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REPORT ON

PROBLEMS IN OPERATION AND PERFORMANCE OF

NEW SLOW SAND FILTERS OF

REGIDESO, BUJUMBURA, BURUNDI

IRC International Water and Sanitation Centre
The Hague
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0. SUMMARY AND RECOMMENDATIONS

REGIDESO, the drinking water company in Bujumbura, Burundi, is facing problems with the operation and performance of the slow sand filters in operation since 1987 and financed by KfW. GTZ gives assistance to the water corporation and so is also involved in the current filtration problems. IRC was requested to look into the problem. Because of the specific nature of the problem, IRC requested the participation of a group of experts. The water treatment plant was visited and an expert meeting discussed the prevailing problems, appropriate solutions and further steps.

The poor performance of the slow sand filters, expressed in short filter runs, is due to precipitation of calcium compounds on the upper filter sand. As the water from Lake Tanganyika is very unstable due to a high pH (pH \approx 9.0), calcium carbonate and magnesium carbonate precipitate on the first sand grains encountered which act as nuclei.

Most promising solutions are limestone pre-filters, coarse sand or gravel pre-filters, non-woven fabrics as filter aid, and modification of the slow sand filters in terms of bed composition and filtration rate. The latter solution was introduced the beginning of 1990 and good preliminary results were obtained. Other options were discussed.

Considering the satisfactory performance of the two recently (out of the total of four), renovated new slow sand filters, it is recommended to continue the present operation procedure. However, tests have shown that progressive calcification is likely in future filter runs. Performance monitoring and investigations on calcification pattern in filter bed and distribution network are needed.

Reviewing the options for solving the problems of calcification of the slow sand filters, it is recommended to carry out pilot studies with limestone and sand/gravel (upflow) filters in Bujumbura. The application of fabrics could be investigated at a laboratory scale.

In view of the proposed pilot projects it is recommended to employ a research fellow for a period of two years who can carry out the research and development work, train laboratory staff on environmental and water quality monitoring and laboratory techniques.

These studies should lead to adjustment of the new slow sand filtration and/or pre-filtration to overcome present problems.

1. INTRODUCTION

The slow sand filters of the new water works of the water corporation REGIDESO of the city of Bujumbura, Burundi, were taken in operation in May 1987. After several filter runs the filter run length of the slow sand filters dropped to about eight days. This extremely short filter run was surprising, particularly for the generally good raw water available from Lake Tanganyika. The upper sand layers of the slow sand filters appeared to be encrusted with hard calcium compounds which were difficult to remove. It was envisaged that a high pH was responsible for the problem.

REGIDESO, with assistance from the GTZ team, did some preliminary investigations to solve the problem including a study on the dosing of acid to reduce the pH, which was viewed as too costly.

REGIDESO, supported by KfW - which had co-financed the new water works - approached IRC to look into the problem and suggest feasible solutions for the problem using its experience from its long involvement in slow sand filtration research, development and promotion in tropical developing countries. Because of the specific nature of the problem, IRC requested the participation of several experts in filtration, slow sand filtration and water chemistry, to review the prevailing problems, and discuss appropriate solutions and further steps to be taken.

IRC would like to acknowledge the valuable inputs received from Dr Boller, Dr Van Breemen, Dr Butoke, Mr Van Eekeren, Mr Elsenhans, Dr. Graham, Dr Graveland, Prof. Ives, Dr Neis, Mr Smet, Dr Stabel, Mr Tjiok, and Mr Visscher.

2. OBJECTIVES

The objectives can be summarized as follows (TOR and Proposal for Expert Meeting attached as appendix 1 and 2):

1. to identify the causes of blockage of the slow sand filters;
2. to evaluate solutions for the blockage of the filters;
3. to propose measures for improved functioning of the filters.

3. METHODOLOGY

In view of the complexity of the problem it was proposed to follow a phased approach.

In Phase I a small group of experts in the field of slow sand filtration and water chemistry reviewed the available water quality data and other information in order to obtain a good insight in the specific problems of the slow sand filters and to identify additional information needed for further analysis of the problem. Because the nature of the problem very much

appeared to be encrustation by calcium compounds, papers on similar problems encountered elsewhere were also reviewed. This Phase I lead to specific views and suggestions of Dr Graveland (Amsterdam Waterworks), Mr Van Eekeren (KIWA, Waterworks' Testing and Research Institute) and Dr Boller (EAWAG), attached as appendices 6, 7 and 8, and a list of data and information needed for further discussion.

Phase II consisted of the visit of one of the experts (Ives) to the REGIDESO water works in Bujumbura, to assess local situation and conditions, and review operation and maintenance procedures, to discuss the problem with local and expatriate staff, and collect additional data needed for proper study of the problem. The report of the visit (11 to 15 July 1990) is attached as appendix 14.

Phase III was the review and discussion of the nature of the problem, its causes and solutions by a group of experts using the field visit report, all other collected data and earlier suggestions presented by some of the expert. In the expert meeting representatives from REGIDESO, GTZ team, and the twinning water corporation, Bodensee Wasserversorgung, participated. The list of participants is attached (appendix 4). Recommendations for further research and pilot studies were made. The full report of expert meeting held at IRC on 19 July 1990 is appended (no. 3).

4. DESCRIPTION OF THE PROBLEM

4.1 Clogging of slow sand filters

In 1987 four new slow sand filters were constructed having generally accepted filter medium and bed thickness characteristics. The first filter run had a duration of 48 days, while following filter runs dropped below about 20 days with a minimum of 5 days (Neis, 1988).

The problem appeared to be cementation of the sand grains. The main precipitate on the sand was calcium carbonate and about 22% magnesium carbonate. This calcification was due to the unstable carbonate equilibrium of the Lake Tanganyika water. The described phenomena caused a serious reduction of the permeability of the upper sand layer, which lead to the short filter runs and difficulties in removing the hard cemented sand layer for cleaning.

Dr Stabel of the Zweckverband Bodenseewasserversorgung, is developing a theoretical model which can show the potential for calcium and magnesium precipitation using raw water characteristics.

Operational experience of the old slow sand filters (constructed in 1967) can not be used to understand the current problems of the new filters (constructed in 1967) because they operate intermittently with filter runs of about three days, contributing about 10% to the total water production of REGIDESO. The causes of short filter runs were reported to be due to the biological film formation (mainly algae) (Heise, 1983).

4.2 Raw water characteristics

The raw water is pumped from Lake Tanganyika at a depth of 25m below the surface. The water has a low turbidity, is colourless, has high hardness (mainly due to magnesium), with a dissolved oxygen content near saturation. The pH of the water is about 9.0. The biological activity in terms of algae density is low. An overview of water quality data from the field visit report (appendix 14) is given in table 1.

Table 1. Overview of water quality Lake Tanganyika, Period March - June 1987

Parameter	Units	Depth 0m	Depth 25 m
Temperature	°C	27	27
pH	-	9.1	8.9
Conductivity	µS/cm	640	640
Dissolved O ₂	mg/l	9.0	7.0
Turbidity	FTU	1.0-8.0	-
Total hardness	mg/l CaCO ₃	190	190
Alkalinity	mg/l CaCO ₃	315	315
COD	mg/l O ₂	5	10
Fe	mg/l	0.08	0.1
Mn	mg/l	0.05	0.01
NO ₃	mg/l NO ₃	0.01	0.01
Cl	mg/l	25	25
Total P	mg/l P	0.1	0.2

source: Field visit report Prof Ives

The calcium carbonate equilibrium pH value, pH_s , is calculated to be around 8.0. Therefore the Saturation Index (SI) according to Langelier ($SI = pH_{actual} - pH_s$) is positive: $SI = 1$. This implies that nearly all the calcium as calcium carbonate can precipitate in slow sand filters and/or pipelines, regulating devices and heating apparatuses. In practice, 5-8 mg calcium/l was retained in the slow sand filters.

5. SOLUTIONS TRIED OUT

When the clogging problems in the filters became apparent a number of possible solutions have been considered by REGIDESO and their advisers. These included pre-chlorination, covering, acid dosing, and filter modifications.

5.1 Pre-chlorination and covering filters

Heise (1983) suggested that operational problems with old filters (built in 1967) were due to algae problems. Pre-chlorination was proposed for the new filters to be built to inhibit algae development. Tests performed in the laboratory of REGIDESO (1988) revealed that encrustation occurred in both covered and uncovered filters. Therefore, pre-chlorination was ceased and the option of covering filters was no longer

considered. However, operation of the old and new slow sand filters are not similar as the old filters were intermittently operated resulting in dry sand surface and very low supernatant water depth (maximum 200 mm).

5.2 Acid dosing

In the laboratory of REGIDESO tests were conducted to test the feasibility of pH correction by dosing acid. It was concluded that the amount of acid needed, calculated from the results of titrations, made this option too expensive.

5.3 Renovation of new filters

Two of the new slow sand filters were renovated in December 1989 - January 1990. The modifications included:

- (i) reduction of the existing sand layer to 300 mm and addition of 450 mm coarser sand ($d_e=0.4$ mm; U.C.=2.0);
- (ii) increase of the actual filtration velocity from 0.23 to $0.5 \text{ m}^3/\text{m}^2\cdot\text{h}$;
- (iii) improvement of the inlet construction to reduce the energy of the incoming water to reduce scouring of the sand bed near the inlet.

Due to the changed granulometry in the modified filter the velocity in the filter bed will be increased with a factor 9. Ives report (appendix 14) gives more details on this feature.

The preliminary results of this modification are positive as the filter run length increased to 142 days, purification performance was good and a regular Schmutzdecke was formed, and no calcification was visible in the Schmutzdecke and on the clean sand below the scraping. Less information is available on possible encrustation in the distribution net, however the impression exists that this is not very serious, which needs to be confirmed.

6. POSSIBLE SOLUTIONS

6.1 Introduction

Several options for solving the calcification problem as suggested by different expert were extensively discussed during the expert meeting. The options primarily aim at reducing the pH of the raw water resulting in stable water (SI=0) or aim at reducing the calcium content of the raw water before the filters.

The discussed options were:

1. slow sand filtration bypass;
2. mixing of lake water with water from other source having a lower pH;
3. dosing of acid;
4. limestone pre-filtration;
5. coarse sand or gravel pre-filtration;

6. use of fabrics;
7. lake bank infiltration;
8. modification of slow sand filters as recently renovated new filters.

Detailed information from the discussions on the options as given in appendix 3, section 5.

Apart from these options technical design modifications of the filter water inlet construction were discussed, which could contribute to a reduction of the calcification capacity.

6.2 Most promising options

6.2.1. Limestone pre-filtration

Calcium is most easily removed on calcium carbonate, i.e. limestone. Considering the technical and economic conditions in Bujumbura, a filter filled with crushed limestone, which is locally available, is most appropriate. The retention time has to be long as the process kinetics is low due to low calcium content. Retained suspended solids may act as nuclei for calcification. Upflow filtration may allow easy removal (through fast drainage) of suspended material and small calcified but not cemented matter.

The existing old filters could be converted into pre-filters reducing the investment, but additional pumping would eventually be needed.

Performance of process (particle size, bed height and filtration velocity) and overall cost needs further study.

6.2.2 Coarse sand or gravel pre-filtration

Although the driving force to remove calcium of a gravel or coarse sand filter will be initially less than of a limestone filter, the process kinetics may improve after the precipitation of some calcium carbonate on the grains.

Further research is needed to optimize design and to compare effectiveness with other options.

6.2.3 Non-woven fabrics

Research has shown that non-woven fabric is an effective filter aid for slow sand filtration (Mbwette, 1987). The surface of the non-woven fabric might be a good precipitation surface for calcification and in addition the suspended solids and organic material retained could act as nuclei and surface for calcification.

The financial and effectiveness of this option has to be further investigated.

6.2.4 Modification of slow sand filters along the line of the recently renovated filters

As reported by Ives and stated above the preliminary results of the modifications are positive. Longer term operation and performance monitoring and investigations on calcification

over the full bed depth and the distribution network are needed to conclude the long term viability of this option. In view of good bacteriological quality and low turbidity of the raw water, high filtration rates are very well acceptable and have the additional advantage that a high production is possible without expanding the surface area. With the high rate applied, the present filter surface would allow expansion of production capacity by 100%.

7. CONCLUSIONS AND RECOMMENDATIONS

- 7.1 Considering the satisfactory performance of the two recently renovated new slow sand filters, it is recommended to continue the present operation procedure. However, tests have shown that progressive calcification is likely in future runs. Performance monitoring and investigations on calcification pattern in filter bed and distribution mains are needed.
- 7.2 Reviewing the options for solving the problems of calcification of the slow sand filters, it is recommended to carry out pilot studies with limestone and sand/gravel (upflow) filters in Bujumbura. The application of fabrics could be investigated at a laboratory scale.
- 7.3 In view of the suggested pilot projects it is recommended to employ a research fellow for a period of two years who can carry out the research and development work, train laboratory staff on environmental and water quality monitoring and laboratory techniques. (Points for Consideration for Terms-of-Reference are attached as appendix 18).

REFERENCES

- Heise, K. (1983). Experience concernant l'Exploitation des Filtres a Sable Lents a l'Usine de Bujumbura. unpublished report
- Mbwette, T.S.A. and Graham, N.J.D. (1987). Improving the Efficiency of Slow Sand Filtration with Non-woven Synthetic Fabrics. Proceedings of the Filtration Society, Jan/Febr. 1987
- Neis, U. (1988). Difficulties in the Operation of New Slow Sand Filters in Africa. Paper presented at International Seminar "Advances in Slow Sand Filtration" London, Nov. 1988.

APPENDICES

1. Termes de Reference pour Etude et Investigations sur l'Exploitation des Filtres Lents dans l'Usine d'Eau du Lac
2. Proposition pour la Participation d'Experts à l'Exploitation des Filtres Lents de la Compagnie des Eaux du Lac Bujumbura du Burundi
3. Report of the Expert Meeting, July 1990
4. Expert Meeting: List of Participants
5. Expert Meeting: Tentative Programme
6. Opinion on SSF Problems of Mr Mark van Eekeren, KIWA
7. Summary of KIWA's opinion to solving SSF Problems
8. Opinion on SSF Problems of Dr Ir. A. Graveland
9. Summary of Dr A. Graveland's opinion to solving SSF Problems
10. Opinion on SSF Problems of Dr M. Boller, EAWAG
11. Summary of EAWAG's opinion to solving SSF Problems
12. Some observations on reports of SSF operation problems in Bujumbura, Burundi by Mr T.K. Tjiook
13. Summary of Mr Tjiook's contribution to discussion on SSF problems
14. Report on Visit to Bujumbura by K.J. Ives
15. Communication with Zweckverband Bodensee-Wasserversorgung on inlet design SSF
16. Communication with Prof Ives on limestone filtration
17. Laboratory results of acid testing of filter sand
18. Points for consideration for Terms of Reference Research Fellow in Water Filtration

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Frankfurt, den 15.8.1989

Om/Wie

Appendix 1

République du Burundi
Régie de Production et de Distribution
d'Eau et d'Electricité

TERMES DE REFERENCE

pour

ETUDE ET INVESTIGATIONS

sur

L'EXPLOITATION DES FILTRES LENTS

dans

L'USINE D'EAU DU LAC

1. Généralités1.1 Problèmes

Approximativement trois quarts de l'eau potable distribuée dans la ville de Bujumbura (env. 230.000 hab.) proviennent de l'eau du lac Tanganyika. Dans l'usine d'eau du lac, l'eau brute est uniquement filtrée (filtres lents à sable) et ensuite chlorée. La filtration s'est révélée problématique apparemment à cause de la qualité de l'eau brute que l'on remarque par une valeur en pH trop élevée. La précipitation des carbonates qui en résulte

provoque le colmatage des filtres et diminue la durée d'utilisation de ceux-ci ainsi que la capacité filtrante.

1.2 Installations existantes

En 1968, 4 filtres à sable lents ont été mis en service à l'usine d'eau de Bujumbura, avec une surface de filtration de 2.600 m². La capacité de ces installations a été augmentée en 1987 par la mise en service de 4 nouveaux filtres de 1.825 m² chacun. L'ensemble des filtres (surface 9.900 m²) est prévu pour une production journalière de 60.000 m³. La charge actuelle s'élève à 33.000 m³/jour. Un plan d'ensemble de l'usine d'eau du lac ainsi que la construction des filtres sont présentés dans les pages suivantes:

1.3 Investigations effectuées

Afin de déterminer la cause du colmatage des filtres et des mesures de remède, la REGIDESO et ses conseillers techniques (équipe GTZ) ont effectué des investigations sur

- l'équilibre chimique des eaux brutes,
- les conditions de flux dans les filtres,
- le prétraitement des eaux brutes au moyen d'un préfiltre à flux horizontal.

Tous les essais effectués pour diminuer les effets du colmatage au moyen d'une préfiltration n'ont pas été couronnés de succès. La réduction de la valeur en pH n'a été traitée que théoriquement parce que la neutralisation n'était pas considérée comme une solution appropriée en raison des coûts trop élevés. Comme autres mesures de remède la modification de la granulation et de la vitesse de filtration sont envisagées.

1.4 Informations supplémentaires

Comme source d'informations additionnelles, les rapports d'activité de la GTZ et les plans d'exécution des filtres sont disponibles auprès de la KfW.

Fig. 1: Plan d'ensemble
de l'usine d'eau au Lac

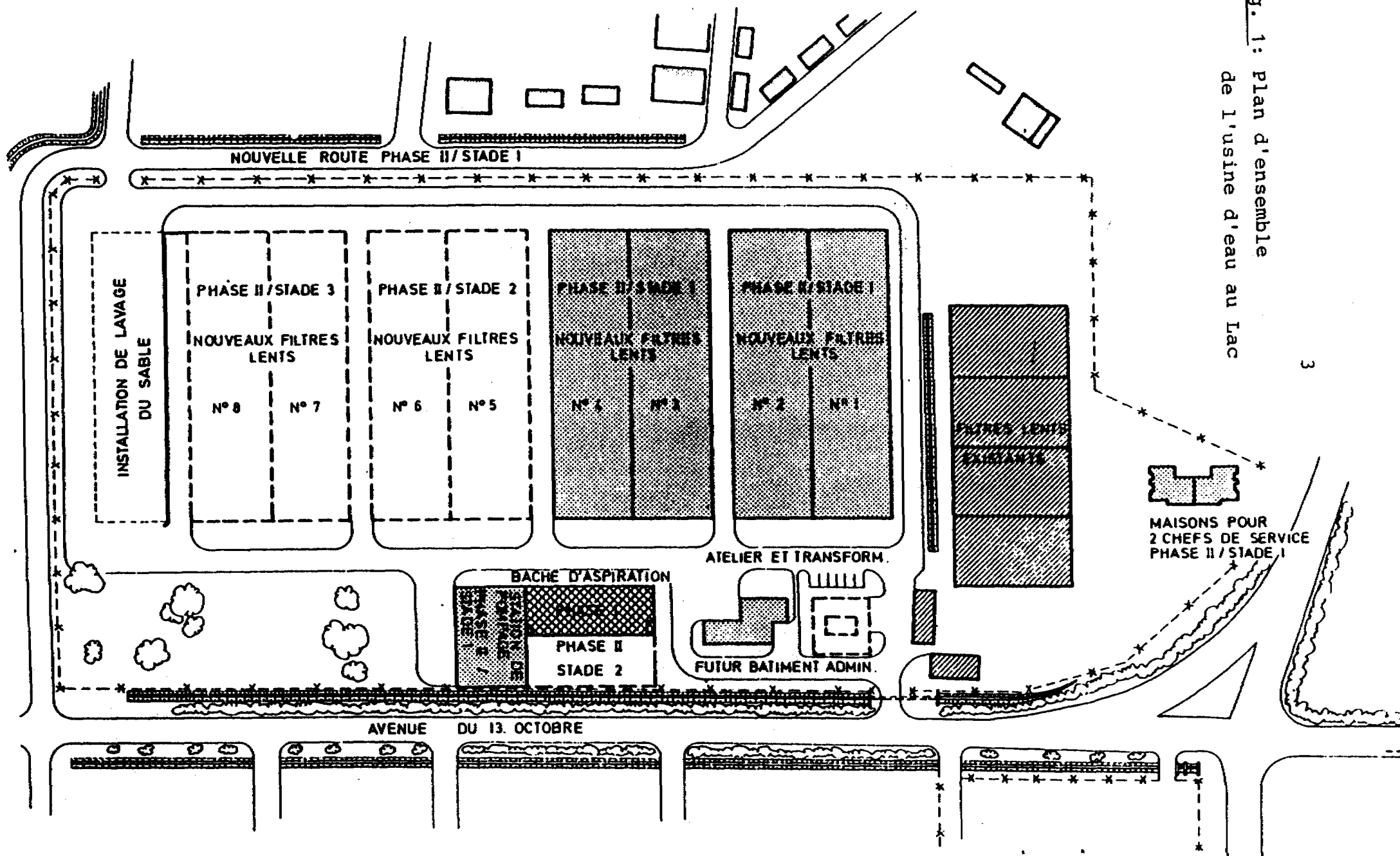
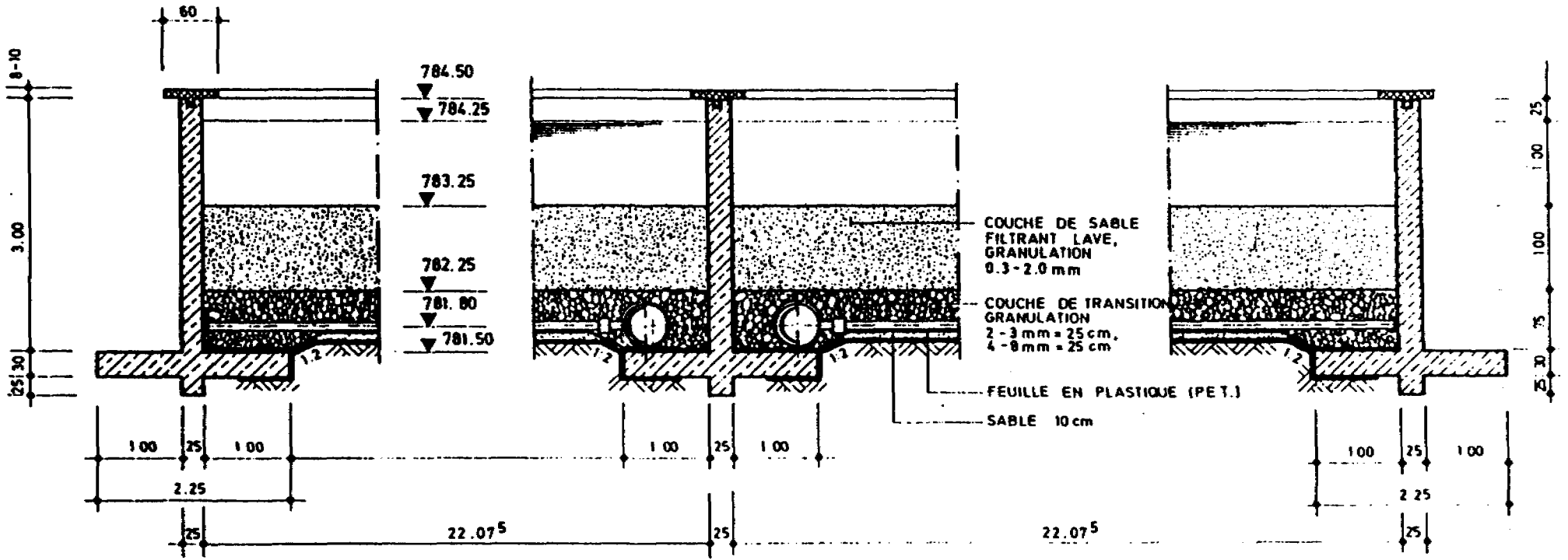


Fig. 2: Construction des filtres lents



2. Objectif des investigations

Les buts des investigations à effectuer sont:

- l'identification des causes du colmatage des filtres;
- l'évaluation des méthodes de remède pour diminuer/éviter le colmatage;
- des propositions de mesures à prendre pour rendre l'exploitation des filtres efficace.

On attend comme résultat des investigations:

- des propositions adéquates au point de vue technique et économique;
- l'élaboration de la base de dimensionnement et d'exploitation des installations proposées;
- l'établissement d'un avant-projet sommaire des mesures proposées y compris la ventilation des coûts.

3. Prestations de l'Ingénieur-Conseil

3.1 Remarques générales

Les termes de référence (TdR) présentés dans les chapitres suivants ne donnent qu'une indication des prestations à effectuer par l'Ingénieur-Conseil (IC).

En élaborant son offre, l'IC utilisera les TdR comme idée générale pour préciser des propositions. Les prestations à fournir doivent permettre de résoudre les problèmes directement liés au colmatage des filtres. Dans son offre, l'IC démontrera comment il envisage résoudre la tâche posée et indiquera ses connaissances et ses expériences dans le domaine du traitement des eaux superficielles.

3.2 Causes du colmatage des filtres

- (a) Evaluation des analyses et des essais effectués par le laboratoire de la REGIDESO.
- (b) Identification des causes principales et des paramètres responsables pour le colmatage.
- (c) Analyses et essais additionnels, si besoin en est pour identifier et quantifier les réactions et paramètres contrôlant le colmatage des filtres.
- (d) Etablissement des interdépendances des rapports entre la qualité des eaux brutes et le colmatage des filtres.

3.3 Remèdes au colmatage des filtres

- (a) Vérification des méthodes/procédés éventuellement appropriés pour le prétraitement des eaux brutes avant le passage des filtres.
- (b) Evaluation des possibilités de modification des filtres qui permettent la réduction du colmatage.
- (c) Jugement des méthodes prises en considération en vue de la faisabilité technique et économique; proposition des méthodes les plus prometteuses.
- (d) Vérification des propositions (alternatives) à l'aide d'essais sur des modèles réduits; comparaison des variantes appropriées; présentation de la solution retenue;
- (e) Vérification de la solution retenue par des essais additionnels; dérivation des paramètres de dimensionnement et d'exploitation; preuve de l'efficacité des mesures et des critères proposés à l'aide d'essais à long terme;

- (f) Conseil pour la conception technique, le dimensionnement, la réalisation et l'exploitation des installations proposées.

3.4 Avant-projet sommaire

- (a) Esquisse du schéma de fonctionnement des installations/modifications proposées.
- (b) Dimensionnement et établissement des plans d'exécution des installations prévues.
- (c) Esquisse du schéma d'exploitation; besoin en matériel et personnel.
- (d) Estimation des coûts d'investissement et des coûts courants ainsi que des économies par rapport à l'exploitation actuelle; Calculation des valeurs du jour et du prix de revient.

4. Conditions particulières

4.1 Présentation de l'offre

L'Ingénieur-Conseil doit élaborer son offre en langue française en deux parties

- proposition technique;
- proposition financière.

La proposition technique comprendra:

- des commentaires sur les TdR;
- la présentation d'une analyse des problèmes et des objectifs à poursuivre;
- la présentation de la méthodologie et des conceptions envisagées pour atteindre les objectifs;
- la proposition d'un programme de travail et du planning du déroulement des activités;

- La description de la composition et la qualification de l'équipe et son intervention prévue dans le déroulement des activités;
- Les curricula vitae du personnel proposé mettant en évidence l'expérience spécifique acquise dans les domaines demandés.

La proposition financière comprendra:

- une description détaillée des prestations offertes avec indication des dépenses en devises et en monnaie locale;
- les montants pour les services spéciaux (p.ex. équipement pour les analyses, fabrication des modèles réduits etc.);
- les modalités de paiement;
- la validité de l'offre.

4.2 Honoraires, droits, taxes, impôts

Les honoraires de l'Ingénieur-Conseil, dont le montant sera indiqué dans la proposition financière, couvriront les salaires de son personnel, les frais de voyage, de séjour et d'autres dépenses afférentes aux services auxiliaires, aux véhicules, aux équipements, à l'achat de documents, à l'élaboration de dossiers et de plans contractuels en nombre convenu. Les prix doivent être fermes et non révisables.

Les prestations de l'Ingénieur-Conseil sont exonérées de tous droits, taxes et impôts au Burundi. Toutefois le règlement d'importation temporaire reste applicable également pour toute importation réalisée dans le cadre de ce marché et pour les besoins de celui-ci.

4.3 Début des prestations

L'Ingénieur-Conseil doit commencer les prestations dans un délai de quatre (4) semaines à compter de la date de passation du marché.

4.4 Rapports avec la REGIDESO

L'Ingénieur-Conseil doit travailler en étroite collaboration avec la REGIDESO, ses conseillers et les autres services locaux.

Le Maître d'Ouvrage souhaite que son propre personnel soit incorporé dans l'équipe de travail de l'I.C. responsable pour l'exécution des prestations demandées. Lors de l'établissement de son offre, l'Ingénieur-Conseil doit évaluer la disponibilité et la qualification de ce personnel et déterminer les diverses possibilités et modalités de son intervention.

A la demande de la REGIDESO, des réunions seront organisées entre ses représentants et ceux de l'Ingénieur-Conseil.

Ces réunions auront pour objet l'évaluation régulière et la coordination des activités, et fourniront des informations sur tous les aspects relatifs aux travaux et aux services exécutés ou fournis par l'Ingénieur-Conseil.

4.5 Documents et rapports

L'Ingénieur-Conseil présentera à la REGIDESO et à la KfW les rapports et documents suivants, rédigés en langue française:

- RAPPORT A: Résultats des investigations sur les causes du colmatage des filtres (voir chap. 3.2)
(3 exemplaires à l'administration; 2 à la KfW)

- RAPPORT B: Proposition des remèdes au colmatage des filtres (voir chap. 3.3)
(3 exemplaires à l'administration; 2 à la KfW)

- RAPPORT C: Avant-projet sommaire (voir chap. 3.4)
(3 exemplaires à l'administration; 2 à la KfW)
- RAPPORTS DÉFINITIFS: 4 semaines après l'approbation du rapport en question (A, B ou C). (10 exemplaires à l'administration; 2 à la KfW).

Les commentaires ou l'approbation des rapports par l'administration ou la KfW se feront dans un délai de quatre semaines.

4.6 Contribution de la REGIDESO

La REGIDESO et ses représentants et conseillers seront prêts

- à mettre à la disposition de l'Ingénieur-Conseil toute la documentation dont ils disposent;
- à rendre possible le travail de l'I.C. dans le laboratoire de l'usine d'eau du lac;
- à prévoir que le personnel du laboratoire et des aides secondent l'I.C. lors des essais.

4.7 Evaluation des offres

Les propositions techniques seront évaluées selon les critères suivants:

- expérience du bureau d'Ingénieur-Conseil dans le domaine de traitement des eaux de surface (10 points);
- analyse de l'objectif et des T.d.R. (10 points);
- conception des investigations et des méthodes proposées; planning de déroulement (20 points);
- conformité entre l'offre et les T.d.R. (20 points);
- qualification et expérience du personnel-cadre dans les domaines d'intervention (40 points).



PROPOSITION POUR LA PARTICIPATION D'EXPERTS A L'EXPLOITATION DES FILTRES LENTS DE LA COMPAGNIE DES EAUX DU LAC BUJUMBURA DU BURUNDI

INTRODUCTION

Les installations de filtres lents sur sable situé sur le site de traitement des eaux du lac font face à de sérieux problèmes dont le colmatage rapide des filtres. La précipitation des carbonates dans les grains de sable en est la cause. Plusieurs enquêtes se sont déroulées concernant (1) L'équilibre chimique de l'eau brute, (2) les conditions de débit dans les filtres, et (3) le prétraitement des eaux brutes au moyen d'un préfiltre à flux horizontal. Toutefois, aucune méthode applicable n'a été identifiée jusqu'à présent.

KfW lance donc un appel aux experts afin d'identifier la cause du colmatage et propose des méthodes d'élimination ou au moins de réduction du colmatage afin d'arriver à un bon fonctionnement du filtre lent à sable.

Le CIR a acquis une grande connaissance et expérience sur les filtres lents sur sable à travers la réalisation de projets de recherche et de démonstration exécutés en collaboration avec les institutions dans plusieurs pays dont l'Inde, la Thaïlande, le Kenya et la Colombie.

2. PROPOSITION

En vue de la complexité du problème, on propose de suivre une méthode par étape. Dans la 1ère phase une petite équipe d'experts en la matière de filtres lents sur sable et de chimie des eaux sera formée. Ils étudieront l'information disponible sur la qualité des eaux et le résultat des enquêtes déjà effectuées. En outre, l'information technique nécessaire et les données sur la qualité des eaux seront compilées et REGIDESO sera informée en conséquence afin de poursuivre sa collecte de données. Un des membres de l'équipe d'experts rendra visite à l'installation afin d'évaluer la situation et l'installation complète de traitement des eaux et de contrôler les opérations d'entretien appliquées. Des membres de l'équipe d'experts analyseront ensuite le problème en utilisant toutes les données recueillies y compris le rapport sur la visite sur le terrain. Un rapport basé sur les résultats de l'analyse et de la visite sur le terrain sera rédigé. Il comprendra une analyse du problème et apportera des recommandations sur les solutions possibles en prenant en compte des conditions prévalentes de Bujumbura. Le rapport sera finalisé au cours d'une journée d'atelier organisée au CIR où l'on invitera l'équipe principale d'experts et quelques experts supplémentaires spécialistes du traitement des eaux dans les pays tropicaux. La participation d'un membre du personnel de la REGIDESO de l'installation de Bujumbura et/ou de l'équipe du projet de la GTZ est envisagée.

La 1ère Phase sera complétée lors de la remise du rapport dans son intégralité (les commentaires et conseils recueillis lors de l'atelier y auront été insérés) à REGIDESO de Bujumbura et à KfW.

La 2ème phase ne peut être formulée qu'après avoir déterminé les solutions techniques possibles et les besoins en recherche. Toutefois, la composition de l'équipe principale permettra la formulation de plusieurs options d'assistance à l'exécution des recommandations et à la confirmation de la viabilité technique des solutions possibles. Ces options se composent, entre autres, de tests au Laboratoire de L'ingénierie Sanitaire de l'Université Technique de Delft et des tests pilotes guidés sur les lieux de l'installation à Bujumbura.

3. PLAN DE TRAVAIL

1ère Phase

Les activités suivantes sont envisagées :

1. Collecte des données existantes sur la qualité de l'eau, opérations de traitement des eaux, et collecte des résultats des expériences faites jusqu'à présent;
2. Etude de l'information recueillie par une petite équipe d'experts, et liste de l'information supplémentaire nécessaire, données à la fois techniques et concernant la qualité des eaux;
3. Collecte de données et d'informations supplémentaires en partie par REGIDESO et l'équipe de GTZ;
4. Visite d'un membre de l'équipe d'experts à Bujumbura afin d'analyser la pratique opérationnelle du traitement des eaux et recueillir les données et informations supplémentaires;
5. Analyse détaillée des problèmes et formulation d'options possibles par l'équipe principale d'experts; ceci résultera en un premier rapport;
6. Atelier formé d'un important groupe d'experts et de représentant(s) de REGIDESO et de l'équipe de projet de la GTZ qui permettra de discuter du premier rapport et de former des recommandations pour les prochaines étapes;
7. Rapport final à REGIDESO ET KfW;
8. Formulation d'une proposition pour la 2ème phase basée sur les résultats de la 1ère phase.

IV. EQUIPE D'EXPERTS

L'équipe d'experts principale sera composée des personnes suivantes (ci-joints leurs Curriculum Vitae);

1. Prof. Dr. K.J. Ives, Professeur d'Ingénierie des Travaux Publics, Department of Civil and Municipal Engineering, Univery College of London;
2. M. M. van Eekeren, Responsable du Groupe de Travail sur l'adoucissement et le conditionnement des eaux, KIWA, Water Material Testing Laboratory, Nieuwegein, Pays-Bas;
3. Prof. Dr. A. van Breemen, (Chimie de l'eau) Responsable du Laboratoire Sanitaire, Technical University of Delft, Pays-Bas;
4. M. J.E.M. Smet, CIR, Centre International de l'eau et de l'Assainissement, La Haye, Pays-Bas

Pour l'atelier qui aura lieu au CIR de La Haye, les personnes suivantes seront invitées en plus du groupe d'expert principal:

- un représentant technique de la REGIDESO de bujumbura;
- un membre de l'équipe de projet de GTZ;
- Dr. B. lloyd, Microbiologiste, The Robens Institute, Environmental Health Unit, University of Surrey, Royaume-Uni.
- Dr N.J.D. Graham, Ingénieur en Travaux Publics, Department of Civil Engineering, Imperial College of Science and Technology, University of London, Royaume-Uni.
- M. M. Wegelin, Ingénieur Sanitaire, IRCWD/EAWAG, Duebendorf, Suisse
- M. J.T. Visscher, Ingénieur Sanitaire, CIR, Centre International de l'eau et de l'Assainissement, La Haye, Pays-Bas
- M. T.K. Tjiok, Ingénieur Sanitaire, CIR, Centre International de l'eau et de l'Assainissement, La Haye, Pays-Bas

5. EMPLOI DU TEMPS

En prenant l'hypothèse que le problème du colmatage n'est pas un problème saisonnier, nous proposons de fixer la visite à Bujumbura, l'analyse du problème, le premier rapportage et l'atelier (activités 5 et 6) dans la période du 19 mars au 14 Avril 1990.

6. ORGANISATION

Le CIR sera responsable de la coordination des activités mentionnées à l'exception de la collecte des données supplémentaires au Bujumbura (art. 3). L'atelier de l'équipe d'expert (act. 6) aura lieu dans les salles de conférence du CIR à La Haye. La coopération étroite de REGIDESO Bujumbura, de GTZ et de KfW caractérisée par la provision de documents sur la qualité des eaux, le fonctionnement des filtres, les tests/essais etc. sera nécessaire. Le CIR prendra soin de la distribution de tous les documents qui se rapportent au sujet aux membres de l'équipe d'experts.



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Appendix 3

**REPORT OF THE EXPERT MEETING ON
SLOW SAND FILTRATION PROBLEMS AT REGIDESO, BUJUMBURA, BURUNDI
HELD AT IRC ON THURSDAY 19 JULY 1990**

IRC International Water and Sanitation Centre

The Hague

December, 1990

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0. General

List of participants present is attached (appendix 4).

Unfortunately, Mr C. Ohnmacht, Mr Ndayegamiye and Dr J. van Puffelen could not be present during the meeting, but hope the participants have fruitful discussions.

Programme of one-day meeting is attached (appendix 5).

The meeting agreed with the proposed chairman of the meeting Prof. K.J. Ives. Mr J.E.M. Smet was rapporteur.

1. Purpose of the meeting

The expert meeting was organized to bring together a group of experts in water treatment technology and water chemistry, and representatives from the water works REGIDESO to (i) discuss the prevailing problems of the slow sand filtration, the causes and effects of these problems, (ii) suggest and discuss appropriate and feasible solutions, and (iii) propose steps for further action on testing and introduction of solutions for faced problems.

2. State-of-affairs

2.1 Water source and treatment system in Bujumbura, by Mr F. Butoke

Mr Butoke gave an overview of the raw water source, the intake and all treatment steps of the water before distribution. The main problems with the slow sand filtration - both with the old (built in 1967) and new filters (in operation since 1987) - and its effects on the operation of the filters and on the water quality were outlined.

Pollution aspects of raw water by sewage, and actual and possible effects on performance of slow sand filters (SSF) were discussed.

Dr Graham pointed out that disinfection efficiencies will be low for water with a high pH.

2.2 Problems with slow sand filtration, by Dr U. Neis

A picture was given of the history of slow sand filtration within REGIDESO. The old SSFs had also some problems but these were poorly designed and operated. As it was thought that algal growth caused the problem, pre-chlorination was done without effect. Soon after the commissioning of the new SSFs (in 1987) performance and operational problems were identified to be due to calcification of the upper filter sand. Very short filter runs (5 to 20 days) were experienced. Recently the characteristics of two filters have been changed by partly replacement of fine sand by coarser sand (two

layer filtration) and by an increase of actual filtration rate from 0.25 to 0.56 m³/m².h. In daily practice the filtration rate varies and filters run under declining rate depending on the need for drinking water and the subsequent clear water stock.

The main problem of calcification of the upper sand bed was prevented by these new filter composition and operations. In not-renovated SSFs the calcium content dropped with 5-8 mg/l while for the renovated ones it was only 3 mg/l. No effervescence with HCl (1:1) (which would indicate presence of calcium carbonate) from the filter sand under the scraped Schmutzdecke was observed.

Temperature and oxygen content of lake water does hardly change by depth (up to 25 m).

Encrustation of CaCO₃ was experienced in steel pipes, resulting in reduction of diameter, although 20 years old mains are still functioning properly. No encrustation was experienced on asbestos-cement pipes.

The option of mixing different raw waters to lower the saturation index was raised; sources of water with lower pH are (i) groundwater (no data available), (ii) river water (but Ndahangwa has very high turbidity during rainy season), (iii) spring water, pH as low as 5.

2.3 Experiences with SSFs Bujumbura and calculation model for calcification potential of water, by Dr. H.H. Stabel

Dr Stabel showed some slides of old and new SSFs at Bujumbura. His institute has a twinning arrangement with REGIDESO.

The situation in Lake Constanz is comparable with that in Lake Tanganyika, but ratio Ca and Mg content is just reverse. The calcified sand was examined and it was found that the precipitate consisted of mainly CaCO₃ with about 22% MgCO₃ (solid solution).

Dr Stabel is developing a model to predict the stability of surface water towards calcium and magnesium precipitation. Usually, water with an oversaturation of calcium and magnesium will not show spontaneous precipitation, but the Ca and Mg seeks nuclei to precipitate upon. The model includes parameters such as pH and conductivity. Algae very much influence increase of pH, but Stabel has not experienced Ca/Mg precipitation on algae.

2.4 Observations and findings of recent field visit to Bujumbura, by Prof. K.J. Ives

Prof. Ives' recent field report (appendix 14) was discussed and several issues got specific attention.

The low turbidity of the lake (Sect. 4.1) was stressed as a great advantage, even the inflowing rivers with

turbidities up to 500 to 1,000 do not influence its turbidity. The stated total phosphorus concentration (Sect. 4.2) is quite high; according to Dr Stabel the stated figures are wrong.

The old SSFs (Sect. 6.1) contribute only about 10% of the total water production. They function poorly and do not develop a Schmutzdecke. Two of the new SSFs (filter 1 and 2) are not in operation.

3. Reporting on contributions/suggestions received

IRC had asked several organizations and individuals (listed below) to give their opinion and put forward suggestions for solving the present problems with the REGIDESO SSFs.

1. KIWA (Waterworks' Testing and Research Institute), Mr M. van Eekeren
2. Dr A. Graveland, Head of Water Laboratory, Amsterdam Waterworks
3. EAWAG (Swiss Federal Institute for Water Resources and Water Pollution Control), Dr M. Boller
4. Mr K. Tjiook, Adviser to IRC

Copies of their contributions were distributed among meeting participants. Their contributions were summarized during the meeting by Mr Smet. Summaries of their contributions are appended as no. 7, 9, 11 and 13.

Some new options for solutions raised by these above mentioned contributors were briefly discussed.

4. Discussed technical modifications

Mr Elsenhans proposed modifications for inlet construction which would have positive effect on the decarbonization. A water inlet construction just above the sand bed, reducing the contact between pumped water and the air, would be beneficial from a energetic and operational point of view. Sketches on the modified inlet constructions of Eng. Elsenhans have been appended (appendix 15). In Germany good results were obtained with such improved inlet constructions for SSFs.

A mechanical schmutzdecke-removal (scraping) device was discussed which would clean the filter bed during operation. As cleaning is done under water, there would then be no need for supernatant drainage and SSF functioning could continue. The construction appeared quite complicated with need for suction of scraped Schmutzdecke by mechanical pump. As labour costs are low and mechanical parts vulnerable for functional problems, this option was not supported.

5. Possible options for solving the existing problems

The following solutions were discussed:

1. Slow Sand Filtration By-Pass
2. Mixing of lake water with water from other source
3. Dosing of acid
4. Limestone pre-filtration
5. Coarse sand or gravel pre-filtration
6. Use of fabrics
7. Lake bank infiltration
8. Modification of SSFs as present renovated new SSFs (filter 3 and 4)

5.1 Slow sand filtration bypass

This option would not be acceptable for reasons of denial the political, professional and economic investment in the newly built SSFs.

5.2 Mixing of lake water with water from other source

The lake water has a high pH in the order of 9.0, while the chemical and calcium equilibrium pH, called pH_s , is about 8.0. According to Langelier a water is oversaturated if saturation index $SI = pH_{actual} - pH_s > 0$, and calcium may then be precipitated. If a water with a Langelier or saturation index less than 0 can be found the ultimate SI may be brought to zero by mixing the raw waters.

Alternative water sources available are: groundwater, spring water and surface water (rivers).

Mixing is to be done prior to application to SSFs, which will create the need for an extra mixing tank.

- a. Groundwater: this source is presently not used for water supply in Bujumbura, perhaps for agriculture, so no data are available on pH and other chemical characteristics, needed to calculate the potential (e.g. through volume of groundwater needed) for mixing.
The option is not attractive for reasons of investment and running costs of pumping and delivering the groundwater to the plant site.
- b. Spring water: it is known that spring water has low pH (± 5). It was estimated that some 20% of spring water was needed for mixing with lake water. This implies that about 8,000 m³/d of spring water is to be captured and transported over a long distance by gravity to the plant.
This option is neither attractive because of high investment costs for captation, mains and mixing chamber.
- c. Surface water: it is known that some rivers in the neighbourhood of Bujumbura have low pH. It is known that the water from Ndahangwa river, used for public

water supply after treatment, has a pH of 7-7.5. However, during rainy season the turbidity levels of this water rise to 5,000-10,000 NTU. Mixing with such surface water would render water unsuitable for slow sand filtration while turbidity levels of lake water are in the range of 1.0-8.0.

Because of the above reason the application of surface water for mixing is not further considered.

It was concluded that mixing with different water is not a viable option.

5.3 Dosing of acid

The dosing of acid was suggested by several experts as the most obvious solution for the problem of high pH. Dr Graveland and Prof Ives calculated the daily cost for HCl needed: they found respectively US\$ 660 and US\$ 75 per day for 40,000 m³ and based on US\$ 300/tonne of 30% HCl.

In many situations this would have been the easiest and cheapest solution. Two main reservations were made on the option to dose acid:

1. economic problem: investment and maintenance cost of acid dosing equipment, and the cost of purchasing the continuously required chemical (not locally available) are all to be paid in foreign currency, which may not always be available for REGIDESO
2. technical problem: the dosage of HCl is to be continuously checked, which is presently not feasible at the waterworks. Proper chemical dosing is often a problem under such conditions. Over-dosage of HCl will render the water aggressive for metals and calcium, creating a new and serious problem for storage and distribution system.

The lime factory in Bujumbura has CO₂ gas as byproduct of the process, but the amount is limited and the distance between factory and waterworks is far, about 100 km. Use of commercially available CO₂ is too expensive.

Because of the above stated reasons the option to dose acid was not further considered.

5.4 Limestone pre-filtration

If calcium carbonate is to be removed by precipitation it will do this best on calcium carbonate, so limestone.

The water treatment practice knows three main technologies of calcium carbonate precipitation on the same material, i.e. in:

1. pellet reactor
2. sludge blanket reactor
3. crushed limestone filter

The pellet reactor is not further considered because of complicated operation procedures although no chemicals have to be added to increase the pH as is the case in the Netherlands situation. The investment and operation cost would also be quite high (for comparison see contribution Dr Graveland), although upflow rates may be high (range 10 to 80 m/h or even higher) and precipitation may be fast on fine quartz seed material (high value SA).

The sludge blanket reactor; the upflow rate can be as low as 1 -5 m/h) and retention times in the order of 1 hour depending on precipitation reaction rates. Sedimentation facilities must be provided and CaCO₃-sludge may be recirculated to function as seed material. For reasons of operational complexity this option is not further considered.

The crushed limestone filter could be a viable option as already described by Prof Ives. The retention times will be high (low velocities) as the reaction kinetics are not very high because the calcium content (the driving force) is low (10 mg/l).

The process could be enhanced by desorption of CO₂ in cascades with gravel prior to the filter.

When an upflow filter is used retained suspended solids and calcium carbonate crystals suspended in the water, will act as nuclei for calcification. This feature depends on the upflow velocity.

Another big advantage of upflow filtration is the ease of cleaning of filtered suspended solids and calcium carbonate crystals by means of fast drainage of water present in the filter. Presently experiences on upflow filtration and fast drainage cleaning are gained in a pretreatment research project jointly executed by CINARA, a research and development group in Cali, Colombia, and IRC.

Limestone is locally available, according to Mr Butoke, and therefore no foreign currency is involved. The investment cost are low as the existing old SSFs could be converted into pre-filters, and the operational costs would also be low. Optimization of particle (gravel) size, bed height and filtration velocity is needed.

A literature review and communication with Prof. Ives after the Expert Meeting (Appendix 16) indicate that present experiences with limestone filtration are very limited.

The use of natural complexing agents such as peat was much discouraged as it would cause serious - difficult to remove - colour problems.

Also the use of small quantities of coagulants for flocculation would not give an optimal effect as kinetics would be poor.

5.5 Coarse sand or gravel pre-filtration

Coarse sand filtration such as rapid sand filtration or gravel filtration, has initially less favourable kinetics compared with limestone, but this may increase after the precipitation of some calcium carbonate on the grains or gravel. The surface acts then probably as nuclei.

This option could become a viable option but research is to be done to compare effectiveness with limestone pre-filters.

5.6 Use of fabrics

Dr Graham has done research on and has experience with non-woven fabrics as aid for slow sand filtration. This material (e.g. polypropylene) has a high porosity (80-90%) and a permeability 15-20 times higher than usual SSF sand. Use in pre-filters to promote calcification may be possible as fabrics retain also suspended solids and organic material which could in addition to the fabric surface act as nuclei and surface for calcification.

It could be investigated whether a stack of fabrics, of which the clogged upper one could be removed, would be effective.

UV resistance of fabric and cost aspects have to be further investigated.

5.7 Lake bank infiltration

The banks of Lake Tanganyika are indeed sandy, allowing for bank infiltration. No data from wells are available. The initial high investment of well construction and collection system make this option not attractive to further consider.

5.8 Modification of SSFs as recently renovated new SSFs

Presently, two new SSFs were renovated: no. 3 and 4 by reducing the original sand bed thickness, adding a layer of coarser sand and increasing the filtration rate. These modified SSFs perform reasonable. Appendix 14 gives detailed information. At the time Prof Ives visited Bujumbura, filter no. 4 was put out of operation. Prof. Ives' report gives information on the tests performed on the sand just below the schmutzdecke. This sand did not show any calcification, visible by eye nor effect of HCl (1:1). Definitely, some calcification has taken place as the calcium content dropped with 3 mg/l over the SSF. It is however unclear how this calcification was distributed over the bed depth. This should be investigated by taking a sand profile after each filter run.

During his field visit Prof. Ives took sand samples from Filter 4 after the first filter run of 142 days for

testing in the laboratory. Although field tests (using simple means) on sand samples were negative for calcification (see previous paragraph), the laboratory test results reveal calcification in upper and lower filter sand layers (appendix 17). Progressive calcification of filter sand in future runs is very likely.

Prof Ives explained in his report that the major reasons for improved functioning of the renovated SSFs were the decrease in surface area with about a factor two, and the increased filtration rate with a factor 2.5. For the precipitation of the calcium carbonate both factors: contact time and available surface area are important.

It was suggested to dissolve any calcium carbonate precipitate in the filter with weak acid. This is actually not advisable as the concrete of the SSF box and clear water tank will also be attacked by the acid.

6. Expansion

Extension of slow sand filtration production is possible as now only two new slow sand filters (no.s 3 and 4) are operative. If filtration rate of $0.5 \text{ m}^3/\text{m}^2\cdot\text{h}$ is acceptable the filtered water production using the four filters can be expanded to $80,000 \text{ m}^3/\text{h}$ against a present production of $40,000 \text{ m}^3/\text{h}$. The pumping capacity of the present pumps is $67,000 \text{ m}^3/\text{h}$.

7. Recommendations

- 7.1 Considering the satisfactory performance of the two renovated new slow sand filters no. 3 and 4, it is recommended to continue the present operation procedure. Performance monitoring and investigations on calcification pattern are needed.
- 7.2 Reviewing the options for solving the problems of calcification of the slow sand filters, it is recommended to carry out pilot studies with limestone and sand/gravel (upflow) filters in Bujumbura. The application of fabrics could be investigated at a laboratory scale.
- 7.3 In view of the recommended pilot projects it is recommended to employ a research fellow for a period of two years who can carry out the research and development work, train laboratory staff on environmental and water quality monitoring and laboratory techniques. (Points for Terms-of-Reference: appendix 18)



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Appendix 4

EXPERT MEETING ON SLOW SAND FILTRATION PROBLEMS

REGIDESO (Regie des Eaux) - BUJUMBURA, BURUNDI

THE HAGUE, 19 July 1990

**LIST OF PARTICIPANTS
(in alphabetical order)**

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* Expected participants who informed IRC that they were not able to participate.



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Appendix 5

EXPERT MEETING ON SLOW SAND FILTRATION PROBLEMS

REGIDESO - BUJUMBURA, BURUNDI

THE HAGUE, 19 July 1990

TENTATIVE PROGRAMME

- 09.00 Introduction
- 09.10 Programme of today
- 09.15 Background papers, and contributions from individuals not present
- 09.30 Presentation on state-of-affairs
 - 09.30-10.00 REGIDESO
 - 10.00-10.30 Dr U. Neis
- 10.30 Coffee break
 - 10.45-11.15 Dr H. Stabel
 - 11.15-11.45 Prof K.J. Ives
- 11.45 Discussion and conclusions on main treatment problems
- 12.15 Main directions for solving present problems
- 12.30 Lunch (groundfloor)
- 13.30 Discussions on possible solutions: Details and Implications
- 15.30 Coffee/Tea break
- 15.45 Discussions and proposals for further investigations, pilot studies etc.
- 17.30 End of meeting

To : IRC, Jo Smet
From : Marc van Eekeren (KIWA)
Concerning : Operational problems of slow sand filters of
REGIDESO, Bujumbura, Burundi
Date : june 15, 1990

Dear Jo,

We herewith send you our opinion concerning the problems with the operation and performance problems of slow sand filters in Bujumbura. Included is a list with additional data required to review the technical aspects and water quality.

With best regards,


Marc van Eekeren

1. CLOGGING PROBLEMS WITH OPEN RECHARGE BASINS

Clogging of sand beds in open recharge basins is a well known problem in the Netherlands. The waterworks of The Hague, Leiden, Amsterdam and the North of Holland (PWN) have to cope with problems concerning clogging of sand beds. These companies use ground water from the dunes as raw water for the production of drinking water.

Pre-treated surface water is used for artificial groundwater recharge in the dunes. Filtration rates vary from 0.1 to 0.5 m/h. Infiltration channels and basins clog and maintenance is needed periodically. The channels and basins are not protected against direct sunlight.

These clogging problems are known since the thirties. Since 1974 pre-treated surface water is used. This pre-treatment was responsible for an increase in the amount of the clogging problems as far as these were related to calciumcarbonate precipitates. Pre-treated water usually is characterised by SI = 0. During storage in the channels and basins this index increases

and becomes $SI > 0$, which will result in the formation of calciumcarbonate.

Until now no measures to reduce clogging problems are operational. The most suitable ones for the dutch situation should be dosing of HCl or H_2SO_4 , and, under certain circumstances, NaHOCl or protection against direct sunlight.

2. CAUSES OF CLOGGING

In dutch literature (KIWA report 82, 1986) several causes are mentioned concerning the above mentioned problems. Some of these causes can be translated to the Bujumbura situation, as follows:

- growth of algae;
- precipitation of calcium carbonate, by:
 - * biogenic softening;
 - * temperature increase;
 - * evaporation of supernatant water;
- sedimentation of suspended solids;
- precipitation of other sparingly soluble salts.

3. CLOGGING OF SLOW SAND FILTERS IN BUJUMBURA

According to the information available, clogging of the slow sand filters in Bujumbura has been caused by the formation of calciumcarbonate precipitates. In our opinion this cause is realistic, although TPCC (Theoretical Precipitable Calcium Carbonate) is low ($< 10 \text{ mg/l}$).

Our hypotheses is:

- Filter bed pores become clogged by diatoms and suspended solids present in the raw water. Diatoms originate from the lake Tanganyika. These small organisms live in the filter bed pores and multiplication takes place;
- TPCC values of 10 mg/l are responsible for a weekly TPCC-load of 500 g/m^2 on the surface of the filter bed. Calciumcarbonate precipitates on the diatom

shell surface resulting in an extreme reduction of filter bed pore size. This is an exponential process;

- TPCC value of the supernatant water will increase as a result of:
 - * evaporation (temperature raise: direct sunlight);
 - * pH increase caused by the growth of algae (Schmutzdecke);
 - * pH increase caused by the reproduction of diatoms in the filter pores;

4. POTENTIAL SOLUTIONS

In the strategy leading to the reduction of the problems, assuming the above mentioned hypotheses, the following goals have to be reached:

- reduction of TPCC in the supernatant water, by
 - * prevention of algae growth;
 - * decrease of pH;
 - * avoiding precipitation;
 - * avoiding increase of water temperature.
- reduction of diatoms on/in the filter bed;

Technical measurements which can be taken:

- dose acid in order to decrease pH of the water;
- avoid direct sunlight (covering the filter bed area);
- change source: use lake-bank infiltrate instead of direct extracted lake water. The lake-bank infiltrate is pre-treated, with the following advantages:
 - * lake-bank infiltrate is in equilibrium ($SI = 0$);
 - * pre-treatment (lake-bank) results in a lower content of nutrient for algae;
 - * lower content of diatoms;
 - * lower content of suspended solids;
- use a second source with $SI < 0$, if available and mix this water with lake water/lake-bank infiltrate, to obtain $SI = 0$.

5. ADDITIONAL DATA REQUIRED (SHOPPING LIST)

Activities to support the hypotheses:

1. measure MFI (Membrane Filtration Index) or SDI (Salt Density Index) of:
 - * raw water, supernatant water on the filter;
2. confirm if diatoms are present in:
 - * raw water, supernatant water, on filterbed surface and in filter bed (depth 2 cm);
3. measure temperature profile:
 - * raw water, several steps in pre-treatment and in the supernatant water;
4. measure pH-profile of:
 - * raw water, several steps in pre-treatment and in the supernatant water;
 - * in schmutzdecke;
5. visual inspection (with microscope) of:
 - * raw water;
 - * supernatant water;
 - * sample 30 cm below filter bed surface;
 - * drinking water.

Collect information concerning the feasibility of the recommendations for the technical measures:

6. feasibility of lake bank infiltration
 - * infiltrate quality;
 - * lake bank conditions;
7. is alternative source , with SI < 0, available;
8. is use of acid possible and accepted;
9. possibilities to avoid direct sunlight;
10. information necessary to make an economic study aof the costst of:
 - * covering of the plant;
 - * periodical maintenance;

Summary of KIWA contribution

The clogging is caused by calcium carbonate, although Theoretical Precipitable Calcium Carbonate (TPCC) is low (± 10 mg Ca/l). Clogging may also be enhanced by diatoms which multiply in filter bed and on which CaCO_3 is precipitated. TPCC value will increase as result of: (i) evaporation, (ii) pH increase caused by growth of algae, and (iii) pH increase by production of diatoms in filter pores.

Solutions should aim for reduction of TPCC in supernatant (by preventing algae growth, decrease pH, avoiding temperature increase) and for reduction of diatoms on/in filter bed.

Technical measurements which could be taken:

- a. dosing of acid to decrease pH
- b. avoid direct sunlight (no temperature increase)
- c. avoid growth of algae and diatoms after pH correction
- d. use second source with Saturation Index ($\text{pH}_{\text{actual}} - \text{pH}_s$) $\text{SI} < 0$, as lake water has $\text{SI} > 0$, to obtain water in calcium equilibrium
- e. use lake bank filtrate, probably in equilibrium, lower nutrient and diatoms content.

DK:PO1221.BRF

Amsterdam, May 28, 1990.

I.R.C.
 T.a.v. Mr. J. Smet
 P.O. Box 93190
 2509 AD 'S GRAVENHAGE

Smet

Dear mr. Smet,

Responding to your letter of May 21, 1990, your reference 45.565/JS, about slow sand filters in Bujumbura, Burundi, a survey and a consideration on the waterquality data, some calculations, technical aspects and conclusion are described.

Waterquality of Lake Tangavika

The data of the different quality parameters are summarized in the next table 1:

Cations			Anions		
	mg/l	meq/l		mg/l	meq/l
Ca ²⁺	11	0.55	HCO ₃ ⁻	403	6.60
Mg ²⁺	41	3.42	CO ₃ ⁼		
Na ⁺	60	2.61	Cl ⁻	27	0.76
K ⁺	31	0.79	SO ₄ ⁼	4	0.04
Total	143 mg/l	7.37 meq/l		434 mg/l	7.40 meq/l

The total amounts in meq/l of cations (7.37) and anions (7.40) are nearly the same.

The total dissolved salts (TDS) = 143 + 434 = 577 mg/l is reasonably in balance with the TDS-value calculated from TDS = 0,7 Elect.Conductivity (EC) = 0.7 x 6.70 μ s/cm = 470 mg/l.

The total content of HCO₃⁻ + CO₃²⁻ = 6.6 meq/l or 6.6 x 50 = 330 CaCO₃/l alkalinity is very well comparable with the values 308-360 mg CaCO₃/l, measured for the alkalinity.

The total hardness (Ca + Mg) is 0.55 + 3.42 = 3.97 meq/l = 1.98 mmol/l = 198 mg CaCO₃/l, nearby equal to the measured values of 188-198 mg CaCO₃/l for the total hardness, described in the available literature.

All these data are sufficiently accurate and reliable for calculations.

The measured average pH-value is 9.0.

The water is abstracted from a depth (25 m) in the hypolimnion. Therefore it is interesting to know the oxygen concentra-

tion in the water; also the phosphate content by reasons of algae growth and the DOC (Dissolved Organic Carbon)-value for reasons of biologic activity of the slow sand filters and the silicate, iron, manganese and ammonium content, for reasons of loading the slow sand filters.

Further, what is the chlorine-dose after the slow sand filtration?

For calculations:

Temperature of raw water = 27°C

pH of raw water = 9.0.

Calculations

Mg(OH)₂

Solubility product of Mg(OH)₂ = $2.3 \cdot 10^{-11}$ (Landolt-Börnstein, 1923-1936) $[Mg^{2+}] = 41 \text{ mg/l} = 1.7 \text{ mmol/l} = 1.7 \cdot 10^{-3} \text{ mol/l}$.

Above pH = 10 Mg(OH)₂ can be precipitated, but not at pH = 9.0 of the raw water abstracted from the Tangayika Lake.

pH_s

The equilibrium pH-value, pH_s, calculated with the Hoover nomograph and the table 38.2 of Water Treatment and Examination (W.S. Holden, Ed. J. and A. Churchill, London 1970) is pH_s = 8.0.

Saturation index (SI)

SI = pH_{act.} - pH_s = 9.0 - 8.0 = 1.0

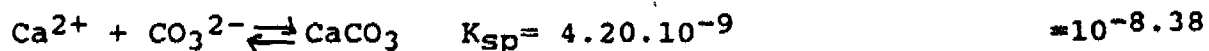
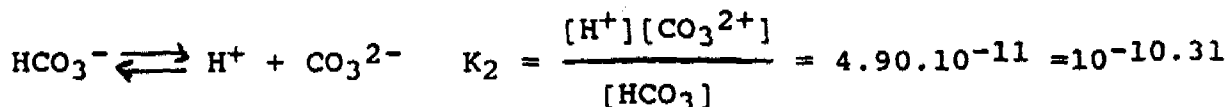
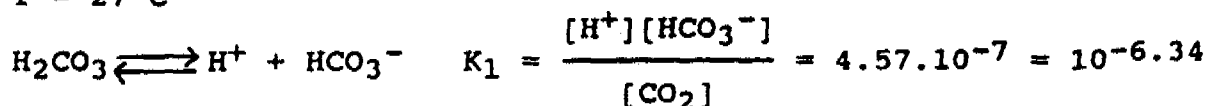
This means that nearly all the Ca as CaCO₃ (27.5 mg CaCO₃/l) can be precipitated, namely around 26 mg CaCO₃/l in the slow sand filters and/or in the distribution pipelines, on regulation equipment and in heating apparatus like geisers and boilers.

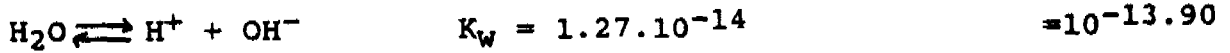
In the available literature a removal of around 10 mg CaCO₃/l is described. More is possible during distribution and/or heating.

These situations occur, assuming that no other reaction, p.e. nitrification, oxidation of organic matter etc., takes place. Because the settled CaCO₃ can function as crystallization seeding material over a longer time the settling can be accelerated.

Needed dose of chloride acid (HCl) for pH-correction from pH=9.0 tot pH_s=8.0

T = 27°C





Raw water, pH = 9.0:

$$\text{HCO}_3^- + \text{CO}_3^{2-} = 6.6 \cdot 10^{-3} \text{ mol/l}$$

$$[\text{HCO}_3^-] = 6.29 \cdot 10^{-3} \text{ mol/l}$$

$$[\text{CO}_3^{2-}] = 0.31 \cdot 10^{-3} \text{ mol/l}$$

Equilibrium, pH = 8.0 :

$$[\text{HCO}_3^-] + [\text{CO}_3^{2-}] = 6.6 \cdot 10^{-3} \text{ mol/l}$$

$$[\text{HCO}_3^-] = 6.46 \cdot 10^{-3} \text{ mol/l}$$

$$[\text{CO}_3^{2-}] = 0.14 \cdot 10^{-3} \text{ mol/l}$$

$$[\text{HCO}_3^-] + 2 [\text{CO}_2] = [6.46 - 6.29] 10^{-3} + 2 \times 0.14 \cdot 10^{-3} = 0.45 \cdot 10^{-3} \text{ mol/l}$$

$$\text{HCl needed} = 0.45 \cdot 10^{-3} \text{ mol/l} = 16.4 \text{ mg HCl/l} = \underline{16.4 \text{ gr HCl/m}^3}$$

For the design capacity of 50.000 m³/day: 820 kg 100% HCl/day.
For the existing production of 30.000 m³/day: 492 kg 100% HCl/day.

On the market 30, 33 and 36% HCl-solution is available.

For 50,000 m³/day: 2733 kg 30% HCl/day is needed.

For 30,000 m³/day: 1640 kg 30% HCl/day is needed.

The HCl-solution can be delivered in drums.

A simple and cheap equipment for storing the drums, a pH-meter and a small pump (3 m³/hr) are necessary.

The world marketprice = 100 US\$/ton 30% HCl.

In Central Africa perhaps twice higher: 200 US\$/ton 30% HCl.

$$\text{Cost/m}^3 = \frac{200 \text{ US\$} \times 2,733 \times 100}{50.000} = \underline{1.1 \text{ US Dollarcent/m}^3}$$

By this cost for pH-correction the following benefits can be reached:

-The frequency of cleaning of the slow sand filters can be strongly decreased and the running time between two cleanings can be increased.

This means lower operation costs and a higher production from 30,000 to 50,000 m³/day or an increase in production of 67% with the same slow sand filters etc.

In this case the capital costs per m³ delivered water will be

lowered with 40%.

- The biological effectivity of the slow sand filters will be improved, by which a lower Cl_2 -dose can be possible.
- The scaling on the distribution pipelines and heating apparatus can be reduced and the white colouring during boiling of water by the consumer can be avoided.

From the economic point of view the proposed dosage of chloride acid (HCl) for pH-correction will be feasible or even advisable.

Other solutions

Where the above described solution is impossible, the next solution is the direct delivering of the reasonably good raw water in the distribution system, only after a dosage of chlorine (Cl_2) or sodium hypochlorite (NaClO) or caporite ($\text{Ca}(\text{ClO})_2$) with excluding the slow sand filtration.

This way has the advantage that no algae growth occurs, but the disadvantage of scaling on the distribution pipelines and on heating apparatus etc. remains.

Conclusions:

1. For a final opinion additional information is desired about:
 - oxygen-concentration of the raw water
 - phosphate-content of the raw water
 - DOC-value of the raw water
 - Iron-content of the raw water
 - Manganese-content of the raw water
 - Ammonium-content of the raw water
 - Silicate-content of the raw water
 - Chlorine-dose after the slow sand filtration.
2. During the filtration no $\text{Mg}(\text{OH})_2$ will be formed.
3. The equilibrium pH-value is $\text{pH}_s=8.0$.
This means a $\text{SI} = 9.0 - 8.0 = 1.0$ with consequences for a settling of CaCO_3 in slow sand filters, scaling on the distribution pipelines, regulation and heating apparatus and white colouring of the water, boiled by the consumers.
4. For a pH-correction from $\text{pH} = 9.0$ tot $\text{pH} = 8.0$ 16.4 mg HCl/l is needed.
This means for a production of 50,000 m^3/day 2733 ton 30% HCl/day .
The cost is 1.1 US Dollarcent/ m^3 delivered water with benefits for:
 - lower operation costs
 - higher (67%) production capacity
 - higher biological effectivity of the slow sand filters
 - no scaling on distribution pipelines and regulation and heating-apparatus
 - no white colouring of the water during boiling.

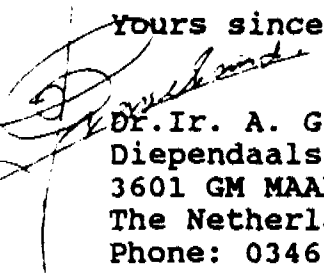
5. Direct delivering only with chlorination and without slow sand filtration with the remaining disadvantages of scaling and colouring.

Literature:

1. Difficulties in the operation of new slow sand filters in Africa; Dr. U. Neis, Corporation Technique Allemande (GTZ) Regiso-Department Eau, Bujumbura/Burundi.
2. Rapport sur la Capacite Productive des nouveaux filtres lents a sable a l'Usine Lac de la Regideso a Bujumbura.
3. Nearshore carbonate deposits in Lake Tangayika, A.S. Cohen and C. Thouin; Geology 15, (May 1987) p.414-418.
4. Precipitation des carbonates et reduction de la capacite de permeabilite du sable dans les bassin de filtration de la "Regie des Eaux" a Bujumbura, M. Stoer et P. Nkurunziza.
5. Usine Lac Bujumbura, Nouveaux Filtre Lent no. 4; Regideso Dept.Eau.
6. Caracteristiques General de l'eau des Lacs. Coop. Techn. Allemande, Regideso-Burundi, Dépt.Eau, Bujumbura/Burundi 26-4-'90.

I look forward to receive more information.

Yours sincerely,



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Summary of contribution Dr A. Graveland

The raw water from Lake Tanganyika is very nice, the only problem is the high pH (≈ 9). The calcium carbonate content is low (10-11 mg Ca/l). A cat-ions/an-ions balance was made. The calculated equilibrium pH_s is about 8.0, while the $\text{pH}_{\text{actual}}$ is about 9.0, so $\text{SI} > 0$. In literature a removal of around 10 mg (out of total of 27.5 mg) CaCO_3/l is reported.

Acid dosing would be a feasible solution, as it costs (taken twice the world market price for HCl) only US\$ 0.01/ m^3 .

Encrustation and calcification is still possible after pH correction if pH increases due to algae and diatoms activity or water temperature increase (pH_s decreases). Acid dosing below pH_s is nor recommendable as water becomes aggressive for copper, lead and cast-iron pipes, and it will be calcium demanding so aggressive for concrete.

Another solution would be the direct delivery of raw water after chlorination but excluding slow sand filtration. No algae growth will occur but scaling of CaCO_3 will occur on distribution pipes, heating apparatuses etc.

Additional point after verbal communication with Dr Graveland:

The pellet reactor is not considered as (i) calcium content is low, (ii) magnesium content is high but will not precipitate easily as pH_s for magnesium is much higher, (iii) the capital and running cost of a pellet reactor is quite high: approx. US\$ 0.05/ m^3 in Amsterdam (but there NaOH is to be added).

EAWAG

Eidg. Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz
 Institut fédéral pour l'aménagement, l'épuration et la protection des eaux
 Istituto federale per l'approvvigionamento, la depurazione e la protezione delle acque
 Swiss Federal Institute for Water Resources and Water Pollution Control

Dübendorf, 13th July 1990

Comments concerning the calcite formation on the slow sand filters at the water treatment plant of Bujumbura, Burundi

The following comments are made on the base of some reports on a few investigations in Bujumbura and represent a few ideas in a brainstorming sense. Therefore, the statements are not based on a sound knowledge of the actual situation in Bujumbura, but they may add to clear up the cause of the clogging problems and to find technical solutions for the problem.

1. Analysis of the lake water quality

Several analytical investigations reveal a lake water with a relatively high Mg^{2+} - and a lower Ca^{2+} -hardness. The other cations are Na^+ and K^+ . The anions are mainly HCO_3^- and Cl^- with HCO_3^- acting as counterion for more than the total hardness which indicates that the water chemistry in respect to precipitation products is dominated by the compounds Mg^{2+} , Ca^{2+} and HCO_3^- . Since CO_2 has a strong influence on the systems to form precipitates of $CaCO_3$ or $MgCO_3$ likewise by the following reactions



It is important to consider the partial pressure of CO_2 (p_{CO_2}).

Under atmospheric equilibrium conditions p_{CO_2} equals $10^{-3.5}$ atm. Since the water intake is in 25 m depth, the normal partial pressure at this depth amounts to $p_{\text{CO}_2} = 10^{-3}$ atm. Additional CO_2 may be present as a consequence of biological decay processes, thus, leading to a further increase of the partial pressure of CO_2 .

The examination of the chemical equilibrium under the conditions of the higher (intake depth) and lower partial CO_2 -pressure (treatment plant) gives a rough idea whether the precipitation of CaCO_3 and MgCO_3 can be expected or predicted.

The chemical species which were considered are

Mg^{2+}
 Ca^{2+}
 CO_3^{2-}
 HCO_3^-
 CaOH^+
 CaCO_3aq
 CaHCO_3^+
 MgOH^+
 MgCO_3aq
 MgHCO_3^+
 $\text{MgCO}_3(\text{H}_2\text{O})_3$
 $\text{MgCO}_3(\text{s})$
 $\text{CaCO}_3(\text{s})$
 H^+

For an accurate calculation some analytical data at the intake depth would be needed. I assume that the pH of the samples taken at different depths was measured under atmospheric conditions and is therefore not representative for the actual pH at the depth indicated in some paper. Nevertheless, the measured concentrations of Ca^{2+} , Mg^{2+} , HCO_3^- , CO_3^{2-} , H^+ lead to the conclusion that up to about $\text{pH} = 7.8$, no precipitation is expected. In addition, the slow process of nucleation has to take place before visible precipitates appear and this may need a higher oversaturation of CaCO_3 and MgCO_3 . At the intake depth, the water is not oversaturated and therefore no precipitation will occur in the lake water at this depth.

From our equilibrium calculations, it is evident that at the intake depth the chemical conditions in the lake water do not promote the precipitation of CaCO_3 or MgCO_3 . However, under atmospheric conditions at pH = 9 (measured) and even higher, a 10-fold oversaturation with respect to CaCO_3 and MgCO_3 is present. So, even with a low biological activity in the lake water, oversaturation and subsequent precipitation takes place simply by lifting the water from the intake to the place of treatment.

Because nucleation and growth of precipitation crystals is a slow process and is only enhanced by the presence of solid surfaces, the first and effective surface is the sand of the slow sand filters where the precipitates have been observed.

From the analysis of the filtered water, it can be seen that the water has not reached equilibrium conditions after the slow sand filters. Precipitation could eventually still go on in reservoirs and distribution facilities.

From the analysis of the water chemistry, it can be drawn that the precipitation of CaCO_3 and MgCO_3 cannot be avoided under the circumstances in Bujumbura. The possibility of adding nucleation inhibitors like HPO_4^{2-} is not considered. Precipitate formation might in addition be promoted by the observed algae growth in the supernatant of the slow sand filters. Therefore, precipitation and separation of the solids have to occur ahead of the slow sand filters in order to avoid rapid clogging of the surface.

This leads to a second part of questions concerning the kinetics of CaCO_3 and MgCO_3 precipitation. Unfortunately, these questions cannot be answered by the present scientific knowledge.

2. Kinetics of CaCO_3 and MgCO_3 precipitation

The reaction rates of calcite formation was investigated at our Institute in pure solutions, in the presence of metal oxides and algae as precipitation surfaces.

Of course, the nucleation reaction rates could be increased by several means like

- increase of pH
- increase of Ca^{2+}
- addition of surfaces for nucleation.

In fact, the addition of lime is a technical process which has often been applied in full scale in lime softening plants. For developing countries, however, the dosing of lime

could be a big operational problem (handling and clogging problems already in the dosing equipments). Also the operation of a pH controlled process is difficult under these circumstances.

It is therefore recommended to look for solutions where natural precipitation can occur under enhanced conditions. These conditions are

- fast and as far as possible complete removal of CO_2
- addition of nucleation surfaces in suspension including the recirculation of solids or exposure to fixed surfaces
- removal of the precipitates by simple means.

How the kinetics of the precipitation reactions under different technical conditions look like cannot be predicted. After having found a technically and economically appropriate solution, the performance has to be tested by pilot or lab scale investigations.

3. Technical requirements for the precipitation of CaCO_3 and MgCO_3

Desorption of CO_2 is the first process to realize. It is therefore worthwhile to study process combinations which allow the CO_2 -stripping and the subsequent precipitation in compact units. CO_2 -desorption may be realized efficiently in simple cascades or water jets. Packed desorption towers are not recommended because of clogging problems.

After a desorption process, nucleation, crystallization and particle aggregation should be performed in open systems. This means the precipitation on surfaces in suspension. All systems with fixed surfaces tend to scaling and as a consequence thereof to clogging. Clogging includes the problem of cleaning. Usually such installations are not cleaned and will no longer be operated.

A solution between nucleation on surfaces in suspension and on fixed solids are fluidized beds which are in fact difficult to operate (unequal water distribution, inhomogeneous particle density, etc) and are therefore not suited as technology in developing countries.

It all depends of course on the achievable reaction rates for the formation of solid CaCO_3 and MgCO_3 with the help of added or recirculated nucleation surfaces under practical conditions, but systems with CaCO_3 -sludge recirculation might be more suited than any other possibilities because of its simplicity. The major questions will be, what are the precipitation reaction rates and the resulting size or settling velocities of the precipitates

when using flocculation tanks with baffle walls (no moving parts) with sludge recirculation (pump needed) and some kind of lamella separators (or horizontal roughing filters ?).

The kinetics of precipitation and particle growth have to be investigated in pilot scale in order to determine the size of the reactors and, hence, the technical and economical feasibility.

13.7.1990
Dr. Markus Boller
EAWAG

Summary of EAWAG contribution

Partial pressure of CO_2 at 25 m depth is 10^{-2} , and at atmospheric pressure p_{CO_2} is $10^{-3.5}$. Water pumped from 25 m depth is not in chemical equilibrium, $\text{SI} > 0$, and algae activities promote precipitation further.

Two lines of solutions:

1. pH correction
2. Forced precipitation

pH correction and lime addition is not further considered as these will create operational problems in Bujumbura.

Enhanced precipitation may be obtained by: (i) fast and nearly complete removal of CO_2 through cascades and water jets, (ii) more surface area for calcification: best solution would be CaCO_3 sludge blanket with recirculation and simple removal of precipitate. No further considerations are given to the application of a fixed surface precipitation process (e.g. gravel) as cleaning would be difficult, and application of surface in suspension (e.g. pellet reactor) or combination of these two processes, as these are too complicated for situation.



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APPENDIX 12

SOME OBSERVATIONS ON THE REPORTS OF THE SSF OPERATION PROBLEMS IN BUJUMBURA, BURUNDI.

by T.K. Tjiok

1. Pumped water from -25 m tends to be degassed at atmospheric pressure at the inlet of the filters, resulting in higher pH and unstable water (cf pH -25 m: 8.78 ; pH surface: 9.18). Prevention of decarbonation by appropriate inlet?
2. The amounts of Ca and Mg in the water are not exceeding health criteria, so
 - a. mixing with water from another source or
 - b. injecting acid, so as to lower pH and stabilize the water to avoid precipitation problems, are good options to study the feasibility.
3. Another optional process to lower Ca and CO₃ ions under controlled precipitation in contact with CaCO₃ particles, which can be monitored simply by the pH decrease, could be worth investigating.
Under certain circumstances this precipitation reaction is of first order and controlled by the specific surface of CaCO₃ particles (S in m²/m³).
4. In lieu of an efficient continuous removal process in an upflow reactor with fine seed crystals (large S), however requiring vigilant operators, one could think of a simplified process in a series of (coarse) marble prefilters although requiring longer retention times.
5. The simple operation requires pH monitoring of the filter effluent; this pH should be set as close to pHs as possible in accordance with an acceptable retention time.
6. Clogging (which should be avoided) determines the cycle of filtration.
7. Upflow filters can be drained easily for cleaning, assisted by pressure water (hose) from the top.
8. If feasible one or more of the old filters can be rebuilt to a series of marble prefilters (with local material).

To be checked:

9. A CaCO₃ stability (marble) test, in which a sample of the water is shaken with CaCO₃ powder; the *total alkalinity * decrease of the filtered water if compared to the raw water would give an indication of the amount of CaCO₃ which tends to precipitate.

Note:

10. For future expansion another optional treatment method (to reduce precipitation and avoid algal problems) is suggested for investigation:

- coagulation with low dosage of Fe salt (sulphate-chloride) followed by
- direct filtration (no settling tanks) and
- chlorination; check whether
- the pH can be sufficiently lowered to reduce post-precipitation.

The Hague, 11-7-90

T.K. Tjiook

Summary of contribution Mr Tjiok

Suggestions which could solve or contribute to solutions are:

1. As pumped water tends to be degassed, an appropriate inlet construction could reduce the increase in pH.
2. Mixing lake water ($SI > 0$) with water from other source ($SI < 0$)
3. Acid dosing to lower pH and stabilize water
4. Reduce Ca and CO_3 ions by controlled precipitation in a coarse limestone bed (marble pre-filters) for simple operation.
 - specific surface is important parameter for process kinetics;
 - process control by monitoring pH of pre-filter effluent which should be as close to pH_s as possible;
 - upflow filter can be easily cleaned from accumulated sludge (fast drainage);
5. For future expansion an other treatment scheme could be proposed for study to lower investment:
 - coagulation with low dosage of e.g. $FeCl_3$, followed by
 - direct filtration (no settling tanks) and
 - chlorinationpH reduction (through this treatment process) should be sufficient to prevent or reduce post-treatment precipitation.



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Appendix 14

**REPORT ON VISIT TO BUJUMBURA (BURUNDI)
by K.J. IVES, UNIVERSITY COLLEGE LONDON**

**OPERATIONAL PROBLEMS WITH SLOW SAND FILTERS
OF REGIDESO - BUJUMBURA**

July 1990

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1. OBJECTS OF VISIT

- 1.1 To review the data available on operation and performance of the Bujumbura slow sand filter, and on the raw water quality.
- 1.2 To formulate the information and data additionally required to review the operation and performance problems both concerning technical aspects and water quality.
- 1.3 To visit water treatment plant in Bujumbura, discuss the problems with operators, responsible authorities and project staff, analyse the operational procedures, and collect the additionally required information and data.

2. VISIT

- 2.1 The visit to Bujumbura took place Thursday 12 July to Saturday 14 July 1990.
- 2.2 The following principal persons were met
Dr. U. Neis, Technical representative of GTZ;
M.F. Butoke, Head of REGIDESO (Eau);
Dr. J. Ndayegamiye, Chief of Laboratory.

Note: GTZ German Aid Agency (Technical Cooperation)
REGIDESO (EAU) Water Supply Authority

3. WATER SUPPLY FOR BUJUMBURA

The water supply is derived from lake Tanganyika, and is treated by slow sand filtration and terminal chlorination with no contact tanks, into the distribution network. No supplementary disinfection is applied in the network. Average flow rate is 40,000 m³/day (80% of total supply). See Documents A and B.

4. SOURCE (Lake Tanganyika)

4.1 Water Source

Inlet is 3.5 km from the port of Bujumbura, west, at 25 m below the surface. This is still in the epilimnion, which is 200 m deep, in this stratified lake, which has a maximum depth of 1700 m. The lake is supplied by the Ruzisi River, bringing water from Lake Kivu. The river water is very turbid, so that it forms a density current about 100-200 m from the mouth of the river. This density current dives to the bottom, leaving the clear lake water above.

4.2 Water Quality

Water quality is determined chemically by Lake Kivu. It is clear, colourless, hard (principally Mg), with high conductivity, and dissolved oxygen near saturation, at least to a depth of 25 m.

The following are typical values; the variation during the year are small (See Document F).

Period March - June 1987

<u>Parameter</u>	<u>Units</u>	<u>Depth 0m</u>	<u>Depth 25 m</u>
Temperature	°C	27	27
pH	-	9.1	8.9
Conductivity	µS/cm	640	640
Dissolved O ₂	mg/l	9.0	7.0
Turbidity	FTU	1.0-8.0	-
Total hardness	mg/l CaCO ₃	190	190
Alkalinity	mg/l CaCO ₃	315	315
COD	mg/l O ₂	5	10
Fe	mg/l	0.08	0.1
Mn	mg/l	0.05	0.01
NO ₃	mg/l NO ₃	0.01	0.01
Cl	mg/l	25	25
Total P	mg/l P	0.1	0.2

A sample was taken at 08.45 h 13/7/90 at the inlet, 25 m below surface. This sample (1 litre) was taken to London.

An electrode probe was lowered to 25 m, and 22 m.

<u>Parameter</u>	<u>Units</u>	<u>Depth 25m</u>	<u>Depth 22 m</u>
Temperature	C	26	26
Conductivity	µS/cm	649	650
Dissolved O ₂	mg/l (at surface 5.9)	5.9	5.9
Alkalinity (titration at surface)	mg/l CaCO ₃	335	-

At the mouth of the Ruzisi River, just below surface the water was very turbid.

<u>Parameter</u>	<u>Units</u>	<u>Mouth Ruzisi River</u>
Temperature	C	22.5
pH		9.16
Conductivity	µS/cm	820
Alkalinity	mg/l CaCO ₃	425

4.3 Biological Activity (See additional Documents, J. Ndayegamiye, 1986).

Phytoplankton is poor, due to poor nutrients and penetration for UV. Water clarity averages 15 m. Turnover of epilimnion (200 m deep) takes 2-3 months. In shallow bays there is more wind-induced circulation, which increases local biomass.

Typical algal production in epilimnion:

Period	Begin Feb.	March	April beg. May	May	Jun-Jul beg. Aug	Begin Sept.	Mid-Sept Oct.
Biomass mg/m ³	160	60	100	100	200	300	930
Algal species	<u>Chloro</u>	<u>Chloro</u>		<u>Chryse</u>	<u>Diatom</u>	Chloro	Chloro
in order of dominance	Cyano	Cyano		Chloro	Chloro		Cyano
Season	Rainy	Rainy		Rainy	Dry	Dry	Begin rainy

Note: Concentration of 10³ algal cells/l, 10 µm diameter has a biomass of 500 mg/m³.

Zooplankton, principally Copepods, few Rotifera, but no Cladocera exist at depths 50-200 m by day, but rise to 0-20 m at night.

- 4.4 Pollution arises from untreated sewage and effluents discharged from Bujumbura. Lake currents convey this southwards, along the eastern shore. Winds from the south may move this water towards the inlet towers which are 3.5 km west of Bujumbura.
- 4.5 The local shoreline is sandy, but calcified rocks exist a few tens of metres from the shore in shallow water (Document D). A sample was taken of this calcified sandstone on 13/7/90, and some broken debris was examined under low power microscopy. It was similar in appearance to calcified sand taken from Filter No. 2 (see later) and effervesced strongly with HCl.

5. PUMPS (LOW LIFT)

At the shore terminal of the pipeline from the lake, 3 pumps are available (2 in operation 12/7/90) to deliver the water via 2 pipelines, which join at the treatment works (Usine Lac) to supply the slow sand filters. The pressure is approx. 14 m, but the pumps can supply 16 m head, max. design flow 50,000 m³/d.

6. TREATMENT (Usine Lac)

6.1 Old Slow Sand Filters

There are 4 old SSF with a total area of 4 x 20 m x 32 m = 2560 m², containing 500 mm sand over 200 mm gravel (Document P).

Currently their operation is intermittent. Water arrives at the centre of each filter, discharging upwards from a central well forming a low fountain about 0.5 m high. This water spreads horizontally and radially, and percolates down through the sand. On 12-13/7/90, three filters were in operation, each with 50%-70% of the central area covered with water varying in depth from about 0.3 m to zero at the edges due to the dished shape of the sand surface.

In 1983 K. Heize (GTZ) reported that fully saturated these SSF operated at an average velocity approx. 0.5 m/h. The filter runs were 4 days, which he attributed to algal growth, following some experiments with covering on part of the filters (Document P). Currently they supply about 10% (~ 4 000 m³/d) of the output from Usine Lac through an old pumping station.

6.2 New Slow Sand Filters

Constructed in 1987 there are 4 new SSF, with a total area of 4 x 82.6 m x 22.1 m = 4 x 1825 m² = 7,300 m². Filtering at 0.23 m/h they can supply on output of 40,000 m³/d.

The original depth of sand was 1.0 m, with effective size (E.S. = d^{10}) = 0.19 mm, uniformity coefficient (U.C. = d_{60}/d^{10}) = 3.7; d_{50} = 0.6 mm (Document E). The filters were commissioned in May 1987, and the original run length was 48 days, terminated when the flow of a filter declined, and water level rose in the filter to a limiting height, 1 m above the original sand level. The second run in Filter 4, for example, declined to 21 days; after 1 year the runs were less than 10 days. Some runs as short as 5 days were recorded (Document E).

Due to successive cleanings, removing about 12 mm each time, the sand depth had fallen to 0.65 m after 1.5 years.

The problem appeared to be due to a cementation of the sand grains, so that for cleaning it was necessary to use a pick to break the sand surface, in order to shovel it away. Sand cleaning is manual. The skimmed sand was too encrusted to re-use. After 5 months of operation, when the run lengths had fallen to about 15 days, the granulometry (sieve size of the sand) has changed markedly to:

E.S. = 0.25 mm U.C. = 3.0 d_{50} = 0.68 mm
(Document E).

No schmutzdecke was evident during the very short filter runs.

The permeability of the sand was estimated in 1987 to be: soft sand 0.4 m depth permeability 0.72 m/h,
encrusted sand surface permeability 0.22 m/h.

The filter inlets also caused a problem of scour of the sand surface due to insufficient destruction of the energy of the incoming water over the inlet weir. Consequently the areas around the inlets contained deep scour holes, and an even surface continued a considerable distance along the length of the filters.

6.3 Renovation of the New SSF

To improve the operation of the new SSF, two items of renovation were undertaken in December 1989-January 1990.

Firstly, the existing sand was reduced to a thickness of 300 mm (above a 450 mm layer of gravel). On top of this was placed a layer of new coarser sand 450 mm thickness. This allowed a maximum depth of water over

the sand surface of 1.25 (Document G).
 The granulometry of the original and new sands were
 (Document H):

original	E.S. = 0.2 mm	V.C. = 3.5	d50 = 0.6 mm
new	0.4 mm	2.0	0.73 mm

From Kozeny's equation, for a given head difference
 across the sand layers velocity $v \sim \frac{(E.S.)^2}{\text{depth}}$

Allowing for the change in granulometry of the original
 sand, by growth from E.S. = 0.19 mm to 0.25 mm

$$v(\text{new}) = \text{const.} \frac{(0.4^2 + 0.25^2)}{(0.45 + 0.3)} = \text{const.} 0.56$$

$$v(\text{old}) = \text{const.} \frac{0.25^2}{1.0} = \text{const.} 0.063$$

$$\frac{v(\text{new})}{v(\text{old})} = \frac{0.56}{0.063} \sim 9$$

In practice the new filtration velocity was 0.56 m/h
 and $v(\text{new})/v(\text{old}) = 2.2$.
 The limit of clogging is approx. = const. $v \cdot C_0 t$ where
 C_0 is the deposit caused by the incoming water and t is
 the length of the filter run. Therefore, for the same
 amount of clogging (deposits and schmutzdecke growth),
 const. $v \cdot C_0 \cdot t$ is the same for old and new conditions.
 A factor $v(\text{new})/v(\text{old}) = 9$ is possible for the same t ,
 but with $v(\text{new})/v(\text{old}) = 2.2$, then t can be extended by
 $9/2.2 \sim 4$ times.

The original initial run of Filter 4 was 48 days, so
 the new initial run, commencing at 0.5 m/h could be $4 \times$
 $48 = 192$ days.

In fact it was terminated at 142 days on 12 July 1990.
 These calculations assume that the conditions for
 clogging were the same May-July 1987 and February-July
 1990, and that the same quality of filters was
 produced.

Data on raw and filtered water quality for Filter 4

<u>April-July 1990 (renovated filter)</u>	Average values	
(Document I)	<u>Raw</u>	<u>Filtered</u>
Turbidity FTU	1.05	0.06
Coliforms/100 ml	48	11
E. coli/100 ml	< 1	< 0.1
Hardness CaCO ₃ mg/l	191	188
Chemical characteristics		no change

March 1988 (original new filter after 10 months)

(Document A)	Raw	Filtered
Turbidity FTU	2.07	0.04
Coliforms/100 m	0-350 (5-∞)	0-∞ (0-∞)
E. coli/100 ml (note ∞ = too many to count)	0-10 (1-∞)	0-4 (0-∞)
absent in	27%	70%
Hardness CaCO ₃ mg/l	198	190
Chemical characteristics	no change	

Similar observations are noted for Filter 3 (Document J).

Secondly, the inlets were modified by a slotted steel baffle after each weir, strongly reducing the energy of the incoming water. In addition, paving was placed on the sand surface, surrounding, the inlet, which reduced the immediately local scour. The result was a very noticeable improvement, with only a shallow depression of the sand surface extending along the centre line from the inlet, for about 10-15 m.

6.4 Chlorination

After filtration the water from the new SSF passes into 2 small covered storage reservoirs. The water was extremely clear when inspected on 12 July 1990. This water supplies the high pressure pumps which served the mains network in Bujumbura. Immediately after the pumps, a solution of calcium hypochlorite is dosed into the force main, to give reading of about 0.6 mg/l total chlorine from probes situated 20 m along the main after the hypochlorite dosing point.

7. INSPECTION OF THE NEW (RENOVATED AND UNRENOVATED SSF (12-13 July 1990)

Filter 4: This is a renovated filter, set into operation in February 1990 at 0.5 m/h. On 12 July it was shut down after a run of 142 days, and its flow rate was measured to be 0.2 m/h, with the water level approx. 0.3 m below maximum. A few patches of floating, and attached to sand surface, green filamentous algae (? Cladophora) were observed. The next day (13 July) the filter was drained down and the wet surface was examined. There was a noticeable green-brown continuous schmutzdecke about 5 mm thick. A sample approx. 100 mm square was taken, with attached sand about 10 mm thick, on the centre line of the filter, approx. 2 m from the wall at the outlet end. No green algal patches were seen, but some white-grey coloured areas were visible at the inlet end. Some small 20 mm pink worms were present. Later on 13 July, the filter has been partially skimmed, very easily with shovels only. The schmutzdecke was drying to a fragile skin. Some algal growth, light green, was on the filter walls. The sand under the skimming was soft and a sample was taken from the upper 20 mm.

Filter 3: This is a renovated filter, which commenced operation on 22 June 1990 at 0.5 m/h. Its appearance was similar to Filter 4 before it was shut down. Water samples (1 litre) was taken from the inlet weir and the outlet pipe sampling tap.

Filter 2: This is an unrenovated filter and was empty, out of operation. The sand surface was very uneven, and was hard like rock, to walk upon. With great difficulty, using a knife and blows with a shoe some lumps of hard sand were removed as a sample.

Filter 1: This is an unrenovated filter, and was empty, out of operation on 12 July. Its appearance was similar to Filter 2. It was filled, and started in operation on 13 July, to maintain the supply while Filter 4 was out of cleaning.

8. **LABORATORY EXAMINATION OF SAND SAMPLES**

Sand samples were examined by low power microscopy at 40 x, principally by transmitted light, occasionally by reflected light.

Sample 1 Wet schmutzdecke from Filter 4.
Sand appears normal (0.3-0.6 mm ?).
Many filaments of green algae (Cladophora).
No visible effect of ~ 50% conc. HCl (1:1).
Some washings were obtained from the sand, and examined under 100x magnification.
Among the debris, several diatoms were observed, with clearly visible structures of silica:
Navicula, Synedra, Melosira (?).
No centric diatoms.
No calcification visible on diatoms.

Sample 2 Cleaned sand after schmutzdecke skimmed from Filter 4.
Sand clean and normal quartz.
No algae.
No calcification visible.
No visible effect of 50% conc. HCl (1:1).

Sample 3 Dried hard sand from empty Filter 2.
Transmitted light: clear and white quartz sand, with dark opaque patches on grains.
Reflected light: mid-brown, rough surfaces, apponently opaque. Very small crystals (calcite?).
Strong effervescence with 50% HCl (1:), breaks up sand aggregates to give clear grains.

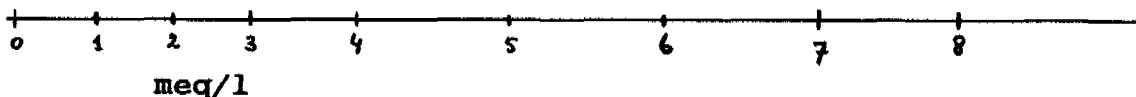
Sample 4 Portions broken from rock taken near shore of Lake Tanganyika like brown sand when broken.
Strong effervescence with HCl (50%)
Similar to Sample 3.

9. CHEMICAL STABILITY OF RAW (LAKE) WATER

9.1 Ionic Balance

Mg ⁺⁺	Ca ⁺⁺	Na ⁺	K ⁺	cation
HCO ₃ ⁻ + CO ₃ ⁼			Cl ⁻	anion

SO₄²⁻



Hardness = Mg + Ca = 4 meq/l = 4 x 50 mg/l = 200 mg/l CaCO₃.
Principally Mg hardness, but little OH in water to form Mg (OH)₂.

The pH is approx. 9.0, above the stability pH_s (8.0) therefore the solution is expected to precipitate CaCO₃(calcite) on suitable surfaces.

9.2 Acid Titration

Titration curves of pH against 0.1N H₂SO₄ and 0.01 N HCl are given on Document K.

To reduce the pH from 9.0 to 8.0, 1.7 ml of 0.1N H₂SO₄ was required in 250 ml water, and 1.35 ml of 0.01 N HCl in 250 ml water.

Sulphuric acid required.

$$1.7 \text{ ml}/250 \text{ ml} = 6.8 \text{ ml/l} = 6.8 \text{ l/m}^3$$

$$\text{Flow} = 40\,000 \text{ m}^3/\text{d}$$

$$\text{Acid (0.1N)} = 6.8 \times 40\,000 = 272\,000 \text{ l/d} = 272 \text{ tonnes/d}$$

$$0.1\text{N} = 4.9 \text{ g/l} = 4.9 \text{ kg/m}^3 \text{ (tonne)}.$$

$$\begin{aligned} \text{H}_2\text{SO}_4 \text{ required} &= 4.9 \times 272 \text{ kg/d} \\ &= 1332.8 \text{ kg/d} \\ &= 1.33 \text{ tonnes/d} \end{aligned}$$

Hydrochloric acid required

$$1.35 \text{ ml}/250\text{ml} = 5.4 \text{ ml/l} = 5.4 \text{ l/m}^3$$

$$\text{Flow} = 40\,000 \text{ m}^3/\text{d}$$

$$0.01\text{N acid} = 0.365 \text{ g/l} = 0.365 \text{ kg/m}^3 \text{ (tonne)}$$

$$\text{Acid (0.01N)} = 5.4 \times 40\,000 \text{ l/d} = 216 \text{ m}^3/\text{d}$$

$$\text{HCl required} = 0.365 \times 216 \text{ Kg/d}$$

$$= 78.84 \text{ Kg/d} = 0.079 \text{ tonnes/d}$$

$$\text{Commercial 30\% HCl required} = 0.26 \text{ tonnes/d}$$

Central Africa price of 30% HCl assumed to be 3 x European price (at 100 US\$/tonne*) = 300 US\$/tonne.
 Cost of HCl = 0.26 x 300 = 75 US\$/day.
 * Price from A. Graveland.

9.3 Deposits on Sand Grains

Sample 3, dried hard sand from filter, which had been in operation 1987-1989 reacted strongly, with effervescence, with 50% HCl (1:1).

Sample 4, cemented sandstone rock from Lake Tanganyika reacted strongly, effervescing with 50% HCl (1:1).

Document C gives details of calcite deposits on sand grains. SEM micrographs demonstrate calcite crystals on sand taken in December 1987 from 1 to 4 cm depth from the filter sand surface. Clean unused sand from the same original source showed surfaces clear of calcite under SEM.

In the document is a discussion and TEM analysis of colloidal deposits from Lake Tanganyika. The TEM micrographs show particles < 1 μm. A size analysis shows kaolinite and ferric oxides, in the < 2 μm fraction (15% of total), of which the < 0.6 μm fraction illite, kaolinite, goethite and quartz. The major fraction of the sample (60%) was in the size range 6.3 μm - 63 μm.

A sample from sand described as "very plastic sand in the 5 mm external part of the filtration basin, caused by colloidal substances", showed under TEM particles from about 0.1 μ to 1-2 μm. The size analysis was 5% < 0.6 μm, but the largest fraction (85%) was > 63 μm.

It is probably that some of these fine particles are responsible for the nephelometric turbidity, particularly the fraction under 1 μm, for although they represent about 5% by weight, they represent a very much larger fraction by number, which cause light-scattering. However, as the average turbidity removed by the filters was less than 2 FTU (approx. 2 mg/l for kaolinite) (See Section 6.3), it is difficult to accept this as the major source of clogging of the slow sand filters during 1987-88.

Assuming (in 1987) a short filter run of 7 days (See Document E) with a removal of 2 mg/l of turbidity.

Flowrate velocity 0.23 m³/m²h

$$\text{Removal of turbidity} = 7d \times 24 \text{ h/d} \times 0.23 \text{ m}^3/\text{m}^2\text{h} \times 2 \text{ g/m}^3 \\ = 77.3 \text{ g/m}^2$$

Although the clay turbidity density is approx 2.5 g/cm³ its self-porosity when deposited will reduce its effective density ~ 1 g/cm³.

$$\text{Volume of removed turbidity} = 77.3 \text{ cm}^3/\text{m}^2.$$

$$\text{Pore volume of top 1 cm in 1 m}^2 = 1 \times 10^4 \times 0.4 \text{ (porosity)} \\ = 4000 \text{ cm}^3/\text{m}^2$$

Consequently only 1/50 th of the pore volume in the top 1 cm of the sand is occupied by deposited turbid matter.

Similarly, for deposition of 10 mg/l of CaCO₃ (calcite)

$$\text{Removal of calcite} = 7 \times 24 \times 0.23 \times 10 = 386 \text{ g/m}^2$$

Density of calcite, assuming no self-porosity = 2.5 g/cm³

$$\text{Volume of deposited calcite} = \frac{386 \text{ cm}^3/\text{m}^2}{2.5} = 155 \text{ cm}^3/\text{m}^2$$

Consequently only 1/25 th of the pore volume of the top 1 cm of the sand is occupied by deposited CaCO₃. However, this may not be within the pores, but coating and cementing the grains together, to form the hard encrusted sand.

9.4 Calcium Carbonate Stability Test

As outlined in Document Q this test involves alkalinity titrations before and after contact of the water sample with fine calcium carbonate. There was no increase in alkalinity, and therefore the water is not aggressive. A small decrease in the alkalinity (315 to 313 mg/l) indicated that the water is supersaturated with calcium carbonate. This is an expected result, considering the chemistry of the water.

10. PILOT FILTER STUDY

A model filter of 1/100 th scale in all dimensions, including sand and water depth was tested as a pilot unit of the new SSF. The experiments included a similarly scaled gravel pre-filter. Because of the scaling-dimension effects, the tests were inconclusive (Document A) (Document O).

11. CONCLUSIONS

- 11.1 All the chemical, experimental and observational data show that the filter sand becomes calcified and cemented with deposited CaCO₃ (calcite), from the unstable carbonate equilibrium of the Lake Tanganyika water.
- 11.2 This cementation reduces the permeability of the sand, particularly in the upper few cm, leading to shorter and shorter filter runs and difficulties with skimming cleaning.
- 11.3 Some algae are present but are not numerous enough to cause serious clogging. The report by K. Heise (Document P) for the old SSF in 1983 concluded that algae (species not identified) were a cause of clogging. But these filters were operated with very shallow water (approx 200 mm) over the sand, which may have encouraged algae growth. It is also possible that the algae caused a local rise in pH, due to photosynthesis, which enhanced CaCO₃ precipitation on the sand.
- 11.4 Renovation of the new SSF with coarser sand with a flow rate increased from 0.23 to 0.5 m/h has led in Filter 4 to an increase in the first run length to 142 days (previous comparable run before renovation 48 days), with no deterioration in filtered water quality. The sand surface was covered with an active biological schmutzdecke, with no detectable calcification. The filter was behaving as a normal slow sand filter.
- 11.5 Chlorination is properly and effectively controlled with doses of about 0.6 mg/l as Cl₂. Unfortunately no post-chlorination samples from the waterworks outlet were taken for bacteriological analysis. Samples taken

at premises in the town were thought to be unreliable because of possible contamination.

12. POSSIBLE SOLUTIONS

12.1 By-pass the slow sand filters. For most of the year the lake water is of good quality, with low turbidity and little biological production. Chlorination would ensure bacterio- logical safety, even for occasional pollution.

Comment. This solution is likely to be unacceptable, as it denies the political, professional and economic investment in the new SSF.

12.2 Reduce the pH to equilibrium pHs. pH reduction with sulphuric acid (1.33 t/d) or hydrochloric acid (30% HCl) (0.26 t/d). This implies importation by road and boat.

Comment. The daily cost of 30% HCl, of 75 US\$/day, makes this solution unlikely. Also investment will be required for acid storage, handling, dosing equipment, etc.

Carbonic acid reduction by addition of carbon dioxide (CO_2). Stoichiometric calculations show that a minimum of 156 kg/d of CO_2 is required to dissolve (stabilise) an excess of 10 mg/l CaCO_3 .

Comment. CO_2 in pressure cylinders is available in Bujumbura at 350 FBU/kg (2 US\$/Kg). Therefore the minimum daily cost = 320 US\$/day. A more realistic cost may be double this value as 100% conversion of CO_2 is unlikely. The technology would be simple with a contact chamber for CO_2 gas with water.

Other methods of producing CO_2 (acid on calcite, burning solid fuel) seem technically unlikely at the scale of operation which is required.

12.3 Pre-precipitate CaCO_3 on Limestone

This requires percolation of the inlet water through a pre-filter containing broken limestone. The quantity of limestone required and rates of flow, dimensions of pre-filters required pilot studies. This should be a satisfactory technical solution. When the limestone is saturated with calcite the limestone would be dumped or sold. There is no continuous cost, but intermittent purchase of limestone.

Comment. There is no known limestone in Burundi. Cement is imported, by boat from Zambia, so presumably Zambia has limestone. A question is how the suppliers of CO_2 make it; if with limestone, where from, what cost?

This solution is technically feasible at Usine Lac possibly utilising the spare 2 m pressure from the raw water pumps to supply pre-filters. It may be possible to use 1 or 2 of the old SSF basins.

12.4 Pre-precipitate CaCO₃ on Gravel

This requires percolation of the inlet water through a pre-filter containing gravel. It is not known if this works. If the gravel filter becomes saturated with calcite, it would be dumped.

Comment. Gravel is available from Lake Tanganyika. Pilot studies would be required, and the old SSF may be utilised, as in 12.3. This would be a low-cost solution, if it works satisfactorily.

12.5 Pre-precipitate CaCO₃ on Fabrics

It is not likely to be possible to cover the new SSF sand surfaces with fabric (non-woven) because of their large areas (1760 m² each). Fabric pre-filters, perhaps of several layers, could be employed. Local foamed polyurethane is available for furniture manufacture, but is unlikely to be useful as its permeability (inter-connected pores) is in question. Imported fabric (FILTREN TR30, See Document M) is available from Belgium at approx 20 US\$/m² ex-factory, transport costs extra.

Comment. Although this is not technically attractive, cheaper fabric may be available. If the fabric becomes saturated with calcite, it may be possible to clean it with mild acid (possibly organic acid, such as citric).

13. PROPOSALS

- 13.1 Continue to operate new SSF 3 and 4 at the higher rate of 0.5 m/h to determine if the advantage of long runs and properly functioning schmutzdecke can be maintained. This will require at least another year of observation.
- 13.2 Explore the use of CO₂, and determine if the source material for its manufacture is limestone.
- 13.3 Construct and test limestone pre-filter at pilot scale, including sources of limestone.
- 13.4 Construct and test gravel pre-filter at pilot scale.
- 13.5 Test fabrics as pre-precipitation material at laboratory scale. Develop to pilot scale if successful and economic.
- 13.6 Appoint a French-speaking Research Assistant, possibly a chemical or public health (sanitary) engineer to work in Bujumbura with REGIDESO for 1 year on the proposals above.

14. SAMPLES TAKEN

1. Wet schmutzdecke from Filter 4
2. Cleaned sand from Filter 4
3. Dried hard sand from Filter 2
4. Calcified rock from Lake Tanganyika
5. Fresh sand from stockpile used for upper layer of renovated filters
6. Water from inlet 25 m below surface of Lake (11)
7. Filtered water leaving Filter 3 (11).

15. DOCUMENTS AVAILABLE

- A. Difficulties in the operation of new slow sand filters in Africa, Dr. U. Neis, 18 pp. (1988)
- B. Rapport sur la capacité productive des nouveaux filtres lents à sable à l'Usine Lac de la REGIDESO à Bujumbura. Dr. U. Neis, 29 pp. (1988)
- C. Precipitation des carbonates et reduction de la capacité de perméabilité du sable dans les bassins de filtration de la "Regie des Eaux" à Bujumbura. M. Stoerr, P. Nkurunziza, 10 pp. (1988)
- D. Nearshore carbonate deposits in Lake Tanganyika. A. Cohen, C. Thouin. *Geology* 15, 414-418 (1987)
- E. Figures 5 and Annex. Nouveau Filtre Lent No.4. Filter running time (days). Analyse granulométrique (1987-1988)
- F. Series of analysis of samples taken at different locations in Lake Tanganyika (March-June 1987) 9 pp.
- G. Sketch of Filter No.4 after rehabilitation. U. Neis, 1 p, (27 December 1989)
- H. Granulometry of sands: original and replacement for new slow sand filters (also support gravel) 1 page. U. Neis (30 June 1989)
- I. Table of water quality, Filter No.4, 9 May-10 July 1990, 2 pp. (1990)
- J. Table of water quality, Filter No.3, 27 June-10 July 1990, 2 pp. (1990)
- K. Titration curves for H₂SO₄ and HCl against pH. U. Neis, 2 pp.
- L. Filtration velocity Filter No.3, June 1990, Filter No.4, July 1990
- M. Quotation for supply of fabric FILTREN TR30, from Recticel Gechem, Brussels, 2 pp., 6 February 1989, addressed to U. Neis
- N. Longitudinal section of inlet pipeline from Lake Tanganyika, 1 p. (undated)
- O. Sketch of section through model of slow sand filter with pre-treatment. U. Neis, 1 p. (undated)
- P. Experience concernant l'exploitation des filtres à sable lents à l'usine de Bujumbura. K. Heise, 39 pp. but with pp.24-33 and 35, 37 missing (1983)
- Q. Calcium Carbonate Stability Test. Method supplied by J. Smet (IRC), (1990).

16. ADDITIONAL DOCUMENTS

- * Contribution à l'étude des apports du bassin versant à la baie nord du Lac Tanganyika (Cote Burundais)
These Docteur de 3ième Cycle, Université de Provence, Faculté des Sciences de Saint Charles. J. Ndayegamiye, 157 pp. 24 June 1986

- * Alimentation en eau potable Phase II, Controlé de qualité des eaux, des aliments et creation d'un laboratoire. Rapport de collecte des données. Republique du Burundi REGIDESO.
SGI - Institute Ecoplan (Suisse), Geneve. 35 pp. + 5 Annex (July 1987)

University College
London

K.J. Ives
16 July 1990

Zweckverband Bodensee-Wasserversorgung



Förder- und Aufbereitungsbetrieb, 7770 Überlingen-Süßenmühle

Mr. Jr. J. Smet
 Projekt Research Officer
 IRC International Water
 and Sanitation Centre
 Postbus 93 190
 25 09 AD The Hague/The Netherlands

16 Aug 1990 53172
 SMET
 cc D. J. Schen (Jull)

Süßenmühle, 6. Aug. 1990

E1/Au

Ref.: Regideso - Bujumbura, Burunde 19.7.90
 Expert meeting on Slow Sand Filtration problems

Sehr geehrter Herr Smet,

zusammenfassend nochmals die von mir vorgetragene Überlegungen zur Lösung der Probleme bei der Langsamfiltration in Bujumbura aus betriebstechnischer praxisbezogener Sicht.

Ausgangspunkt meiner Überlegungen ist, daß sich das Wasser vor dem Pumpen auf die Langsamfilter im Gleichgewicht befindet, auch wenn es übersättigt ist, da am Seeufer trotz ab und zu Wellenschlag durch Wind etc. praktisch keine Verbackungen auftreten.

Dies bedeutet, daß durch das Pumpen bzw. Einleiten eine nachteilige Veränderung auftritt, die das Gleichgewicht stört und die Verbackung an der Filteroberfläche hervorruft.

- 2 -

Bereits in einem ersten Gespräch am 2.3.90 mit Dr. Neis war auf die sehr ungünstige Einleitung mit teilweise freiem Überfall beim Einleiten in die Langsamfilter hingewiesen worden. Die von Dr. Neis vorgeschlagene und nun verwirklichte "Vorkammer" bringt in Verbindung mit dem groberen Sandgefüge und der erhöhten Filtergeschwindigkeit ja bereits hohe Laufzeiten. Welcher Effekt bei diesen drei durchgeführten Änderungen der entscheidende ist, kann durch die gleichzeitige Ausführung nicht genau festgestellt werden.

In jedem Fall wäre es energetisch und betriebstechnisch sinnvoller, wenn die Einleitung in die Filter direkt über der Sandoberfläche, aber unter Wasser nahezu stoßfrei mit einer Einlaufkonstruktion gemäß beiliegender Skizze erfolgt. Damit könnte die Pumpenförderhöhe um fast 2 m reduziert werden und es wäre in jedem Fall einer Gleichgewichtsstörung des Wassers durch den freien Überfall vorgebeugt (auch wenn der Effekt im Moment noch nicht erkannt wurde, der diese Störung verursacht). Ein Auskolken neben dem Einlauf wird durch die Führung der "Strömungsfäden" verhindert. Beim Wiederauffahren nach einer Filterentleerung zur Reinigung etc. muß in allen Fällen mit gedrosselter Pumpmenge durch Eindrosseln der Auslaufarmatur vor dem Filtereinlauf gefahren werden. Dies gilt für den jetzt vorhandenen hohen Überfall natürlich in verstärktem Maße, da sonst extreme Auskolkung auftritt.

Da offensichtlich geplant ist, in absehbarer Zeit weitere Filter zu bauen, sollte in diesem Fall von Anfang an eine andere Einleitung gemäß Skizze 2 ausgeführt werden. Dies ist

eine ähnliche aber verbesserte Einleitung wie bei den ganz alten Filtern.

Im Notfall würde auch eine Mitteneinleitung genügen.

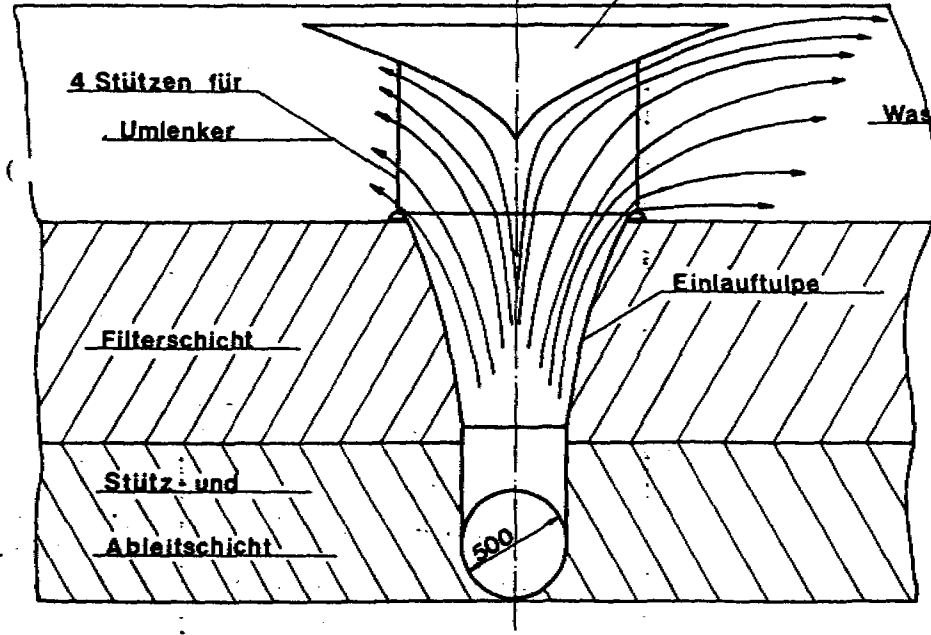
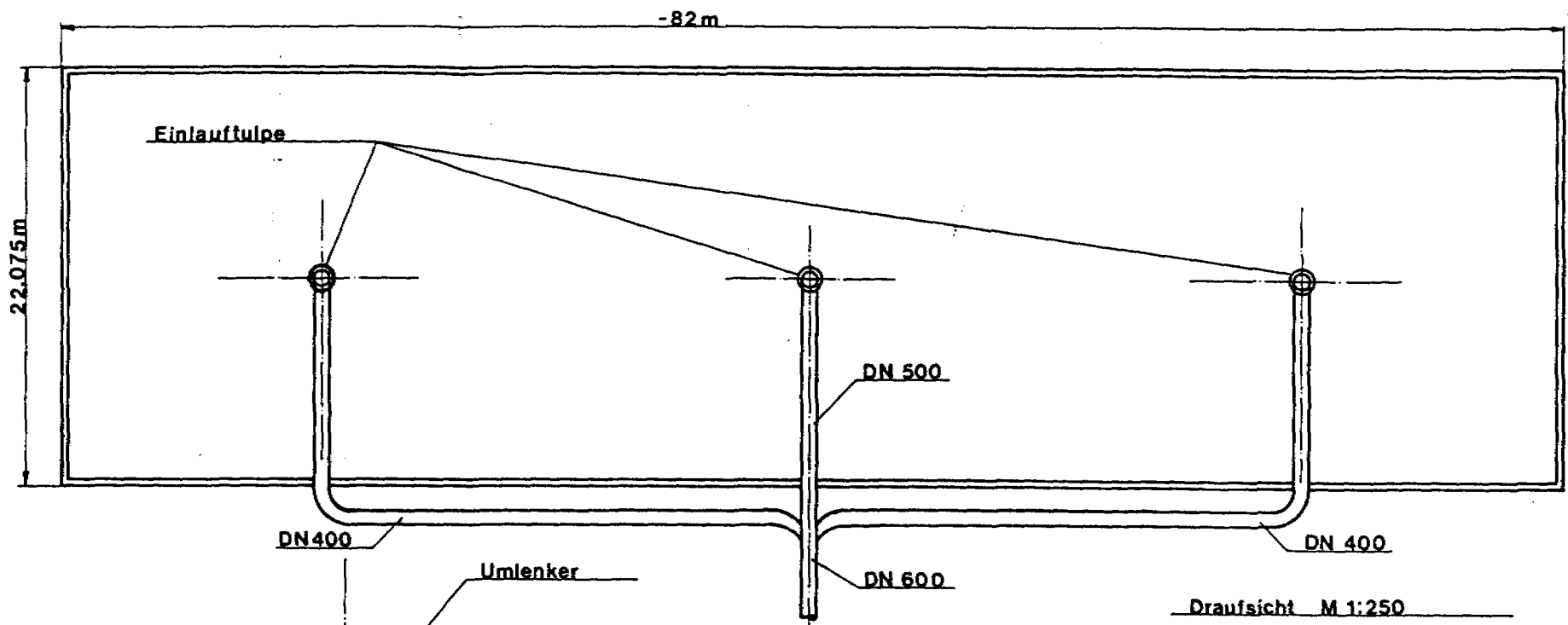
Mit freundlichem Gruß

ZV BODENSEE - WASSERVERSORGUNG

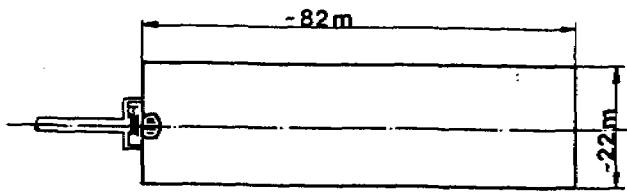
- Die Geschäftsleitung -

i. V. E. Senfens *i. D. J. Habel*

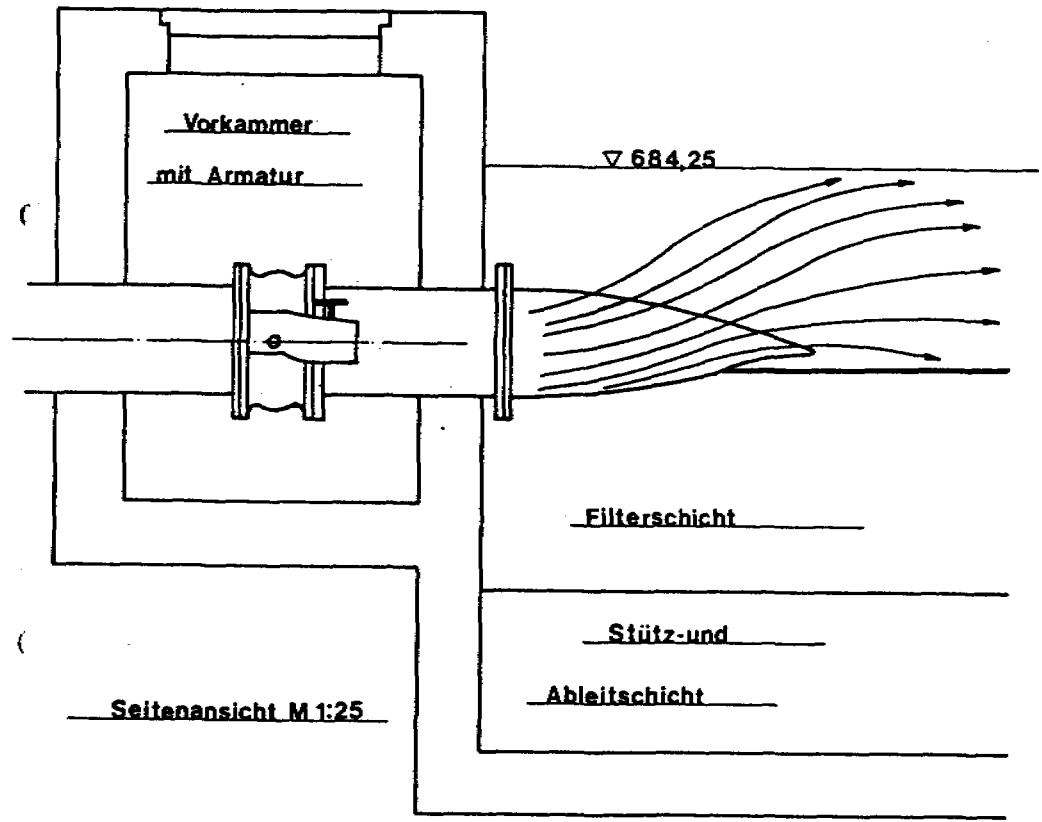
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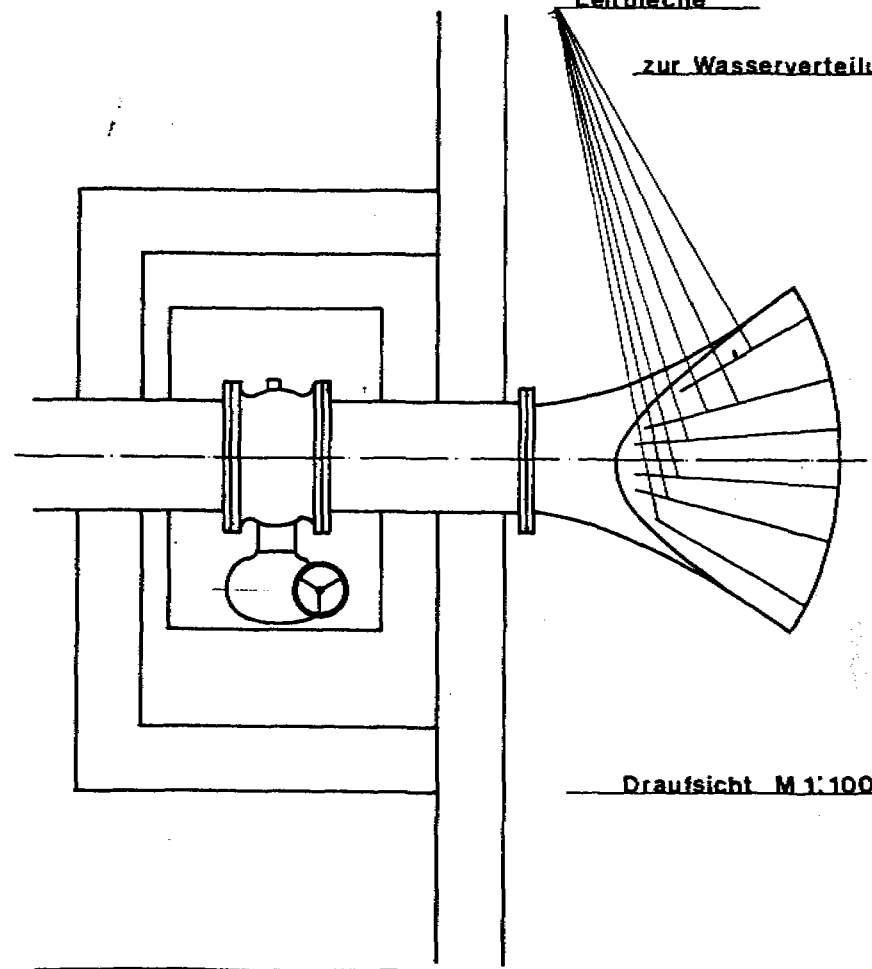
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						Bearb. 09.08.90 Gepr. Norm.		Neuer Filter-Einlauf REGIDESO BURUNDI	
						ZWECKVERBAND BODENSEE- WASSERVERSORGUNG		Z. Nr. FA 1000-1 Ers. 1.: Ers. d.:	
Zust.	Änderung	Datum	Name					Blatt Bl.	



Draufsicht M 1:1000



Leitbleche
zur Wasserverteilung



Pos.	Stck.	Benennung	DN	PN	Bau- länge	DIN-Nr.	BWV-Nr.	Werkstoff	Bemerkungen
					Maßstab				
					1:25 / 1:1000				
					Verbesserung Filtereinlauf REGIDESO BURUNDI				
					Z. Nr. FA 1000-2				
					Ers. f.: Ers. d.:				
Zust.		Änderung		Datum		Name		Blatt	
								Bl.	

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30 October 1990

Ir. Jo Smet
 Programme Officer
 IRC
 P.O. Box 93190
 2509 THE HAGUE NL

01 OCT 90	53578
Smet	

Dear Jo,

Slow Sand Filtration, Bujumbura

I have at last been able to contact the UK expert on limestone filtration. He is Mr. D. Watts, formerly of Barr & Wray Ltd. (associated with pHlorite Ltd.).

He has not experienced limestone for precipitating supersaturated calcium carbonate, except when it has occurred in error, due to wrong high pH adjustment of water being brought up to equilibrium by filtering through partly calcined dolomitic limestone. Then it was necessary to break up the cemented dolomite due to precipitation.

Mr. Watts suggests that we commence pilot trials with limestone crushed and sieved to approximately 2-4 mm, about 0.5 m deep at about 10 m/h. These values can be adjusted by the pilot experimental results. He mentioned backwashing with air scour and water about every 3 days to delay cementation of the limestone, but I informed him that this would be inappropriate technology. He has experience of dolomitic limestone filtration in Nigeria, but that was in a package plant for iron removal.

Will you copy this to Uwe Neis (and GTZ if appropriate).

With best regards.

Yours sincerely,

K.J. Ives

SLOW SAND FILTRATION - BUJUMBURAACID TESTINGACID TEST

Approximately 50 g of sand is oven dried and then immersed in 20% vol/vol hydrochloric acid, at 20°C, and occasionally gently stirred, for 24 hours. Any effervescence, and discolouration of the acid, is noted. The sample is rinsed in distilled water to remove residual acid and dissolved matter. After oven-drying the sand is reweighed. The percentage loss of weight is calculated. A loss of weight of more than 2% is unsatisfactory in filter media testing.

SAMPLES

Taken at Bujumbura Waterworks 14 July 1990.

A Unused clean sand from stock

B Dried schmutzdecke and associated surface sand from Filter No. 4.

C Surface sand after skimming off the schmutzdecke from Filter No. 4.

D Dried cemented sand from surface of Filter No. 2.

RESULTS

Mean of two.

Sample	A	B*	C	D
Effervescence	Moderate	Moderate	Moderate	Excessive
Acid colour	Slight yellow	Slight yellow	Slight yellow	Slight yellow
Loss of weight	0.6	1.3	1.6	6.9

Dried organic matter pre-washed out of sample.

COMMENT

Sample A is clean unused sand derived by hand-dredging from shallow water (approx. 2 m) in Lake Tanganyika. due to contact with the Lake water, some calcification of the sand is expected. The sand is satisfactory with only 0.6% weight loss.

Sample B shows that the top surface of the Filter 4 has calcified during the long first run (142 days) to give 1.3% weight loss. This calcification was not visible, and the sand was uncemented (although linked by organic deposits of the schmutzdecke). The weight loss is acceptable (less than 2%), but has doubled during the first filter run.

continued

Sample C This cleaned (skimmed) sand under the schmutzdecke of Filter 4 has calcified during the long first run (142 days) to give 1.6% weight loss. Although this value is satisfactory (less than 2%) it indicates that calcification has proceeded under the schmutzdecke, and therefore the precipitation of CaCO_3 is not prevented by an active schmutzdecke.

Sample D Not surprisingly, this sample of dried cemented sand from the surface of Filter 2 gave an excessive reaction and loss of weight (6.9%). The sand is totally unsatisfactory for further use.

CONCLUSIONS

The increase in calcification (weight loss in acid) from 0.6% to 1.3 and 1.6% in Filter 4 during the first run, indicates that progressive calcification is likely in future runs, in spite of the development of a schmutzdecke and otherwise satisfactory performance of the first run after filter reconstruction. Consequently, the need to prevent this progressive calcification, by appropriate pretreatment, is urgent.

University College
London

K.J. Ives
5 October 1990

DRAFT - POINTS FOR CONSIDERATION

TERMS OF REFERENCE FOR RESEARCH FELLOW ON WATER FILTRATION

- . tests to be done in Bujumbura, Burundi
- . period of research at least 12 months to incorporate seasonal variations.
- . allow for sufficient time for project development and commissioning pilot filters
- . pilot filters: diameter 20 cm?? (in research project in Colombia 60 cm was used)
- . research protocol
- . development and establishment of environmental and water quality surveillance system and programme:
aspects: eutrophication, frequency, location
parameters: algae (biomass or chlorophyll), turbidity, phosphorus, nitrogen
- . list additionally required equipment
- . not a student, should be able to work independently with backing of recognized technical institution; on chemistry perhaps some backstopping of Dr Stabel
- . European lab. should function as reference laboratory (Dr Stabel?)
- . french speaking