RIVERS AND STREAMS ON MADAGASCAR

by

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The survey of Malagasian rivers was started in 1948–49 by a team from Electricité de France investigating the prospects of hydroelectric development in several river basins. From 1951 the Hydrology Section of ORSTOM (Office for Overseas Scientific and Technical Research) took over the stations set up in 1948 and completed the network, extending it gradually as requests were received from users (agricultural engineering, public works, development companies, etc.)

There are now 75 stations in the main regions of the island, and ORSTOM is responsible for running them.

Since 1966, a team from the Meteorological department, trained by ORSTOM, has been studying the hydrology of Madagascar. It will become a hydrometeorological department, and take over from ORSTOM the running and maintenance of the hydrological network.

Despite the fact that the hydrological data available consist of a series of surveys which are of too short a duration and are sometimes incomplete, they are nevertheless sufficient to provide a preliminary review of the hydrological regimes of the Great Island.

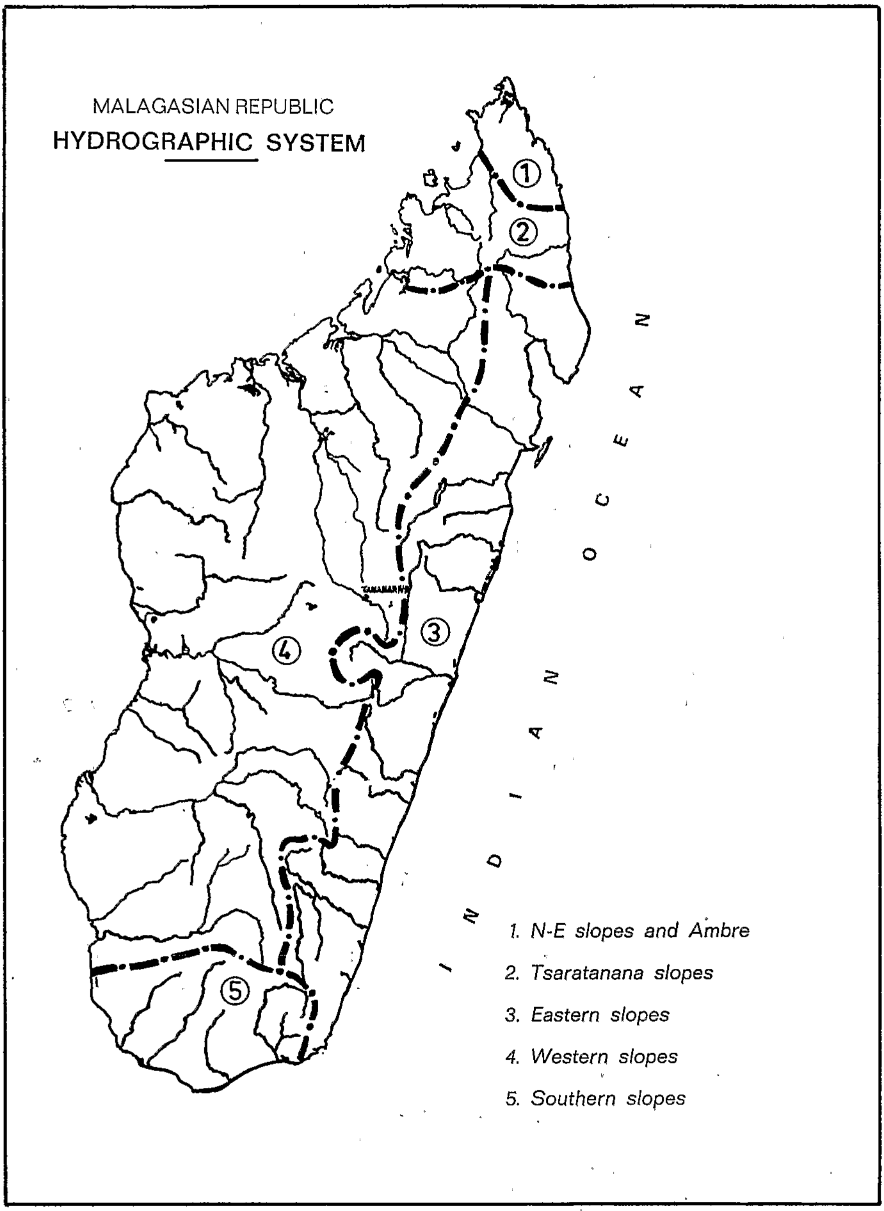
In the first part, we shall describe the hydrographic network and in the second part we shall examine the main features of the regimes.

I. Hydrography

The rugged relief of Madagascar divides its hydrographic network naturally into five groups of basins of very different sizes.

1. The slopes of the Ambre mountain
2. The Tsaratanana slopes
3. The east slopes running into the Indian Ocean
4. The western and north-western slopes whose waters run into the Mozambique Channel
5. The southern slope

The watershed between the Mozambique Channel and the Indian Ocean runs through the three large mountain ranges of the island and then generally follows the eastern escarpment of the highlands. However, it has two very well marked diversions towards the west, one corresponding to the basin of the Onive, a tributary of the Mangoro flowing down from the eastern slopes of the Ankaratra and the other corresponding to the basin of the upper Mananara which, through the Ranotsara gap,



MALAGASIAN REPUBLIC
HYDROGRAPHIC SYSTEM
TANANARIVE
INDIAN OCEAN
1. N-E slopes and Ambre
2. Tsaratanana slopes
3. Eastern slopes
4. Western slopes
5. Southern slopes

Fig. 1.

flows over the Andringitra massif in the south and extends to the vicinity of Ihosy.

1. THE SLOPES OF THE AMBRE MOUNTAIN

This volcanic massif is drained by small, narrow torrents running in beds littered with blocks of basalt. The basins are very narrow and elongated: there are no tributaries worthy of note. The main rivers are the Irodo, the Saharenana and the Besokatra whose waters are used to supply the town of Diego-Suarez. These slopes cover only about 11,200 sq.km, barely 1.8 % of the area of Madagascar.

2. THE TSARATANANA SLOPES

The Tsaratanana massif, with its very rugged relief and its position equidistant from the Indian Ocean and the Mozambique Channel, is the source of rivers with a very typical longitudinal having very steep gradients (30 or 40 m/km) in the upper reaches and gradients of only a few m/km when crossing the coastal plains, on both the western and eastern slopes. This is why the Tsaratanana slopes, which cover little more than 20,000 sq.km. (3.3 % of the area of the island) have been taken as a separate geographical unit.

The main rivers on the Tsaratanana slopes are:

The North Mahavavy which rises east of the central dorsal ridge of the Tsaratanana near Andohanisambirano (2,501 m) at about 2,200 m above sea level. It first flows north to the Andranomafana water falls (100 m over about 4 km). At the foot of the falls, the Mahavavy is 200 m above sea level, representing a drop of 1,900 m in 60 km or a gradient of more than 30 m/km.

The river then turns north-north-west and the slope decreases. Down to the sea, it averages only 2 m/km. The bed is wide, cut by several rapids up to about 50 km south of Ambilobe. The Mahavavy ends in an immense delta on which the Sosumav plantations are situated. At low water, a regulator near Ambilobe diverts the whole of the flow into the Sosumav canal.

There is only one large tributary on the right bank, the Antsiatsia (60 km long).

From its source to the sea, the North Mahavavy is 160 km long*. Its basin covers an area of 3,270 sq.km.

The *Sambirano* rises on the western face of Andohanisambirano, at a height of about 2,200 m. It runs north-west with a slope of 46 m/km over 45 km. It then enters a wide flat-bottomed valley where it spreads out

* The lengths of the rivers and areas of their basins were measured on the 1 : 500 000 map (1963 type) of the Madagascar Geographical Department.

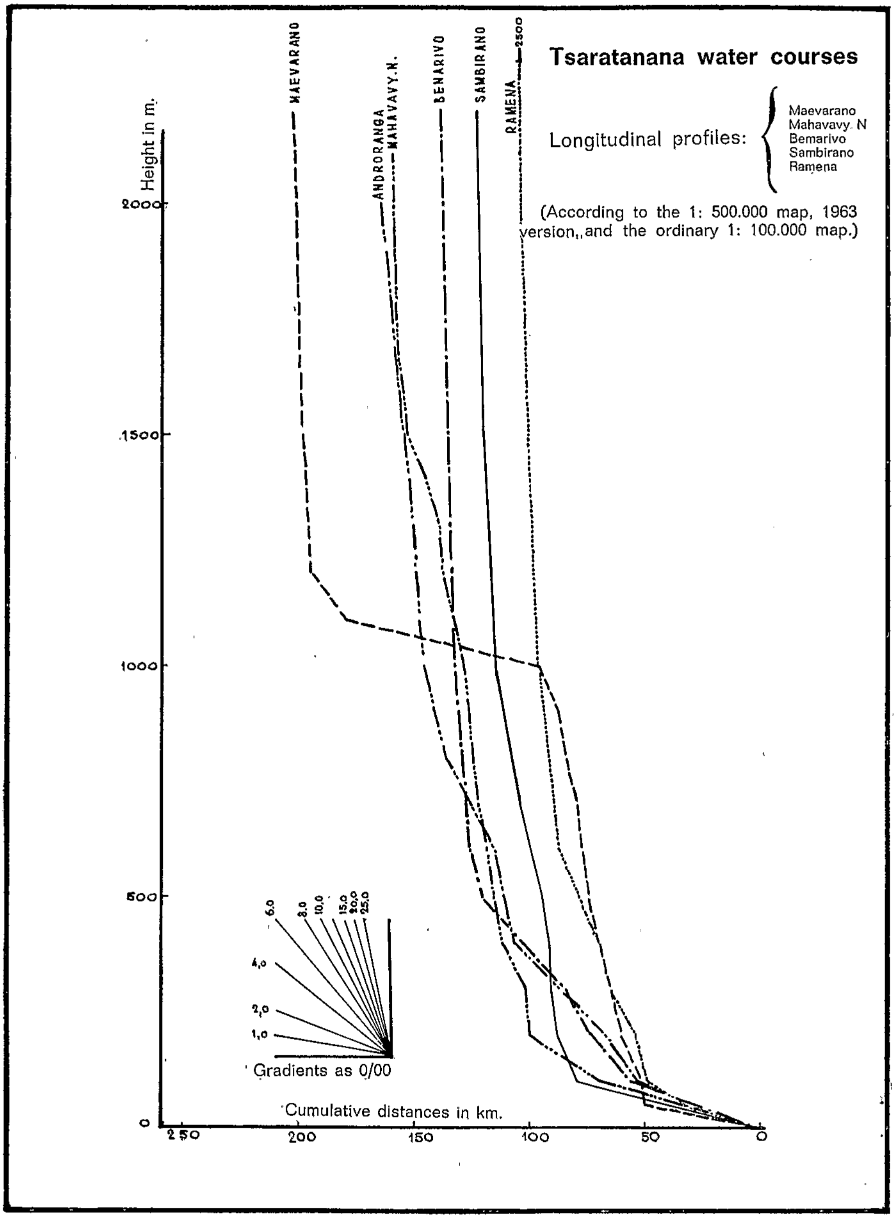

Tsaratanana water courses
Longitudinal profiles:
Maevarano
Mahavavy. N
Bemarivo
Sambirano
Ramena
(According to the 1: 500.000 map, 1963 version,,and the ordinary 1: 100.000 map.)
Height in m.
2000
1500
1000
500
0
250
200
150
100
50
0
MAEVARANO
ANDRORANGA
MAHAVAVY.N.
BEMARIVO
SAMBIRANO
RAMENA
2500
6,0
8,0
10,0
15,0
20,0
25,0
4,0
2,0
1,0
Gradients as 0/00
Cumulative distances in km.

Fig. 2.

over a sandy bed, bordered with large rice fields. Its slope is then only 1.3 m/km. At Ambanja, the Sambirano forks to the west and runs out into the Ampasindava bay through a delta.

At 28 km from its mouth, it is joined by the Ramena which flows down from the Maromokotra, the highest point of the Tsaratanana, through a very wooded zone. The direction of its course is south-east- north-west to Antseva, with an average fall of 40 m/km. At Antseva, the Ramena turns south-west and joins the Sambirano just below Ambodimanga, after 78 km.

The total length of the Sambirano is 124 km. It has a drainage basin of 2,950 sq.km. of which the Ramena accounts for 1,115 sq.km.

The Maevarano rises south of Andohanisambirano, not far from the sources of the North Mahavavy and the Sambirano, at a height of about 2,200 m. As far as Mangindrano, it has a steep gradient (48 m/km approx.) and runs north-south. It then crosses the swampy hollow of the Ankaizina. Its slope is about 1 m/km and south of Bealalana it takes a very meandering course.

It leaves the Ankaizina at a height of about 1,000 m and runs west. Its slope is about 20 m/km to a height of 50 m, when it is about 50 km from the sea and crosses the coastal plain in a very wide and meandering bed. It flows out into the Loza bay through a small delta after covering 203 km. At a height of about 200 m, it is joined on its right bank by the Sandrakota which flows down from the Ambondrona (2,262 m). The area of the basin is 5,360 sq.km.

The Bemarivo flows down the eastern slope of the Tsaratanana. Over about 70 km the river drops 2,100 m giving an average gradient of 30 m/km. The Bemarivo is 140 km long and drains an area of 5,400 sq.km. Its main tributary on the right bank is the Androranga.

3. THE EASTERN SLOPES

With an area of about 150,000 sq.km., the eastern slopes account for 25.2 % of the area of Madagascar. They range over more than 1,200 km from Fort-Dauphin to Antalaha. The average width from the divide to the sea is about 100 km, with a maximum of 190 km at the latitude of Ankaratra. The narrowest parts are at the latitude of Fort-Carnot (60–70 km) and along Beampingaratra, north of Fort-Dauphin, where the mountainous summits are only some 50 km from the coast as the crow flies.

In this narrow elongated rectangle, the water courses are comparatively short with a very accentuated profile: from time to time they have calm reaches, not very wide, interspersed with rapids and falls. The eastern slopes therefore have a considerable energy potential.

Because of the relief with secondary chains parallel to the coast, defining fairly deep valleys linked by transverse faults perpendicular to the scarps, some rivers are three to ten times as long as the direct distance between their source and the east coast.

In the narrow coastal plain the rivers wander from their courses with numerous meanders. They supply a chain of lagoons separated from the sea by a range of sand dunes. At low water, the waters of the small streams reach the sea by infiltration under the spits of sand.

The hydrographic network of these slopes is very complex and there is a dense system of water courses.

The main rivers are the Mananara, Mangoro, Rianila, Maningory and Mananjary.

The Mananara is formed by the confluence of the three streams Menarahaka, Itomampy and Ionaivo upstream of the Soakibany sill.

The respective lengths from the sources of the Ionaivo, Itomampy and Menarahaka are 418 km, 295 km and 284 km. Thus the Ionaivo is presumably the parent branch of the Mananara. Taking the Sahambano, the length is 323 km.

The sources of the various rivers making up the Mananara are all within about 50 km of the coast, sometimes less, which shows the enormous influence of the relief on the hydrographic system. The Mananara basin is certainly the most typical from this aspect: the rivers are often ten times the length of a straight line drawn from their sources to the sea.

Possibly the rivers of the east slopes captured the Itomampy and Ionaivo, formerly tributaries of the Ihosy, but this has not been decisively proved.

The Ionaivo rises on the northern buttresses of the Beampingaratra massif, on the slopes of the Tsimahamory, about 1,500 m above sea level. It runs generally south-north to Ranotsara.

After about ten kilometres, between Ranotsara and Ranotsarabe, in a north-easterly direction, the Ionaivo makes a new 90° turn and runs south-east in the Ranotsara plain until it is joined by the Itomampy. From here it runs north until it meets the Menarahaka.

The Itomampy rises near the Ionaivo 40 km from the sea, near the Vohilafy massif (1,812 m) at a height of 1,600 m. It runs north until it meets the Ionaivo. It has a fairly steep gradient for the first 60 km from its source. Then the gradient decreases to about 1.30 m per km as far as the Soakibany sill.

The Menarahaka rises in the Andringitra massif about 2,000 m above sea level. It flows along the southern edge of this massif and takes a westerly direction to Sakalalina.

From Sakalalina to the confluence with the Sahambano, it runs south-west, then north-west- south-east in the Ranotsara plain. Before meeting the Ionaivo, the Menarahaka runs some 10 km south, in the same valley as the Ionaivo, but in the opposite direction.

The Mananara starts eastwards towards the Soakibany sill and the sea, which it reaches in the region of Vangaindrano. After Soakibany, its slope is about 10 m/km up to 36 km from its mouth. The area of the basin drained by the Mananara is 16,760 sq.km. Above the Soakibany ridge it is 14,160 sq.km.

The Mangoro rises north-east of Anjozorobe, at a height of about 1,100 m, and runs into the depression or plain of Ankay, between the Angavo escarpment and the mountainous plateau also known as the Betsimisaraka escarpment. It first runs north-south across very marshy regions. As far as Ambodimanga, the average slope of the bed is 70 cm/km. Then it continues its course to the south. The slope becomes steeper, with many water falls whose development for hydroelectric purposes has been studied. With the low slopes in the upper part of its course, the Mangoro is a perfect example of a young profile still far from equilibrium, probably due to a fairly recent uplifting of the relief.

At 200 km from its source, it is joined on the right bank by the Onive, its largest tributary, which flows down from the Ankaratra massif. This river has a very steep gradient and between Tsinjoarivo and the confluence there are many possibilities for hydroelectric projects.

The Mangoro – Onive confluence takes a very curious form: the two rivers run in the same valley in precisely opposite directions for a few dozen kilometres. Then the Mangoro forks east through deep narrow gorges with slopes of more than 10 m per km. At 25 km from the river mouth, the slope decreases slightly, the bed widens but there are still many rapids. The Nosivolo, which rises east of Fandriana, is the second important tributary on the right bank.

The total length of the Mangoro is 300 km. It has a drainage basin of 17,175 sq.km. The Onive basin above the confluence covers an area of 4,860 sq.km.

By the area of its basin and the volume of water it carries, the Mangoro is the largest river on the eastern slopes.

The Rianila rises at the edge of the Betsimisaraka heights, in the Fahona massif (1,510 m), about 1,450 m above sea level. It runs in a general west-east direction with occasional north-south reaches corresponding to the structural direction of the relief. The river drops from 1,450 m to 200 m in 46 km, an average slope of 26 m/km. At Fetraomby, the Rianila crosses the last waterfall on its course. It is then navigable to its mouth, near Andevoranto. The effect of the tide can be felt well upstream of Brickaville.

The main tributaries on the right bank are as follows: firstly, the Vohitra, which rises in the plain of Ankay, south of Andaingo, at a height of 1,200 m. It first crosses a marshy zone in a southerly direction, in the region of Fierenana. In the second escarpment the slope increases and there are some sites suitable for dam construction. After its confluence with the Samatandra, above Rogez, the Vohitra runs east. A large waterfall below Rogez has been surveyed for the installation of a hydroelectric station. The Vohitra enters the Rianila near Anivorano.

The Iaroka is the second large tributary. It comes from the heights south of Perinet and, after flowing almost west-east enters the Rianila near Maromandia a few kilometres from the sea.

On the left bank, the only notable tributary is the Rongaronga.

The Rianila has a drainage basin of 7,820 sq.km., of which 2,540 sq.km. are drained by the Vohitra upstream of the confluence and 1,263 sq.km. by the Iaroka as far as the Ampitambe ferry. The total length of the Rianila is 134 km. It would be longer (170 km) if the Vohitra were taken as the parent branch.

The Maningory and the Lake Alaotra basin

This basin has two depressed zones with an almost horizontal bottom, of very different sizes: the large lake basin of Alaotra and the marshy bowl of Andilamena.

The average level of Lake Alaotra is about 750 m while that of the Andilamena bowl is about 900 m above sea level. The area of the clear water surface of Lake Alaotra is about 200 sq.km., and the lake is 30 to 35 km long and 5 to 7 km wide. The marshy zone around the Lake, populated with 'Zozoro' (Cyperus Emyrnensis) covers rather more than 800 sq.km. On the edge of these marshes are the finest expanses of rice fields in the island, irrigated by dams built on the main tributaries entering the Lake: the Sasomangana and Sahabe to the south and the Sahamaloto and Anony to the north.

These rivers are short and generally drain marshy zones with a low gradient. Their sources are at a height of about 1,000 m, except for the Sahabe which rises in the south at about 1,300 m. All round the lake there is very severe erosion which raises grave problems for agricultural irrigation projects. Each river ends in a conical area of deposits forming a delta with shifting watercourses.

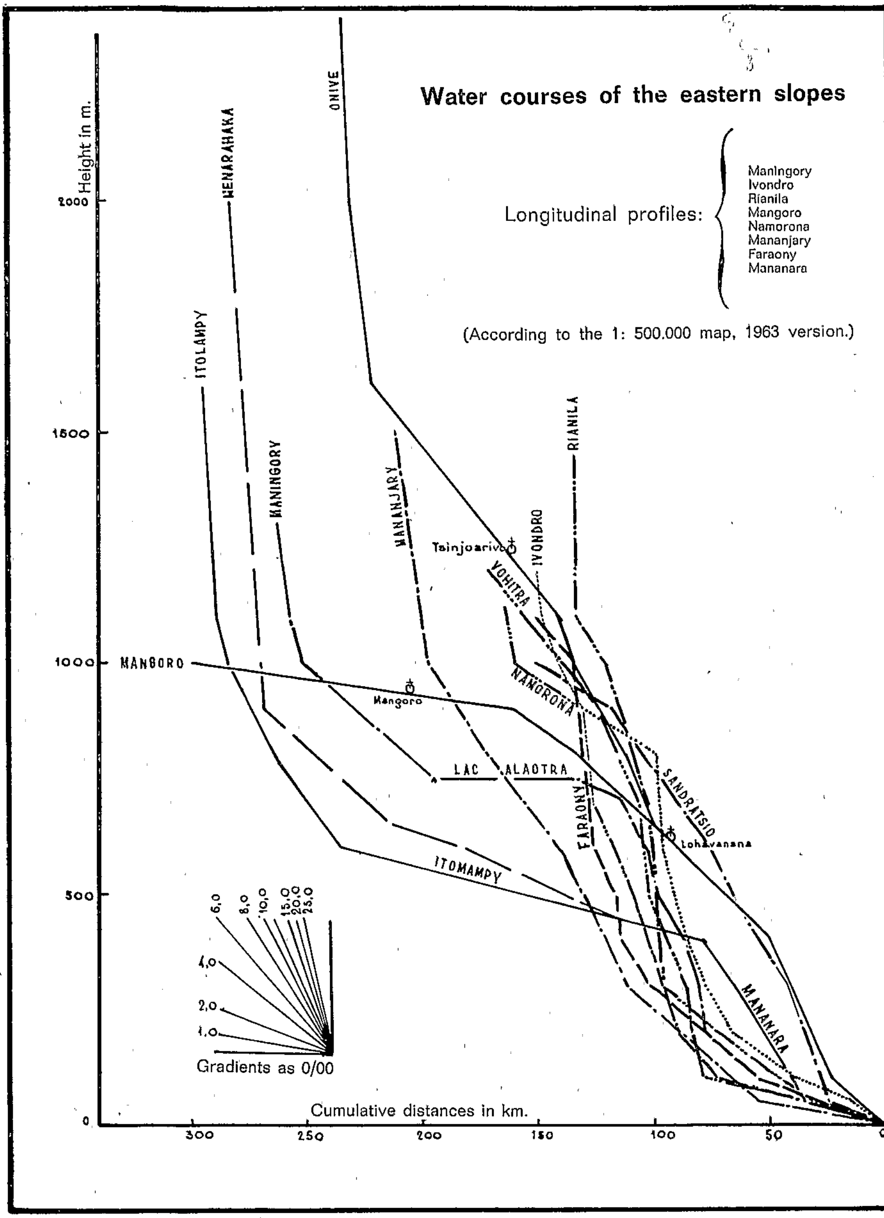
The outlet from Lake Alaotra is the Maningory. The basic level of the Lake is fixed by the rocky sills of Ambatomafana. From Ambatomafana, the Maningory runs east-west and has a gradient of about 14 m/km through the mountainous system of the east down to a height of 200 m.

After Anjahambe, the Maningory flows south-west – north-east to its confluence with the Sandratsio, its main tributary on the left bank. The river then runs east to the sea, at a slope of 1 m/km.

The Sandratsio rises in the west of the Andilamena bowl.

The Maningory and the tributaries above Lake Alaotra have a drainage basin of 12,645 sq.km. The total length of the river from the source of the Sahabe is 260 km. The Sandratsio is 125 km long from its source to the confluence.

The Mananjary rises in the same massif as the Nosivolo, a tributary of the Mangoro, to the east-south-east of Fandriana at a height of about 1,500 m. It runs more or less north-south, parallel to the schistosity plane



Water courses of the eastern slopes
Longitudinal profiles:
Maningory
Ivondro
Rianila
Mangoro
Namorona
Mananjary
Faraony
Mananara
(According to the 1: 500.000 map, 1963 version.)
Height in m.
Cumulative distances in km.
Gradients as 0/00
ONIVE
MENARAHAKA
ITOLAMPY
MANINGORY
MANANJARY
RIANILA
IVONDRO
VOHITRA
NAMORONA
MANGORO
Mangoro
Tsinjoarivo
LAC ALAOTRA
FARAONY
SANDRATSIO
Lohavanana
ITOMAMPY
MANANARA

Fig. 3.

of the crystalline rocks through which it flows. Some parts of its course take a north-west-south-east direction corresponding to the system of parallel faults found as far as the latitude of Vohipeno and typical of the hydrographic system in the region. The right bank tributaries of the Mananjary have almost parallel courses running generally north-west – south-east.

At the height of Ifanadiana, the Mananjary forks east. Its longitudinal slope decreases and is about 1 m/km to the sea, into which it flows some kilometres south of Mananjary. The longitudinal profile of the Mananjary is fairly regular for a river on the eastern slopes. There are some falls in the region of Ambodimanga. The Antsindra waterfall had been considered for a hydroelectric project. Even on the tributaries the hydroelectric possibilities are high: the Ivoanana falls at Fatihita are the most advantageous, and have already been surveyed with a view to the mining of nickel.

The Mananjary, which rises about 100 km from the coast, covers a distance of 212 km before reaching the sea. The area of its river basin is 6,780 sq.km.

Of the secondary streams, the following are worthy of mention: *The Ivondro* or Ivondrona, which rises west of the marshy plain of Didy. It flows east and the fall increases to below the Volobe works supplying Tamatave with electricity. The slope then decreases to the sea, into which the river runs slightly south of Tamatave. Its total length is 150 km and its catchment area 3,300 sq.km.

The Namorona has a long narrow basin of 2,150 sq.km. running west-east. This river has a very rugged profile in crossing the escarpment, where falls of 250 m have been reconnoitred for the installation of a power station. The Namorona is 103 km long.

The Faraony rises in the eastern escarpment, east of Fianarantsoa, and runs alternately north-west – south-east and north-south. It has a drainage basin of 2,695 sq. km. and has a total length of 150 km.

Mention is also made of: *The Matitanana*, a Vohipeno river, with a distinctive hydrographic system in which the various rivers, in plan view, form perfectly regular parallelograms. Its drainage basin covers an area of 4,395 sq.km.

The Manampatrana, a Farafangana river, rises on the eastern slope of the Andringitra. It has a basin of 4,050 sq.km.

In the south there is the Manampaniry, which runs along the *Anosyenne* chains in a south-west – north-east direction.

4. THE WESTERN SLOPES

This is the largest group. It covers almost 365,000 sq.km. or 61.3 % of the area of Madagascar. There are two groups of basins:

1. The large rivers which flood widely over the high plateaux. The

drainage basins are roughly triangular with the apex towards the coast.

2. The coastal streams flowing in between the basins of the large rivers, and whose sources are on the western edge of the high plateaux.

The profiles of the large rivers show a considerable change in gradient as they leave the crystalline bed-rock. On the highlands, the rivers pass through a series of calm reaches and rapids, while in the sedimentary zone the profile is more regular with a much lower average gradient. However, the small streams of the sedimentary bed have a regular profile without falls or rapids but with relatively steep slopes.

Another feature of the rivers of the west coast is the fact that often, mainly to the south of the Tsiribihina, the flow at low water stages decreases from the source towards the mouth. The smaller rivers with basins of less than about 1,000 sq.km. are dry from April to November.

a. The large rivers

From north to south, the main rivers are: The Sofia which rises south of Ankaizina about 1,100 m above sea level. It first runs north-south to the confluence with the Mangarahara, a stream running down from the Mandritsara ridge. It then flows west. The first part of its profile has a steep gradient to Antsakalay (10 m/km approx.) then a more gradual one from Antsakalay to level 200 when it enters the low plateau of Androna. Across this plateau there are, rapids and falls, the largest of which, 10 km above Maroaka, has a drop of 60 m over a distance of 4 km. The general direction remains east-west and the Sofia runs out into Mahajamba bay through a delta 20 km long and some 10 km wide. The drainage basin, which covers an area of 27,315 sq.km., does not extend far to the north; the tributaries on the right bank are small and short (about 20 to 50 km). However, it extends a long way to the south, as far as the plateau of Analaromaso, not far from the Andilamena bowl.

The main left-bank tributaries are: The Mangarahara which flows south from the Mahakira plateau, crosses Mandritsara and then turns north until it joins the Sofia.

The Anjobony which rises near the Ampariririmbaratra (1,201 m) and flows generally south-east – north-west to its confluence.

The Bemarivo, which runs into the Anjobony a few kilometres before its confluence with the Sofia, rises on Mount Antolana (1,199 m) west of Andilamena. From its source to Miarinarivo, the Bemarivo is known as the Ankobaka. It flows north. After Miarinarivo, the slope decreases considerably and the river meanders widely following a general direction parallel to that of the Anjobony. Slightly north-east of Mampikony, the Bemarivo enters the permotriassic depression and follows a south-north direction until it reaches the Sofia.

In the lower part of their courses, all these streams have a very wide bed

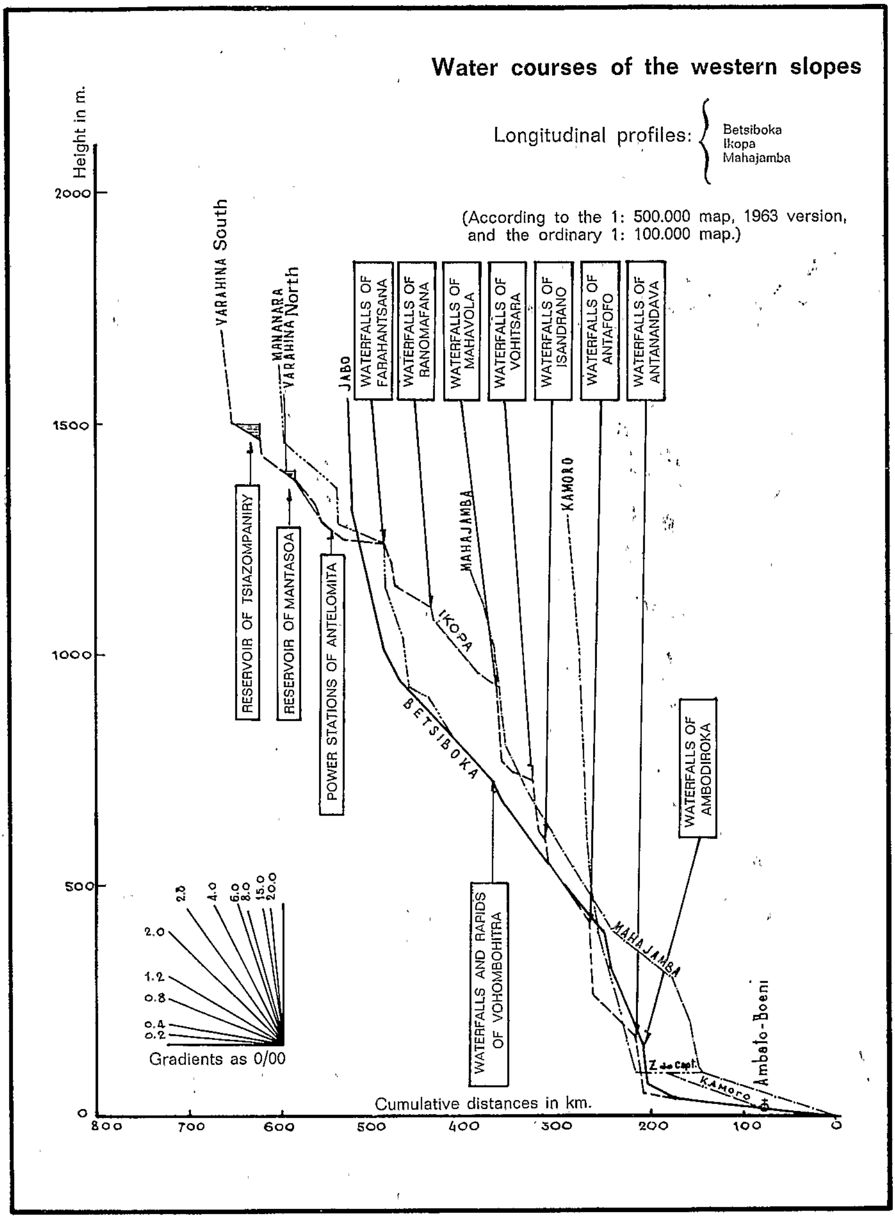

Water courses of the western slopes
Longitudinal profiles:
Betsiboka
Ikopa
Mahajamba
(According to the 1: 500.000 map, 1963 version, and the ordinary 1: 100.000 map.)
Height in m.
2000
1500
1000
500
0
VARAHINA South
MANANARA
VARAHINA North
JABO
WATERFALLS OF FARAHANTSANA
WATERFALLS OF RANOMAFANA
WATERFALLS OF MAHAVOLA
WATERFALLS OF VOHITSARA
WATERFALLS OF ISANDRANO
WATERFALLS OF ANTAFOFO
WATERFALLS OF ANTANANDAVA
RESERVOIR OF TSIAZOMPANIRY
RESERVOIR OF MANTASOA
POWER STATIONS OF ANTELOMITA
KAMORO
MAHAJAMBA
IKOPA
BETSIBOKA
WATERFALLS OF AMBODIROKA
WATERFALLS AND RAPIDS OF VOHOMBOHITRA
MAHAJAMBA
Z. de Capt.
KAMORO
Ambato-Boeni
2.5
4.0
6.0
8.0
15.0
20.0
2.0
1.2
0.8
0.4
0.2
Gradients as 0/00
Cumulative distances in km.
800
700
600
500
400
300
200
100
0

Fig. 4.

dotted with sandbanks at low water, with very large flood plains on either side.

The total length of the Sofia is 328 km. The Anjobony is 200 km long and the Bemarivo 265 km. The Bemarivo river basin has an area of 15,270 sq.km., more than half the Sofia basin.

The Betsiboka-Mahajamba group

As the Mahajamba is captured by the Kamoro in the Morafeno region east of Tsaramandroso, although some of the Mahajamba's flow still runs into the Mozambique Channel, it is difficult to separate the two catchment areas of the Betsiboka and the Mahajamba. This is therefore the largest river basin in Madagascar since it covers 63,450 sq.km. The largest river in this system is the Betsiboka.

In its upper course, the Betsiboka is formed by the junction of the Jabo and the Amparihibe. These two streams rise north of Tananarive: the Jabo in the Iangana mountains at a height of 1,550 m and the Amparihibe, known as the Lelosy at its source, in the Ankiranjay massif. The very dense hydrographic system makes it difficult to determine the main stream.

Their general direction is south-north with a very steep slope of about 10 m/km. The confluence is at the outlet from the Antanetibe plain at a height of 938 m and 471 km from the sea.

The river then takes the name of Betsiboka. It is already a large river with several tributaries, including on the right bank the Mananara, the length and height of the source of which could make it the parent branch of the Betsiboka (to the confluence the Mananara is 186 km long and the Betsiboka 112 km). The Mananara crosses three large plains (Alakamisy, Anjozorobe, Andakana) separated by sills and large falls.

Swollen by the Mananara, the Betsiboka continues north towards the Vohombohitra massif. After turning sharply west, it flows round this massif on the west, in fairly deep, narrow gorges, for a distance of 16 km. The slope is fairly steep and consideration has been given to constructing a regulating dam at this point. The drainage basin upstream from the Vohombohitra has an area of 6,315 sq.km.

After the Vohombohitra, the river again runs south-north, then south-east – north-west. The Betsiboka crosses a series of mountainous chains with rapids and falls, the largest of which are at the bridge on main road No. 4. These falls have a difference in level of 78 m over 4 km and a survey has been made of their development for hydroelectric purposes (possible annual production 3,000 million KWH).

The drainage basin to this point covers an area of 11,800 sq.km. Above the falls, the Betsiboka is joined on its right bank by the Isinko coming from the Tampoketsa Kamoreen and on its left bank by the Andriantoany.

Below the falls, the Betsiboka runs north in a bed 200 to 250 m wide with an average slope of 78 cm/km.

At 179 km from Majunga, the Betsiboka is joined on its left bank by the Ikopa, its largest tributary. The Ikopa is formed by the junction of the South Varahina and the North Varahina, on which the Tsiazompaniry dam was built in 1956 and the Mantasoa dam in 1938, to regulate low water flows. Since 1956 the Mantasoa dam has been supplying the Mandraka hydroelectric station through the Ampasimpotsy spill way. The waters of this basin are thus used under a fall of 250 m instead of 36 m at the Antelomita stations on the Ikopa.

The confluence of the two Varahina rivers is 6 km upstream of the Antelomita falls where since 1909 and 1918 there have been two hydroelectric stations supplying electricity to Tananarive.

After the confluence the river becomes the Ikopa. It runs east-west in a relatively deep, narrow bed, with an average slope of 2 m/km as far as Ambohimanambola. It then enters the plain of Tananarive. Its course is revetted almost as far as Bevomanga over a distance of 45 km. The average slope is very low, about 25 cm/km and possibly only 13 cm/km upstream of the confluence with the Andromba. In the Tananarive plain, the Ikopa is joined on the left bank by the Sisaony and the Andromba swollen by the Katsaoka and on the right bank by the Mamba.

The basic level of the Betsimitatatra plain is formed by the Bevomanga-Farahantsana sill which the Ikopa crosses in a series of falls and rapids, the largest of which, Farahantsana, has a change in level of 37 m. At Farahantsana, the drainage basin of the Ikopa is 4,498 sq.km.

From the Farahantsana falls to below the Antanandava falls, where the river leaves the crystalline bed-rock, we find a new river, with a very young profile and large falls. 259 km upstream from the Betsiboka confluence and 44 km downstream from Farahantsana, the Ranomafana waterfall is the first large waterfall (40 m) in the second part of the Ikopa's course. 14 km downstream, where the river crosses the Ambilobe massif, there is a drop of 160 m over 6 km at the Mahavola falls. 32 km below them are the Vohitsara falls (100 m over 5 km), then the Isandrano falls 9 km further on (about 50 m over 4 km) and 44 km further downstream the Antafofo falls with a drop of 180 m in 10 km. At this point the area of the drainage basin is about 19,000 sq.km.

The last important falls are those of Antanandava with a total drop of 135 m over 10 km. At the foot of the falls, at the entrance to the peripheral depression, the river is 50 m above sea level and has another 31 km to travel to the confluence with the Betsiboka. The Ikopa then runs north-east in a very wide bed between large flood plains sometimes 3 km wide. The slope is only 26 cm/km.

The main tributaries of the Ikopa are the Kotoratsy, Isandrano and Menavava on the left bank and the Manankazo, Andranobe and Namokomita on the right bank.

Above their confluence, the Ikopa and the Betsiboka have very marked profiles, with features that differ greatly from the source onwards.

The Betsiboka has a fairly clear regular concavity from the source of the Jabo to the Vohombohitra massif. The river appears to have reached equilibrium in its profile here. At places (Jabo-Amparihibe confluence) it is below the equilibrium profile, which causes considerable alluviation injurious to the rice fields. Below Vohombohitra, the profile is marked by falls and rapids and has a very steep slope difficult to use for hydroelectrical purposes because of the absence of any large vertical falls and the configuration of the bed, often wide with fairly low banks.

Throughout the central part of its course, although the suspended load carried is considerable there is no sedimentation as the slope gives the river a high transport capacity.

From its source to its mouth, the Ikopa has three very different profiles: As far as the Farahantsana sill, there is the very regular equilibrium profile of a mature river, sometimes even at the limit of under-adaptation (Tananarive plain).

Further downstream, the profile shows very great variations in slope due to the local geological conditions and the average slope is very high (4.40 m/km), the river dropping from 1,150 m to 50 m in 296 km.

The third section downstream of Antanandava is well below its equilibrium profile. Its average slope is 50 cm/km approximately. Over the last twenty kilometres, the slope is equal to 26 cm/km. It is therefore three times less than that of the Betsiboka over the same distance upstream.

Because of the topographical and geological features, the Ikopa has the greatest hydroelectric resources on the island, estimated at some fifteen thousand million KWH per annum.

The Ikopa-Betsiboka confluence is in a marshy zone in which the beds shift frequently. The distance from the sea is 179 km. Between the confluence and Ambato-Boeni, the slope is 40 cm/km. It is only 10 cm/km between Ambato-Boeni and Majunga. At Ambato-Boeni, the Betsiboka is joined by the Kamoro on its right bank. At Marovoay, 61 km from Majunga, the Betsiboka forms a large delta through a dense mangrove swamp. Above Majunga, a narrowing at the Antanandava headland changes the delta into an estuary which is known as Bombetoka.

The total length of the Betsiboka is 531 km from the source of the Jabo to the sea and 605 km starting from the source of the Mananara. The Ikopa, from the source of the South Varahina, is 485 km long to the confluence with the Betsiboka and 664 km to the sea. The Betsiboka basin covers 49,000 sq.km. (this number does not include the upper Mahajamba).

The Mahajamba, captured by the Kamoro, flows almost entirely into the Betsiboka basin. It rises on the high plateaux of Anjafy, in the Amparihinandriambavy lake, about 1,100 m above sea level. It runs roughly south-north with a fairly steep slope over the first 60 km (8 m/km). This slope reduces slightly as far as Tsaratanana, after which it again increases when crossing the western edge of the high plateaux (about 200 m over 26 km, or 7.6 m/km).

In contact with the sedimentary cover, the slope reduces (70 cm/km). This sudden change in slope is probably the cause of the capture of the Mahajamba by the Kamoro.

The Mahajamba has a high transport capacity and because the slope decreases this capacity declines suddenly so that there is intense aggradation which has forced the Mahajamba to cut a course towards the west when in spate. At low water, all its water goes to the Kamoro and the bed, as far as the sea, receives only the waters from small streams such as the Andranolava and the Kimangoro.

Since 1903, the capture appears to have been stable. However, the Mahajamba might resume its former course when the bed of the Kamoro has risen sufficiently.

The remainder of the Mahajamba reaches the sea through a delta.

The distance from the capture zone to the sea is 145 km. The length of the Mahajamba above the capture is 153 km and it has a basin of 9,750 sq.km. The distance from the source of the Kamoro to Ambato-Boeni is 145 km.

The South Mahavavy rises in the Andranofotsibe massif at a height of about 1,000 m. On the right bank it is joined by the Kiranomena and the Manamidona which flow down from the Famoizankova.

The general direction of its course is south-north. The slope is very steep as far as Kandreho, 125 km from its source (about 7 m/km). The Mahavavy then enters the peripheral depression and is joined on its left bank by the Mahakambana which flows down from the Manerinerina sill and runs entirely in the depression. The very sudden change in gradient greatly modifies the form of the river. It becomes wider with very marked meanders. The Mahavavy then crosses the Ankara and Kelifely limestone plateaux in fairly deep gorges.

Below Sitampiky, at 280 km from its source, the slope is only 40 cm/km. The river is bordered with large lakes and marshes (Kinkony, Katondro) which at high water periods are filled by the waters of the Mahavavy.

The Mahavavy runs out into the Mozambique Channel through a very wide delta on which there are the Namakia sugar cane plantations.

With a length of 410 km, running roughly along the meridian 46 °E, the Mahavavy has a drainage basin of 16,475 sq.km.

The Manambolo rises in the Ankaroka chain at a height of 1,250 m, about 25 km north-east of Tsiroanomandidy. It flows west, skirting the Bevato mountain to the south, across the peneplain of Tsiroanomandidy and then down the Bongolava escarpment. In the Betsiriry depression, its general direction becomes north-south with much less of a slope. The Bemaraha plateau, which the Manambolo crosses in deep, narrow gorges above Bekopaka, turns it west again. It runs out into the Mozambique Channel through a small delta. Its basin has an area of 13,970 sq.km.

and it has a total length of 370 km. Its main right-bank tributary is the Manambolomaty which drains the north of the Betsiriry depression.

The Tsiribihina has the third largest river basin in Madagascar and probably occupies second place after the Betsiboka as regards the volume of water it carries annually. It is constituted by the junction, on leaving the crystalline bed-rock, of the Mahajilo and the Mania, which drain the high plateaux, the Sakeny and the Manandaza running south-north and north-south in the Betsiriry plain.

The largest streams are obviously those coming from the high plateaux.

The Kitsamby rises in the Ankaratra massif near the Tsiafajavona at a height of about 2,500 m. To the confluence with the Sakay it is a real torrent which drops 1,800 m in less than 140 km, an average slope of almost 13 m/km. The Sakay rises east of Tsiroanomandidy on a marshy plateau 1,400 m high. The waters of Lake Itasy flow into it on its left bank through the Lily.

Across the rugged relief of the region, the streams take a very sinuous course with valleys that are often precipitous.

After their junction, the Kitsamby and the Sakay form the Mahajilo. The general direction becomes east-west to Miandrivazo, then in the Betsiriry plain the Mahajilo runs south to the confluence with the Mania and the Sakeny. The slope is very steep to Miandrivazo and particularly down the Bongolava where the river drops 200 m in 17 km.

The Mania rises on the edge of the eastern escarpment, north-east of Fandriana, at a height of about 1,800 m, where it is known as the Fisakana. Its course is very sinuous, running generally east-west. It crosses several mountain chains and the finest falls are downstream of the Soavina plain, with a loss of height of about 200 m over 10 km. In the Bongolava, the slope is slightly less steep than that of the Mahajilo. The Mania is joined on its right bank by the Manandona which drains the Antsirabe region, then the Iandratsy which comes from the Betafo region. On the left bank, the main tributary is the Ivato.

The Sakeny rises in the north of the Makay massif and runs south-north into the Betsiriry depression. Its slope is relatively gentle and its bed is very wide and very mobile at low water.

The three rivers join in the Betsiriry, in a low marshy zone, with numerous lakes that are full at high water and empty in the dry season by infiltration and/or evaporation.

The Tsiribihina then runs west and crosses the Bemaraha plateau in a steep-sided gorge. On leaving this plateau, the Tsiribihina becomes very wide, with numerous flood plains and lakes all the way to the sea. At flood water periods, large areas of land are carried away almost every year, which raises serious problems for the plantations near the banks. After Belo, the Tsiribihina enters the sea through a huge delta which extends over 35 km in a north-south direction and which is slowly moving out to sea.

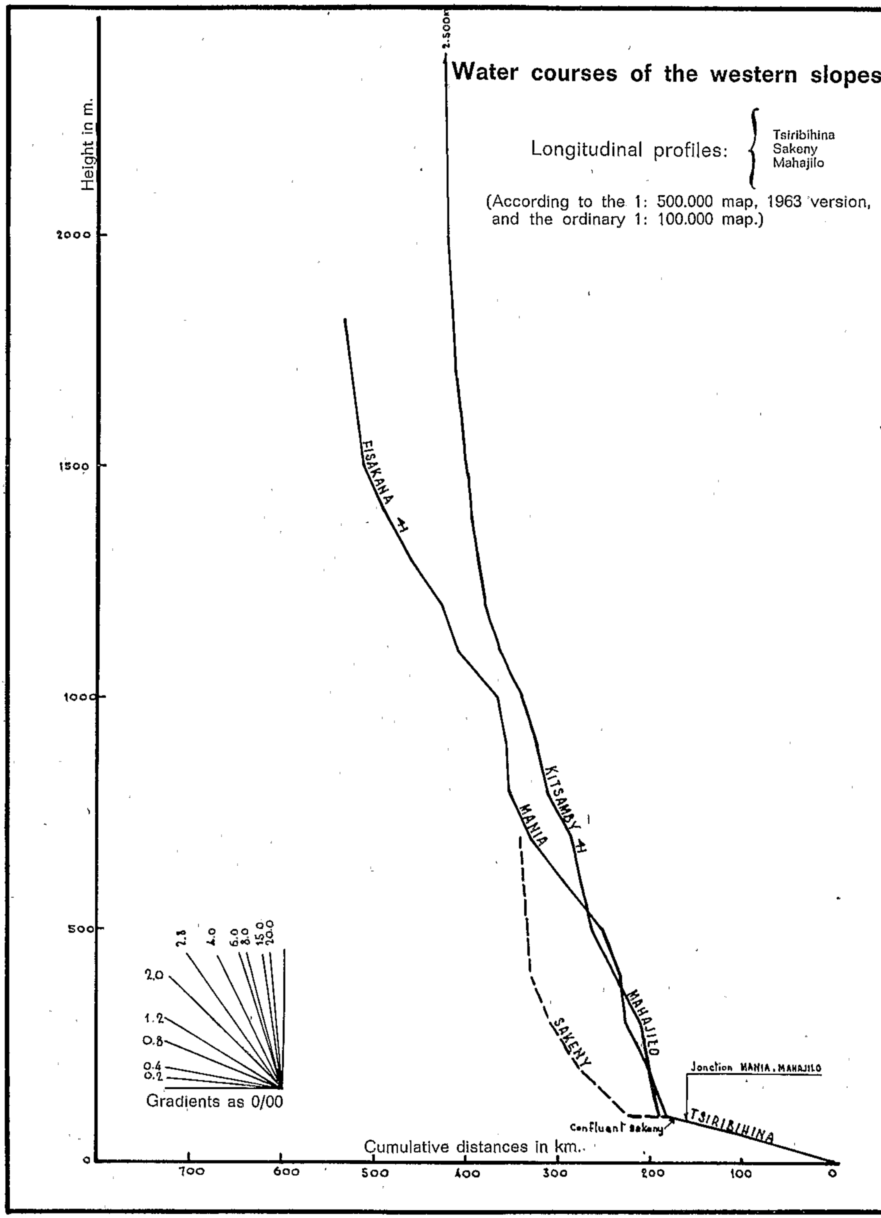

Water courses of the western slopes
Longitudinal profiles:
Tsiribihina
Sakeny
Mahajilo
(According to the 1: 500.000 map, 1963 version, and the ordinary 1: 100.000 map.)
Height in m.
2.500
2000
1500
1000
500
0
FISAKANA
KITSAMBY
MANIA
MAHAJILO
SAKENY
TSIRIBIHINA
Jonction MANIA. MAHAJILO
Confluent Sakeny
Cumulative distances in km.
700
600
500
400
300
200
100
0
2.8
4.0
6.0
8.0
15.0
20.0
2.0
1.2
0.8
0.4
0.2
Gradients as 0/00

Fig. 5.

The total length of the Tsiribihina from the source of the Fisakana is 525 km. The Sakeny is 170 km long and the Mahajilo-Kitsamby 260 km.

The total drainage basin covers an area of 49,800 sq.km. of which 7,025 sq.km. is accounted for by the Sakeny. 14,500 sq.km. by the Mahajilo and 18,565 sq.km. by the Mania.

There are extensive possibilities for power projects in the upper reaches of the two main rivers. The only part in use at present is a small falls on the Manandona which supplies Antsirabe.

The Mangoky, with the largest drainage basin in Madagascar, consists of the Matsiatra, the Mananantanana and the Zomandao which meet in the crystalline-sedimentary contact zone about 300 km from the Mozambique Channel.

The Matsiatra rises at a height of 1,250 m in the Tsitondroina massif. For the first five kilometres of its course it runs south. It then crosses flat and marshy regions for 80 km and as far as the confluence with the Fanindrona on the right bank the slope is about 0.50 m/km.

In the Isandra granite massif, the slope is 14 m/km in places. There are numerous rapids, but no real falls. The last quartzite foothills of the Itremo give it a relatively steep slope. Then the Matsiatra runs, at an altitude of 750 m, into the Ikalamavony plain. Its bed widens and several calm reaches are defined by rocky sills with scattered islands.

At Iovolo, the Matsiatra slants north and runs in an east-south-east – west-north-west direction to Fitampito. The average slope is about 2.3‰. It is joined by two large tributaries on the right bank: the Isaka and the Matanaika. Below Fitampito it again turns east-west and the slope increases slightly (3.6 m/km) until it leaves the Malakialina gorges, with sections of 8.6 m/km in the Vohimena gneiss. On leaving these formations the Matsiatra turns south and runs in a very wide bed (200 to 300 m in places) dotted with sand banks at low water.

The average slope over this stretch is 1.1 m/km. At about 310 m above sea level, a fault again brings the strata of the upper Sakoa into contact with the micaschists and gneiss of the Vohimena series through which the Matsiatra cuts in gorges 200 to 300 m deep before it enters the Sakamena depression and joins the Mangoky at a height of 206 m. The average slope in the gorges is about 4.8 m/km. The total length of the Matsiatra is 410 km. The loss of height is about 1,050 m, an average slope of 2.6 m/km. Above the confluence the Matsiatra river basin has an area of 13,370 sq.km.

The Mananantanana rises on the eastern slopes of the Tsitondroina (2,019 m) at a height of about 1,850 m and for the first few kilometres it flows east. After 10 km the torrent is at a height of 1,000 m. Various granitic massifs divert it first south then west and finally on an east-south-east – west-north-west course in the direction of Ambalavao. Its course is very sinuous and the huge loop south-east of Ambalavao is very spectacular. The general slope is about 0.5 m/km.

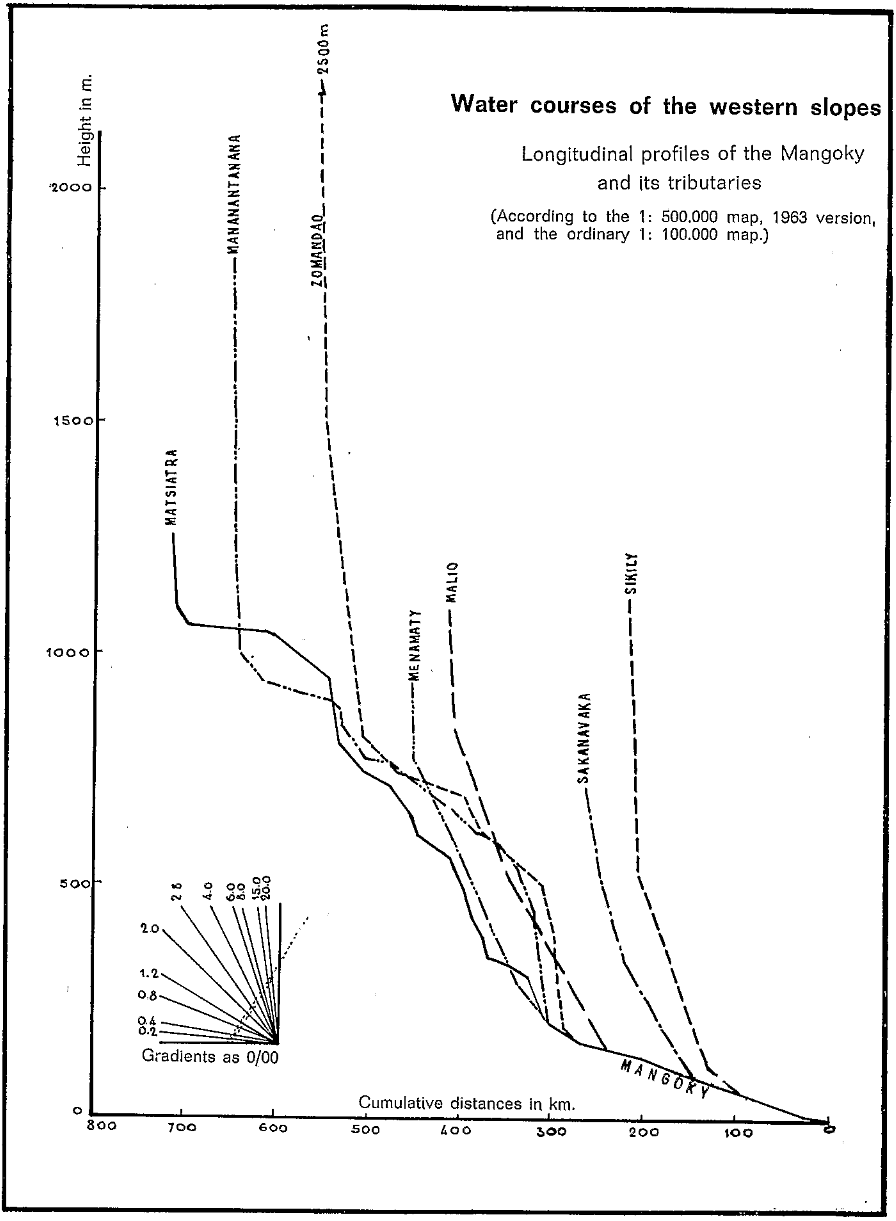

Water courses of the western slopes
Longitudinal profiles of the Mangoky
and its tributaries
(According to the 1: 500.000 map, 1963 version,
and the ordinary 1: 100.000 map.)
Height in m.
2000
1500
1000
500
0
800
700
600
500
400
300
200
100
0
Cumulative distances in km.
2500 m
MATSIATRA
MANANANTANANA
ZOMANDAO
MENAMATY
MALIO
SAKANAVAKA
SIKILY
MANGOKY
2.0
1.2
0.8
0.4
0.2
2.8
4.0
6.0
8.0
15.0
20.0
Gradients as 0/00

Fig. 6.

It has two left-bank tributaries, the Manandriana and the Manambolo. When it crosses the Ringoringo quartzite massif (1,456 m), the slope increases (4.3‰ for 12 km) and then drops to less than 1 m/km as far as Solila.

From Solila to Tsitondroina, the Mananantanana continues its course towards the west – north-west. It is a majestic river, flowing between low banks, generally bordered with wide strips of forest. The general slope of the bed is 1.5 m/km. On this stretch, the largest right-bank tributary, the Manambovo enters the Mananantanana.

At Tsitondroina, the gauge is approximately at level 600. Then the river turns south-west because of the obstacle formed by the Ambohibola massif. The slope increases slightly (2.5‰). It crosses the Betainamboa (911 m), Ambararatakolo (933 m) and Mahatsinjoroa (695 m) massifs in an east-west direction in fairly narrow gorges with a slope of 4 to 5 m/km from a height of about 450 m.

The Mananantanana joins the Mangoky at a height of 206 m. The average slope over the last 21 km is about 12 m/km, or about three times as steep as that of the Matsiatra upstream of the confluence. This is due to the different direction taken by the two rivers when crossing the Vohimena micaschists and gneiss: the Matsiatra roughly follows the axis of the various folds, while the Mananantanana crosses them at right angles, which gives it a 'staircase' profile with a steeper slope. From its source until it joins the Mangoky, the Mananantanana is 350 km long. It falls about 1,640 m with an average slope of 4.7 m/km. The total area of its basin is 7,680 sq.km.

The Zomandao rises on the north-eastern face of the Boby peak, in the Andringitra massif, about 2,500 m above sea level. Over the first 51 km the slope is steep, as the river drops from 2,500 to 824 m. After Ankaramena, at a height of about 760 m, it enters the Zomandao plain and the average slope is then only 1 m/km. The main tributary is the Fenoarivo on the right bank which comes from the quartzite chains of the Ampizaramaso (1,464 m). After this confluence, the appearance of the river changes. The bed is cut by numerous sills and the slope increases, sometimes to as much as 4 m/km.

At 213 km from its source, the Zomandao is joined on its left bank by the Ihosy, whose very narrow upper basin is in places only about 6 km wide, from one ridge to the other. The common course of these two rivers runs east-south-east – west-north-west to the western edge of the crystalline structure, with an average slope of about 2 m/km. The Zomandao then runs west through gorges similar to those of the Matsiatra and the Mananantanana, cut in the same formations of the Vohimena. In this section, the longitudinal slope is very steep, averaging 9.5‰ with stretches of 20 m/km in the central part.

The Zomandao enters the Mangoky slightly upstream of Iaviry at a height of about 177 m. Over the last 10 km, when it is already in the lower Sakamena formations, the slope is only 2.3 m/km. The Zomandao is 283 km long from its source to the confluence with the Mangoky. Its average slope is 8.2 m/km and the area of its basin 10,300 sq.km.

The Ihosy is 304 km long from its source to the confluence with the Zomandao, its average slope is 2.4 m/km, and its drainage basin 3,700 sq.km.

After the confluence of the Matsiatra and the Mananantanana, the Mangoky flows west in a bed cut into the last outcrops of gneiss of the Androyen system and the Vohimena.

At 25 km from Salio, the Mangoky is joined by the Zomandao and to Beroroha the general direction is north-east – south-west. The very wide bed is bordered by large flood plains, probably vestiges of old abandoned beds. The slope is about 1.2 m/km.

Slightly below Beroroha, at a height of 153 m, the Mangoky is joined by the Malio and the Isahena which rise in the Isalo massif. These two rivers transport large quantities of sand which are deposited in the Mangoky, considerably widening its bed (2 to 2.5 km below Beroroha). The slope, 0.45 m/km immediately above Beroroha, is 0.60 m/km below it, because of the sandy deposits.

From Beroroha to the confluence with the Sikily, 61 km from the sea, the Mangoky runs more or less east-west and crosses in turn the jurassic calcareous cuestas of Ianbinda, Isalo III and the hard Arcovian sandstone in a series of narrows and gorges. The Banian hydrological station is situated in the latter.

The main tributaries join it on the left bank; they are the Sakamavaka and the Sikily. These streams, which flood very suddenly, are dry for six months from June to November.

The calcareous cuesta of Nosy-Ambositra diverts the Mangoky to the north-west. It keeps this direction to the sea. The bed becomes very wide (1 to 2 km) with flood plains up to 5 or 6 km wide. Traces of former beds can be seen on the right bank, opposite Bevoay.

The Mangoky delta forms a characteristic triangle 80 km in height and some 50 km wide along the coast. In the south the Ihotry lake may indicate a former course of the river which followed a east-west direction from Nosy-Ambositra and entered the sea south of Morombe.

At the level of the Samangoky station at Tanandava, the Kitombo is a perfectly preserved former bed which ceased to be used about a century ago.

The Mangoky now seems to be about to abandon the northern distributary, known as the Anzakomangabe, which only contains water at flood periods. A movement south has already started. During the years 1964–65 and 1965–66 we were able to travel by canoe on distributaries which only two years before had been tiny channels no more than 1 to 2 m wide and a few tens of centimetres deep. This is the case with the Andranolava south of Antongo which in less than two years has become an enormous channel averaging 100 m wide and 3 to 4 m deep. The whole region along this watercourse resembles a flooded zone, the trees are dying because they are always under water and in the delta the eastern border of the mangroves is receding as the quantity of salt water is probably becoming too low. The main distributary, the Antongo, is gradually sanding up and the vezo canoes now travel up the Mangoky along the new arm. Even at medium water levels, the Andranoleva arm resembles a river in spate with water to the top of the banks, often with a strong current, trying to cut a path through the forest and the 'baiboho'.

The Mangoky is 304 km long from its source to the Matsiatra-Manan-antanana confluence and has an average slope of 0.67 m/km. If the Matsiatra is considered as the parent branch of the Mangoky, the total length is 714 km. From the source of the Ihosy it is 821 km or about 100 km longer. The Mangoky is thus the longest river in Madagascar, considerably longer than the Betsiboka which, even measured from the source of the Mananara, is only 605 km long to the sea. The total area of the Mangoky basin is 55,750 sq.km. It is the largest river basin in Madagascar, as the Betsiboka, not counting the Mahajamba, has a basin of only 49,000 sq.km.

The Onilahy is formed by the junction of the Isoanala, the Ihazofotsy, the Mangoky and the Imaloto. The main branch of the river is the Mangoky which rises in the Ivakoany massif at about 1,300 m. Its general direction is south-north to Betroka. It runs through a relatively low and marshy zone where numerous rice fields have been established along the river.

After Betroka, the Horombe counterforts divert the Mangoky west then south-west. The slope of the bed increases considerably up to the confluence with the Imaloto, as it crosses the eastern edge of the high plateaux (7 m/km average, but more than 20 m/km in places).

The Imaloto, then known as the Lalana, rises east of Betroka in the Kalambatitra counterforts at a height of about 1,200 m. The Lalana first runs north, then slants west and crosses the Horombe plateau. On leaving the plateau, it is joined on the right bank by the Ihazofotsy which flows east of the Isalo in a general north-south direction.

After their junction, the river is called the Imaloto and continues south to the confluence with the Mangoky.

The Ihazofotsy and the Isoanala drain the southern part of the basin.

On leaving the Isalo, the Onilahy runs due west in a very wide bed dotted with sandbanks at low water and meandering extensively, especially in the latter part of its course. The Onilahy enters the Mozambique Channel through an estuary, into Saint Augustine Bay. The river loses considerable quantities of water as it crosses the calcareous plateaux, as is shown by the resurgences found all along the coast, particularly at Sarodrano. In the sedimentary zone, the main tributaries on the right bank are the Sakamare and the Taheza which flow down from the Isalo

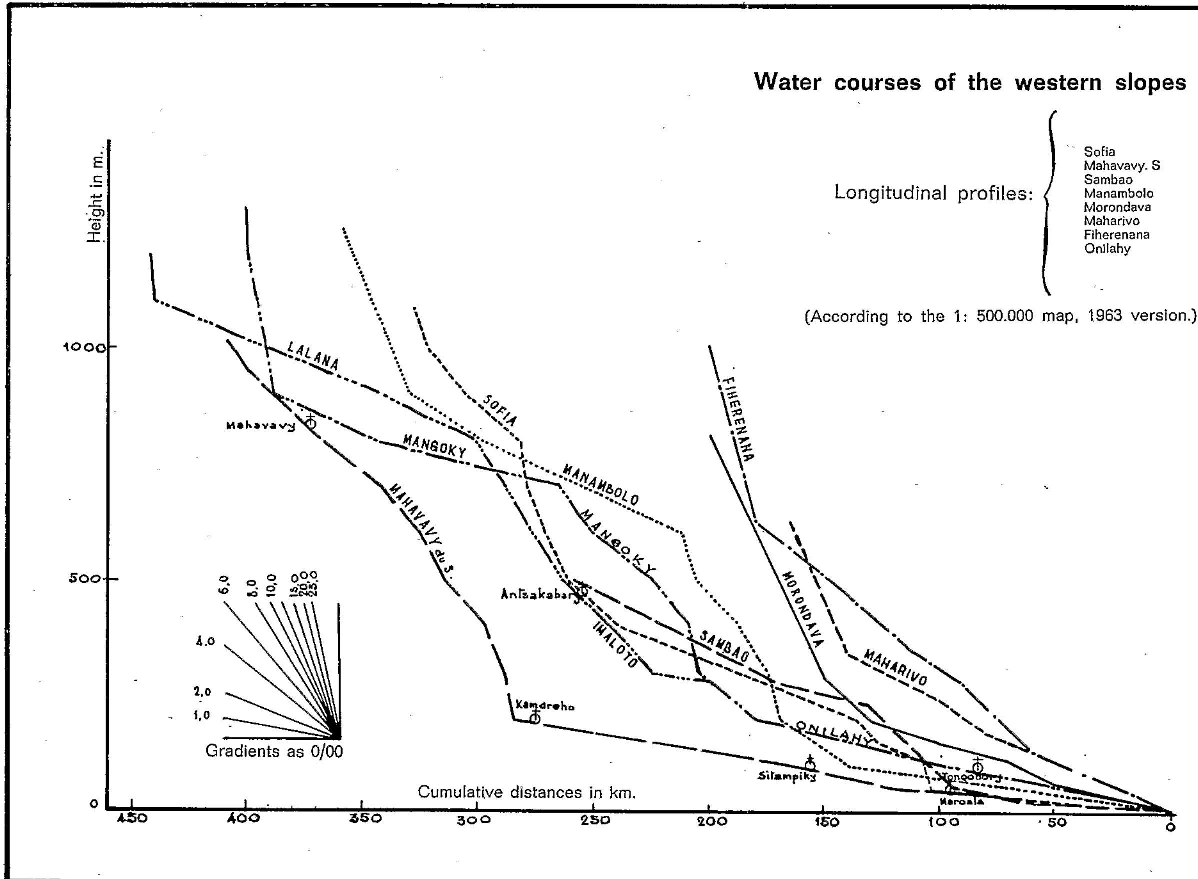

Water courses of the western slopes
Longitudinal profiles:
Sofia
Mahavavy. S
Sambao
Manambolo
Morondava
Maharivo
Fiherenana
Onilahy
(According to the 1: 500.000 map, 1963 version.)
Height in m.
1000
500
0
Cumulative distances in km.
450
400
350
300
250
200
150
100
50
0
LALANA
SOFIA
FIHERENANA
MANGOKY
MANAMBOLO
MAHAVAVY du S.
MANGOKY
MORONDAVA
SAMBAO
IMALOTO
MAHARIVO
ONILAHY
Mahavavy
Antsakabary
Kandreho
Sitampiky
Tongobory
Marosia
6,0
8,0
10,0
15,0
20,0
25,0
4,0
2,0
1,0
Gradients as 0/00

Fig. 7.

massif and are never dry. On the left bank there is no large tributary. The Onilahy is 400 km long from the source of the Mangoky. The Imaloto and Lalana are 242 km long to the confluence. The area of the drainage basin is 32,000 sq.km.

b. The small coastal rivers

We shall only mention the most important, from north to south:

The Ankofia rises north of Northern Befandriana, has a basin of 2,500 sq.km. and runs into the Loza.

The Tsinjonorona rises in the Analamontana (1,005 m) and runs north-west. It is joined on its left bank by the Doroa. The drainage basin has an area of 3,980 sq.km. The two rivers enter the upper part of the Loza through a delta.

The Sambao runs down from the Maherinerina sill and drains the region of the Bekobaba domes. North of Besalampy, it crosses a marshy zone, and enters the sea through a delta. The area of the drainage basin is 6,040 sq.km. and its total length is 250 km.

The Manabaho with its main left-bank tributary, the Bemarivo, has a basin of 8,060 sq.km. Its length is 340 km.

The Morondava rises in the Makay massif. Below Ankilizato, it crosses the escarpment of the sandstone-marl complex in a deep valley, then on leaving the valley spreads out into a wide and very shifting bed. Near the Mahabo, the Kabatomena is a former bed of the Morondava. The drainage basin has an area of 6,400 sq.km. and the length of the watercourse is about 200 km.

The Maharivo also runs down from the Makay massif. However, its basin is smaller than that of the Morondava, only 4,700 sq.km. At low water, the upper course is dry for much of the year. From its source to the sea, the Maharivo is 165 km long.

The Fiherenana is a very capricious river running down from the Isalo massif and subject to very high spate waters which sometimes flood Tulear. The course runs south-west. The Fiherenana enters the sea above Tulear in a low region where the bed is not yet stabilised. It is about 200 km long and has a basin of 7,600 sq.km.

5. THE SOUTHERN SLOPES

These cover an area of 48,750 sq.km. or about 8.2% of the area of Madagascar, and the whole region is south of the Tropic of Capricorn.

They may be divided into three parts: In the East, the Mandrare basin, the shape and situation of which make it a separate geographical entity.

In the centre, three rivers Manambovo, Menarandra and Linta, making up the majority of the hydrographic network of the Androy region.

In the West, the calcareous Mahafaly plateau almost totally void of surface water and rivers.

In the Androy region there are also several closed bowls, without any outlet to the sea, the largest of which is the Ampamalora bowl north of Ambovombe.

The Mandrare. Surrounded on the east by the Anosyenne chains and in the north by the Ivakoany massif, the Mandrare basin has a very typical circular shape.

The Mandrare rises in the Beampingaratra massif, near the Trafonaomby peak (1,957 m) at almost 1,800 m. During the first few kilometres of its course, it runs north in a deep, narrow tectonic valley. It has a steep slope and its bed is interrupted by numerous falls and rapids. A hydro-electric development project has been considered in the Andetsy region.

On leaving the granitic massif, and as far as Mahaly, the direction becomes east-west and the slope decreases considerably (2.5 m/km). The river crosses the rhyolitic chain of the Ivohibaria and the Ampahigolo a few kilometres downstream of Mahaly, at a height of about 200 m, in a relatively narrow defile in which a regulating dam has been considered. It then runs south – south-west to Ifotaka where a recent volcanic outflow diverts it south – south-east towards the sea. The slope is only about 1.3 m/km. The bed between steep banks makes it difficult to use the water for irrigation. It is the only Malagasian river with such a regular longitudinal profile very close to the equilibrium profile.

The main tributaries are the Manambovo which runs down from the western slope of the Trafonaomby, first flowing west then north, and entering the Mandrare on its left bank a few kilometres above Mahaly. The second large left bank tributary, the Mananara, rises in the south spurs of the *Anosyenne* chains and enters the Mandrare above Amboasary South. A dam at Beraketa enables its waters to be used to irrigate the Behara plain.

On the right bank, a whole series of small streams drain the southern slopes of the Ivakoany massif, the largest being the Andratina.

The Mandrare has a basin of 12,570 sq.km. and its total length is 270 km.

The Manambovo. This river, with a relatively small basin (4,450 sq.km.) rises north of Antanimora, in the Androy peneplain. It runs roughly north-south. It very rapidly digs a deep bed in the alluvial material. The average slope is fairly steep, between 2.5 and 3 m/km. For 7 to 8 months, there is no surface flow. The total length is 165 km.

The Menarandra. After the Mandrare, this is the largest river in the south. It rises west of the Isoanala in the Tsikoriky massif (1,425 m) at a height of about 800 m. It first flows north-east – south-west, then north-south.

As far as Bekily, the bed is barred by rocky sills which are frequently not continuous. At Bekily it is joined on its left bank by the Manantanana.

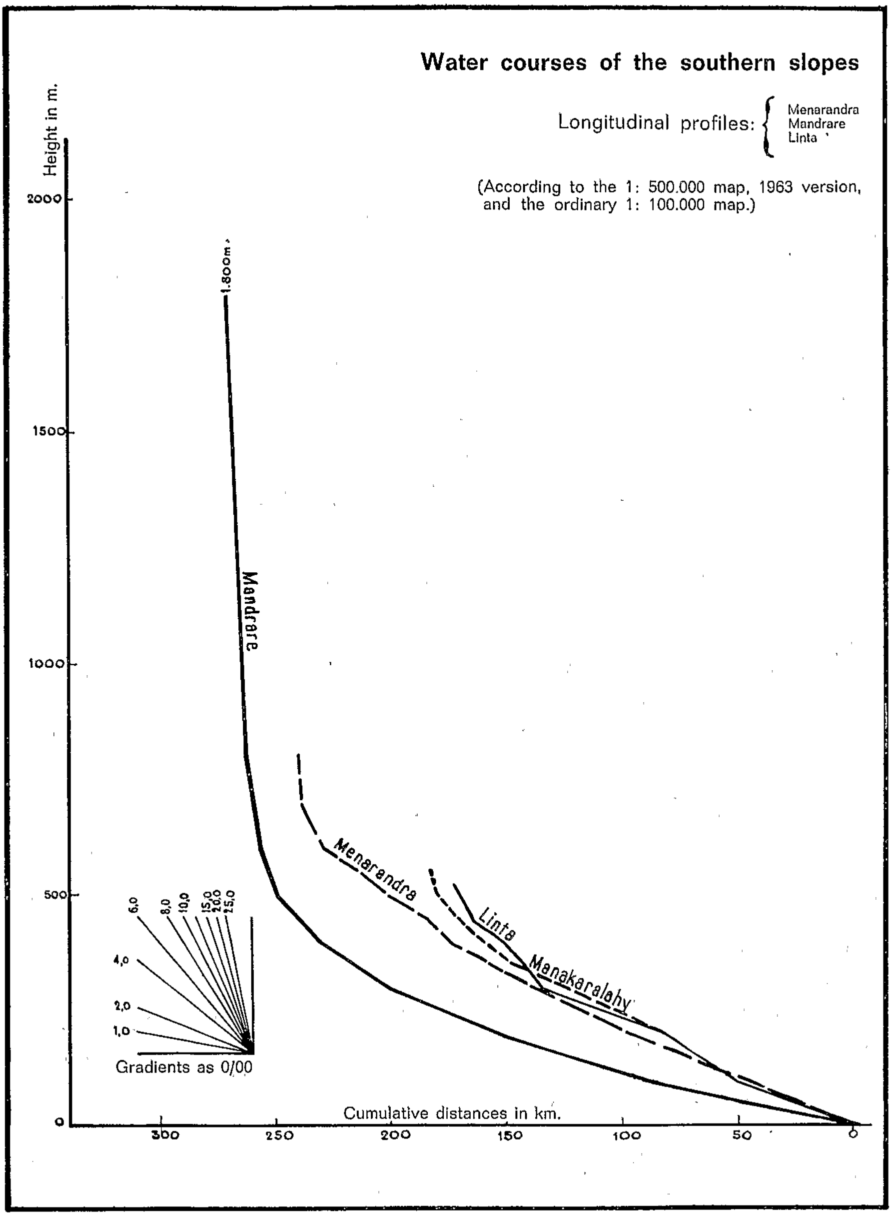

Water courses of the southern slopes
Longitudinal profiles:
Menarandra
Mandrare
Linta
(According to the 1: 500.000 map, 1963 version, and the ordinary 1: 100.000 map.)
Height in m.
2000
1500
1000
500
0
1.800m.
Mandrare
Menarandra
Linta
Manakaralahy
6,0
8,0
10,0
15,0
20,0
25,0
4,0
2,0
1,0
Gradients as 0/00
Cumulative distances in km.
300
250
200
150
100
50
0

Fig. 8.

These two branches may dry up completely in the dry season. The main tributary, which has water throughout the year, is the Menakompy which joins the river on its right bank 30 km below Bekily.

The Menarandra runs south – south-east in a wide bed, dug into alluvial material, where at low water there is a thin trickle of water which often disappears above Ampotaka. On the Menarandra, the low water flows increase regularly as far as Tranoroa, then decrease from Tranoroa to the sea.

Below Bekily, the bed is interrupted by two rocky and very fissured sills, one at Tranoroa, the other at Riambe. These are not visible on the profile which shows a steep but regular slope of about 2.50 m/km from a height of 600 m to the sea. The drainage basin of the Menarandra has an area of 8,350 sq.km. Its total length is 235 km.

The Linta. This river, less well supplied, drains a smaller basin (5,800 sq.km.) On leaving the gneiss formation, it has a very wide bed, completely dry from April to December. It rises in the Fotadrevo region at a height of about 520 m. Below Ejeda, it has two main tributaries on its left bank, the Manakaralahy and the Manakaravavy, which are dry from July to November. The Linta enters the sea east of Androka after covering 173 km.

A few kilometres above its mouth, a well has been dug near the bed and the underground water is pumped up by a windmill to supply the livestock in the region.

II. Hydrology

GENERAL FEATURES OF THE VARIOUS REGIMES

The hydrological regime of a water course is subject to the influence of various factors, the main ones being: rainfall, the size, shape and exposure of the drainage basins, the relief, the geological characteristics, vegetation, etc.

The primary factor is always rainfall and the curves of discharge variations show great similarity with the rainfall curves. Other factors sometimes conceal or slightly modify the rain-river discharge relation, but there is always a correlation, in particular between annual rainfall and annual average discharge.

During the year, the discharges follow the seasonal variations in rainfall and over the island as a whole there is a high water period from November to March-April corresponding to the rainy season and a low water period from April to October during the dry season. In some regions, particularly on the eastern coast and the high plateaux, the rainy season is sometimes interrupted at the end of January or beginning of February by a drier period during which the discharges may dwindle to fairly low values, but this generally lasts only a few days and cannot be

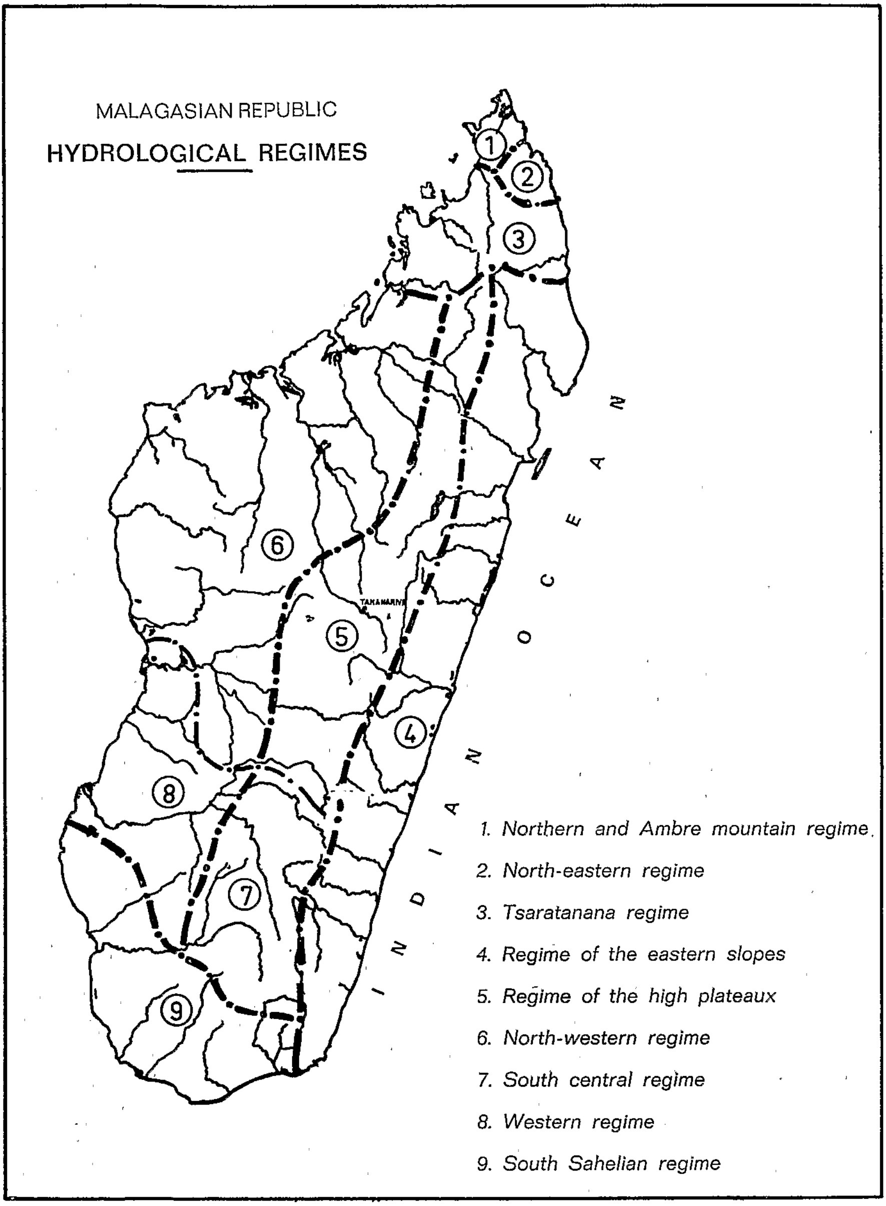

MALAGASIAN REPUBLIC
HYDROLOGICAL REGIMES
1
2
3
4
5
6
7
8
9
INDIAN OCEAN
1. Northern and Ambre mountain regime
2. North-eastern regime
3. Tsaratanana regime
4. Regime of the eastern slopes
5. Regime of the high plateaux
6. North-western regime
7. South central regime
8. Western regime
9. South Sahelian regime

Fig. 9.

compared to the minor dry season of the regimes in Equatorial Africa. The regime of the Malagasian watercourses is therefore a tropical one with two clearly defined seasons.

When this regime is studied in detail, it is striking to see that the rivers react almost instantaneously to precipitation. Any storm or period of rain immediately swells the waters. The curves of discharge variation take a sawtooth form, with a peak almost every day during the rainy season. These daily flood peaks are not very well known because the maxima generally occur at night and, except in cases when hydrological stations have automatic stage recorders, they are never observed.

It should also be noted that the use of water for irrigation, ranging from the family channel to the large agricultural hydraulic development project causes a modification, sometimes a very large one, of low water flows.

The distinction between the various hydrological regimes is not always obvious. However, on the basis of the interannual isohyets and the shape of the relief, the following regimes can be distinguished from north to south:

- The northern or Ambre mountain regime
- the north-eastern regime
- the Tsaratanana regime
- the eastern coast regime
- the high plateaux regime
- the north-western regime
- the southern central regime
- the western regime
- the South Sahelian regime

However, another regime must be added to these, which will be called the 'mixed regime' and which occurs most frequently. This is in particular the regime of the large rivers whose very large drainage basins extend over several regions having different regimes. It is generally difficult to determine the share of each elementary regime in the overall regime, but the effect of each of them on high or low water is very clear.

1. The northern or Ambre mountain regime

Little is as yet known of this regime. Rain is abundant from November to April but is largely absorbed by the fissured basalts.

The drainage basins are very small (about a hundred sq.km. maximum) and always very elongated. The ground is very permeable. Therefore the low water discharge is fairly abundant but the flood waters are relatively low.

On the Sakaramy-Be, with a drainage basin of 18 sq.km. the low water discharge is about 20 to 30 l/s (1 to 2 l/s/sq.km). The high water discharge values are not really known (the peaks occurring at night are not recorded) but the annual high water discharge must be about 10 to 15 cu.m./s (200 l/s/sq.km approx.) These high waters are of very short duration (a few hours) and the discharge rapidly reverts to a value close to that at the start. As a result the modules (or annual mean discharges) have lower values than would be indicated by the amount of annual rainfall, close to 1 cu.m./s (30 to 50 l/s/sq.km.

The run-off coefficients are difficult to determine with the information available. They are certainly low, which implies a considerable *drainage deficit* of about 1,400 mm.

2. *North-eastern regime*

This distinction is based on the relief and the rainfall. Between Tsaratanana and the Ambre mountain, the relief is not very accentuated and the rainfall is much less than on the Ambre Mountain (1,200 mm average compared to 2,500 mm). The hydrology of this region has not as yet been studied precisely and we cannot therefore give figures to define the regime. The low water discharge must be less abundant than that noted in the Ambre mountain.

3. *Tsaratanana regime*

The Tsaratanana massif receives a high annual rainfall averaging about 2,500 mm. Little is known about the sheets of water falling on the peaks. They are probably very high, at least 3,000 mm. This high rainfall occurs from November to April, but during the dry season there is still an appreciable quantity of rain. The steep slopes observed on all the rivers running down from the Tsaratanana causes very sudden flood waters with very high specific peak discharges, the maximum of which, corresponding to late afternoon rain, almost always occurs during the night. Because of the 'relative humidity' of the dry season, the low water flows are well sustained.

This regime is at present studied only on the western and northern slopes: Sambirano at Ambanja, Ramena at Ambodimanga and Northern Mahavavy at Ambilobe. The discharge of the first two basins is best known. The respective areas are 2,800 sq.km. for the Sambirano and 1.080 sq.km. for the Ramena. No observations have been made on the eastern slope.

The low water discharges generally occur in the second half of November: they are from 10 to 15 cu.m./s (3.5 to 5 l/s/sq.km) for the Sambirano and 2 to 8 cu.m/s (1.8 to 7.4 l/s/sq.km.) for the Ramena.

The first high waters occur at the beginning of November with values close to 100 cu.m./s, but the highest are in January, February and March. The annual spate values are between 400 and 1,000 cu.m./s on the Sambirano (130 to 350 l/s/sq.km) and between 200 and 700 cu.m/s for

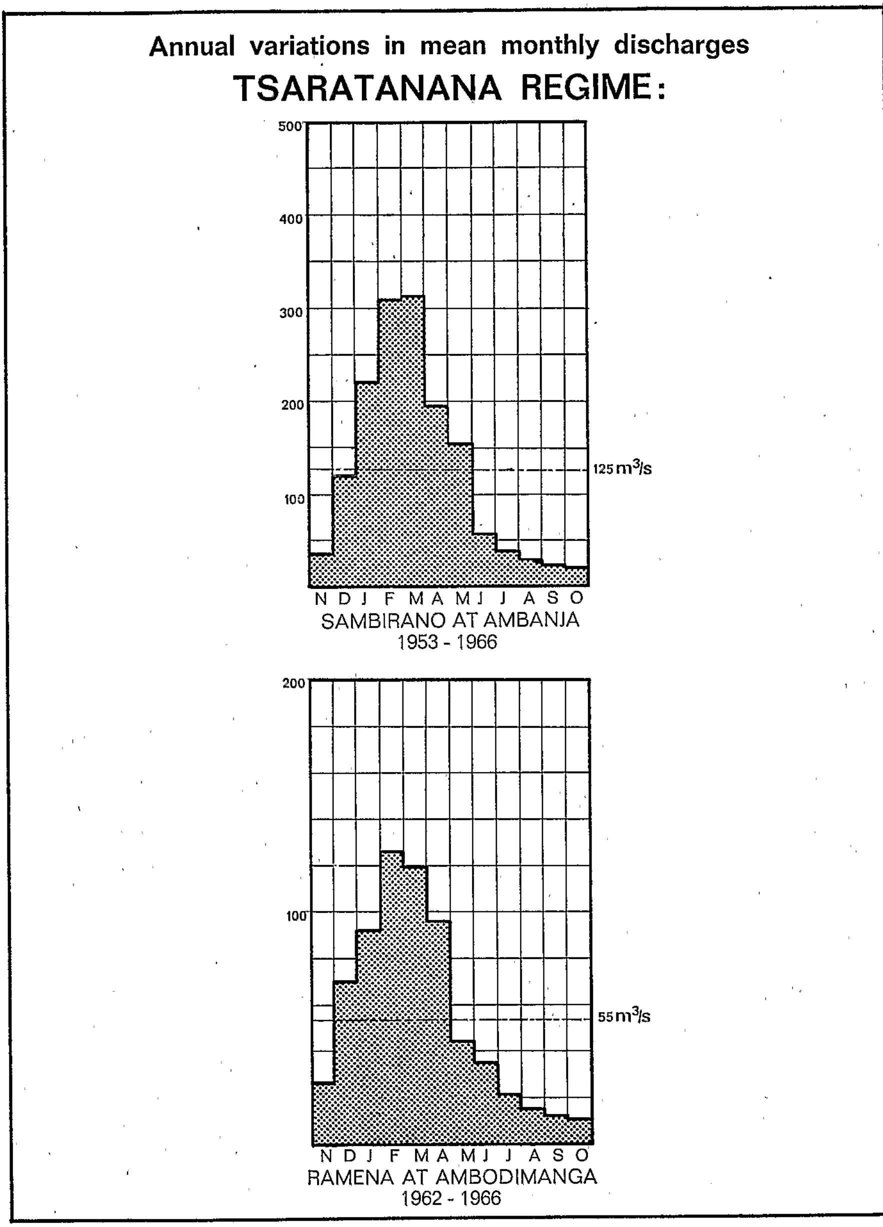

Annual variations in mean monthly discharges
TSARATANANA REGIME:
500
400
300
200
100
125 m³/s
N D J F M A M J J A S O
SAMBIRANO AT AMBANJA
1953 - 1966
200
100
55 m³/s
N D J F M A M J J A S O
RAMENA AT AMBODIMANGA
1962 - 1966

Fig. 10.

the Ramena (180 to 650 l/s/sq.km). The exceptional high waters occurring after a cyclone may reach much higher values. During the cyclone in March 1959, the Sambirano at Ambanja rose to a level of 12.59 m, corresponding to a discharge of about 2,500 to 3,000 m cu.m/sec, or about 1,000 l/s/sq.km. The annual modules are between 100 and 180 cu.m/s on the Sambirano at Ambanja (35 to 65 l/sec/sq.km.) and between 50 and 11 cu.m./sec on the Ramena (45 to 93 l/s/sq.km.). The annual drainage deficits must be about 1,000 mm.

4. Regime of the eastern slopes

The annual average rainfall is very high, between 2,500 and 3,000 mm from north to south. The highest rainfalls are recorded from December to May. During the dry season, the trade winds from the south-east bring drizzling rain which, despite its low intensity, can sometimes cause fairly high waters. The driest months are generally September and October.

This rainfall regime gives rise to abundant rivers throughout the year. Because of the rugged relief and the direct exposure of the slopes to the cyclones coming from the Indian Ocean, the flood waters are always very violent.

The low water discharge is very high, about 15 to 30 l/s/sq.km. Exceptionally, however, the values may be much lower. The following have been noted:

13 cu.m./s on the Vohitra at Rogez (or 7 l/s/sq.km.)
2 cu.m./s on the Namorona at Vohiparara (or 4.5 l/s/sq.km.)
31 cu.m/s on the Ivodro at Ringaringa (or 11 l/s/sq.km.)
16 cu.m./s on the Faraony at Vohilava (or 8 l/s/sq.km.)

Generally the lowest discharge is observed during November or December. However, sometimes the rivers run completely dry in July.

The specific discharges in the annual spates vary according to the dimensions of the basin, its relief, its geological nature and its plant cover. They are always very high and are generally between 200 and 800 l/s/sq.km. for basins of more than 1,000 sq.km.

The cyclones in March 1959 produced flood waters with much higher values:

1,935 cu.m/s on the Ivondro, or 700 l/s/sq.km.
3,950 cu.m./s on the Vohitra, or 2,160 l/s/sq.km.
840 cu.m/s on the Ivoanana or 1,000 l/s/sq.km.

During cyclone floods, the water level varies very rapidly and very greatly. Ten to fifteen metres difference in level between low water and the highest flood level are quite common. In February 1945, the Faraony even rose to the first floor level of the Sahasinaka station, 21 m above low water level.

The average annual specific discharges are between 20 and 100 l/s/sq.km. This high discharge results from favourable conditions. The high rainfall is only partly lost through evaporation, as the relative humidity of the air is always very high and the average temperature relatively low.

For annual modules, the maximum, minimum and average values recorded in the observation periods available to us at the various stations are as follows:

ANNUAL MODULES

Stations	Drainage basin sq.km.	Maximum m^3/s	$l/s/km^2$	Minimum $m^3/2$	$l/s/km^2$	Average m^3/s	$l/s/km^2$
Vohitra at Rogez	1 950	130	67	40	21	76	39
Ivondro at Ringaringa	2 175	118	48	59	23	93	33
Rianila at Brickaville	5 875	625	105	332	55	408	70
Namorona at Vohiparara	445	25	56	7.5	17	13	29
Ivoanana at Fatihita	835	73	87	29	35	48	57
Mananjary at Antsindra	2 260	145	64	95	42	116	51
Faraony at Vohilava	1 987	172	86	67	34	102	51
Efaho at Fanjahira	195	18	92	7	36	12	61

With the high average annual discharge and the steep slope of the beds, the eastern slopes have a vast potential from the point of view of hydroelectric projects.

The *drainage deficits* on the eastern slopes are probably between 700 and 900 mm.

5. *The regime of the high plateaux*

This regime applies in the region extending south of Tsaratanana to the Ambalavao escarpment more than 1,000 m. high.

The seasons are clearly marked: the rainy season from November to April with maximum rainfall in January, the dry season from April to October with a few showers or drizzle particularly in July-August, corresponding to the strengthening of the trade winds. The average annual rainfall is between 1,200 and 1,800 mm.

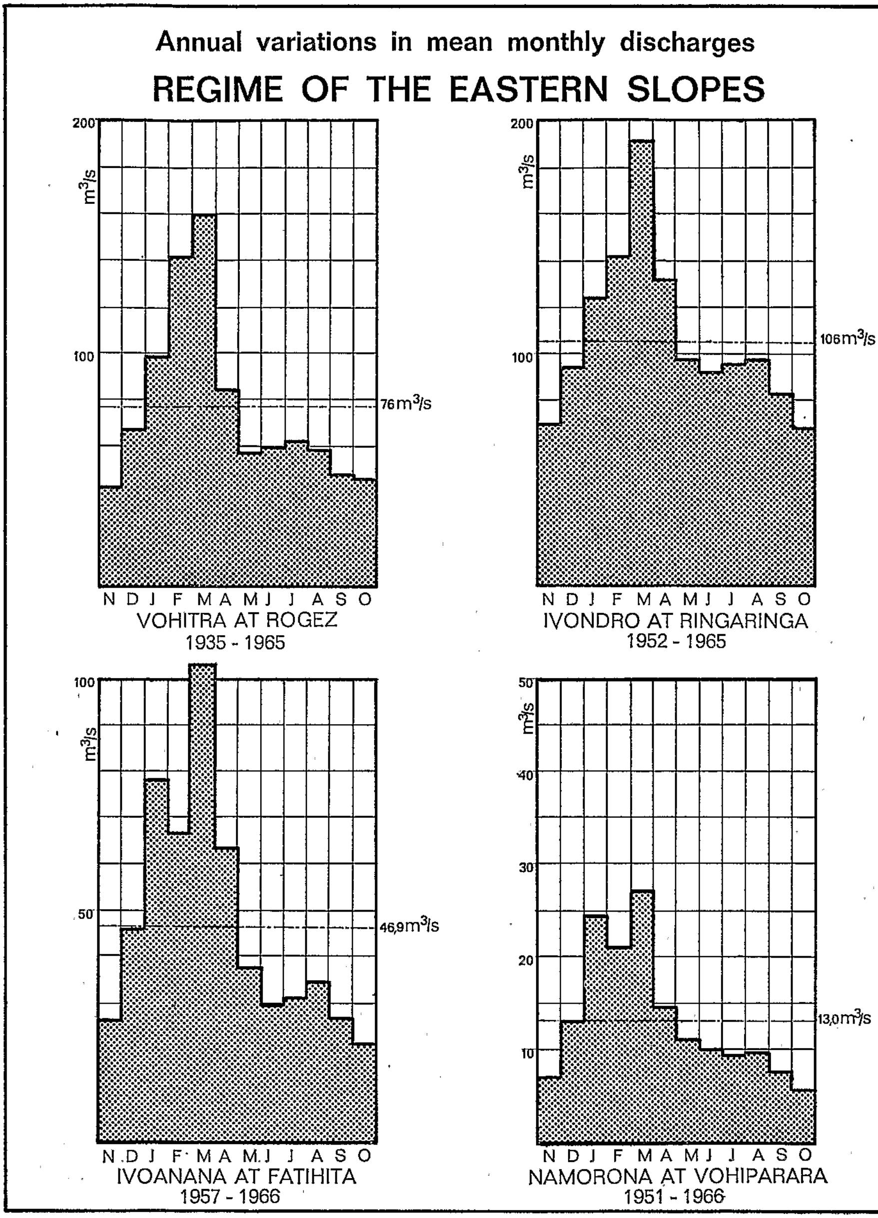

Annual variations in mean monthly discharges
REGIME OF THE EASTERN SLOPES
200
m3/s
100
76m3/s
N D J F M A M J J A S O
VOHITRA AT ROGEZ
1935 - 1965
200
m3/s
100
106m3/s
N D J F M A M J J A S O
IVONDRO AT RINGARINGA
1952 - 1965
100
m3/s
50
46,9m3/s
N D J F M A M J J A S O
IVOANANA AT FATIHITA
1957 - 1966
50
m3/s
40
30
20
10
13,0m3/s
N D J F M A M J J A S O
NAMORONA AT VOHIPARARA
1951 - 1966

Fig. 11.

The rivers are well supplied. The generally abundant annual modules, however, have specific discharge rates lower than on the east coast. The high waters are also less violent (less steep slopes, often with plains or marshes at the head of the basin). Exceptional flood waters are always recorded during cyclones and the specific discharge may then be high. Low waters, although less abundant than on the east coast, are generally well sustained because of the high retention capacity of the laterites forming almost the whole of the cover of the basins. However, as already pointed out, these low water levels may be greatly modified by irrigation of the ricefields extending over very large areas on the high plateaux.

This regime applies to the upper part of the catchment basins of all the large rivers in Madagascar.

The low water discharge varies from 1 to 15 l/s/sq.km. The lowest value is due to diversion for irrigation. However, in a basin of the high plateaux where there are no ricefields the specific low water discharge should probably be about 5 l/s/sq.km. The low water period is from 15th October to 30th November approximately.

There follow some of the maximum and minimum values observed on the plateaux:

Stations	Drainage basin sq.km.	Low water discharge Maximum		Low water discharge Minimum	
		m^3/s	$l/s/km^2$	m^3/s	$l/s/km^2$
Andromba at Tsinjony	350	4.9	14	0.8	2.3
Mandraka at P.K. 68	57	0.95	14.7	0.15	2.6
Sisaony at Andramasina	318	0.87	2.7	2.0	0.63
Ikopa at Bevomanga	4 247	23	5.4	8	1.9
Ikopa at Fiadanana ferry	9 450	42	4.2	24	2.5
Mania at Fasimena	6 675	54	8.0	32	4.7
Mangoro at Mangoro	3 600	24.5	6.8	18	5.0
Amborompotsy at Antsampandrano	95	0.87	9.7	0.68	7.2
Onive at Tsinjoarivo	2 990	17.4	6.0	3.2	1.1

The rivers come into spate with the first storms at the end of November or beginning of December and continue thus to the end of March. These waters are generally not very high. The highest discharge is recorded during cyclones. However, on the Ikopa, at the Fiadanana ferry (9,450 sq.km) a high water discharge of 1,710 cu.m./s was recorded in February 1964, caused solely by a succession of violent storms, whereas the figure for the high water discharge caused by the cyclone in March 1959 was only 1,330 cu.m./s.

The specific discharge for annual spates is generally about 200 l/s/sq.km. while exceptionally high waters may amount to 200 to 1,000 l/s/sq.km.

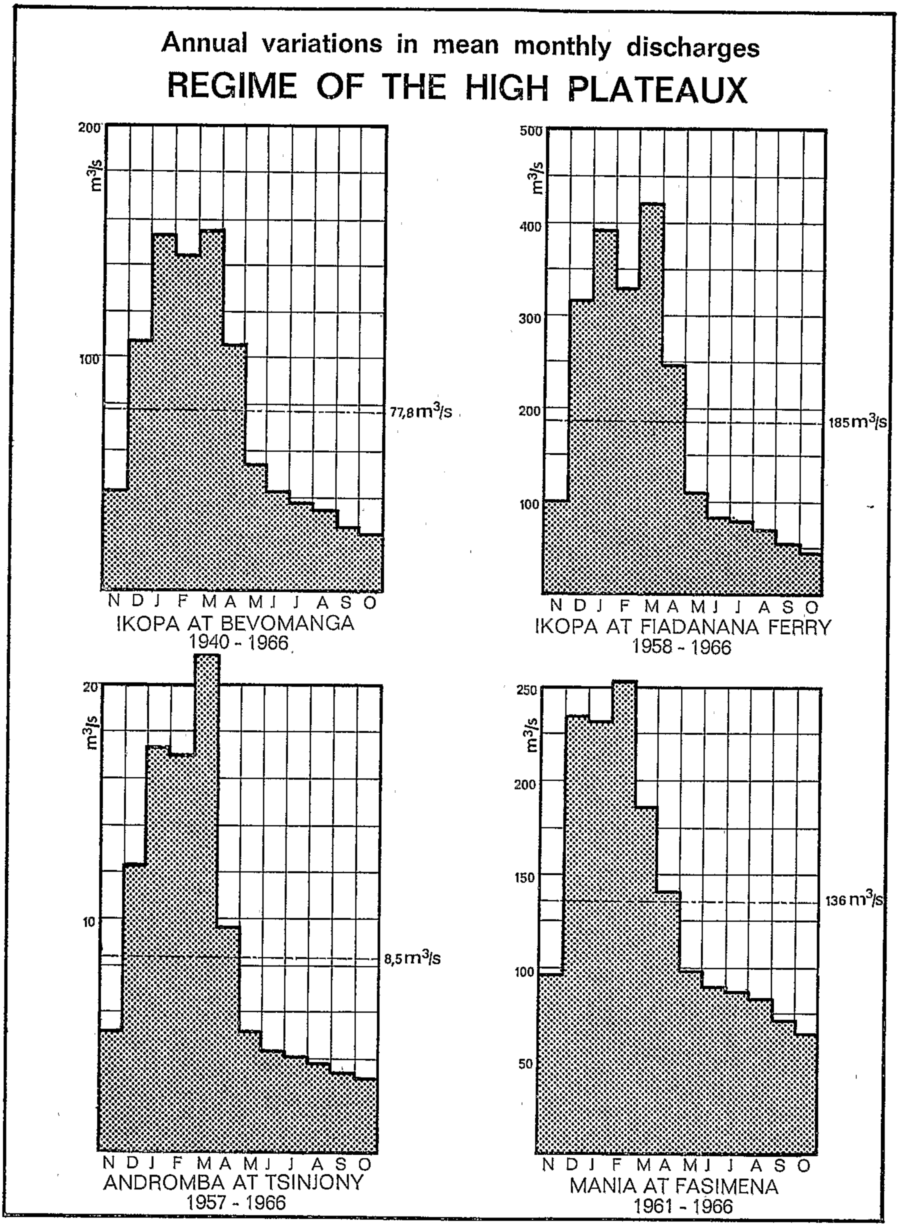
During the cyclone in March 1959, we observed the following, values:

	710 cu.m./s on the Ikopa at Antelomita	or 580 l/s/sq.km.
	565 cu.m./s on the Ikopa at Bevomanga	or 133 l/s/sq.km.
	1330 cu.m./s on the Ikopa at Fiadanana ferry	or 141 l/s/sq.km.
	297 cu.m./s on the Sisaony at Andramasina	or 930 l/s/sq.km.
	360 cu.m./s on the Sisaony at P.K. 22	or 570 l/s/sq.km.
	206 cu.m./s on the Andromba at Tsinjony	or 590 l/s/sq.km.
about	2500 cu.m./s on the Mangoro at Mangoro station	or 695 l/s/sq.km.

These numbers clearly show the influence of the flat marshy zones on high water discharge. On leaving the Tananarive plain, the exceptional high water discharge is 130 l/s/sq.km. whereas it was almost 600 on entering it. Across the plain, the high waters spread out considerably as they flood the low parts. The specific high water discharge also depends on the size of the basin. On a catchment area of 5 sq.km near Tananarive, the specific discharge for the highest water level observed is about 10

ANNUAL MODULES

Stations	Drainage basin sq.km.	Maximum		Minimum		Average	
		m^3/s	$l/s/km^2$	m^3/s	$l/s/km^2$	m^3/s	$l/s/km^2$
Amborompotsy at Antsampandrano	95	3.65	38	1.70	18	2.91	30
Ikopa at Bevomanga	4250	123	28	55	11	76	18
Ikopa at Fiadanana ferry	9450	277	29	119	12	187	20
Andromba at Tsinjony	350	14	40	6.5	18	9.0	25
Mangoro at Mangoro station				54	15		



Annual variations in mean monthly discharges
REGIME OF THE HIGH PLATEAUX
200
m3/s
100
77,8 m3/s
N D J F M A M J J A S O
IKOPA AT BEVOMANGA
1940 - 1966
500
m3/s
400
300
200
100
185 m3/s
N D J F M A M J J A S O
IKOPA AT FIADANANA FERRY
1958 - 1966
20
m3/s
10
8,5 m3/s
N D J F M A M J J A S O
ANDROMBA AT TSINJONY
1957 - 1966
250
m3/s
200
150
100
50
136 m3/s
N D J F M A M J J A S O
MANIA AT FASIMENA
1961 - 1966

Fig. 12.

Annual variations in mean monthly discharges

NORTH-WESTERN REGIME

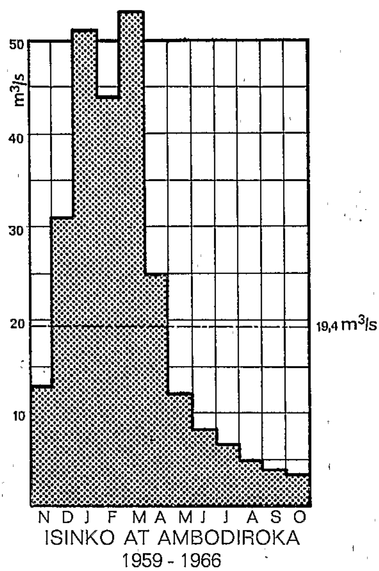


Fig. 13.

cu./s/sq.km. The annual average discharge on the high plateaux with a rainfall of 1,500 mm is about 15 to 50 l/s/sq.km. The above table shows some values of the modules observed on the rivers of the high plateaux.

The average annual run-off coefficients are between 40 and 60%. The drainage deficits are about 650 to 700 mm.

6. The regime of the north-west coast

This regime applies to the rivers between the Maevarano in the north and the Tsiribihina in the south. This region has an average annual rainfall of about 1,600 to 1,800 mm.

There is little flow at low water and the dry bed curves are fairly clear because of the almost total absence of rain during the cool season. On leaving the crystalline bed-rock the discharge generally decreases further downstream because of the lack of any supply in the sedimentary region. However, this phenomenon is less marked than in the regimes of the west and south coasts.

There are few hydrological stations in this zone. According to data available to us, the low water discharge is a few litres per second per sq.km.: 2 l/s/sq.km. on the South Mahavavy at Sitampiky, 1.8 to 5.8 l/s/sq.km. for the Isinko at Ambodiroka.

The high waters come very suddenly and for basins of 500 to 1,000 sq.km. the specific discharge is about 1,500 to 1,000 l/s/sq.km. On smaller drainage basins, the high waters are even more violent. At Ambodiroka we recorded a high water discharge of 30 cu.m/s for a basin of 1.64 sq.km. and 40 cu.m./s for a basin of 4.08 sq.km., representing a specific discharge of 18,000 l/s/sq.km. and 10,000 l/s/sq.km. On small basins in the west, exceptional spate waters must reach even higher values of about 20 to 30 cu.m/s/sq.km.

The annual average modules in the northern part are about 30 l/s/sq.km. They must be a little lower towards the south, in the Morafenobe-Tsiribihina region.

7. The south central regime

This is a transition regime between those of the east, the high plateaux and the west coast. It corresponds to the region between the Ambalavao escarpment in the north, the Ivakoany chain in the south, the eastern escarpment and the Isalo massif in the west.

The average rainfall is between 1,000 and 800 mm. The relief is still fairly rugged, but the altitude is more variable than on the high plateaux: there is a series of chains or massifs generally separated by fairly deep valleys. The Horombe plateau is included in this regime. Low water is always very insignificant, possibly only 1 l/s/sq.km. or even less.

LOW WATER DISCHARGE

Stations	Drainage basin sq.km.	Maximum m³/s	l/s/km²	Minimum m³/s	l/s/km²	Average m³/s	l/l/km²
Manananantanana at Tsitondroina	6 510	22.5	3.5	1.0	0.15	8.2	1.25
Ihosy at Ihosy	1 500	3.0	2.0	0.20	0.13	0.96	0.64
Zomandao at Ankaramena	610	0.80	1.3	0.09	0.14	0.35	0.57

Low water generally occurs in October-November, but sometimes the lowest discharge is observed in July-August. The annual spate waters are always very fast, with specific discharges between 100 and 200 l/s/sq.km. for the large basins and 200 and 600 l/s/sq.km. for the basins smaller than 1,000 sq.km. Below a few tens of square kilometres, the specific high water discharge is certainly about 5,000 to 10,000 l/s/sq.km.

On the Ihosy relatively low specific discharges are recorded, often below 100 l/s/sq.km., because this river runs in a very narrow valley, with a relatively flat and marshy bottom.

The highest values observed are as follows:

2,150 cu.m/s or 330 l/s/sq.km. on 13th January 1964 on the Manananantanana

433 cu.m/s or 710 l/s/sq.km. on 24th January 1964 on the Zomandao

580 cu.m/s or 386 l/s/sq.km. on 30th January 1954 on the Ihosy

Obviously the cyclonic high waters must have a much higher specific discharge: between 500 and 1,000 l/s/sq.km. in the large basins and above 1,000 l/s/sq.km. in the smaller ones.

The average annual modules are between 10 and 20 l/s/sq.km.

ANNUAL MODULES

Stations	Drainage basin km²	Maximum m³/s	l/s/km²	Minimum m³/s	l/s/km²	Average m³/s	l/s/km²
Manananantanana at Tsitondroina	6510	150.4	23.0	58.3	8.9	87.5	13.4
Zomandao at Ankaramena	610	13.1	21.5	4.9	8.1	9.4	15.4
Ihosy at Ihosy	1500	37.0	24.6	10.6	7.1	16.1	10.7

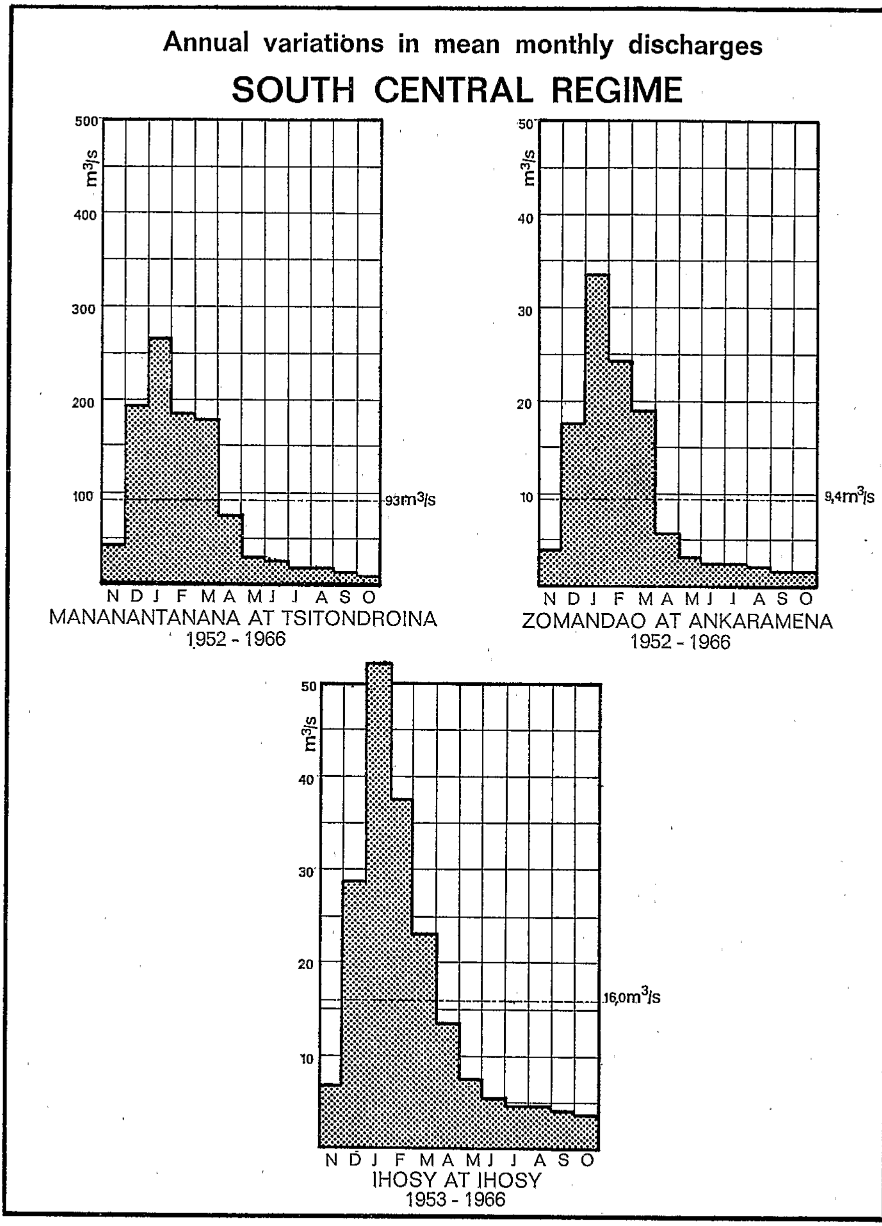

Annual variations in mean monthly discharges
SOUTH CENTRAL REGIME
500
m³/s
400
300
200
100
93m³/s
N D J F M A M J J A S O
MANANANTANANA AT TSITONDROINA
1952 - 1966
50
m³/s
40
30
20
10
9,4m³/s
N D J F M A M J J A S O
ZOMANDAO AT ANKARAMENA
1952 - 1966
50
m³/s
40
30
20
10
16,0m³/s
N D J F M A M J J A S O
IHOSY AT IHOSY
1953 - 1966

Fig. 14.

The run-off coefficients vary with the type of drainage basin. They are generally between 30 and 60 %. The drainage deficit is between 500 and 800 mm.

8. The West coast regime

This has an average annual rainfall of between 500 and 800 mm.

The dry season is very marked with an average temperature that is still high and a very low relative humidity. On small drainage basins, the water courses dwindle as they progress down-stream and the waters are lost by seepage into the water table. Low water is very low and almost all the small streams have a dry sandy bed from April-May to November. However, the rivers which drain the Isalo massif are an exception. Because of the permeability of the ground through which they pass, the low water discharge is high even at the end of the dry season. This applies to the Taheza, the Sakamarebe and the Sakamarekely, tributaries of the Onilahy, and the upper reaches of the Fiherenana. On these rivers, the low water discharge is between 3 and 6 l/s/sq.km. while on the basins of similar size, such as that of the Morondava at Dabara, it is less than 1 l/s/sq.km.

The spate waters are very sudden and sometimes appear like a tidal wave in an initially dry bed. They generally last only a few hours and afterwards there remains only a trickle of water in an excessively wide bed. Because of this suddenness, the high water discharge is not precisely known. The specific discharge must be very high, about 1,000 l/s/sq.km. or more.

The run-off coefficients are relatively low, the region considered being almost completely covered by red sand. A study of run-off on a small basin (0.5 sq.km.) near the Mangoky above Vondrove gave run-off coefficients of between 2 and 10 % for the few high water periods observed. The peak specific discharge of the highest waters was 12 cu.m/s/sq.km.

9. The South Sahelian regime

The rain, with an annual average level of between 300 and 500 mm, falls mainly from October to May. The dry season is generally clearly defined, but considerable rainfall may occur in July-August. The very violent storms with extremely intensive rain cause very sudden spates with extremely rapid variations in stage. On the Menarandra we observed rises of almost 3 m in the water level in less than 20 minutes. These flood waters are followed by a rapid drying up of the bed until often there is apparently no flow at all. During the dry season, the flows decrease considerably as the rivers run downstream and there are few rivers that carry water to the sea throughout the year. However, there is an under-

Annual variations in mean monthly discharges

SOUTH SAHELIAN REGIME

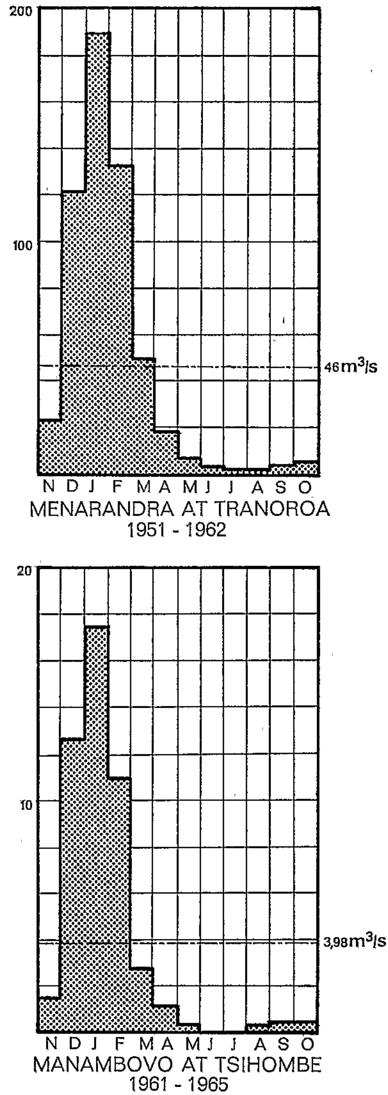


Fig. 15.

ground water in the sand which is used by the people for their water supply.

Throughout this southern region, the hydrological system is not very developed. The Mahafaly plateau between the Linta and the Onilahy is totally devoid of rivers: the run-off water is lost in the sand and fissured limestone.

Discharge at low water, even in the upper parts of the basins where there is permanent drainage, is extremely small (1 l/s to a few tens of l/s). There are generally two minima: the first in May-June, the second in October-November. The June one may be as severe as the October one. Between the two, rain in the dry season causes fairly high waters which help to prolong the surface drainage.

The annual high waters, always very brief (a few hours at the most) have a high peak discharge, with a specific discharge of about 500 to 800 l/s/sq.km. Exceptional high waters may easily reach double those values (1,000 to 1,500 l/s/sq.km.)

The average annual discharge is low: a few tens of cu.m/s (5 to 6 l/s/sq.km. on the Menarandra at Tranoroa, 2 to 3 l/s/sq.km on the Manambovo, 1 to 2 l/s/sq.km. on the Linta).

10. The mixed regimes

All the large rivers have a mixed regime

Sofia:	High plateaux + north-west
Betsiboka:	High plateaux + north-west
Tsiribihina:	High plateaux + north-west
Mangoky:	High plateaux + north-west + west + south central
Onilahy:	South central + west + south
Mandrare:	East + south + south central
Mananara:	South central + east
Mangoro:	High plateaux + east
Maningory:	High plateaux + east

Of all these rivers, only the Mangoky has been studied near the mouth, at the Banian station, below a basin of 50,000 sq.km. (total drainage basin 55,750 sq.km.)

There is a station on the Tsiribihina, but like all the western rivers it is difficult to ascertain the discharge because of the shifting bed and the violence of the rivers in spate. On the Mangoky, a cableway station with a span of 425 m has enabled high water discharge values of up to 5,000 cu.m/s to be measured. On the Tsiribihina there are no such installations and so far we have only a few measurements at low water.

In the Betsiboka basin, two cableway stations with a span of about 250 m above the confluence give readings for 18,500 sq.km. on the Ikopa and 11,800 sq.km. on the Betsiboka. No measurements have been made below the confluence.

On the Mandrare, there are numerous low-water and average water measurements, but here too the shifting sand bed makes it impossible to establish an unambiguous stage-discharge curve.

The Mananara is studied above the Soakibany sill: 14,160 sq.km. of the total 16,760 sq.km. of the basin.

The other rivers are not well known or else measurements refer only to drainage areas representing a very small fraction of the total basin.

On the large rivers, the low water discharge has variable specific values depending on the situation and the proportion of elementary regimes of which they are composed. We noted on the Mangoky 13 cu.m/s for a drainage area of 50,000 sq.km. or 0.27 l/s/sq.km. On this river mean absolute low water is equal to 46 cu.m/s or 0.92 l/s/sq.km.

On the Betsiboka, at the Ambodiroka station (11,800 sq.km.) the lowest water observed had a discharge of 43 cu.m/s or 3.6 l/s/sq.km. The mean absolute low water over the period 1948–65 is 61 cu.m/s or 5.1 l/s/sq.km.

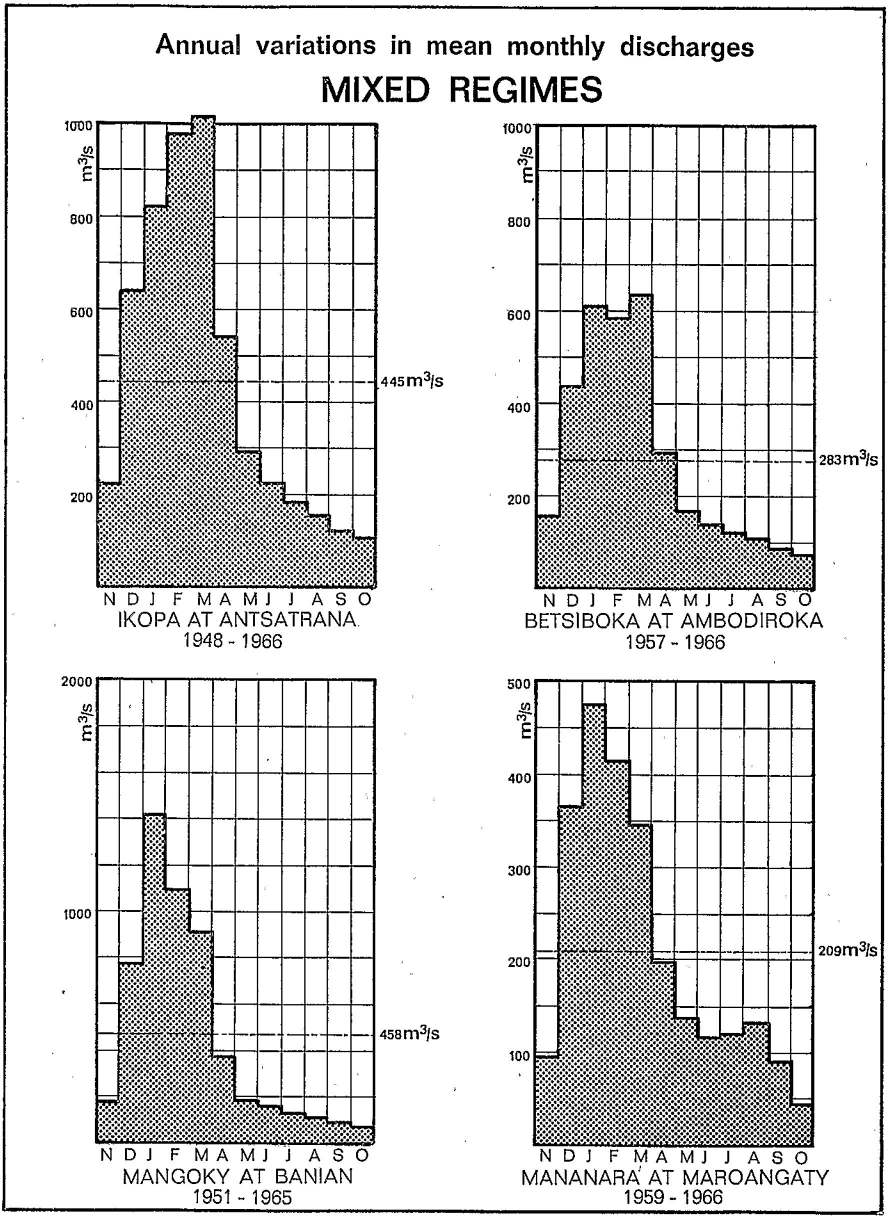
On the Ikopa at the Antsatrana station (18,550 sq.km.) the discharge was only 66 cu.m./s in November 1960 (3.6 l/s/sq.km.) The average low water discharge over the period 1951–65 was 87 cu.m./s (4.7 l/s/sq.km.)

The values obtained on the two drainage areas agree perfectly. Below the confluence, the low water discharge of the Betsiboka in a very dry year must be about 120 cu.m/s and in an average year it must be about 150 cu.m/s.

The above figures clearly show the effect on low water of the situation of and supply to the drainage basins: the Betsiboka has specific low water discharge values about 10 times greater than those of the Mangoky. On the Betsiboka, unlike the Mangoky, the rainfall increases from top to bottom of the basin, which accounts ıor the high low water discharge. The Tsiribihina low water values are not well known but they must be very much higher than those oı the Mangoky. In the South, the Mandrare has a very small low water discharge, sometimes nil, at Amboasary.

The Mananara at the Soakibany sill has a fairly irregular low water discharge, probably because of the effect of the south central regime. During the period 1955–66, we noted 11 cu.m/s (or 0.78 l/s/sq.km.) in 1960 and 83 cum./s (or 5.8 l/s/sq.km.) in 1965. The mean absolute low water discharge is 29 cu.m./s (or 2.0 l/s/sq.km.).

The high waters of the large rivers may come very suddenly. On the Betsiboka, in March 1959, we recorded a spate of more than 10,000 cu.m/s which lasted barely a few hours. On the Mangoky, in 1964, the tropical depression 'Christine' caused extremely rapid flood waters—on 12th January the discharge increased from 265 to 4,360 cu.m/s in three hours. The river dropped in the night and about midnight there was only slightly more than 3,000 cu.m/s. At 6 a.m. on the 13th 5,350 cu.m/s were again recorded. The waters fell very rapidly and on the 14th the discharge dropped to 1,300 cu.m./s.



Annual variations in mean monthly discharges
MIXED REGIMES
1000
800
600
400
200
m3/s
445m3/s
N D J F M A M J J A S O
IKOPA AT ANTSATRANA
1948 - 1966
1000
800
600
400
200
m3/s
283m3/s
N D J F M A M J J A S O
BETSIBOKA AT AMBODIROKA
1957 - 1966
2000
1000
m3/s
458m3/s
N D J F M A M J J A S O
MANGOKY AT BANIAN
1951 - 1965
500
400
300
200
100
m3/s
209m3/s
N D J F M A M J J A S O
MANANARA AT MAROANGATY
1959 - 1966

Fig. 16.

Spates of this kind also occur on the Mandrare in the south, on the Mananara on the Eastern slopes and on the Tsiribihina and the Sofia in the north-west.

The annual spates have fairly low specific discharges:

100 to 150 l/s/sq.km. on the Ikopa at Antsatrana

100 to 300 l/s/sq.km. on the Betsiboka at Ambodiroka

30 to 100 l/s/sq.km. on the Mangoky at Banian

100 to 200 l/s/sq.km. on the Mandrare

about 100 l/s/sq.km. on the Mananara.

Exceptional spate waters give a much higher specific discharge: 1,000 l/s/sq.km. on the Betsiboka at Ambodiroka in 1959 (10 to 12,000 cu.m/s) and 296 l/s/sq.km. on the Mangoky at Banian (14,000 cu.m/s) in January 1956. The Mandrare must attain values of about 500 l/s/sq.km. in full spate.

The annual average modules are as follows:

20 to 30 l/s/sq.km. on the Ikopa at Antsatrana (average over 17 years 450 cu.m or 24.2 l/s/sq.km.)

15 to 35 l/s/sq.km. on the Betsiboka at Ambodiroka (average over 9 years 283 cu.m/s or 24.0 l/s/sq.km.)

5 to 15 l/s/sq.km. on the Mangoky at Banian (average over 14 years 458 cu.m/s or 9.2 l/s/sq.km.

3 to 10 l/s/sq.km. on the Mandrare at Amboasary (average over 6 years, 88 cu.m/s or 7 l/s/sq.km.)

10 to 20 l/s/sq.km. on the Mananara at Maroangaty (average over 6 years, 213 cu.m/s or 15 l/s/sq.km.)

On the Betsiboka, above Ambato-Boeni, the annual average module must be about 1,000 cu.m/s.

The annual run-off coefficients and drainage deficits are as follows:

48 % and 783 mm on the Ikopa at Antsatrana

54 % and 685 mm on the Betsiboka at Ambodiroka

28 % and 715 mm on the Mangoky.

On the Mandrare, the values should be slightly lower than on the Mangoky.

It should be noted that for each individual spate, the run-off coefficients obtained are often lower than those given above. On the Mangoky, the spate of 12th and 13th January 1964 gave a run-off coefficient of 17 %. These coefficients vary to a very great extent with the type of ground and above all the state of saturation of the ground before the spate concerned.

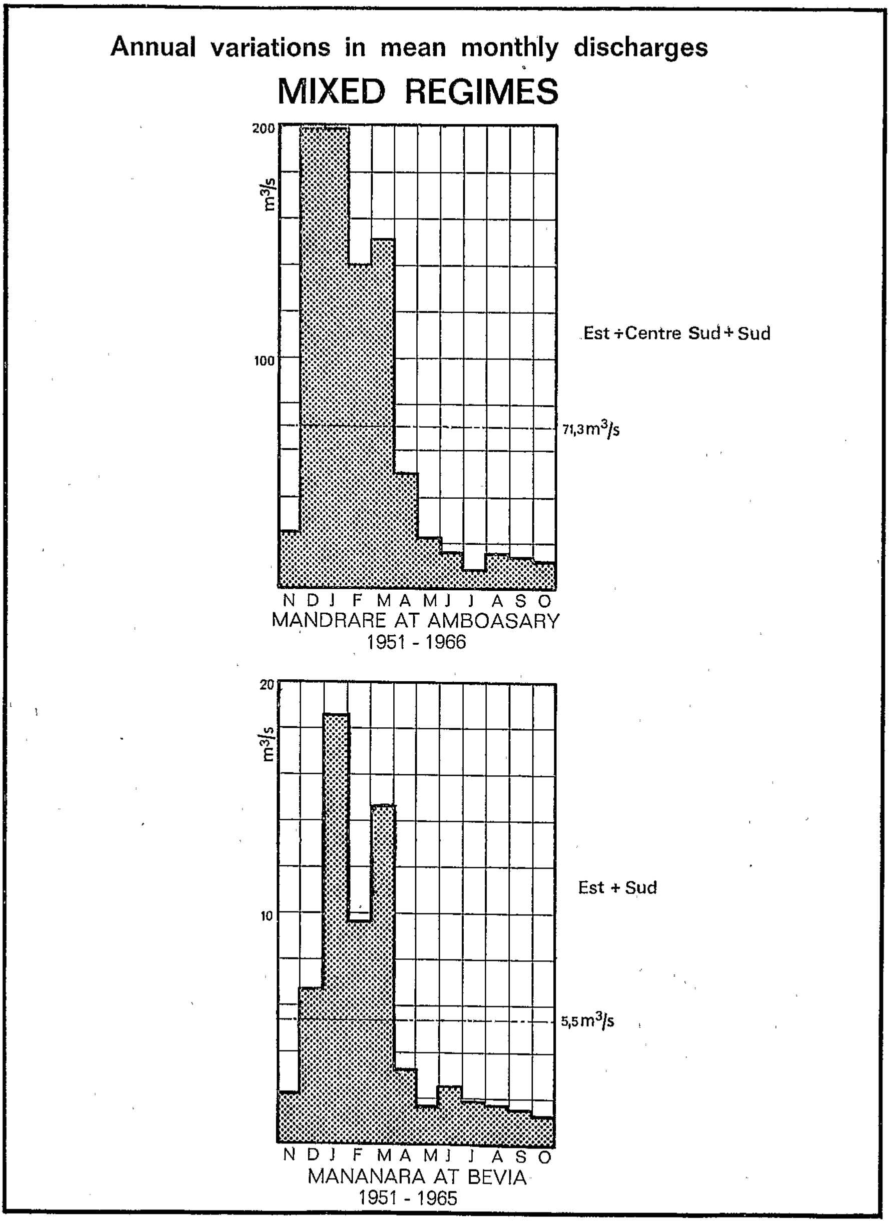

Annual variations in mean monthly discharges
MIXED REGIMES
200
m3/s
100
71,3 m3/s
Est + Centre Sud + Sud
N D J F M A M J J A S O
MANDRARE AT AMBOASARY
1951 - 1966
20
m3/s
10
5,5 m3/s
Est + Sud
N D J F M A M J J A S O
MANANARA AT BEVIA
1951 - 1965

Fig. 17.

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