fluoride is too low to constitute a significant hazard to animals. This conclusion is supported by the finding that only 3 to 6 ppm of fluoride was present in the urine of the cows which had been eating contaminated hay for 4 days. The normal urinary fluoride for cattle is age-dependent, and only one of the four specimens was higher than the limit set by Shupe (5). A 10 percent contamination of hay would raise the absorbable fluoride by only 2 ppm, which is about one-fifth of the amount that Shupe considers normal for hay and one-twentieth of the amount allowed in Washington State for a yearly weighted average (6).

There are, however, some additional points that need clarification. The higher concentration of water-soluble fluoride in the finer fallout samples suggests that ash from areas farther away from Mount St. Helens would have higher water-soluble fluoride concentrations. Analyses from such samples would be of interest. The ash collected from site 8 on 21 May showed twice as much water-soluble fluoride as the earlier material. Therefore, it would seem desirable to monitor fluoride concentrations in ash from future eruptions. Further work seems desirable to develop a chemical measurement that more accurately reflects the biologically available fluoride. The relationship between particle size and the amount of water-soluble fluoride is consistent with earlier findings (1) and appears to be reasonable in light of the encrustation of soluble material during volcanic eruptions (7). Individuals who would like to make additional measurements may obtain gram quantities of the above samples by writing to the author.

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Deforestation and Increased Flooding of the Upper Amazon

Abstract. *The height of the annual flood crest of the Amazon at Iquitos has increased markedly in the last decade. During this same period, there has been greatly increased deforestation in the upper parts of the Amazon watershed in Peru and Ecuador, but no significant changes in regional patterns of precipitation. The change in Amazonian water balance during the last decade appears to be the result of increased runoff due to deforestation. If so, the long-predicted regional climatic and hydrological changes that would be the expected result of Amazonian deforestation may already be beginning.*

The Amazon is the world's greatest river (1, 2). One of the most striking aspects of the Amazonian water balance is the marked seasonal fluctuation in water level of the upper Amazon and its major tributaries in synchrony with the differential precipitation of the region's wet and dry seasons. The annual difference between high and low water levels may reach 20 m, and life in the Amazon basin is intimately related to the predictable annual flood cycle (2).

Although Amazonia remains by far the largest area of tropical forest on earth, it is being subjected to the same rapid ravages of deforestation as the rest of the world's tropical forests (3, 4). Perhaps as much as a fifth or a fourth of the Amazonian forest has already been cut (3, 4) and the rate of forest destruction is accelerating. Until recent years, most of this deforestation had been concentrated in lower Amazonia, especially in the region of Belem. However, opening of new roads across the Andes, especially in the last decade, has led to settlement of large new areas of upper Amazonian Bolivia, Peru, Ecuador, and Colombia. During the last decade the population of Amazonian Peru has doubled (3, 5) and that of Amazonian Ecuador more than doubled from 1962 to 1974 (3, 6). This rapid increase in population has been accompanied by large-scale deforestation all along the base of the Andes; 51,000 km^2 of Peruvian Amazonian forest has been destroyed, mostly in the last decade (3, 5). The Valley of the Huallaga, opened by construction of the Carretera Marginal, is now almost completely deforested. Similarly large areas of the upper Marañon have been deforested, mostly subsequent to construction of the new oil pipeline and access road. The Apurimac Valley was mostly virgin forest in 1968, but has now been virtually clear-cut (7). The same pattern is prevalent in Ecuador where the expanding strip of newly cleared and settled land at the base of the Andean foothills is obvious on the map of the country's remaining forests developed by the Food and Agriculture Organization (8).

Table 1. Annual high and low water levels of the Amazon at Iquitos, 1962 to present; N.S., not significant.

Year*	High (m)	Low (m)
1962	25.82	18.24
1963	25.35	16.50
1964	24.29	20.26
1965	24.05	20.97†
1966	24.89	19.43
1967	25.35	19.31
1968	25.23	20.85
1969	25.06	19.54
1970	27.13	20.49
1971	27.36	21.91
1972	26.65	22.51
1973	27.13	18.81
1974	27.49	19.42
1975	27.08	19.10
1976	27.51	18.80
1977	27.54	18.80
1978	26.21	17.57
$\bar{X}$(1962–1969)	25.0 ± .6	19.4 ± 1.4
$\bar{X}$(1970–1978)	27.1 ± .4	19.7 ± 1.6
	t = 3.4274, $P << .001$	N.S.

*Data from 1962 to 1972 were extracted from (19). Data from 1972 to the present were extracted from original records by C. Díaz and H. de Díaz. †Year began with an even lower peak because of prolonged low water of previous year.

Extensive deforestation has been linked to major climatological and hydrological changes (9). In Venezuela, for example, deforestation of the south slopes of the coastal cordillera and northeasternmost Andean spur has led to loss of water retention capacity and more rapid runoff. Streams draining this region which formerly were continually flowing across the llanos now dry up during the dry season (10). With reference to Amazonia, Saleti and his co-workers (11) have shown that about half of the precipitation of the entire Amazonian basin results from water recycled by transpiration, and Sioli (12) has emphasized that the volume of runoff leaving Amazonia at the mouth of the Amazon or entering it via the tradewinds is only a fraction of the volume of water continually recycled through transpiration and rainfall in the Amazon basin. Extensive deforestation would be expected to greatly reduce the transpired water available for rainfall and might eventually convert

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much of now-forested Amazonia to near desert (*12, 13*).

Potentially the river itself might provide an indication of changes in the patterns and amounts of runoff and drainage associated with deforestation in the Amazon basin, since deforestation has been shown to result in increased runoff (*14*). That major changes in the Amazonian water balance are indeed taking place is suggested by the observations of many riverside dwellers in Amazonian Peru that the seasonal flood crests of recent years have been higher than ever before. Unusually prolonged flood stages also have occurred in Amazonian Brazil in the last few years (*15*).

Has deforestation in upper Amazonian Ecuador and Peru already resulted in significant changes in the water balance of Amazonia? To test this hypothesis we analyzed water level data for the Amazon at Iquitos, Peru; these records, which have been maintained since 1962 by the Instituto Hidrográfico de la Amazonia Peruana, show a pronounced and statistically highly significant increase in height of the annual crest of the Amazon at Iquitos during the last decade (Table 1 and Fig. 1). Before 1970 the annual flood crest at Iquitos had never reached a depth of 26 m; after 1970 it has never been lower than 26 m. The height of the annual low water mark has remained virtually unchanged during this time. Clearly the runoff of water from upper Amazonia has increased during the last decade.

The fact that this period spans that in which extensive deforestation in upper Amazonia has taken place suggests a causal relationship. However, the time period for which records are available might be too short to exclude the alternative possibility of normal long-term cyclical variations in precipitation and runoff (*16*).

To test this alternative possibility we have attempted to correlate available rainfall data from the upper Amazon watershed with data for heights of the annual crests in river level. Direct comparison of pre-1970 and post-1970 annual precipation gives inconclusive results (Table 2). Although average annual precipitation at all reporting stations is slightly greater for the 1970 to 1978 period than for the 1961 to 1969 period, this difference is significant for only three of the eight stations analyzed (*17*). Analysis of precipitation and river level data for specific years undermines even this weak suggestion of a causal relationship. Of the few years which show enough synchronization among the various

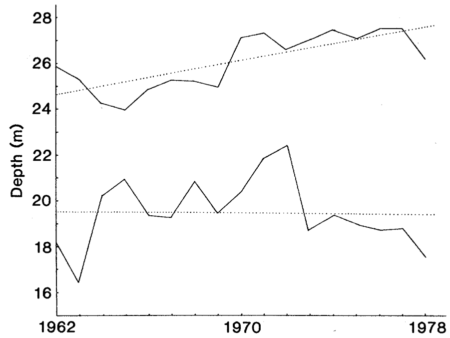

Fig. 1. Depths of annual high and low water marks of the Amazon at Iquitos, 1962 to 1978. Dotted lines are the calculated regressions. Data are from Table 1.

weather stations to suggest meaningful regional patterns in precipitaiton, 1965 (that is, seven of eight stations with rainfall noticeably below average, none above average) and 1966 (six of eight stations noticeably below average, one above average) are most obviously correlated with parallel trends in river level. Of the entire 17-year record period, the lowest high water mark was in 1965 and the third lowest was in 1966.

In contrast, after 1970, dry years during the period of high river level maxima show relatively small decreases in annual high water levels. Even in 1978, generally regarded as a drought year in much of Peru, the high water level, though the lowest in almost a decade, exceeded that of any year prior to 1970. The low water mark in 1978 was the second lowest of the entire period for which records have been kept. Unfortunately, complete precipitation data for 1978 are as yet available from only two weather stations. Of these, the 1285.8-mm rainfall at Pucallpa in 1978 is the third lowest annual total in the 22 years for which complete data are available, while Yurimaguas reported slightly above average rainfall. Data for the first 2 or 3 months of 1978 are available from three other stations and tend to support the popular view of 1978 as a drought year: Tarapoto had the driest February in its 15-year weather record and the second driest January-February on record; San Ramon had the driest February in its 7 years of records; Jaen reported a 3-month total of 174.1 mm, the third driest first quarter in its 14-year records. That a year as dry as 1978 still showed a high water mark in excess of

Table 2. Annual precipitation in the upper Amazon watershed in Peru. Data of Servicio Nacional de Meterologia e Hidrologia de Peru (SENAMHI) (*17*); N.S., not significant.

Locality	Records (years)	Cumulative average	$\bar{X}$ (mean) 1961–69	$\bar{X}$ (mean) 1970–78	t	d.f.	P
Tingo Maria	16	3122.8	2785.1	3460.5	3.0561	14	< .01
Iquitos	26	2904.9	2745.1	3097.3	1.8537	13	N.S.
Yurimaguas	28	2136.0	2031.0	2177.1	1.2929	15	N.S.
Pucallpa	22	1658.7	1360.8	1858.2	2.4870	15	< .05
El Porvenir (Tarapoto)	14	1074.9	1060.6	1085.8	.3521	12	N.S.
Chachapoyas	9	825.0	734.2	938.5	4.9829	7	< .01
Jaén	12	829.4	692.2	927.3	2.1569	10	N.S.
Huanuco	11	454.6	393.4	505.7	1.4973	9	N.S.

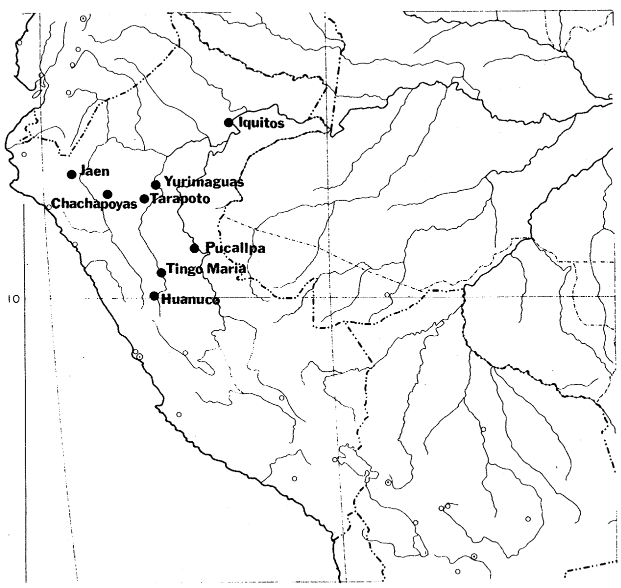

Fig. 2. The upper Amazon drainage in Peru and adjacent countries. Cities indicated are those for which precipitation data were analyzed.

that produced by much wetter years prior to 1970 suggests that the general recent tendency of increased high water levels is largely independent of precipitation and thus is more likely related to the changes in drainage and runoff associated with deforestation.

Thus, the irreversible changes in Amazonian water balance predicted by Sioli (*12*) seem already to have begun. Increased settlement in upper Amazonia, where richer soils lessen the agricultural constraints imposed on much of central and lower Amazonia, could result in increased annual flooding and economic and ecological damage thousands of kilometers away in central and lower Amazonia. Since most of Amazonia's population and agriculture are concentrated along the seasonally flooded strip immediately adjacent to the main river, the magnitude of the damage is potentially great.

According to current predictions, present rates of forest destruction will result in elimination of tropical rainforest from the face of the earth not long after the turn of the century (*3, 18*). However, most of the Amazonian rain forest remains uncut at this moment. The rapidity with which relatively limited forest destruction appears already to have altered the Amazonian water balance, suggests the need for planned development that takes into account this delicate ecological balance.

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Chemical Species in Fly Ash from Coal-Burning Power Plants

Abstract. *Fly ash specimens from four power plants in the Tennessee Valley Authority system have been separated into three matrices: glass, mullite-quartz, and magnetic spinel. Chemical species of trace elements are defined to a large extent by the matrices that contain them. The magnetic component of fly ash is ferrite. The mullite-quartz phase is relatively pure and can be recovered as a resource.*

We have studied fly ash specimens from the Kingston, Bull Run, Johnsonville, and Paradise plants in the Tennessee Valley Authority system. Specimens were taken from electrostatic precipitators and cyclone devices. Firing characteristics and coal sources have been described (*1, 2*). Each of the ashes was size-fractioned and magnetically separated. Aluminosilicate materials were sintered to the magnetic particles, which prevented a complete separation by physical means. The magnetic fractions were then treated with concentrated HCl, which dissolved most of the iron-containing spinels and oxides, leaving the aluminosilicate materials as residue. Glass phases were removed from the nonmagnetic phases by etching in 1 percent HF. This separation is believed to be effected by differences in dissolution rates; the glass phases dissolve rapidly, whereas the crystalline mullite and quartz react much more slowly. A weight loss curve showing the kinetics of the glass removal is discussed in (*2*). The residue that remained consisted of mullite and quartz skeletons of the original particles. Thus we have separated each of the fly ash specimens into its three main matrices: glass, mullite-quartz, and magnetic spinel. These have been individually characterized and analyzed for trace element distributions (Table 1). Because of space limitations, only the results for the Bull Run plant are given here. Compositions for the other three plants were very similar.

Before discussing the trace element distributions, let us consider the nature of the matrices that contained them. If we represent the glass phases as $(SiO_2)_x \cdot (R_2O_3)_y$, where R is Al or Fe, we find from Table 1 that $x/y \simeq 11/2$ for the Bull Run ash. For the other three ashes, x/y varied between 9/2 and 14/2. Figure 1 shows scanning electron micrographs of the mullite and quartz phases left after the glasses had been extracted with 1 percent HF. Clusters of acicular mullite crystallites are shown in Fig. 1, a, b, and c. Their spherical symmetries reflect the original shapes of the ash particles before etching. The glass phases that were removed occupied interstitial positions between the needle crystallites. Figure 1d shows a quartz skeleton remaining after the glass phases have been etched away. The identities of the particles in Fig. 1 have been established by means of x-ray fluorescence induced by the beam of the scanning electron microscope and by x-ray diffraction. Analytical results for individual acicular mullite crystals varied by as much as 20 percent for the four ashes studied, but the compositions were approximately that of the natural mineral, $3(Al_2O_3) \cdot 2(SiO_2)$. Quartz phases such as that in Fig. 1d contained Al concentrations ranging between 2 and 10 percent (by weight). Table 1 shows that the magnetic material extracted by HCl contained an appreciable amount of Al and Fe. We take this to mean that the magnetic spinel material in fly ash is ferrite, rather than magnet-