Dr. U. Neis
Coopération Technique Allemande (GTZ)
REGISO - Département Eau
BUJUMBURA/BURUNDI

DIFFICULTIES IN THE OPERATION OF NEW SLOW SAND FILTERS IN AFRICA

ABSTRACT:

In Bujumbura, Burundi, new water works with slow sand filtration treatment went into operation in May 1987. Within a short time filter running time dropped to an unacceptable 8 days. The reason is that there are unusual characteristics in the raw water which is taken from Lake Tanganyika. A high pH-value of 9.0 is responsible for the precipitation of calcium carbonate substances in the filter. The sand surface is heavily encrusted and costly efforts are necessary to remove the encrusted material. Neutralisation of the raw water is economically not feasible. A higher filtration velocity is recommended to reduce the formation of deposits in the filter. Algae growth is not a serious problem and should not be controlled.

Key words:

Slow sand filtration, Lake Tanganyika, sand encrustation, calcium carbonate precipitation, high pH-value, filtration hydraulics.

1. Historical Background of the Slow Sand Filters in Bujumbura

Since 1969, Bujumbura, the capital of Burundi in Central Africa, draws raw water from Lake Tanganyika for its drinking water. The raw water is treated by slow sand filters with subsequent chlorination.

In the early 80ies, the existing treatment plant could not match the increased water demand. As a result, improvements of the whole water supply system had to be faced. After preliminary studies, the execution of the extension of the supply system was undertaken from 1985 to 1987. REGIDESO, the parastatal company for the distribution of drinking water, is currently serving approximately 200,000 people in Bujumbura.

The new raw water inlet construction in Lake Tanganyika is situated 3.5 kilometers offshore in 25 m depth below sea level. Recently, details about the construction of the long lake intake pipeline have been published (1).

A new pumping station at the shore conveys the sea water to large slow sand filters at the water works, "Usine Lac", one kilometer inland. The operation of the new slow sand filters began in May 1987.

A sketch in figure 1 represents the actual situation of the sea intake and the treatment works. Figure 2 gives a survey of the water works plant with the old and new slow sand filters. Figure 3 shows a cross-section of the new filter tanks. Information about the filter sand grain size used is included.

There are now four new filters with 1.825 m^2 surface (L = 82.60 m, W = 22.10 m) each. The filtration velocity was calculated as v = 0.26 - 0.32 m/h.

2. Raw water quality (Lake Tanganyika)

Lake Tanganyika represents a water reservoir with unique characteristics. In this respect its physico-chemical data are unique, too. This is due to its unusual geohydrological origin.

Unfortunately this uniqueness was grossly neglected in almost every past report or survey dealing with Bujumbura's drinking water supply.

In the area of the central-african graben in very recent geological eras with heavy volcanic activities (Virunga), Lake Kivu was separated from the northen lake system. Lake Kivu then created an outlet southward to Lake Tanganyika, the Rusizi River. Lake Tanganyika, without any outflow, then showed increasing water levels until the year 1878, when the level reached the Lukuga threshold and found an outflow to the river system of the Zaire (see map in figure 4). Thus, the Rusizi River connects Lake Kivu with Lake Tanganyika. The Rusizi only contributes a small amount of water to the overall hydrological budget of Lake Tanganyika, but because of its volcanic origin, it imposes its physico-chemical characteristics upon the lake water. It has a highly alcalic pH-value, and high concentration of Mg^{2+}, Na^{+}, and K^{+} ions are typical as can be seen from table 1 and 2.

The total hardness is approximately 1 meq/l or 200 mg $CaCO_3$/l. Magnesium is the dominant hardness constituent. Also the high Sodium concentration is quite unusual.

The pH-value of the lake water is 9.0. This is clearly above the equilibrium level of 8.2. Hence, the water tends to precipitate carbonate substances ($CaCO_3$).

Table 1. Concentrations of different cations in the water of Lake Kivu, Lake Tanganyika and several of its tributaries (in mg/l)

	Na	K	Ca	Mg
1. Lac Kivu	121.6	97.4	4.8	87
2. Lac Tanganyika:				
Nord	61.7	32	10.7	37.9
Centre	63.1	32.8	11	38.8
Sud	62.9	32.2	11	39.1
3. Rivière Ruzizi	117		4.6	88
4. Rivière Malagarasi	16.4	2.4	12.9	9.1
5. Rivière Kanyosha	3.61	1.50	2.49	1.37
Rivière Ntahangwa	7.32	3.33	6.65	4.25
Rivière Muzazi	4.97	1.47	6	2.89
Rivière Mpanda	6.15	1.70	3.4	2.6

1. u. 3. von DEGENS et al. (1973) , (cit in (2))
2. von HECKY (1978) - " -
4. von BEAUCHAMP (1939), - " -
5. von NDAYEGAMIYE (1984), (2)

Table 2. Comparison of important chemical parameters for Lake Tanganyika

Ref.	Parameter					
	pH	Cl^- (mg/l)	Mg^{2+} (mg/l)	Conductivity (µS/cm)	Alkalinity ($mgCaCO_3/l$)	Total hardness ($mgCaCO_3/l$)
1. GKW - 1978 (3)	8,1*	-	39,5	680*	360	196*
2. REGIDESO - 1974 (Heise) (4)	8,8*	35,6	-	660*	360	192*
3. Dahlem, Schröder 1974, (5)	8,7*	32,0*	42,0*	620*	360	198*
4. IGIP, 1974 (6)	9,1*	32	40	-	340	188*
5. SGI - Ecoplan 1987 (7)	8,8*	22	40*	650*	308*	191*
6. GTZ - REGIDESO 1988	9,0*	-	-	646	326*	198*

* Mean value from several analyses

3. The Actual Situation

In May 1987 the new slow sand filters went into operation. Very soon, however, a rapid decrease in filter running time could be observed, as is shown in figure 5.

In spite of the fact that the filters are not always stopped according to an exactly defined criterion (the personnel does not wait every time until the filter resistance has increased such that the spillover level has been reached), the operation time today can be taken as only one week. This value is extremely disadvantageous for slow sand filters.

Even when cheap personnel is available for the cleaning of the filters (removal of the upper "Schmutzdecke" and the chopping of the encrustations), considerable additional operation costs occur. Also, the complete replacement of the removed sand must be repeated more often. The minimum height of the sand layer in Bujumbura was defined as 0.50 m. Today, from the original sand layer thickness of 1.0 m already 0.35 m have been removed. This is equivalent to a loss of 1.2 cm of sand height per cleaning process.

Photo No 6 shows the personnel at work while cleaning a filter. Clearly the encrusted sand crumbs can be seen which have already been broken out of the filter surface and were put aside for removal with the dredger.

There might also be a problem of water quality, i.e. of the efficiency of the filters. The very short filter runs and the consequent very frequent cutting off of the "Schmutzdecke" probably inhibits the development of an active biological layer. Especially due to biological activity in the upper sand layers, slow sand filters are known to be very effective.

Frequent microbiological analyses in the past months, however, do not yet show a significant decrease in filtrate quality (see data in figure 3). On the other hand, only minor differences between the very good raw water and the filtrate quality can be observed. So, one also could claim that the filters are scarcely effective in respect to microbiological parameters. The frequency of the analyses has been increased to gain a better insight into the problem.

Table 3· Microbiological analyses of inflow to and outflow of the slow sand filters at the "Usine Lac" waterworks in Bujumbura

Date	Total counts (1)		Coliform counts (2)		E. coli (3)	
	E.B.	E.F.	E.B.	E.F.	E.B.	E.F.
7.6.88	27	3	∞	2	0	0
8.6.88	56	55	0	1	0	0
10.6.88	--	1	-	0	-	1
13.6.88	--	3	-	0	-	0
17.6.88	∞	∞	1	2	0	0
22.6.88	109	72	∞	0	∞	0
28.6.88	∞	62	∞	4	10	1
29.6.88	∞	21	∞	2	10	0
4.7.88	∞	∞	∞	2	7	0
5.7.88	80	83	-	-	1	0
29.7.88	--	246	-	20	-	0
10.8.88	--	21	-	3	-	1
12.8.88	--	17	-	0	-	0
16.8.88	22	30	65	13	7	4
24.8.88	23	31	25	25	8	0
29.8.88	40	15	27	6	9	0
19.9.88	64	93	350	11	4	0
11.10.88	43	92	40	63	0	0
12.10.88	47	41	16	24	1	1
14.10.88	34	51	37	29	1	1

(1) = Colonies / ml sample
(2), (3) = Colonies / 100 ml sample
E.B. = Eau brute (Raw water)
E.F. = Eau filtrée (Filtrate)

4. Reasons for the Low Operation Time of the Filters

4.1 Hypothesis of Examination

Observations showed·

-1. Algae growth in the filter tanks,
-2. Encrustations of the upper sand layers.

Both phenomena are not new and were known principally by operation of the old sand filters.

To clarify to what extent these two factors contribute to the sharp decrease of filter operation time, a plexiglass model of a filter was built (scale 1/100). This model filter was run with the same raw water and the same filtration velocity for several weeks.

The hypothesis to be proved with the model examinations was as follows·

- Encrustations of the filter sand are due to chemical precipitation of carbonate species. This is independent of algal growth. It is furthermore independent of the origin and the type of the filter sand used. It is only originated by the composition of the water of Lake Tanganyika.

4.2 Results

4.2.1 Biological and Chemical Aspects

During the first phase of operation (10 weeks), the model filter was covered completely to inhibit algae growth. Thus, it could be clearly shown, that the encrustations of the filter sand always occurs, whether or not algae are present. The surface of the filter sand was covered with a thin white crust at the end of operation. The inflow and outflow device of the model filter showed also a considerable amount of white deposits.

Tests in the laboratory of REGIDESO then proved that the deposits were carbonate substances ($CaCO_3$). Maybe precipitates of Magnesium hydroxyde are also involved.

Similar chemical analyses demonstrated·

a - encrusted filter sand from slow sand filters
b - new sand kept as reserve
c - sand from the Ntahangwa River

also showed marked difference of carbonate content of sample a) compared to b) and c)

A second period of investigations with the uncovered plexiglass filter did not yield additional results. Naturally algae growth occurred. But also filter sand encrustation continued.

Intensified studies of the big filters proved the disappearance of substances which contribute to hardness, alkalinity and conductivity as can be seen from table 4. There, results of chemical analyses of samples taken from filter inflow and outflow are presented. Differences in the concentration of the parameters listed above between in and out are obvious.

Algal growth on the filters is not disturbing the operation. We do not recommend as yet any means of control. Covering the filters would be very costly and could result in difficult maintenance operations. Meanwhile, the installed pre-chlorination has been put out of operation. At pH 9.0 the efficiency of chlorine for algal growth control is reduced anyway, and the available solution of calcium hypochlorite would contribute furthermore to the precipitation of $CaCO_3$.

4.2.2 Hydraulic aspects

Thorough examination of the superficial sand configuration of the dry filters leads to the suggestion that the flow through the filter tanks is rather irregular. In February and March 1988, we recognized that areas with higher flow velocity showed only few algae deposits and also no encrustations, whereas areas where we could assume lower flow velocities or even dead zones showed algae sedimentation and deposits of white precipitates which made the surface of the sand very hard.

Tests were performed to determine the permeability of the hard surface material and of sand 40 cm below the surface. The permeability of both sites was clearly different. See table 5.

Table 5· Determination of the permeability of different sand layers in the slow sand filters

I Samples taken from the surface (encrustations)

Sample No.	-. (m/s)	1	2	3	4	Mean	Mean (m/h)
Permeability, K	$x10^4$	2.4	2.2	1.7	1.7	2.0	0.72

II Samples from 0.40 m depth (soft sand)

Samples No.	- (m/s)	1	2	3	4	Mean	Mean (m/h)
Permeability	$x 10^5$	1.0	11.7	8.4	3.6	6.2	0.22

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Table 4: Comparison of raw water and filtrate quality for slow sand filters in the "Usine Lac" water works.

March 1988		Temperature water, °C			Turbidity in TE/F			pH			Conductivity in µS/cm			Alkalinity in mg Ca CO_3/l			Total Hardness in mg Ca CO_3/l		
Date	Temp. Air	E.B	E.F	D	E.B	E.F	D	E.B	E.F	D	E.B	E.F	D	E.B	E.F	D	E.B	E.F	D
3.3.	30,2	27,2	26,6	0,6	0,43	0,04	0,39	9,06	8,93	0,13	648	643	5	332	315	17	200	190	10
4.3.	29,2	27,2	26,8	0,4	0,15	0,01	0,14	9,06	9,00	0,06	650	639	11	331,5	321	10,5	201	191	10
7.3.	29,2	27,2	26,8	0,4	0,20	0,08	0,12	9,07	8,98	0,09	650	642	8	326	314,5	11,5	197,1	187,6	9,5
8.3.	29,5	26,8	26,6	0,2	7,6	0,00	7,6	8,95	8,90	0,05	642	640	2	322,5	317,5	5	195,2	190,1	5,1
9.3.	31,0	26,9	26,3	0,3	5,1	0,06	5,04	8,96	8,89	0,07	640	638	2	322,5	326,5	- 4	196,4	190	6,4
10.3.	31,0	27,1	26,6	0,5	0,5	0,06	0,44	8,96	8,90	0,06	646	639	7	329,5	323,5	6	197,5	188	9,5
11.3.	28,4	27,1	26,5	0,6	0,5	0,04	0,46	8,96	8,88	0,08	646	641	5	322,5	312	10,5	198,5	191,3	7,2

Légende : E.B = Raw water   E.F = Filtrate   D = Difference(Raw water./. Filtrate)

5. Recommendations

Theoretically, the precipitation of calcium carbonate could be inhibited by lowering the pH of the raw water. Filtration curves performed on the laboratory, however, indicate that there is pratically no reasonable economical way of achieving this at the water works.

There is evidently no possibility of influencing the character of the raw water. Aside from the calcium carbonate problem, there also is no reason in doing so because the raw water quality is excellent.

Some operational changes may, however, improve the situation somewhat. For example·

1 - additional inlet construction to reduce the kinetic energy of the inflow and to promote a more regular flow through configuration,

2 - increase of the filtration velocity by keeping only two of four tanks in operation.

This should be done only after all the encrusted sand has been removed and replaced and the original sand height of 1.0 m has been reinstalled. Also a slightly higher grain size could be used.

We can compare the principal data then·

	Dimensioning by consultant	Actual situation	Proposal
Daily flow Q (m^3/d)	49,920	30,000	30,000
Filters in operation	4	3/4	2
Filtration velocity V_F (m/h)	0.26-0.32	0.23	0.34

These measures, however, are not expected to be more than "a drop in the bucket". The objective now cannot be more than to maintain a rather reasonable way of operation of the slow sand filters.

The story tells us that planning water treatment in the tropics, subtropics or arid zones of the world should carefully take into account the characteristics of raw water. Often we find circumstances atypical of European standard values. If one is not aware of that, the very well-known slow sand filtration technique loses its outstanding advantage which is simple and economic operation. These are values which are essential for applications in the Third World.

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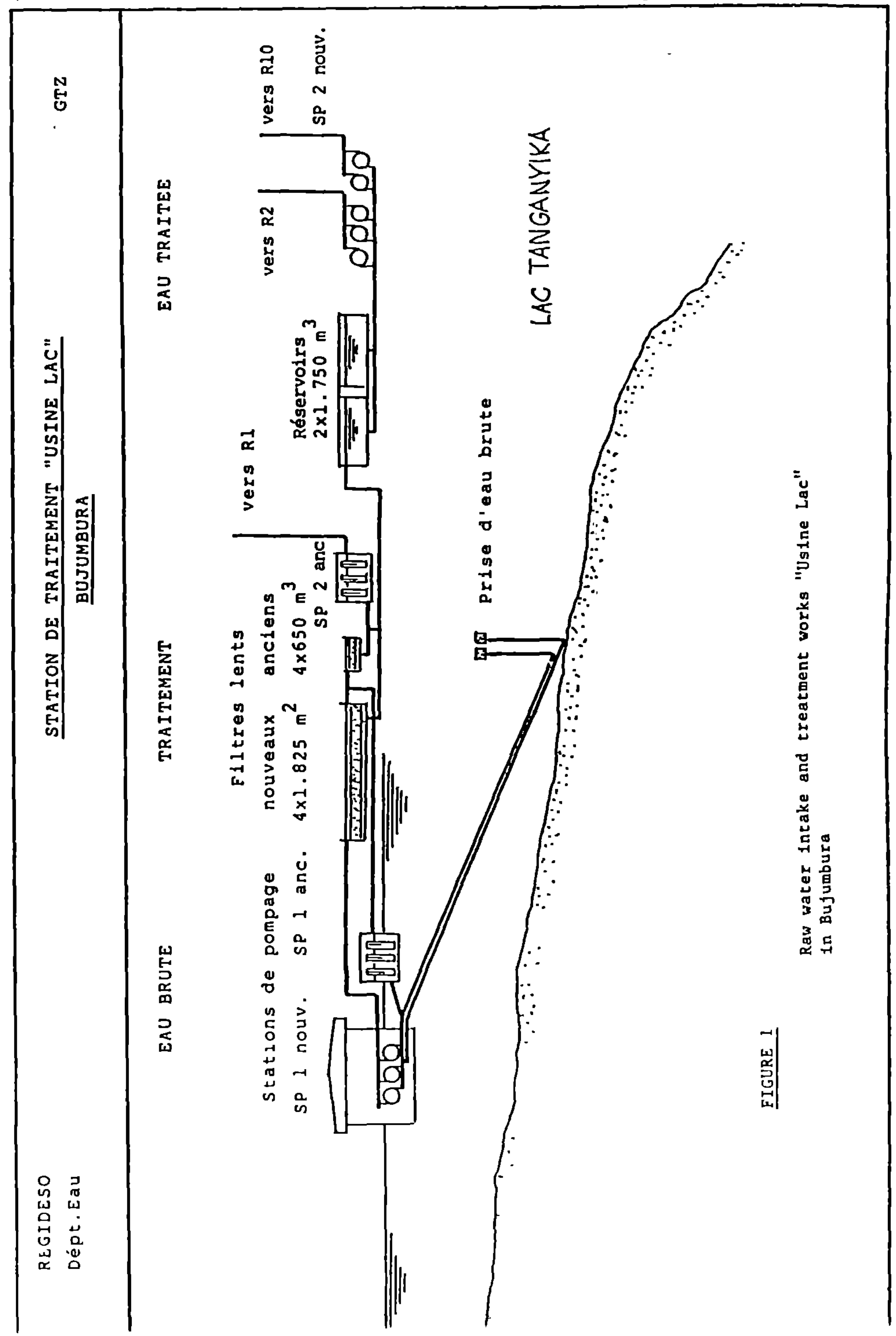


FIGURE 1

Raw water intake and treatment works "Usine Lac" in Bujumbura

FIGURE 2: Water works

USINE D'EAU DU LAC

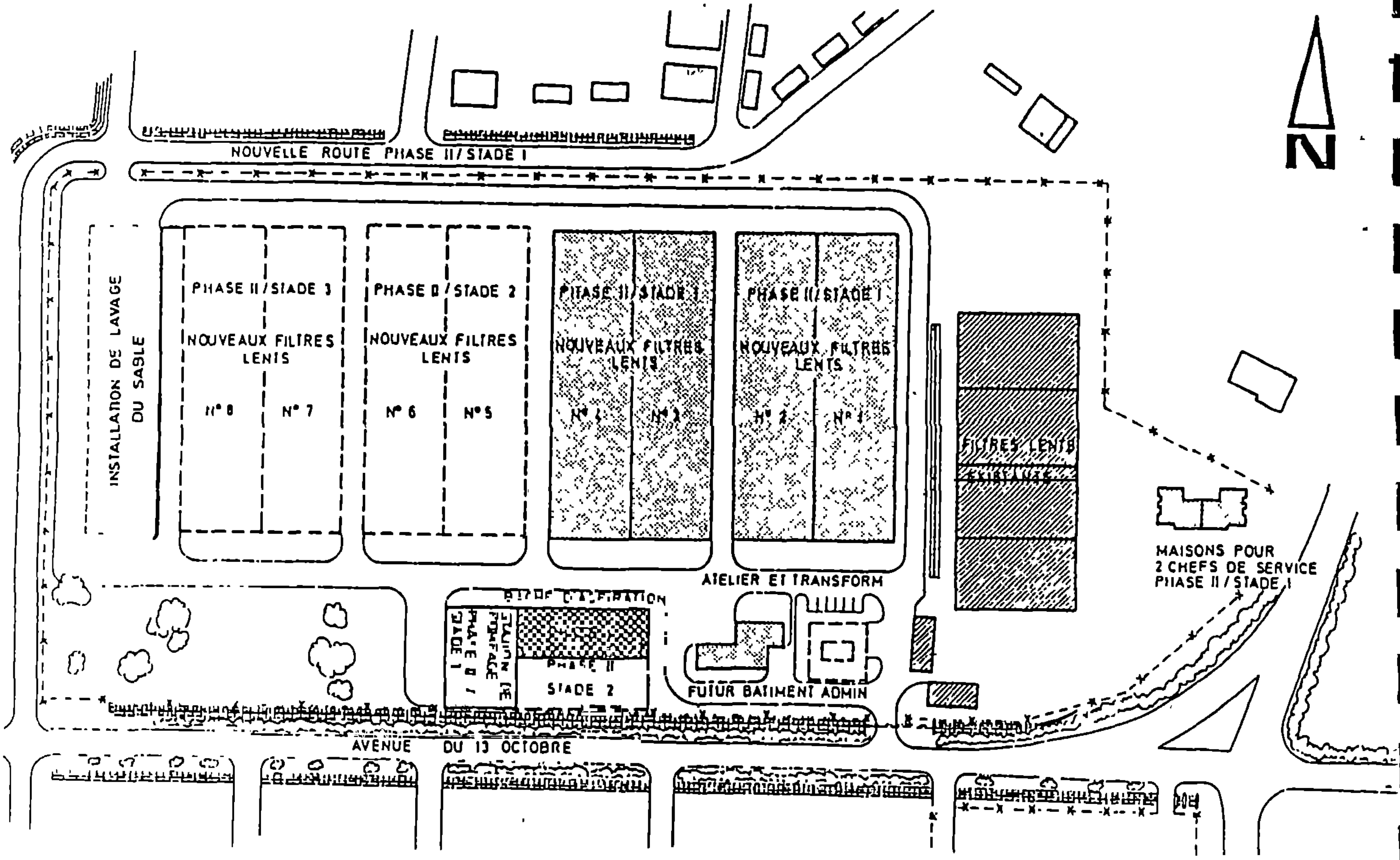
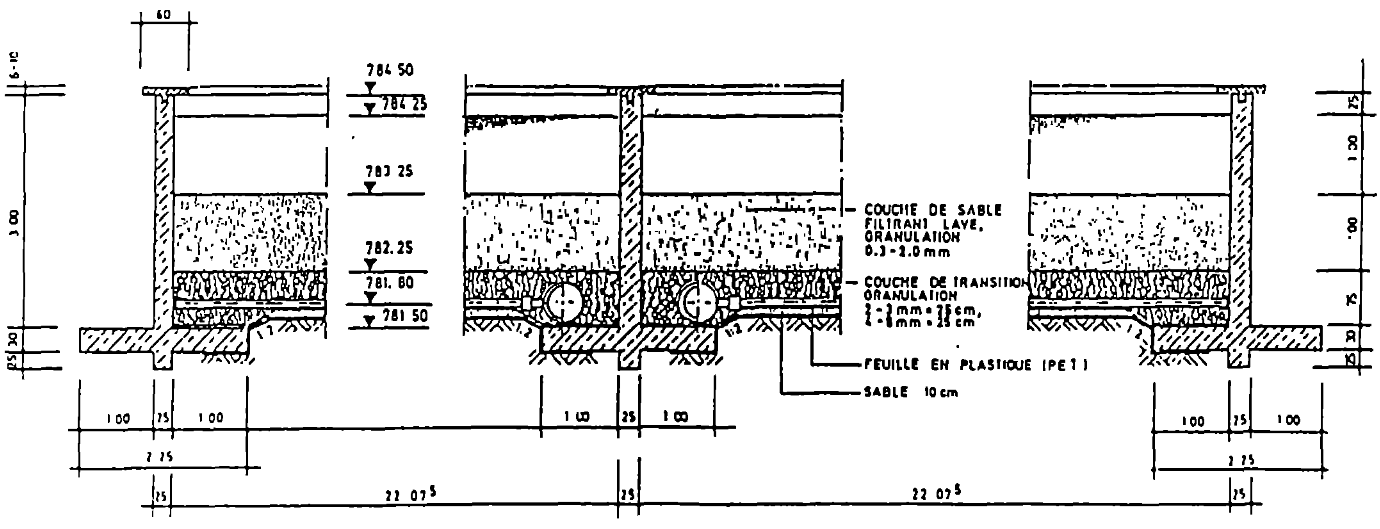


FIGURE 3:

ELEMENTS CONSTITUTIFS DU FILTRE LENT

Elements of slow sand filter tanks



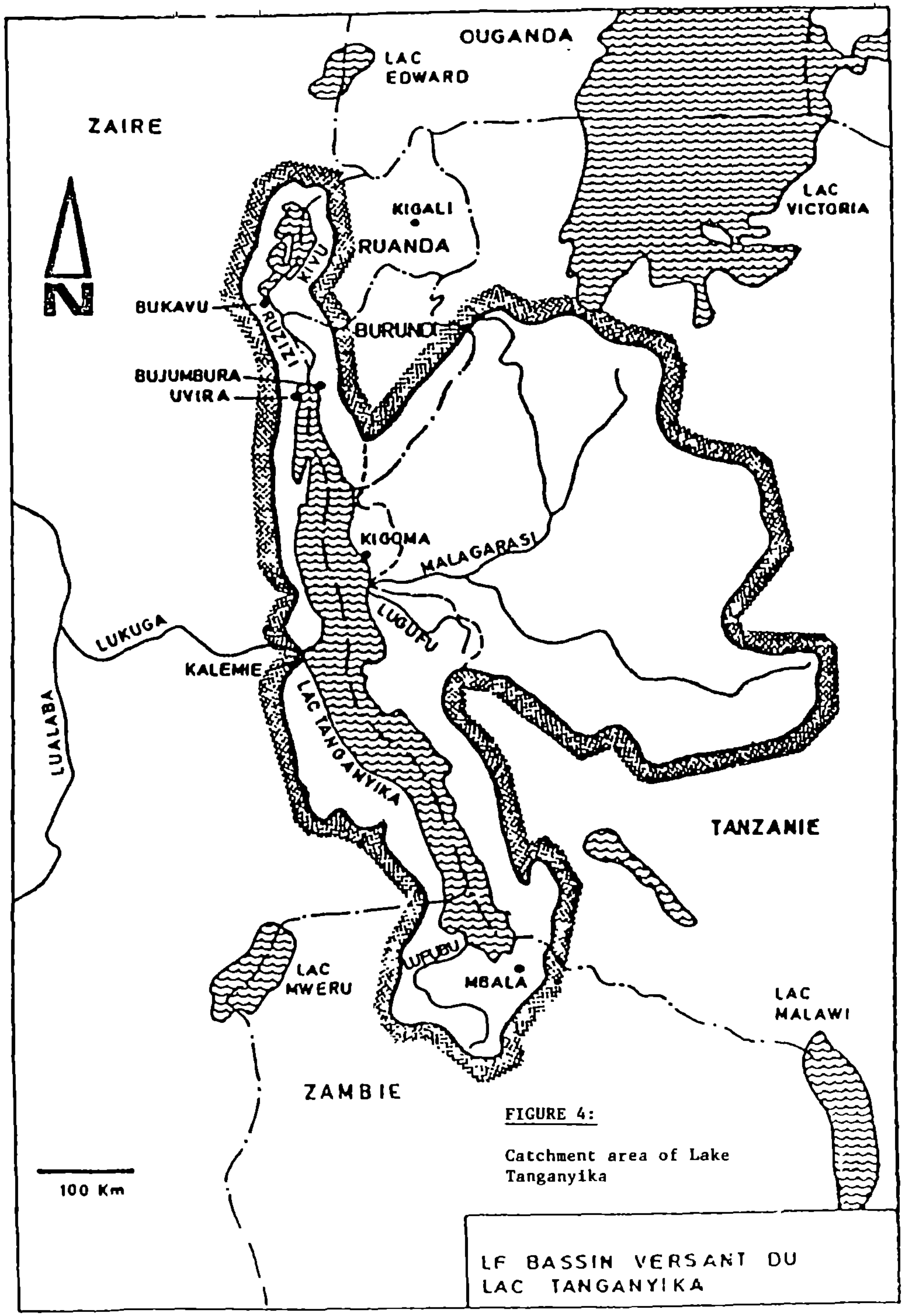


FIGURE 4:

Catchment area of Lake Tanganyika

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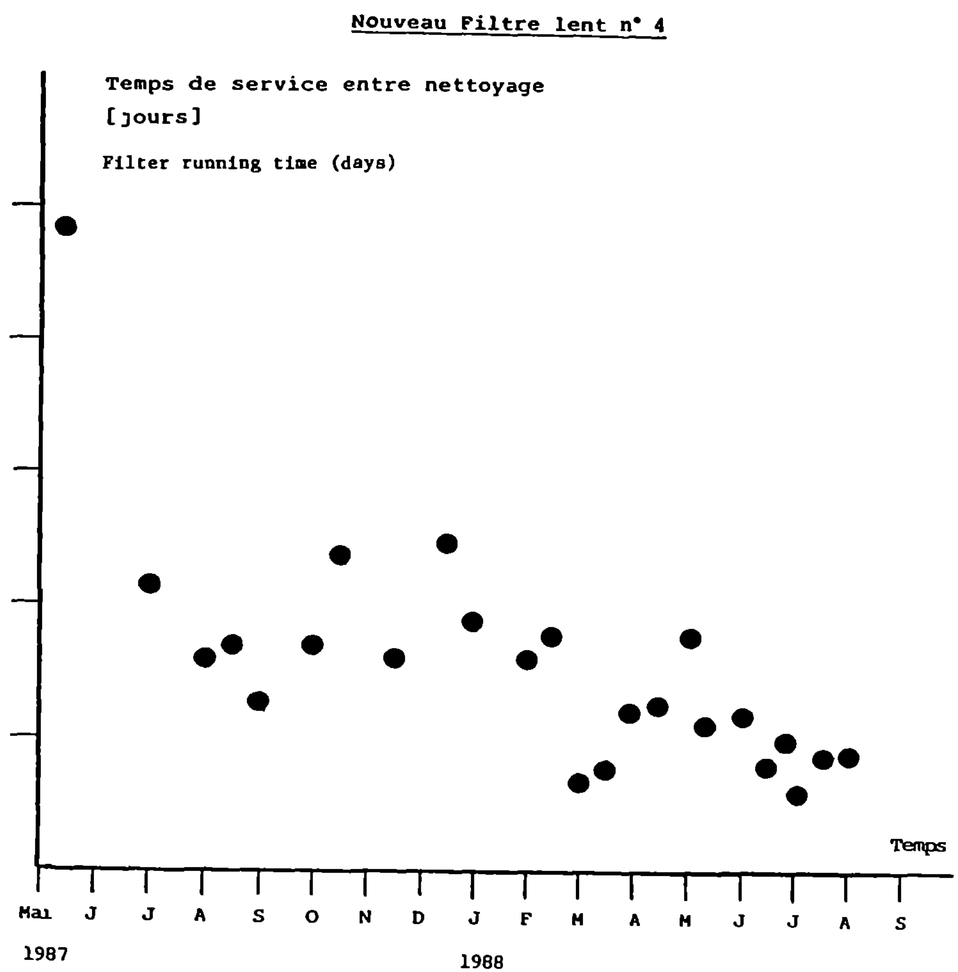

FIGURE 5: Decrease of filter operation time since start of work in May 1987

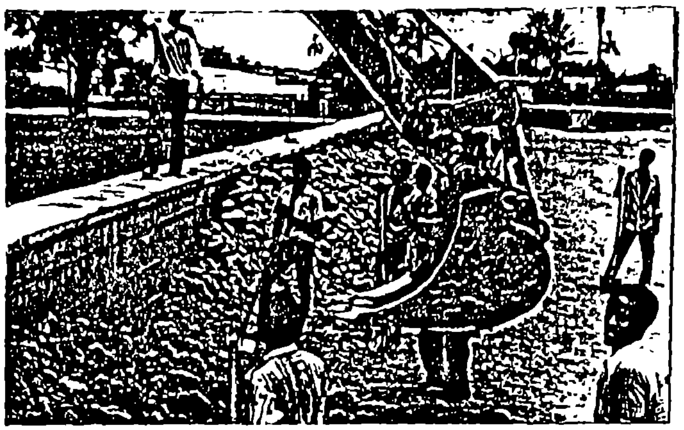

Photo n° 6.

Ramassage des morceaux de sable durci.

Entnahme der harten Sandbrocken.

Removal of hard sand crumbs