Simulating the Past: Reconstructing Historical Land Use and Modeling Hydrological Trends in a Watershed Area in Java

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SUMMARY

Historical data on land use can be used as input into watershed models to simulate past hydrological conditions and erosion. A better understanding of past conditions is useful to position the present situation on a dynamic scale and to assess future trends and options therefrom. Conversely, knowledge acquired from biophysical studies of the present can be used to get a better grasp of certain phenomena in the past. This has been done with a watershed model which was developed for the upper Konto watershed area in Java.

After a general introduction on conditions in the upper Konto watershed area and the purpose and design of the watershed model, this article describes the origin, nature and quality of the historical land use data, and how they were interpreted, complemented, balanced and eventually incorporated into the model. The results of the simulation of historical watershed conditions are presented and their plausibility is discussed in the light of historical evidence. A comparison of the modeling results for past conditions and for present conditions shows that the hydrological effects one may wish to achieve with land use changes in the future specified in different development scenarios are unlikely to be of the same order of magnitude as the changes that have occurred over the last 150 years.

INTRODUCTION

In natural sciences mathematical models have become a major tool designed to simulate, and thereby to analyse and predict real life phenomena. Predictions of future conditions can be made on the basis of different scenarios assuming different lines of action or different circumstances. Rarely, however, are *historical* data put into models in order to establish what these same types of phenomena may have been like in the past. By doing this, two goals can be achieved at the

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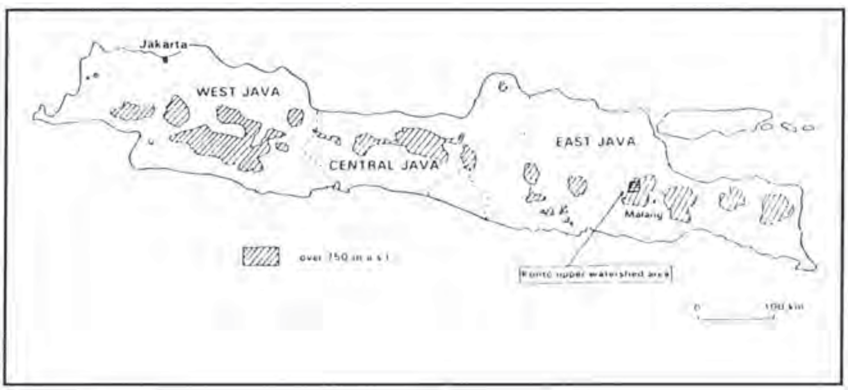
same time. Firstly, knowledge about relations underlying present phenomena may be used to estimate the extent and intensity of the same type of phenomena in the past. Secondly, the new historical insights we obtain in this manner may enable us to 'position' the present on a dynamic scale and to assess future trends and options therefrom. History and environmental development studies may then become involved in a process of cross-fertilisation. This was done with a watershed model developed for the upper Konto area in Java.[1]

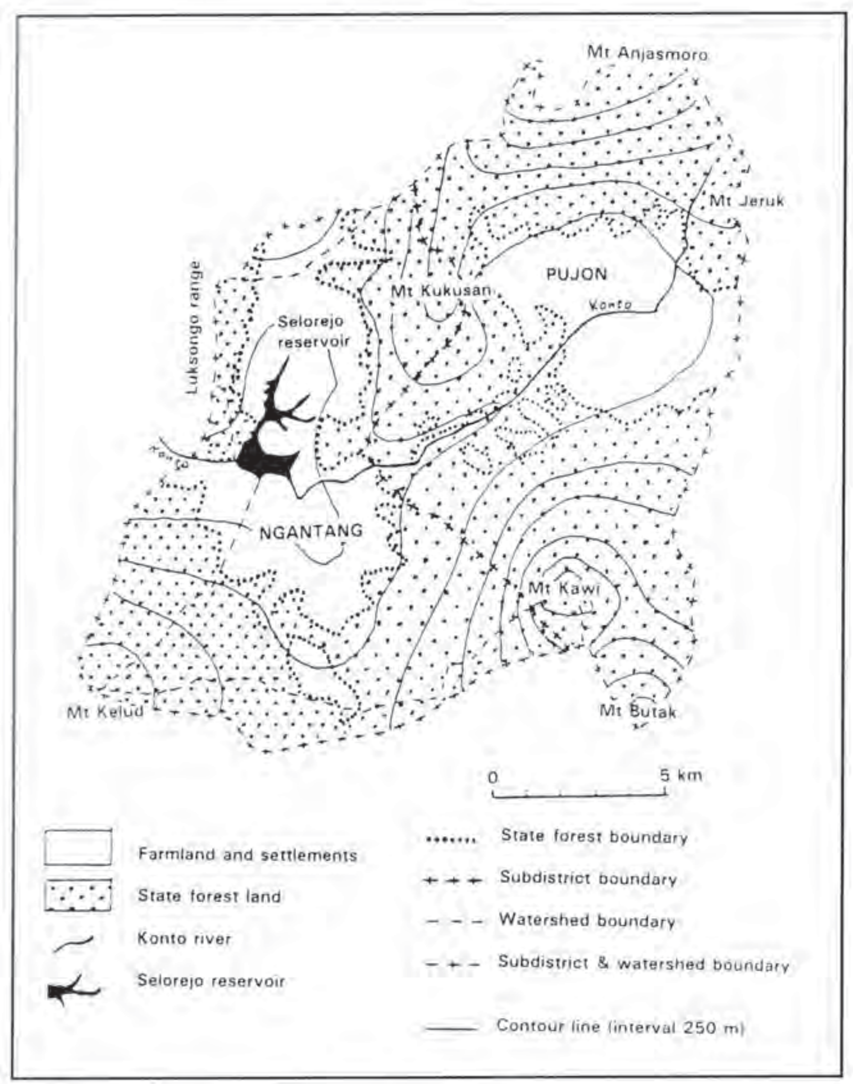
THE UPPER KONTO WATERSHED AREA

The Upper Konto watershed area is a highland area of approximately 250 km^2 in size with a total population of about 100,000 in 1990 (Nibbering 1993). The area roughly corresponds to the two subdistricts Ngantang and Pujon, situated in Malang District, in the province of East Java (Map 1).



MAP 1. Distribution of highland areas in Java and location of the upper Konto watershed area

The landforms of the area consist of geologically young volcanic complexes with interconnecting highland plateaus, raised with eruption material and colluvial sediments, which have formed thick layers of highly permeable and relatively fertile soils. Except for Mt. Kelud in the extreme south-west, all volcanoes in the area are dormant. A tropical monsoon climate prevails, modified by the area's mountainous conditions. The dry season lasts about two to four months with less than 100mm of rainfall in each month. Average annual rainfall amounts to 2400 mm, but it varies greatly across the area (Konto River Project 1984a). The area is drained by the Konto river, a tributary of the Brantas river, the largest river in East Java. The combination of steep slopes, fine textured soils and high rainfall makes the area susceptible to run-off and erosion, when the closed vegetation is removed and the land is cultivated. However, the high permeability of the young volcanic soils has some neutralising effect (de Graaff 1996: 194).



MAP 2. Relief and land use in the upper Konto watershed area

PLATE 1. Natural forest in the southwestern part of the Konto Upper watershed area. It has been estimated that in 1845 as much as 93 per cent of the total area was still under natural forest
(Photo by Jan de Graaff, December 1994)

PLATE 2. Fruiting Coffee shrub under shade tree at the end of the rainy season. As a rule, coffee was, and still is, grown under shade trees. In the past, shade trees were either natural trees left over from the forest or planted trees such as *Erythrina* spp. Nowadays *Leucaena* or *Gliricidia* are used for this purpose.
(Photo by Jan de Graaff, March 1987)

One third of the area consists of privately owned farmland and settlements. This occupies the valleys, the lower and middle plateaus, and the footslopes of the mountains (Map 2). The altitude of this part of the area ranges between 620m and 1250m above sea level. The farmland is used for intensive forms of agriculture, highland vegetable and maize cultivation in the upper parts (Pujon subdistrict); and maize, wet rice and perennial crop cultivation, notably coffee, in the lower parts (Ngantang subdistrict). In addition, dairy husbandry is an important activity, particularly in Pujon subdistrict. The other two thirds of the area consists of state forest land covered with forest plantations, waste land dominated by exotic shrubs and the remains of the, largely degraded, natural forest. This comprises the hilly and mountainous parts of the area with an altitude ranging between about 700m and 2900m above sea level. The state forest land is managed by Perum Perhutani, the island's state forest corporation.

The Konto River Project

In 1979 the Konto River Project was started by Perum Perhutani with technical and financial assistance from the Netherlands. Its aim was to draw up a planning and management model for a study area on Java as an example for all watersheds in densely populated areas in Indonesia (Konto River Project 1979: 11). Besides improving the livelihoods of the local population, one of the main objectives of the project was to reduce erosion in the area and thereby to slow down sedimentation in the Selorejo reservoir at the lower end of the upper Konto watershed area. The reservoir was formed after the completion of a dam in the river in 1970. The functions of the reservoir are flood protection, supply of irrigation water during the dry season, generation of hydro-electrical power and recreation. Soon after its formation it was noted that excessive sedimentation in the reservoir threatened to reduce its lifetime,[2] thereby jeopardising the benefits it was supposed to provide downstream. After a reconnaissance and planning phase, the project, then placed directly under the auspices of Indonesia's newly established Ministry of Forestry, undertook, between 1986 and 1991, a large number of soil conservation and reforestation projects, as well as supporting socio-economic activities, both on farmland and on forest land.

THE WATERSHED MODEL

In December 1994, a joint Indonesian-Dutch team visited the area to assess the performance of the measures introduced several years earlier. This assessment was part of a case study conducted in the framework of a larger research programme aimed at methodology development for economic evaluation of soil conservation and watershed development. A watershed model was devised to serve as a quantitative tool in estimating the effects of changes in land use and land management on biomass production, stream flow and downstream sedimentation. Information thus obtained on the physical impact of actual changes in land use and land management, as well as of alternative changes, was subsequently used as a basis for the economic assessment of their costs and benefits (de Graaff 1996).

Changes in land use and land management may affect hydrology, erosion and plant growth in a number of ways, notably through a change in vegetation cover. The reduction in vegetation cover generally increases the impact of rain on the soil surface, resulting in a reduction of infiltration and the detachment of soil particles. The reduction in infiltration rates may both reduce the soil water content, which hampers plant growth, and increase overland flow. The quantity and intensity of overland flow then determines, in combination with the detachment of soil particles, the amount of erosion and sediment transport. At the same time, due to reduced infiltration rates, less water may reach aquifers located at greater depths in the soil, which emerge as wells on the hillsides and mountain slopes in the area, providing water throughout the dry season (base flow).

The watershed model has been constructed by means of a multiple spreadsheet. It calculates the water balance at various spatial levels for specified land use scenarios and time periods. On the basis of the water balance, the model then calculates water availability for plants, water flows and sediment flows for each level. Inputs to the model are soil parameters necessary for the calculation of water balances, the distribution of land use and land management, rainfall and various land and crop characteristics. All this data had been collected during the first phase of the Konto River Project (Konto River Project 1984a, 1984b). The major output consists of (agricultural, sylvicultural or natural) biomass production resulting from land use and water availability, and of stream-flow and sedimentation at the outlet of the watershed, in this case, the Selorejo reservoir. The stream-flow and sedimentation data can subsequently be used to calculate the downstream effects on irrigation water supply, hydro-electricity and flooding.

In the model the watershed is divided into two agro-ecological zones, each of which is divided into an upper and a lower hydrological unit. The agro-ecological zones correspond with the two subdistricts and the upper and lower hydrological units in each agro-ecological zone coincide more or less with the steeper forest land and the flatter farmland respectively. In each hydrological unit land use and land management types were identified for which water balance parameters were determined. For each land use and land management type water storage in the soil, run-off, erosion, evapotranspiration and percolation are calculated. Summation of these parameters, multiplied by their respective area, gives the water balance for each hydrological unit, and eventually for the entire watershed. Because land use is very much scattered, the spatial organisation of land use and land management types is not specified in the model. All water flows[3] and sediment flows go from the upper to the lower hydrological units, then enter the main stream and eventually reach the Selorejo reservoir. Land use and land management types include roads and built-up areas, irrigated fields, terraced or non-terraced rain-fed fields, coffee gardens, two different types of reforestation, grassland, shrubs, degraded forest and natural forest. The various data on land use and land management, their water requirements and their impact on the soil were derived from field data and literature. The water flow and sediment flow modules in the model were calibrated with data from the Konto River Project's hydrological monitoring programme carried out from 1987 to 1990 (Rijsdijk and Bruijnzeel 1990-1991). For a more detailed description of the model, see van Loon *et al.* 1995.

A number of alternative future land use scenarios were designed and an economic evaluation was conducted on the basis of the results of the watershed model, taking into account both upstream and downstream costs and benefits (de Graaff 1996).

RECONSTRUCTION OF HISTORICAL LAND USE SITUATIONS

In addition to modelling the impact of different future land use and land management scenarios, it was decided also to run the model for historical land use situations. On the one hand, this would provide an extra opportunity to test the model with whatever hydrological data might be available from the past; and on the other hand, it would give an idea of hydrological trends over time, of the rate at which these changes have been taking place and of the range within which hydrological conditions may vary. Through all this, it would help planners and policy makers to avoid misconceptions about changes in the past and would thus insure against unjustified land use decisions.

Historical land use situations were reconstructed for three points in time i.e. 1845, 1895 and 1935. For these moments in history direct information on land use and circumstantial evidence from which the occurrence of certain land use types could be inferred were available. Conditions at these points in time fairly reflect historical stages in population and land use change in the area (Nibbering, 1988). The year 1985 was taken as a fourth point in time, representing conditions immediately before the Konto River Project started to implement its programme.

The information obtained from these historical sources was used to arrive at a plausible area distribution of land use and vegetation types for the four hydrological units for each point in time. In order to structure the process in a systematic fashion, another spreadsheet model was used, in which relevant variables could be linked, assessed and reconciled with one another. It is hardly necessary to repeat that as part of the objective of achieving historical plausibility, the variables had to be logically consistent for each point in time, and, also between points in time, for instance, with respect to population growth. In the following pages, the available data, their interpretation, and, the procedure adopted in complementing and reconciling various data and assumptions, will be explained.

Historical data

1845

Information about 1845 was derived from a description of the region by the geographer-botanist F.W. Junghuhn (1850; 1853-54), who travelled the area in 1844. According to his description, at that time nearly the entire region was still covered in forest, largely consisting of primary closed and high-stemmed montane forest with a considerable floristic complexity. Only on the central plains were a small number of scattered hamlets found surrounded by small patches of irrigated land separated from one another by large tracts of forest, woodland and grassland. The number of settlements in the area was much smaller than it is today. Parts of the area, now occupied by many villages, were still uninhabited[4] (Junghuhn 1850: 1194-1201). The Atlas van Nederlandsch Indië (1843/62) also shows a mere seven villages out of the 23 now present in the area.

Junghuhn gives no details on land use activities, but, as was observed in other upland areas, his description of woodland and grassland suggests that, in addition to irrigated agriculture, fallow-based rain-fed agriculture may have been practised, and probably also regular burning of grassland for the procurement of young shoots for fodder (Veth 1896-1907, vol. 3: 182, 434-5, 468, 508; Burger 1938: 434). Whereas Junghuhn describes it extensively for other highland areas he visited (Junghuhn 1853-54, vol. 1: 409-10), he makes no mention of coffee cultivation in the upper Konto area. We can therefore safely assume that the area had not yet been touched by compulsory coffee cultivation at the time of his visit.

According to figures collected by Bleeker (1847: 163) the total population in Ngantang *district*, which must have covered more or less the present day subdistricts Kasembon, Ngantang and Pujon, amounted to 7627 persons.

1895

In the second half of the 19th century many highland areas in East Java became the scene of large scale clearing of natural forest for the establishment of coffee plantations. The population had to tend the coffee plantations under the compulsory cultivation system imposed by the colonial government. The people were obliged to grow a certain number of coffee trees on cleared land in the neighbourhood of their villages. They obtained fixed prices for the produce after subtraction of land rent, transport and marketing costs. The upper Konto area was also affected by these developments. Although he gives no figures, Veth mentions the presence of coffee plantations everywhere in both subdistricts, Ngantang and Pujon, and considers them the most productive coffee areas of the Brantas region (Veth 1896-1907, vol. 3: 537; see also note 15).

Land transfers by the governmental coffee service to the population after coffee plantations had become unproductive due to age were common practice. The population used this land for growing food crops, as the coffee service continued clearing new forest land for exploitation further uphill (Altona 1914: 254-5; Burger 1938: 424). This also appears to have occurred in the upper Konto area, where, for instance, a Madurese minority can be found in the southern part of Pujon. They are the descendants of coffee 'labourers' who settled on former coffee land[5] (Nibbering 1986: 55).

A clue to the area under government coffee and its reserves in the upper Konto area can be had from Altona (1914), who mentions that at the time he wrote his article there were still as much as 7000 *bouw* (4900 ha) of government coffee land in Ngantang district, most of which was located in the upper Konto watershed area[6] (Altona 1914: 330). Compulsory coffee cultivation, however, was already on its way out and the area under coffee may have been larger in earlier years. The governmental coffee lands were eventually handed over to the newly established forest service and added to its forest domain which included all land still under natural vegetation. This transfer was effected around 1925.[7]

Altona also gives a description of the state of the vegetation in the forest lands of the upper Konto area. Conditions varied. The forest cover of some of the newly acquired coffee gardens and reserves (still under forest) was regarded as satisfactory, whereas other parts had become entirely bereft of trees. Vast stretches of *alang-alang* (*Imperata cylindrica*) occurred, notably on the northern slopes of Mt Kawi (see Map 2). Here the total deforested area within the already existing forest reserve was estimated as large as 2500 ha. It included former coffee lands. Some smaller stretches of former coffee land were covered with the exotic shrub species *Lantana*. However, the entire extent of *alang-alang* areas cannot be attributed to previous coffee cultivation. Areas of *alang-alang* infested slopes, once established, were maintained by annually recurrent fires while gradually pushing back the surrounding forest vegetation. These fires were almost invariably caused by human activity[8] (Altona 1914: 256, 328-32, 421).

The fallowing of upland fields by the population may still have occurred, but generally it was rapidly declining in the uplands due to the growth of the population (Veth 1896-1907, vol 4: 492; Onderzoek 1904-14, vol. 5a: 83, 337; Palte 1989: 57). Population growth must have been rapid during the preceding period in line with the general migratory flux from the lowlands to the relatively empty uplands (Palte 1989: 42-43, 49). With it, the number of villages increased considerably. New hamlets continued to be founded. Schmit (1981), for instance, reports that around 1880 three of the hamlets of the village of Pagersari in the southernmost part of Ngantang subdistrict were founded by settlers from the Blitar region. A fourth hamlet was founded in 1890.

1935

For 1934, quantitative data on land use is available from a forest planning document for the East Brantas region (Dienst van het Boschwezen, 1934). In Ngantang subdistrict 1354 ha of irrigated land was reported and 3358 ha of rain-fed land, including home gardens, whereas in Pujon this was 691 ha and 2247 ha respectively. This farmland was divided over the territories of the same 23 villages that we know today. According to census data, Ngantang subdistrict had a total population size in 1930 of 27,894 and Pujon subdistrict had a total population of 19,465 (Volkstelling 1930). Schuitemaker describing the situation in the late 1930s speaks of permanently cultivated rain-fed fields in the region (Schuitemaker 1949: 165-7).

The forest domain had now been completely delimitated. A forest management map, also dating from the early 1930s and showing the various forest compartments, indicates that the state forest land boundaries then drawn are still intact today. The same planning document presents an inventory of the forest cover on state forest land in the area (Table 1). This preoccupation with forest cover stems from the fact that the Forest Service's main task in this highland area was to safeguard the protective function of the forest. A sufficient forest cover was deemed necessary to maintain a favourable hydrological balance in the interest of downstream activities, by ensuring a sufficient supply of irrigation water and adequate flood control (Smiet 1990: 293).

Vegetation type	**Forest cover**						**Total forest land**	
	None		*Insufficient*		*Sufficient*			
Grass	888	5%	-	-	-	-	888	5%
Bamboo	-	-	1390	8%	-	-	1390	8%
Casuarina	-	-	1099	7%	-	-	1099	7%
Natural forest	-	-	2502	15%	10610	63%	13110	78%
Plantation	-	-	-	-	383	2%	383	2%
Total forest land	888	5%	4991	30%	10993	65%	16676	100%

TABLE 1. Vegetation types and forest cover in the forest domain of the upper Konto watershed area in 1934, in ha.

Source: Dienst van het Boschwezen, 1934.

The 888 ha of grassland recorded in this inventory were largely areas invaded by *alang-alang*. The area appears to be smaller than it had been twenty years before. Apparently, the Forest Service had been able to stimulate forest regeneration by preventing forest fires. Other factors, such as a declining role of fires in the strategies of the local population and the spread of exotic shrubs, may also have contributed to this decrease (Nibbering, 1988: 161). Measures taken by the Forest Service included the cutting of wide fire corridors, the prohibition of a number of activities in the forest area, combined with strict and relentless surveillance, but also the planting of fast-growing pioneer species, as these would quickly suppress the growth of *alang-alang* and improve the soil. Starting in 1928 and throughout the 1930s the Forest Service in Malang District tackled the reforestation of grasslands with *Acacia decurrens*. In a field report de Haan (1935: 8) stated that the ridges of the slopes radiating from Mt Kawi were planted with this tree species so as to immobilise the fires, should they occur. The recorded 383 ha of forest plantations are therefore likely to be stands of this species.

1985

Data for 1985 was taken from land use and vegetation inventories conducted by the Konto River Project (Rijksinstituut voor Natuurbeheer 1984; Nibbering 1986). The total area of non-forest land in Ngantang did not change between 1934 and 1985. The area of privately owned farm land decreased by 260 ha due to the formation of the Selorejo reservoir in 1970. The land that was thus lost consisted largely of irrigated fields. The total non-forest area in Pujon in 1985 exceeds the area in 1934 by 680 ha. This cannot be explained by continued forest clearing because the boundaries on the 1930 forest map still apply today. Whatever the reason for this difference may be[9], in the reconstruction of the land use situation in 1935 a compromise was found, from a hydrological point of view, in assigning these 680 ha to an intermediate form of land use[10]. On their farmland, Pujon farmers managed to bring an additional 189 ha of rain-fed land under irrigation. In the 1980 census the size of the population was found to be 46,954 in Ngantang and 44,384 in Pujon (Biro Pusat Statistik 1983). This brings the average annual growth rate to 1.1 and 1.7 per cent respectively between 1930 and 1980.

From the forest inventory conducted by the Konto River Project in the period 1979-1982 it appeared that the area still under genuine forest vegetation (with a canopy closure of more than 20 per cent) had become very small and was confined to high altitudes and inaccessible places. On the lower slopes of the mountains near the forest boundary the forest had virtually disappeared. Here shrub areas were found. They largely consisted of treeless brushwood and thickets of alien species (*Chromolaena inulifolia, Lantana camara*) with occa-

PLATE 3. Rain-fed annual crop cultivation on terraced hillsides in Ngantang subdistrict. Intensive agricultural activities now characterise land use on private land.
(Photo by Jan de Graaff, December 1994)

sional isolated, large-crowned trees. Whatever the precise definition of sufficient forest cover in 1934 was, conditions had obviously deteriorated since. In 1934, the forest area with no or insufficient tree cover -casuarina and bamboo excluded- made up only 20 per cent of the total forest area, whereas by 1985 the shrub area alone already amounted to 41 per cent (Table 2). The shrub areas form a pioneer vegetation which is maintained and extended by continuous exploitation by the population for firewood and fodder, by repeated clearing for plantations that have afterwards failed, and perhaps by occasional fires.

However, the area under forest plantations had increased considerably from 383 ha in 1934 to 2465 ha in 1979. Around 1960 the programmes with *Acacia decurrens* were stopped and other species with longer rotations became more important, mainly *damar (Agathis),* mahogany and eucalypt for timber, and, pine (*Pinus merkusii*) for pulpwood (Perum Perhutani 1978).

Total forest areas mentioned in the 1934 and 1979-82 inventories differ somewhat. This may be due to a different interpretation of watershed boundaries. In the reconstruction of the 1935 situation, the total forest area and some of the forest land use types were adjusted to the total forest land area of 1985.

Floristic composition	Ecology		Canopy closure (%)*	Area ha	%
Euphorbi-urticaceous	Man-made shrub area with pioneer species		<20	6328	41%
Casuarina	Fire climax forest		n.a.	1026	7%
Engelhardia	Post fire climax invaders		n.a.	51	0%
Fago-myrtaceous	Natural climax forest:	D	20-40	2939	19%
		C	40-60	1683	11%
		B	60-85	603	4%
		A	>85	312	2%
Elfin	Subalpine forest		n.a.	33	0%
Plantation	Planted species		n.a.	2465	16%
Total				15440	100%

*at 20 m above ground level
n.a.: not applicable

TABLE 2. Vegetation types and canopy closure in the upper Konto watershed area (1979)

Source: adapted from Rijksinstituut voor Natuurbeheer, 1984.

Estimating and reconciling variables

The next step was to interpret the historical data in terms of land use distribution. Gaps in data also needed to be filled, and various types of data and estimates needed to be reconciled so as to strike a satisfactory balance between various historical and logical considerations. A systematic procedure was adopted, and it was applied to each subdistrict separately, as each represented one of the two agro-ecological zones in which the watershed model was divided. The model also required the specification of land use per hydrological unit. This proved no problem for 1935 and 1985, where all agricultural land use was, by definition, confined to the lower hydrological units of each agro-ecological zone and all forest land to the upper hydrological unit. Also for 1845, the little agricultural land use there was, was assumed to be located in the lower hydrological units only. But for 1895, an estimate was required as to how much of the coffee plantations was located in the lower hydrological units and how much in the upper hydrological units.[11] The results of the reconstruction are presented in Table 3. For the sake of conciseness, the upper and lower hydrological units have been amalgamated in the table.

	Ngantang subdistrict				Pujon subdistrict			
Period	1845-95	1895-35	1935-85		1845-95	1895-35	1935-85	
Annual population growth (%)	3.0	2.0	1.1		4.0	2.5	1.7	
Year	1845	1895	1935	1985	1845	1895	1935	1985
Population size								
district			28699	49594			20787	48287
watershed	2668	11698	25829	44635	1089	7742	20787	48287
Household size	5	5	5	5	5	5	5	5
No. of households	534	2340	5166	8927	218	1548	4157	9657
Average farm								
irrigated land	0.60	0.41	0.25	0.13	0.50	0.32	0.17	0.09
rainfed: annuals	0.20	0.26	0.26	0.11	0.30	0.39	0.42	0.22
rainfed: perennials	0	0	0.04	0.13	0	0	0.03	0.03
home garden	0.20	0.17	0.11	0.07	0.10	0.08	0.07	0.04
grassland	1.00	0	0	0	1.50	0	0	0
Total farm size	1.00	0.83	0.66	0.44	0.90	0.79	0.68	0.35
Total agro-ecological zone								
natural forest	7146	4600	3957	1200	9287	6100	5300	1975
degraded forest	2627	1937	2100	1240	2850	2700	2868	1700
shrub	534	490	300	2900	327	271	532	3960
plantation	0	0	83	1100	0	0	300	1365
irrigated land	320	950	1270	1150	109	500	691	880
rainfed: annuals								
not terraced	107	400	632	0	65	400	500	0
terraced	0	200	1700	1000	0	200	1356	2080
rainfed: perennials								
not terraced	0	900	0	0	0	1250	0	0
terraced	0	950	200	1200	0	1100	802	240
home gardens	107	398	568	660	22	124	291	400
built-up areas	0	15	30	130	0	15	20	60
reservoir	0	0	0	260	0	0	0	0
non-agricultural	10306	7027	6440	6440	12464	9071	9000	9000
private agricultural	534	1963	4400	4140	190	1239	3660	3660
state agricultural	0	1850	0	0	0	2350	0	0
Total area	10840	10840	10840	10580	12660	12660	12660	12660

TABLE 3. Reconstruction of historical land use in Ngantang and Pujon subdistricts (in ha)

Source: see text

The changing size of the population is one of the variables which were taken into account in the reconstruction process. Various calculations and estimations were made to arrive at a figure for the population at each point in time. Some of these were no more than corrections with less significance for the outcome of the model.[12] Other estimates were more crucial such as the population size for 1895 and 1845 which were estimated assuming certain growth rates for the periods in between, while taking the figures for 1935 as point of departure. The population size for 1845 also had to be compatible with the total population of what was then Ngantang district. It was assumed that half of the population of the district lived in the upper Konto watershed area.[13] In the period 1845-1895 the entire area must have known high immigration rates, most of all in the Pujon area, since this higher part of the watersehed area was probably until then least populated. For the period 1895-1935 a decline in the annual growth rate seems likely as a result of decreasing immigration rates. From the total population numbers, the total number of households was derived, assuming that the average household size was five persons for all points in time[14]. Each household was considered to represent one farm. This is probably not far beyond reality in the past, and even nowadays, compared to conditions in the lowlands, there is little landlessness in the area.[15] The number of farms was specified because area estimates for the various types of land use on the watershed level had to be consistent with the average land use type distribution *per farm*. As much as land use distribution for the entire area had to be plausible, land use type distribution per farm also had to be acceptable from a historical as well as logical point of view.

With respect to land use distribution per farm, the following historical considerations played a role. For 1845 it was assumed that land was not yet scarce and that labour availability and the physical environment determined farm size and the average land use distribution per farm. Irrigated fields, rain-fed fields and home garden, each of a plausible size, were supposed to constitute an average farm (see Table 3). Irrigated land was considered to be the core of the farm. The cultivation of rain-fed fields was still alternated with fallow periods. The land use components of the average farm were then multiplied by the total number of households, to obtain total areas for the various land use types in the two subdistricts. For each hectare of rain-fed fields five hectares of fallow land (grassland, *alang-alang* etc.) were added. At the same time this grassland also served as pasture land for water buffaloes and cattle.

For 1895 it was assumed that the irrigated area had expanded, but that this increase had been less than proportionate with population growth, due to physical limitations. The increase in the rain-fed area was made more than proportionate to allow for the transfer of written-off coffee areas to the population and for some forest clearing by the population. The average home garden area was put at a lower value than for 1845. It was assumed that the average homegarden area per farm had been decreasing from one point in time to the others throughout the 1845-1985 period. Total farm size had to decrease with respect to the 1845 level as a result of population growth, also because the local population could not cultivate the land in use as coffee plantation or earmarked for compulsory coffee cultivation, and thirdly because compulsory coffee cultivation placed heavy labour demands on the conscript families (Palte, 1989: 47). All coffee plantations belonged to the government and were therefore not defined as part of the farms operated by the local population. If farmers grew their own coffee – and Veth tells us they did[16] – then it is assumed they did so in their home gardens (so-called *pagger* coffee). The area under government coffee as reported by Altona was taken into account in estimating both productive and abandoned coffee areas for 1895.

Various estimates also had to be made for 1935, for instance, estimates of the proportion of home gardens and perennial crops on rain-fed land and the state of terracing on rain-fed fields.

A framework was necessary in order to perform the reconstruction process in a systematic and transparent fashion. For this framework a spreadsheet was used, in which a number of constant values, fixed equations, and variables were defined. Constant values were: the total area of each agro-ecological zone or subdistrict (for all points in time), total area of private farmland, and total area of state forest land (for 1935 and 1985 only). Fixed equations were: average household size = 5 persons; 1 household = 1 farm. Variables were: population size, average farm size, average area of each land use type per farm, and the total area of each land use type on the level of the agro-ecological zone. The values of the variables, insofar as they could not be taken directly from the historical sources, or calculated unilaterally from other variables, had to be obtained through a reiterative process of interpreting historical information and balancing this with the values of other variables until a consistent and plausible compromise had been reached. This process of balancing or 'reconciliation' meant that the value of a variable could be adjusted if it appeared to cause another variable to assume an unacceptably low or high value.

The final step was to classify the various land use types into land use and land management classes distinguished in the watershed model. Several problems had to be solved in the process. Forest land use type classes used in the 1934 inventory differed from those used in the Konto River Project inventories. For the 1985 situation it was decided to classify all forest with a canopy closure of more than 50 per cent as 'natural forest' and all forest with a canopy closure between 20 and 50 per cent as 'degraded forest'. For 1935 it was decided to consider forest with a sufficient cover as 'natural forest' and insufficient forest as 'degraded forest'. For both years casuarina and bamboo forests were classified under 'degraded forest'.

Assumptions also had to be made concerning the actual nature and the actual management of the historical land use types. In the compulsory coffee cultivation system two common clearing methods were practised. In the first, the forest area was thoroughly cleared of trees and undergrowth before the shade trees and the coffee seedlings were set out. These became the so-called regular coffee plantations (*geregelde tuinen*). In the other case the existing forest was only thinned out, whereupon the coffee was planted in between the remaining undergrowth (*boschkoffie*). Some terracing of the slope was practised in either clearing method, but always rather loosely. In the regular coffee plantations the soil became heavily eroded after twenty years or so. These soils would have deteriorated so much that the fields were given up as useless for further coffee production. The forest coffee stands, on the contrary, suffered little from erosion and remained fairly productive (Palte 1989: 46). In the upper Konto area, if the cultivation of forest coffee occurred at all, it does not seem to have been practised in later years.[17] As for rain-fed fields, it was assumed that in 1895 rain-fed fields were less fallowed, and that terracing was under way. In 1935 permantent cultivation of rain-fed fields had become the rule. Schuitemaker (1949: 166) observed in the late 1930s that only small patches of rain-fed land, where too much soil had been washed down, were fallowed. The majority of the population had also terraced their fields in some way or another. In Ngantang subdistrict the agricultural extension service even ran a terrace improvement programme (Schuitemaker: 167). Pujon subdistrict was not mentioned in Schuitemaker's report, but farmers here must also have adopted terracing, and perhaps even earlier, for the cultivation of commercially attractive temperate climate vegetables. The cultivation of potatoes (*Solanum tuberosum*) was already common practice here at the start of this century (Meier 1915).

Not all of the land use and land management types occurring in the past could be defined in their own right in the watershed model, as the number of land use classes had to be kept to a minimum. In such cases the nearest land use type, nearest from a hydrological point of view, was selected to represent these historical types. For *alang-alang*, for instance, the land use type 'shrub' was selected for the upper hydrological units.

LAND USE TRENDS

The region-wide land use trends in the upper Konto area during the last 150 years that emerge from the land use reconstructions appear to be quite in line with general trends in highland areas of Java, as described by various authors (Palte 1989; Smiet 1990). Figure 1 recapitulates some of the trends and changes that have occurred. Clearly, during the 1845-1895 period the conversion of forest into agricultural land was a dominant feature of the land use scene, while between 1935 and 1985 it was the degradation of the remaining natural forest that was most striking.

That deforestation, here defined as the disappearance of natural and degraded forest, has been particularly rapid during the last five or six decades, is illustrated more clearly by Table 4. Although the absolute annual decrease of natural and

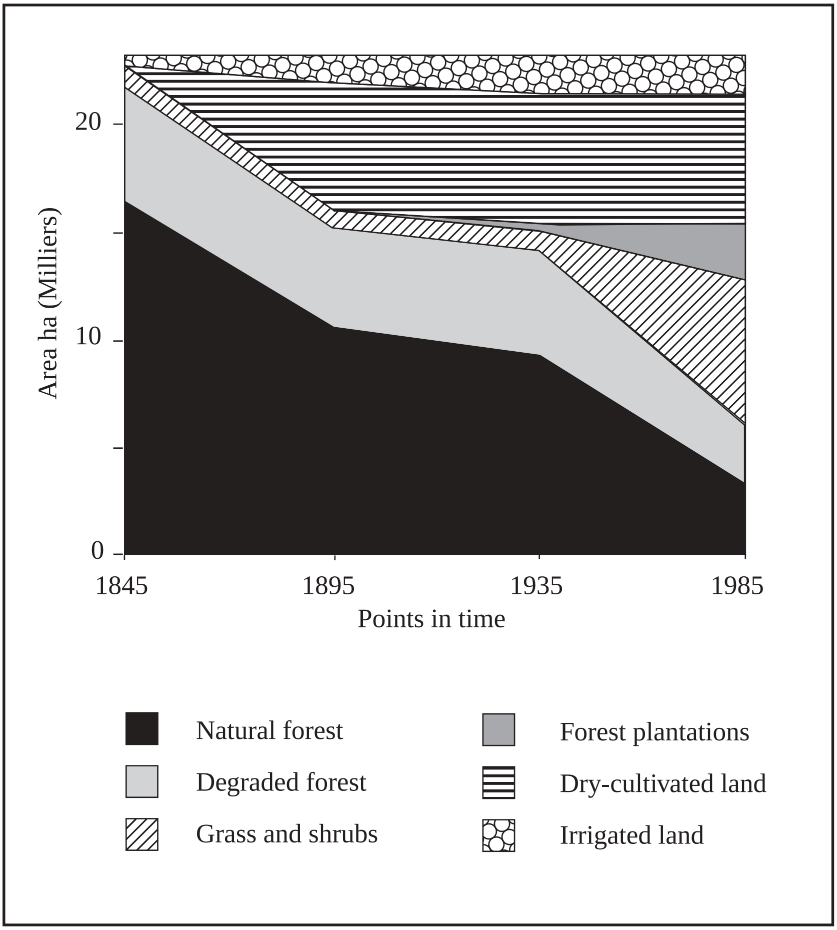


FIGURE 1. Land use trends in the Upper Konto watershed area, 1845-1985

Note: rainfed land includes annually cropped fields, perennial gardens and home gardens
Source: reconciled data and estimates (see text)

degraded forest for the periods 1845-1895 and 1935-1985 is the same, the relative annual decrease for 1935-1985 is much greater, because in 1935 there was far less forest left than in 1845. The annual deforestation rates are not meant to suggest that deforestation has been a smooth, continuous process. It may have known a period of acceleration during the Japanese occupation and the subsequent revolutionary years, when there was much distress and little surveillance.

Type of forest	hectare per year				% per year			
	1845 –1895	1895 –1935	1935 –1985	1845 –1985	1845 –1895	1895 –1935	1935 –1985	1845 –1985
Ngantang subdistrict								
natural forest	-51	-13	-55	-42	-0.9	-0.4	-2.9	-1.3
natural & degraded forest	-65	-10	-72	-52	-0.8	-0.2	-2.2	-1.0
plantation	0	+2	+20	+9			+5.3	
Pujon subdistrict								
natural forest	-64	-16	-67	-52	-0.8	-0.4	-2.4	-1.1
natural & degraded forest	-67	-13	-90	-60	-0.6	-0.1	-2.0	-0.8
plantation	0	+8	+21	+12			+3.1	

TABLE 4. Deforestation and reforestation rates derived from reconstructed historical land use situations

Source: see text.

It is also noteworthy that deforestation was apparently been somewhat relaxed between 1895 and 1935. This is not surprising, as the clearing of forest for agricultural purposes was no longer possible in the upper Konto area during this period. Some of the forest was restored by natural regeneration, and pressure of the population on the forest for firewood, timber and fodder was still relatively low compared to the subsequent period and compared to other areas at that time. Woodcutting was not generally seen as the greatest problem in forest management in those days. Closer to the town of Malang, for instance, the pressure was reported to be much greater.[18] When taken over the entire period of 1935-1985 reforestation rates, in the form of forest plantations, are far below the deforestation rates, but reforestation was stepped up substantially over the last decade of this period.

HYDROLOGICAL TRENDS

The reconstructed historical land use area distributions as well as the land use area distributions for a number of future land use scenarios were entered into and processed by the watershed model. Before we consider the results of the hydrological modelling exercise which are shown in Table 5, the physical parameters used for this must be discussed briefly. Erosion rates were calculated in two ways, with the Universal Soil Loss Equation (Wischmeier and Smith

1978) and according to a model developed by Morgan *et al.* (1984). The former is better known, but the latter has the advantages over the USLE formula that it is more closely linked to the actual processes and that it focuses on erosive rainfall.[19] Sediment leaving the watershed is the total amount of sediment that is eventually transported by the Konto river out of the upper Konto watershed area. It has been calculated as a linear function of the average erosion rate (according to Wischmeier) with a constant sediment delivery ratio. The minimum and maximum monthly stream flows are the flows that occur at the lower end of the upper Konto Watershed and that are now collected in the Selorejo reservoir. They are conventionally indicated with Q_{min} and Q_{max}. Since we are concerned primarily with downstream effects in this article, evapotranspiration and biomass production will not be considered here. It should also be made clear that we are

Scenario	Year	Erosion Wischmeier (tonne/ha)	Erosion Morgan (tonne/ha)	Sediment leaving watershed* (10^3 tonnes)	Lowest monthly streamflow (10^6 m^3)	Highest monthly streamflow (10^6 m^3)	Ratio lowest/ highest streamflow
Historical development							
	1845	1.9	0.8	23	7.8	28.0	0.28
	1895	7.6	3.4	129	6.3	32.7	0.19
	1935	17.3	7.6	187	6.3	34.1	0.19
	1985	17.6	7.9	327	6.1	37.6	0.16
Alternative future scenarios							
A	2010	17.9	8.3	336	5.9	38.3	0.15
B	2010	17.3	7.8	306	5.9	38.3	0.15
C	2010	16.5	7.8	299	5.9	39.5	0.15
D	2010	21.6	9.8	368	5.9	39.5	0.15

*based on erosion rates calculated after Wischmeier

Scenarios:

A. Scenario reflecting actual watershed development, based on Konto River Project implementation activities and the present state thereof
B. Scenario emphasising watershed protection
C. Production-oriented scenario on agricultural development
D. Autonomous development scenario with no government interference and purely based on farmers' preferences

TABLE 5. Erosion, sedimentation and stream flow in the Upper Konto watershed area for four points in the past and four future scenarios (based on 1987/89 rainfall patterns)

Source: adapted from de Graaff 1996.

PLATE 4. The Konto river near the Tokol check dam at the end of the rainy season. Soon after the selorejo dam had been constructed, check dams and silt traps were built upstream to normalize streamflow and reduce sedimentation in the reservoir.

(Photo by Jan de Graaff, April 1987)

primarily interested in trends and the order of magnitude of changes rather than in the absolute sediment or water flow values. Considering the crudeness and simplifications in the model, these values should not be regarded as precise.

If we look at the hydrological trends through history, the following can be observed: an increase in erosion according to both formulae (but smaller if calculated after Morgan *et al.*), an increase in sediment load, a decrease in Q_{min} and an increase in Q_{max}. A declining Q_{min}/Q_{max} ratio indicates a higher tendency for overland flow and a smaller base flow during the dry season. The Q_{min}/Q_{max} ratio and the sediment load in streams show their biggest change between 1845 and 1895, whereas erosion continued to increase considerably between 1895 and 1935. The differences between 1935 and 1985 are but slight in all respects. From this, we may conclude that the conversion of forest into agricultural land is most responsible for changes in the watershed's hydrological balance; the subsequent replacement of forest for shrub has had little impact. The conversion of land with permanent vegetation into rain-fed agricultural land, particularly when it is cropped with annuals, is largely responsible for erosion. These conclusions seem reasonable, and could be expected to some extent, on the basis of the water balances that were incorporated into the model for each land use and land management type.

These findings are also in line with what was generally reported on land use and hydrology in the uplands of Java in the colonial past. During the first decades of this century there was a growing concern, notably within the irrigation service and the sugar estates in the lowlands, about the hydrological conditions on the island. These were considered to have been put into jeopardy by large scale clearing of forest for agricultural production. The frequency and severity of floods had increased and most rivers had been experiencing declining discharges during the dry season. This threatened to disrupt both agricultural production in the lowlands by the increasing population and the development of the booming Dutch sugarcane enterprises. In 1914 there were already as many as 80 sugar plants operating in the Brantas river basin. They still had land available for expanding their cropping activities, but water availability for irrigation had become a constraint. As an increasing number of expensive large scale irrigation structures had been embarked upon or were envisaged for the future (Altona 1914: 253), an increase was required in the area under forest cover, by extending the reserves of protected forest, and speeding up reforestation efforts (Encyclopaedie van Nederlandsch Indië, part VI: 4-5).

In the Konto area, the situation was regarded as particularly grave. A number of springs had become exposed as a consequence of deforestation and no longer supplied water. Land slides measuring up to 1.5 *bau* (over 1 ha) occurred on steep hillsides that had been deforested and taken into cultivation. At the same time it was observed that the Konto which used to be a gentle river, had become a torrential one.[20] The Konto river, described by Altona as 'more than notorious' (Altona 1914: 251) had flooded several time during the wet monsoon causing great damage to infrastructure and irrigated areas in its lower reaches.[21] Excessive sedimentation downstream also occurred. From 1901 to 1914 the bottom of the Konto river bed had risen by 7 metres near the village of Badas 25 km downstream from the present Selorejo dam (Altona 1914: 261). Unfortunately, comparison of the results of the watershed model with quantitative hydrological data on conditions in the upper Konto watershed area before 1915 were not possible, since data for before this time are unavailable. Discharge data of the Konto river measured at Selorejo are available for the period of 1915-1942 and 1951-1971. Pre-war and post-war stream-flow and rainfall patterns were compared by fitting sinusoidal functions to the respective average monthly data. Whereas the amplitude of the post-war rainfall pattern, i.e. the difference between the highest and lowest monthly rainfall during this period, was only 7 per cent greater than the amplitude of the pre-war pattern, the post-war stream-flow pattern showed an increase in amplitude of 57 per cent over the pre-war pattern. Since it could be established that there had been no change in the way in which amounts of stream-flow were obtained during the two periods of observation, it seems very likely that the deterioration in stream-flow pattern is indeed related to changes in land use over time (Rijsdijk and Bruijnzeel, 1990, part II: 48, 52). The measured increase in stream-flow amplitude appears to be much higher than the 19 per cent increase between 1895 and 1985 which can be calculated using the results of the watershed model. The fact that Altona mentions the drying up of springs and the occurrence of landslides may also suggest that the changes had been more drastic than indicated by the model. The main reason for this is that the model is essentially linear and cannot deal with scale-connected phenomena, such as the exposure of springs, gully erosion or mass wasting.

In the period between 1915 and 1930 Dutch scientists debated the value of reforestation efforts in restoring or maintaining the hydrological values of montane forest. One party maintained that hydrological values were mainly determined by geological conditions and soil properties, while the other party advocated the ‘sponge theory’, which regards forest cover as the best regulator of river flows. After much debate, hampered by the lack of data, the sponge theory was accepted and became the basis for the practical management of natural forest and for the establishment of forest plantations throughout the island to guard hydrological values. In view of more recent discussion about the influence of forests on hydrology, Smiet (1990: 298) states that the reforestation policy was the right one, albeit defended with the wrong arguments. (See for example the reviews of Hamilton and King 1983, and Smiet 1987 on this subject.) As the water balances of permanent forest vegetation in the watershed model allow for higher infiltration rates than the water balances of other forms of land use, the results of the model could not but support the so-called sponge theory. The changes in the hydrological output values at the scale of the upper Konto area are less than expected, however. Hydrological trends would probably be more pronounced, if they were considered on a greater geographic scale, such as the entire Brantas watershed area. This would be a more appropriate level at which to analyse the historical problems in the lowlands with water supply and flood control as well as the perception of these problems by those concerned. The upper Konto watershed area is perhaps too small for that and, with two thirds of the area still under permanent vegetation, probably also not so representative of the wider upper Brantas region. In fact, the hydrological conditions in the upper Konto watershed area still compare favourably with conditions in other watersheds in Java.

The main purpose of the watershed model, however, was to provide a basis for the economic evaluation of various future land use and land management scenarios. Four such scenarios, A, B, C and D, were designed, with end situations projected to the year 2010. Each scenario is based on certain assumptions: Scenario A is a projection of present developments based on the Konto River Project implementation activities. It entails less shrub and more forest plantations on forest land than in 1985. On farmland terracing improves. In scenario B the emphasis is on watershed protection. There is less shrub and a larger reforested area than under scenario A. On farmland terracing is even better and there are more perennial gardens than under scenario A. Scenario C concentrates on production and agricultural development and less on watershed protection. It entails less natural forest, more reforested land, more grass planting (for feeding dairy cattle) and more coffee plantations on forest land than under scenario A. On farmland there is pure grassland and no extra effort in terracing. Scenario D is an autonomous development scenario with no government interference. It is exclusively based on farmers preferences. There is less natural forest, more shrub, and more coffee plantations than under scenario A, but there is also much grassland and rain-fed annual cropping on forest land. On farmland there is no extra effort in terracing.

Evidently, for the present land use situation and future land use planning in the upper Konto area, valuable insights can be gained from the historical land use reconstructions. The model clearly shows that the effects one may wish to achieve with the land use and land management changes specified in different development scenarios are unlikely to be of the same order of magnitude as the changes that have occurred over the last 150 years. For example, according to the model, average erosion rates calculated with Morgan's formula increased from 0.8 tonnes/ha for 1845 to 7.9 tonnes/ha for 1985, largely as a result of forest clearing for intensive agricultural use. The rates found for the four development scenarios which cover together a wide range of land use conditions – but which leaves the division between (state) forest land and (private) farmland largely intact – only vary between 7.8 and 9.8 tonnes/ha. While, historically, the effect on the annual Q_{min}/Q_{max} ratio of the Konto river declined from 0.28 to 0.16, the model calculated a ratio of 0.15 for all development scenarios alike. There is an important message for policy makers here to the effect that they should remain realistic in their expectations. Land use and land treatment measures will have positive effects, but there will be no miracles. The modelling results and their economic and policy implications are discussed in full by de Graaff (1996).

CONCLUDING REMARKS

The validity of the conclusions with respect to the hydrological trends in the upper Konto watershed area depends on the one hand on the accuracy of the reconstructed land use situations and on the other hand on the reliability of the watershed model. The reconstruction of past land use situations has the status of best bet under conditions of limited knowledge; the watershed model is hydrologically rather crude. This is why we have pointed out that the results should be viewed with caution and that only the differences in order of magnitude have any significance. There is a another caveat which we would like to add. Our main conclusion that future development scenarios are unlikely to reproduce the favourable conditions of the past is not meant to suggest that if historical land use situations were to be re-created, the same hydrological conditions from the past would automatically come into effect. This is not likely to be the case, due to changes in the geo-hydrological structure that have undoubtedly occurred in the area over the years as a result of the changes in land use. As has been indicated before, springs have disappeared and may not come back into existence even if the original land cover is restored. Drainage patterns have also changed and it may take considerable time for the hydrological regime to find a new balance.

One way of coping with the crudeness of the watershed model or uncertainty about the land use data which is made possible with modeling is sensitivity analysis. One can vary a land use variable or a hydrological coefficient in the model about which one has doubts in order to see to what extent this variation will affect the outcome of the model. If the variations in the outcome are relatively small, then we need not worry too much. If they vary much, then we have to make them transparent and the output of the model could be presented in terms of ranges for likely ranges of data values or coefficient values. This could be done, for instance, for the area under government coffee cultivation in 1895. We could ask ourselves what the hydrological effects would have been, if the area under coffee had been, say, twice as large. For the sake of simplicity, we have refrained from such an exercise in this article, and also because it would add little to our principal message, which is to demonstrate the insight for the benefit of future developments to be gained from simulating past hydrological conditions.

NOTES

[1] Some of the work underlying this paper was reported on briefly in the Indonesian Environmental History Newsletter no. 5 (Nibbering and de Graaff 1995). We would like to thank David Henley and Sampurno Bruijnzeel for providing some of the data used in this paper.

[2] It was calculated that the sediment yield, equivalent to a soil loss of about 0.9 mm $ha^{-1}yr^{-1}$, would reduce the lifetime of the reservoir with some ten years as compared with the feasibility study (Nippon Koei, 1962; Fish, 1983).

[3] Three types of water flow are distinguished: 1) overland flow: water that cannot infiltrate into the soil; 2) sub-surface flow: water that infiltrates into the soil surface but cannot be stored in the upper soil layer or infiltrate into a deeper soil layer (overland flow and sub-surface flow are components of quickflow, i.e. water that moves quickly from land to open water); and, 3) base flow: water that moves slowly through deeper soil layers to open water.

[4] Junghuhn states that coming from the village of *Welingin* (present day Wlingi in Blitar district), *Gresik* (now Krisik) was the last village he passed before reaching the village of *Ngantang* (now called Kaumrejo). Today, this part of the Upper Konto area is studded with large villages.

[5] According to the population statistics of 1845 (Bleeker 1847) the population was, apart from one Chinese couple, still exclusively Javanese.

[6] A substantial part of these coffee lands were situated in the area around Mt Kukusan (Map 2). Other complexes were found between the Luksongo range and Mt Kelud, between Mt Kelud and Mt Kawi, on the northern and northwestern slopes of Mt Kawi and on the southern slopes of Mt Jeruk (Altona 1914: 318-22).

[7] The system of compulsory coffee cultivation was gradually abandoned in Java because of declining yields, partly as a result of a disease caused by the leaf mycosis *Hemileia vastatrix*, the need for forest protection and under the pressure of more liberal views as to the colonial exploitation of Java's resources. It was formally abolished in 1916 (Encyclopaedie van Nederlandsch Indië 1918: 387-8; Paerels 1949: 90-91).

[8] Altona sums up a number of causes for the occurrence of fire on forest land: burning of vegetation and crop residues on rain-fed fields lying at the edge of forest land, unattended charcoal burning, hunting, burning grass to stimulate the growth of young shoots as fodder, and, production of ash to be washed down onto lower situated rain-fed fields by run-off (Altona 1914: 428).

[9] Some of the farmland in 1935 may still have had a special status or farmland may have been consistently underestimated.

[10] The 680 ha concerned were assumed to be under perennial crops. From a hydrological point of view, the land use type perennial crops can be considered to be situated about halfway between forest and annually cropped rain-fed fields.

[11] It was estimated that for Ngantang subdistrict 1150 ha of the coffee plantations were situated in the lower hydrological unit and 800 ha in the upper hydrological unit. For Pujon subdistrict this was 1150 ha and 1200 ha respectively.

[12] Two estimates of this type were as follows: (1) Pujon subdistrict entirely coincides with the eastern half of the upper Konto watershed area, but Ngantang subdistrict slightly exceeds the boundaries of the watershed area. It was therefore estimated that for all points in time 90 per cent of the population of Ngantang subdistrict lived in the watershed area. (2) To arrive at total population numbers for 1935 and 1985, the average annual growth rate over the period 1930-1980 was used to calculate the figure for 1935, starting out from the census figure for 1930, and the same was done for 1985, starting out from the census figure for 1980.

[13] About 40 percent of the district was situated outside the upper Konto watershed area. The assumption that a greater proportion of the population lived here is based on the fact that it is the lowest and most accessible part of the district.

[14] In 1980 the average household size was 4.6 for both subdistricts. It must have been larger in the past, but probably not a great deal. Also historically, a taxable household (*cacah*) was considered to be a unit of five persons.

[15] In a village survey held in 1980 it was found that 71 and 73 per cent of the households controlled farmland (house lots excluded) in Ngantang and Pujon subdistricts respectively. Moreover, nearly every household owns its house lot and especially in Ngantang house lots can be quite large and are used as perennial or mixed gardens (Nibbering 1986: 98).

[16] Veth mentions that, when travelling in the area, one could observe signs near the coffee gardens indicating their status. So there were gardens established under compulsion (*prèntah*); that there were gardens that were voluntary undertakings (*månåsukå*), and, he adds with some irony, there were also signs stating that the gardens had been established with "gentle persuasion" (*prèntah alus*) (Veth 1903, vol. 3: 537).

[17] *Erythrina* sp. (*dadap*) and *Albizzia falcataria* (*sengon*) were species commonly planted as shade trees in coffee plantations on clear-felled land. Especially the former species can still be found even today in large numbers and regularly spaced on former coffee lands in the forest area.

[18] Here, on the eastern slopes of the Kawi range, the provision of firewood for the populous area of Malang town and surroundings had led to the cutting of large amounts of live wood (Reboisatiecommissie 1931: 19).

[19] Morgan compares the predictions of detachment by rain splash and the transport capacity of the run-off and assigns the lower of the two values as the annual rate of soil loss, thereby denoting whether detachment or transport is the limiting factor (Morgan *et al.* 1984).
[20] Altona uses the German term *Wildbäche* (violent streams) in this connection (Altona 1914: 255).
[21] Near the town of Kandangan in the lower Konto watershed area a bridge and irrigation works were swept away by a flood of the Konto river, and thousands of *bau* were covered with sand making the area no longer suitable for irrigation (Altona 1914: 254, 261).

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