivity and sustainability. N. T. Vergara and N. D. Briones (eds.), Los Baños: EWC and SEARCA.

Erickson, K. R. and P. D. Heideman. 1984. Notes on the avifauna of the Twin Lakes Region, Negros Oriental, Philippines. Silliman J. 30: 63-72.

Gale, J. 1972. Elevation and transpiration: Some theoretical considerations with special reference to mediterranian-type climate. J. Appl. Ecol. 9: 691-701.

Heaney, L. R., P. D. Heideman, and K. M. Mudar. 1982. Ecological notes on mammals in the Lake Balinsasayao Region, Negros Oriental, Philippines. Silliman J. 28: 122-131.

——— and R. L. Peterson. 1984. A new species of tube-nosed fruit bat (*Nyctimere*) from Negros Island, Philippines (Mammalia: Pteropodidae). Occ. Pap. Zool., Univ. Mich. (Ann Arbor) 708: 1-16.

Heideman, P. D. 1987. The reproductive ecology of a community of Philippine fruit bats (Pteropodidae, Megachiroptera). Unpublished Ph.D. dissertation, Univ. Mich. (Ann Arbor). 334 pp.

Heideman, P. D., L. R. Heaney, R. L. Thomas, and K. R. Erickson. 1987. Patterns of faunal diversity and species abundance of non-volant small mammals on Negros Island, Philippines, J. Mamm. 68: 884-888.

Holdridge, L. R. 1959. A simple method for determining potential evapotranspiration from temperature data. Science 130: 572.

Jordon, C. F. and J. Heuveldop. 1981. The water budget of an amazonian rain forest. Acta Amazonica 11:87-92.

Kenworthy, J. B. 1971. Water and nutrient cycling in a tropical rainforest. *In* The water relations of Malesian forests. (J. R. Flenley, ed). Department of Geography, University of Hull. Miscellaneous Series no. 11.

Leopoldo P. R., W. Franken, E. Mastui, and E. Salati. 1982. Estimativa de evapotranspiraacao de floresta amazonica de terra firme. Supl. Acta Amazonica 12:23-28.

Lockwood, J. G. 1974. World climatology: An environmental approach. Arnold, London.

Low, K. S., and K. C. Goh. 1972. The water balance of five catchments in Selangor, West Malaysia. J. Trop. Geog. 35: 60-66.

Lowrie S. 1983. Measures of soil fertility in Balinsasayao region. Pp. 44-54 *in* Comprehensive small-scale upland agroforestry: An alternative to shifting cultivation in the Balinsasayao Rainforest Region, Negros Oriental, Philippines. (B. C. Agregana, ed.). Silliman Univ., Dumaguete City, Philippines.

Manalo E. B. 1956. The distribution of rainfall in the Philippines. Phil. Geog. J. 4:103-181.

Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London (A) 193:120.

Quisumbing, E. 1936. The evaporation from the free surface of large bodies of water. Bull., Nat. Res. Council Phil. Islands 11: 37-42.

————. 1941. The evaporation from the free surface of large bodies of water. Corrections and additions. Bull. Nat. Res. Council Phil. Islands 28: 81-92.

Rabor, D. S., A. C. Alcala, and R. B. Gonzalez. 1970. A list of the land vertebrates of Negros Island, Philippines. Silliman J. 17: 197-315.

Ramage, C. S. 1971. Monsoon meteorology. Academic Press New York. 296 pp.

Rand, A. L., and D. S. Rabor. 1952. Two new birds from the Philippine Islands. Nat. Hist. Misc. 100: 1-3.

Richards. P. W. 1952. The tropical rain forest, Cambridge Univ. Press, Cambridge. 450 Pp.

Salati, E. A. Dall'olio, E. Matsui, and J. Gat. 1979. Recycling of water in the Amazon Basin: an isotopic study. Water Resources Research 15: 1250-1258.

Shpak, I. S. 1971. The effect of forests on the water balance of drainage basins. (Z. Shapiro, translator). Keter Press. Jerusalem.

Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geographical Review 30:55-99.

———— and Hare, 1965. The loss of water to the air. Meteorological Monograph 6: 163-180.

Utzurrum, R. C. B. 1985. Fig fruit consumption and seed dispersal by frugivorous bats in the primary forest of Lake Balinsasayao, Negros Oriental, Philippines. Unpublished M. S. thesis, Silliman University, Dumaguete City. 104 pp.

Wernstedt. F. L. 1953. Agricultural regionalism on Negros Island. Philippines. Unpublished Ph. D. thesis. Univ. Cal., Los Angeles.

————,1972. World climatic data. Climatic Data Press. Lemont, Pennsylvania.

Whitmore, T. C. 1964. Tropical rain forests of the far east. 2nd. ed. Clarendon Press, Oxford.

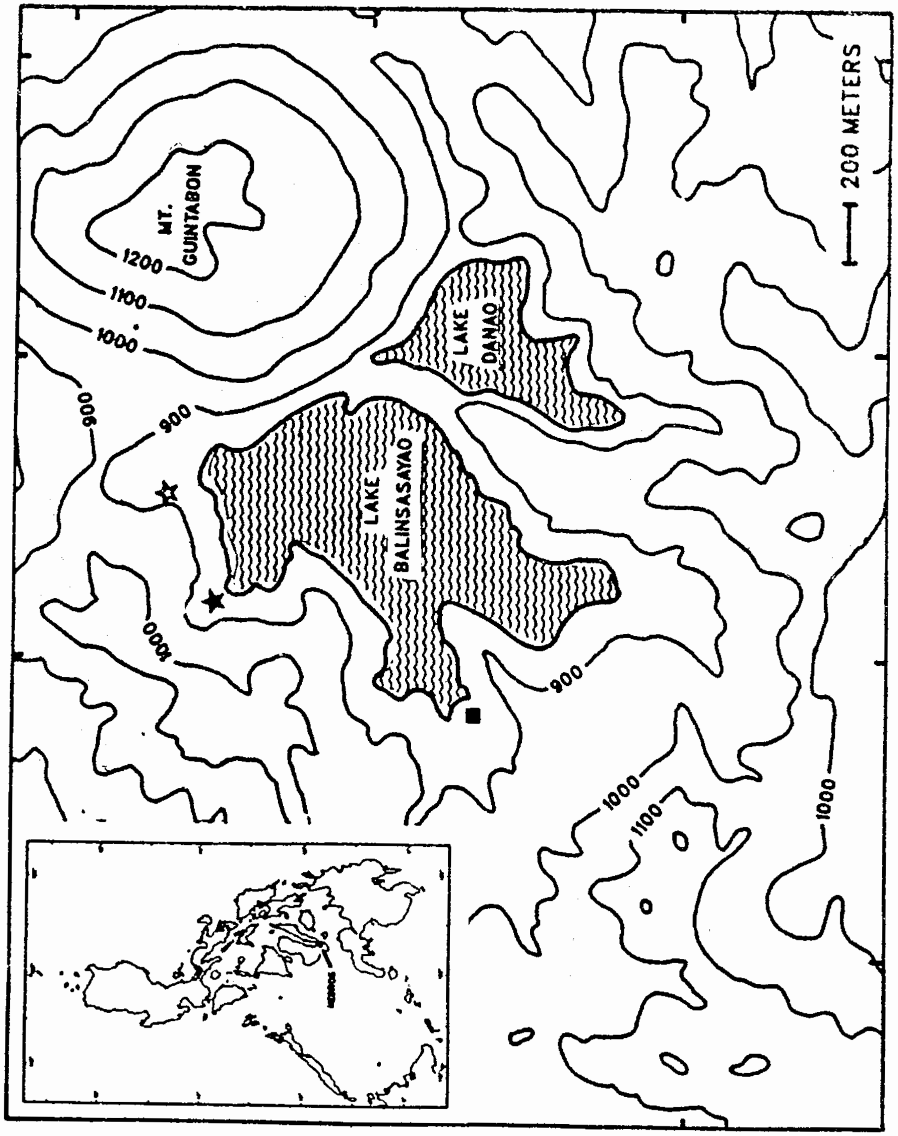

Figure 1. Map of the study sity; inset shows the location of the study site within the Philippines (the top of both figures is north). The solid star marks the primary data collection site; the open star marks the location of the rainfall gauge furing the monthly periods when the authors were absent from the site; the solid square marks the data collection site of Cadelina and Meats (1985.

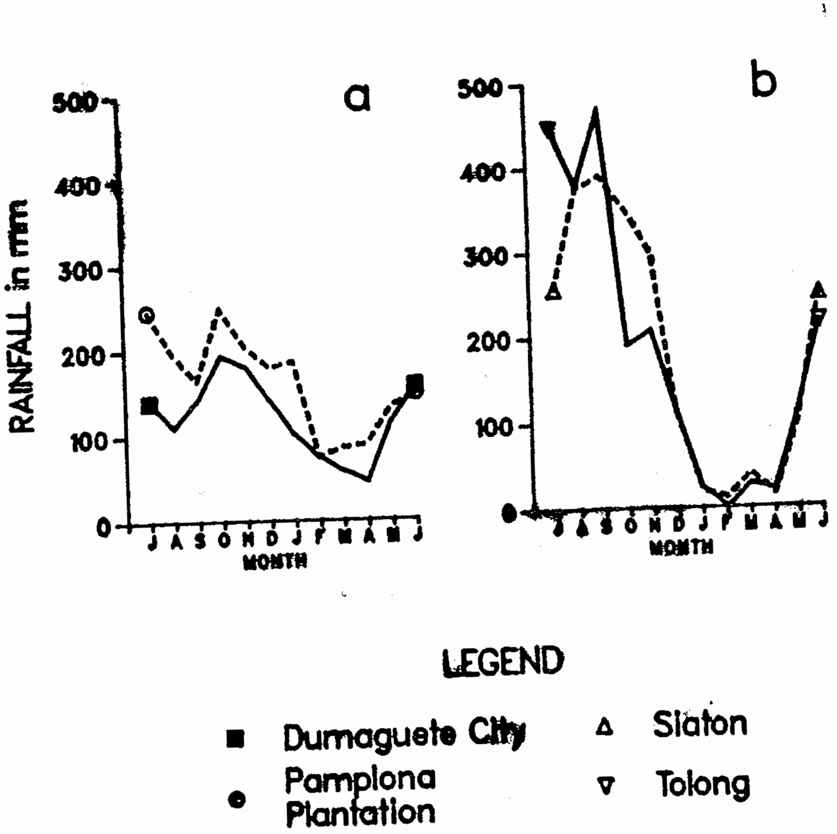

Figure 2. Mean monthly rainfall at four sites on southern Negros. a) Stations on the east slope of the island. b) Staions on the west and south slopes of the island (Data from Wernstedt, 1972, and Dumaguete City Weather Station).

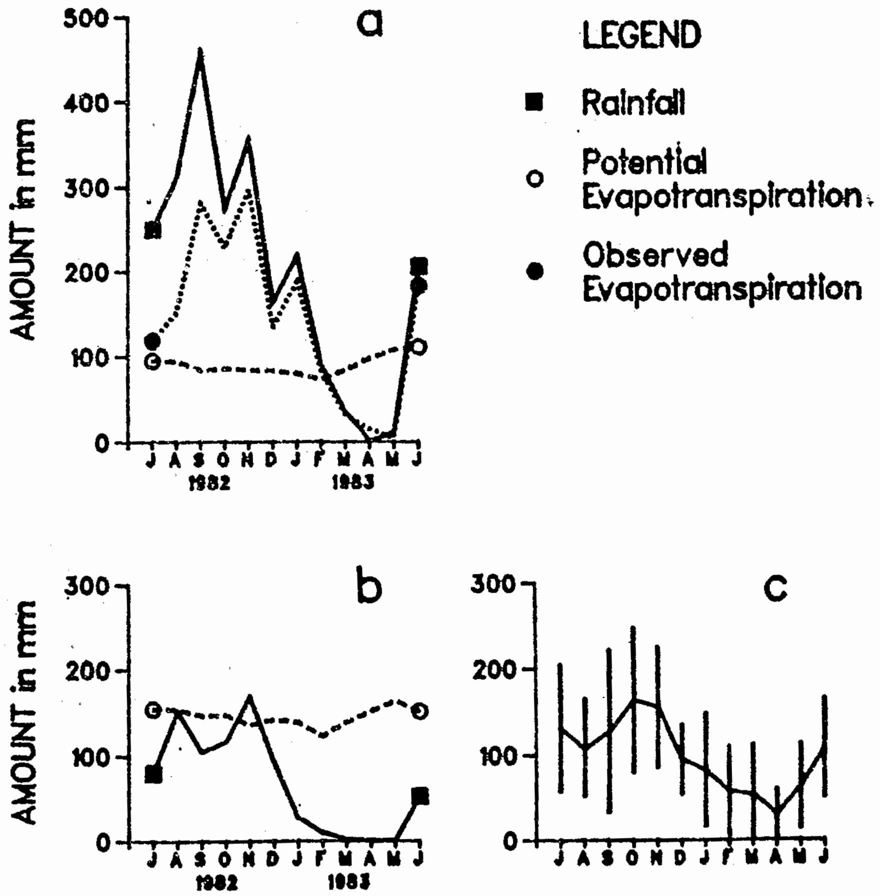

Figure 3. Monthly rainfall, observed evapotranspirtion, and potential evapotranspiration at Dumaguete City and Lake Balinsasayao. a) Monthly rainfall, observed evapotranspiration, and potential evaotranspiration at the Lake Balinsasayao study site from July 1982 through June 1983.. b) Monthly rainfall and potential evapotraspiration at Dumaguete City from, July 1982 through June 1983. c) Mean monthly rainfall at Dumaguete City for the period 1964 - 1983. The bars represent one standard deviation above and below the mean (Source for Dumaguete City rainfall data: Dumaguete City Weather Station).

Table 1. Monthly mean and annual mean temperatures at Lake Balinsasayao and Dumaguete City (July 1982 - June 1983; June data for Dumaguete City from 1982).

	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Year
Lake Balinsasayao													
N (days)	12	17	10	17	22	22	19	19	17	27	25	13	220
Mean High	25.8	26.2	24.6	25.1	24.9	24.5	24.0	24.7	25.0	26.0	26.7	26.8	25.4
Mean Low	18.6	18.3	18.5	18.6	19.1	19.2	18.0	17.4	18.2	18.5	19.7	20.2	18.7
Mean Temp.	22.2	22.2	21.5	21.8	22.0	21.8	21.0	21.1	21.6	22.3	23.2	23.5	22.0
Mean Range	7.2	7.9	6.1	6.5	5.9	5.3	6.0	7.3	6.8	7.5	7.0	6.6	6.7
Dumaguete City													
Mean High	31.8	31.6	31.9	31.2	30.3	30.4	29.7	30.1	30.1	31.0	31.3	32.0	31.0
Mean Low	22.9	23.0	23.1	23.3	23.9	24.1	23.9	22.8	23.3	26.0	24.7	25.3	23.9
Mean Temp.	27.4	27.3	27.5	27.3	27.1	27.3	26.8	26.5	26.7	28.5	28.0	28.6	27.4
Mean Range	8.9	8.6	8.8	7.9	6.4	6.3	5.8	7.3	6.8	5.0	6.6	7.3	7.1

Table 2. Annual distribution of extreme temperatures at Lake Balinsasayao, 1982-83.

COLD		WARM	
DATE	TEMPERATURE	DATE	TEMPERATURE
6 February	15.5	23 May	28.5
10 "	"	6 June	"
4 "	16.5	14 May	28.0
11 "	"	16 "	"
17 "	"	17 "	"
18 "	"	18 "	"
14 January	"	19 "	"
9 March	"	18 February	"
11 "	"	4 July	"
Days in Jan-March	17.0	28 August	"

Table 3. Monthly and annual rainfall and evapotranspiration (in mm) on southern Negros, July 1982 - 1983. Approximate change in lake level (July - Sept) or measured change in lake level also provided for same period. Values of observed evapotranspiration most likely to be inaccurate due to probable changes in groundwater reserves enclosed in parentheses.

	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual
LAKE BALINSASAYAO													
Rainfall	250*	310	457	274	355	164	219	89	35	2	11	206	2372
Change in lake level	100*	200*	500*	-220	-70	-400	-330	-490	-620	-700	-630	-350	-3010
Observed Evapotranspiration	118*	169*	281*	228	297	139	189	(82)	(32)	(15)	4	183	1727*
Potential Evapotranspiration													
Thornthwaite	95	94	84	86	84	83	80	73	84	98	108	111	1060
Holdridge	111	111	104	109	106	109	105	95	108	108	116	114	1296
DUMAGUETE CITY													
Rainfall	80	152	105	116	168	73	27	20	2	0	1	53	762
Potential Evapotranspiration													
Thornthwaite	155	154	147	147	136	142	139	123	139	152	164	154	1750
Holdridge	137	136	133	136	131	136	134	129	133	135	141	134	1614

*estimated or extrapolated value

Table 4. Mean monthly and mean annual rainfall (mm) at four sites on southern Negros Island.

	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual
1958-1983 Dumaguete City	131	109	128	164	156	95	82	57	53	30	63	108	~~[illegible]~~ 1176
(N)-Year Means up to 1955:													
(38) Dumaguete City	139	110	141	192	180	140	100	73	57	45	114	154	1445
(11) Pamplona Plantation Co.	245	196	163	247	203	179	185	73	84	88	131	146	1939
(9) Siaton	257	376	390	351	300	111	20	12	40	15	99	248	2307
(5) Tolong; (Poblacion)	447	378	467	191	207	113	23	1	27	20	111	215	1997