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DANISH INTERNATIONAL DEVELOPMENT AGENCY

DANIDA

TECHNICAL REPORT ON

MISSION TO ASSESS IRON REMOVAL TECHNOLOGY IN DANIDA SPONSORED RURAL WATER SUPPLY PROJECTS IN SRI LANKA, BANGLADESH AND ORISSA, INDIA

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1 / INTRODUCTION

1 INTRODUCTION

1.1 BACKGROUND

The invitation to conduct a Mission to assess iron removal technology in Danida sponsored rural water supply projects was received under cover of a letter dated 11th September 1985. This letter and the accompanying Terms of Reference are included as Appendix A to this report. The Mission comprised Mr. Miles Burton and Mr. Erik Buhl-Nielsen of Carl Bro International A/S, Consulting Engineers and Planners, Copenhagen.

1.2 OBJECTIVES AND SCOPE

The objective of the Mission as defined in the Terms of Reference was to assess the "state of the art" in iron removal at hand pump level, review the experience gained so far in this respect in Bangladesh, Orissa and Sri Lanka, and make recommendations on future action by Danida.

The scope of the work was outlined as:

- Review state of the art in village level iron removal.

- Study and assess potential of iron removal unit under development by a Danish supplier.

- Visit the Danida sponsored water projects in Bangladesh, Sri Lanka and Orissa in addition to the Finnida project in Sri Lanka. During these visits, the Mission to discuss iron removal problems, study relevant data and reports and inspect selected iron removal plants.

- Prepare a report containing assessment of iron removal plants under development or consideration as detailed above and recommendations on future action by Danida, including proposed programme for testing and monitoring.

1.3 PROGRAMME AND ITINERARY

In accordance with the letter of invitation, the initial period of the Mission was spent abstracting, from literature and personnel sources, background data on iron removal and on reviewing the state-of-the-art in respect of village level units. In this period, the prototype plant being developed by a Danish supplier was also studied.

A three week period was spent visiting Danida sponsored water projects in Sri Lanka, Bangladesh and Orissa State, India. In Sri Lanka, the other water supply projects being constructed in the country under Finnida, UNICEF and GTZ sponsorship were considered.

The period subsequent to the field visits of the Mission was spent in supplementary information review as necessitated by the findings of the field visits and on reporting.

The outline timing of the Mission is given below, and a detailed field itinerary is included as Appendix B.

16.09.85 - 18.10.85	Abstract background data and review state of the art
22.10.85 - 27.10.85	Sri Lanka
28.10.85 - 03.11.85	Bangladesh
04.11.85 - 09.11.85	Orissa State, India
11.11.85 - 05.12.85	Draft reporting

1.4 STRUCTURE OF THE REPORT

The report on the Mission has been structured such that individual country related information can be separately studied. Thus Chapters 4, 5 and 6 respectively contain information individual to Sri Lanka, Bangladesh and Orissa respectively. Each chapter contains an assessment and recommendations particular to the situation in the relevant country.

Background information and an assessment thereof is separately presented in Chapter 3.

The conclusions and recommendations of the Mission, as assessed from the information gathered from all projects visited and background data and relevant material reviewed, is presented in Chapter 2.

2 / CONCLUSIONS

2 CONCLUSIONS

2.1 STATE-OF-THE ART

Much of the available literature in respect of iron removal techniques is prepared with relevance to large scale publically operated supplies. The objective of these plants is to obtain a dependable effluent level of iron content of the W.H.O. maximum desirable value of 0.3 mg/l or lower. Consequent utilization of chemicals and high performance filter cleaning procedures, employing high pressure systems and often additional mechanical aids, are completely inappropriate for village level iron removal plants (I.R.P.'s).

The simple chemical process of aerating the incoming supply to oxidize soluble ferric iron followed by the equally straightforward mechanical process of removing the resultant insoluble ferrous iron by sedimentation, filtration or a combination of both is the only technology of iron removal appropriate to village level water supplies, from present knowledge of the topic. Fortunately, this process operates fairly successfully within the range of chemical composition of groundwater normally encountered. Only in cases of water with a low pH, high carbon dioxide value or containing manganese or considerable organic matter is the iron removal process further complicated.

The required aeration of the water sufficient to allow oxidation of the soluble iron is generally easily achieved within the limits of iron level normally encountered due to the low amount of oxygen necessary. The removal of the insoluble iron is again achieved with little complication. Depending on the size of floc created and the quality of effluent required, the only questions are to what extent sedimentation can be used and the nature of filter media to be employed.

Problems only start to arise in village iron removal plants therefore when, due to generally successful removal of iron in almost all units irrespective of design, the deposited iron reaches a degree that the removal process no longer operates satisfactorily or that unacceptable flow conditions result. The plant must then be cleaned to return its operating condition to as near that of original as practical and then returned into service. The fact that, generally, cleaning within a village level context, will not restore the full operating performance of the plant, results in the plant requiring a more major rejuvenation of media at some other regular interval. <u>It is the appropriateness, efficiency and user acceptability of these cleaning processes that result in the major complications and failures of iron removal plants connected to village water supplies.</u>

The need to optimize a cleaning and/or rejuvenation process for village conditions in turn introduces the significance of design concepts, such as flow rates, loading rates, media size, number of chambers, upwards or downward flow, etc. Unfortunately, the state-of-the art in respect of testing and proving such criteria in respect of village level plants is very poor. Iron removal plants which have recently been installed on the schemes inspected by the Mission, and it was the Mission's findings that the plants investigated were as advanced as that available or reported in an international context, generally suffer from not having been adequately tested in a scientific way regarding the necessary design criteria. Therefore current development of these plants while indicating very promising direction, which has mainly resulted from experience, fails to prove the optimization or even correct magnitude of order of many critical aspects.

The research which has been proceeding in the Technical University of Denmark as a follow up to the Danida Mark II iron removal plant installed in pilot studies in Orissa, India, indicates the potential value of such work. However, this research, which was only available to the Mission in draft form, is not conclusive enough to be of much direct practical use.

Without the testing and proving of the basic design concepts, little advance can be made with certainty on the development of an optimum iron removal plant for village level supplies. Current developments are conducted primarily on a trial and error basis. Although this procedure will always have a place in a research and development programme, the Mission very strongly believes that a more scientific approach to such field programmes would result in considerable improvements in performance and a significant reduction in the overall time taken for development.

2.2 REVIEW OF EXPERIENCE

In reviewing the experience with iron removal in particularly the Danida sponsored water projects visited by the Mission in Sri Lanka, Bangladesh and Orissa, it is important to identify the extent of the problem. The scale of problem is inevitably related to the criteria of acceptance. The Mission found that it would be impractical to adopt W.H.O. international limits, either 0.3 mg/l or 1 mg/l in all cases (Bangladesh would require 70-90% I.R.P.'s), and that further this was not necessitated if judged according to user acceptability. The situation as reflected on the Danida water projects in each country is shown in the table below.

COUNTRY	LIMIT OF UNACCEPTABLE IRON (MG/L)	CONSEQUENT NO. NUMBER OF BOREHOLES AFFECTED (NO.)	USER POPULATION AFFECTED (NO.)
Sri Lanka	1-3	60-20	15,000-5,000
Bangladesh	5	10,000	650,000
Orissa	3	2,000	200,000

Summary of Iron Removal Plant Requirements in Danida Sponsored Water Projects.

The figures in the above table have been presented, for reasons of simplicity, based on the generally acknowledged user level of acceptability. Variable levels of acceptability either presently considered or postulated to be applicable in the future are discussed in further detail in the appropriate chapters. The above figures show that the magnitude of the problem in Bangladesh and Orissa justifies an intensive effort in achieving a successful solution in order to avoid a significant reduction in the effectiveness of the borehole programme.

In Sri Lanka the problem related to formation iron (iron resulting from natural sources) is minimal. However, the occurrence of unacceptable iron levels in groundwater supplies which have been shown to result from corrosion of the metal pump and pipe elements due to aggressive water is extensive. This is expected to occur in some 65-75% of boreholes. The problems resulting therein and the efforts to achieve a solution, together with the Mission's recommendations are separately recorded in Chapter 4. It is obviously not feasible to consider the installation of iron removal plants in the cases of unacceptable iron level being caused by corrosion alone, and the solution must be to install a non-corrosive pump.

It must be concluded that the situation in respect of iron removal is different in each country visited, and these differences must be considered in evaluating the solutions to be applied. The basic situation can be summarized as below:

Sri Lanka — Low degree of formation iron problem but high degree of user sensitivity. Contrary high degree of problem with corrosive water.

Bangladesh — High degree of iron occurrence at very high levels, but corresponding high level of user acceptability and conviction of the benefits of borehole supply versus untreated surface water sources. Authorities' attitude to appropriate local technology and material is critical to the plant selected.

Orissa	Fairly extensive problem, but as yet uncertain village attitude to iron level tolerance or to adoption/operation of iron removal plants.

Four differing types of reasonably large scale operational iron removal plants were inspected by the Mission in the course of their field visits. These are summarized in the table below which gives relevant features of each unit.

LOCATION/ TYPE CHARACTERIS.	SRI LANKA UNICEF PRE-FABRI.	SRI LANKA FINNIDA PRE-FABRI.	BANGLAD. UNICEF IN-SITU	ORISSA DANIDA MK II
Materials	Glass Fibre Reinforced Plastic	Concr. Rings	Brick	Concr. Rings or brick
Features	3 Chamber Aeration-Sediment. Upflow-Filtration Downflow Filtration	2 Chamber Aeration-Upflow Filtration-Downflow Filtration	3 Chamber Design Features As Sri Lanka	1 Chamber Aeration-Sediment. Upflow Filtration
Flow Rates-Design	14-20 l/min	14-20 l/min	14-20 l/min	14-20 l/min
-Actual	3-20 l/min	5-15 l/min	10-20 l/min	10-20 l/min
Filter Loading	2.5 m3/m2/h	1.7 m3/m2/h	2.5 m3/m2/h	1.3 m3/m2/h
Actual Effluent Quality	Variable	<0.3 mg/l	5 mg/l	<0.1 mg/l
Filter Run	2 weeks	< 1 week	Variable	2 weeks
Rejuvenation	4 weeks	4 weeks	Variable	3 months
Maintenance Syst.	Caretaker/ Community	Caretaker	Caretaker/ Community	Proj. Staff
User Acceptance	Low	Medium	Low	Uncertain
Rejection Level				
Stage of Development	2-3 years (only 3 mon. latest model)	3 years (6 months latest model)	6 years	1½ years
Remarks				Unit not yet tried under village operating conditions (cf. 6.6.1)

Iron Removal Plants Inspected by the Mission.

The above iron removal plants indicate a wide variety of application of the basic aeration/filtration iron removal principle. The results of utilization of the units show that none can yet be considered the "final solution" mainly due to problems with the maintenance system and user acceptability. The rejection levels of iron removal plants, for a variety of reasons, in all cases where these have been installed and operated under entirely village level conditions have been of a completely unacceptable order of up to 50 per cent. Until and unless the problems resulting in this order of rejection are identified and seen to be solved, the Mission cannot recommend further large scale implementation of iron removal plants.

The developments in respect of iron removal plants that have taken place to date are neither conclusive, nor complete. The main points in respect of the current status in individual countries are summarized below.

Sri Lanka — Only very recent experience on the Danida project, but initial reaction to the UNICEF plant not positive. Other long term experience with UNICEF plant elsewhere in Sri Lanka also not positive, but recent developments of the plant are promising although not yet proven over long term field trials.

Bangladesh — Completely unacceptable high failure rate of up to 50% in certain areas, but even within such areas similar plants have been operating successfully for 2-3 years adjacent to villages where plants have been abandoned since inception without obvious difference between the two cases.

Orissa — The Danida Mark II is a well designed and constructed unit where the basic principles appear correct, but due to its not yet having been tested under actual operating conditions, the optimization or even long term acceptance of the unit by villagers is still uncertain.

The extent and details of the problems and unanswered questions in respect of individual iron removal plants in each country are much more complex and are itemized in each country report, Chapters 4 to 6. Some main features are, however, summarized below to illustrate the present state of uncertainties in respect of the correctness of the solutions which have presently been applied.

Sri Lanka UNICEF Plant:

- Many users will not accept or cannot operate the cleaning and rejuvenation system.
- Uncertainties as to the benefits or the optimization of the graded media system.

FINNIDA Plant:

- Problems with flow rate.
- Uncertainties in respect of user acceptability of the cleaning process.

Bangladesh UNICEF Plant:

- Many users will not accept or cannot correctly operate the cleaning and rejuvenation system.
- Uncertainties regarding the sedimentation and filtration design optimization in respect of flow rates, media size, retention period, etc.
- Poor construction standards and inappropriate materials for operational requirements.

Orissa DANIDA MARK II Plant:

- Uncertainties, due to lack of experience, with respect to user operation and acceptability.
- Problems with the effective cleaning of an upward flow filter.

In addition to the units identified above, two other types of iron removal plants were considered by the Mission. One plant, the Danida Mark III in Orissa, was not sufficiently developed or tested in the field to fully evaluate its performance. Although interestingly, an adaption of this model has been constructed and installed by UNICEF in a village in Bangladesh. Despite some initial operating problems further development of this model should be considered in an appropriate location.

The other iron removal plant inspected by the Mission is a full scale prototype recently developed by I. Krüger A/S in Denmark. This plant is more fully reported upon in Chapter 3. It depends on similar aeration and filtration techniques as the other systems studied, although at the time of the Mission's inspection the aeration part of the unit was not yet finalized. The unique aspect of this plant is the filter cleaning system. By incorporating a single size media in a circular drum, the filter can be effectively cleaned by rotating this unit to achieve agitation of the bed and re-suspension of the iron floc before being washed out. The trials carried out to date indicate a very effective cleaning process. This fact combined with the relatively minor effort necessitated and avoidance of removal of media or contamination of the unit in the cleaning process, results in a system which answers many of the basic problems experienced to date with village level iron removal units. However, it would be premature to judge the complete success of this unit before trials are carried out under village conditions and user acceptability is evaluated. The potential of the unit is such that the Mission considers that this village level testing must be carried out as a matter of urgency. The main drawback is the pre-fabricated and non indigenous nature of the unit. Because of strong objections in Bangladesh to such units , the unit should first be tried in the Orissa project, India. In evaluation of the plant, careful consideration must be given to durability. The prototype model is constructed in steel. In aggressive waters, this will lead to problems, even if galvanized. An alternative construction in glass fibre reinforced plastic may not be sufficiently robust. These aspects should not, however, detract from extensive field testing of the options.

With the present lack of firm conclusions on so many technical design aspects and user acceptability of the iron removal plants studied, it is not possible for the Mission to firmly conclude on the acceptability or otherwise of these plants for full scale implementation at this point of time. It can therefore only be concluded at present what further steps must be taken in order to arrive at such a conclusion on the implementation of plants as soon as possible.

If the basic requirements of village level I.R.P.'s were to be considered from the beginning, the most logical development would be for a very detailed and concentrated product development involving experimental testing, field development and site trials. Such a programme would take considerable resources and time and the result would not necessarily be successful due to the all important villager attitude to the technology which may be proven to be necessary. With the possible exception of the Bangladesh project, the resources available and the time schedule of existing and future stages of the projects in question make such a complete project development unfeasible.

The Mission therefore concludes that urgent further testing and proving of the existing most promising units is the most appropriate course of action. The significance of the timing of the implementation phases of the projects in question makes this requirement urgent. All projects are well advanced into implementation and most will be within a period of no more than 1 year, and in some cases much less, advanced to a stage where unavoidable major disturbance of the implementation programme will result if an acceptable solution is not found.

Consideration was made by the Mission of the possibility of solving the problem of iron removal by avoiding iron bearing sources. The Mission believes that wherever practical, existing hydrogeological investigation, or further investigations where these can be justified in producing likely results, should be utilized in order to minimize the degree of occurrence of the problem. However, the Mission also concludes that, given the hydrogeological nature in most cases, and complexity in others, limited benefit would be achieved from this work.

2.3 RECOMMENDATIONS

2.3.1 General

The Mission believes that urgent action must be taken to establish an acceptable iron removal plant or plants. This action should take the form of a monitoring and development programme as outlined below. Development of units will result in country specific solutions. The varying acceptability criteria and maintenance systems in particular will often result in direct conflict in the development of units for different countries. This aspect, however, must also form an integral part of the evaluation and development programme.

It should be noted that only the principles and outline structure of the monitoring and development programme is given in 2.3.4. If such a programme is to be effectively and efficiently applied a detailed structuring much greater than possible within the constraints of the Mission's Terms of Reference needs to be carried out. The existing project staff must be involved in such a programme development in order to ensure its appropriateness and applicability. However, the limited resource availability on existing projects and the need to ensure an objective evaluation will probably lead to the additional input of specialist assistance also being necessitated.

2.3.2 Immediate Action Required

Sri Lanka

The scale of the problem in Sri Lanka does not merit extensive independent investigations. It is recommended that the Danida project benefits as much as possible from the work being done by UNICEF and Finnida. In particular:

- The project should try to find more definite information both supporting the claimed performance of the UNICEF MK III Plant via the UNICEF office in Colombo and regarding the latest Finnida model.

- The Mission believes that the Finnida unit will be found to be more favourable and the project should explore ways of working closely with the nearby Finnida project. The extensive Finnida experience is directly relevant and solutions found and proved by Finnida can be directly adopted by the Danida project, thus benefitting the time schedule considerably.

Bangladesh

The dual flow in-situ construction IRP has the potential and, despite a high overall failure rate, in many instances has realized this potential, of being a successful unit. On the basis of evidence discussed in the country report, the mission recommends that the following action is carried out immediately.

- Re-design of unit defects. These are presented in Section 5.2.2 (c). Many of the adaptions are very simple and will have an immediate and very beneficial effect.

- Adoption of new installation criteria. As mentioned in the county report, iron removal plants should only be installed at tube well locations where:

  a) There are strong indications that the community would reject the water without treatment.

  b) Physical quantity testing confirms an unacceptable iron level.

  c) The existing maintenance system in the village is considered capable.

Orissa

The Danida MK II unit should be used for Phase I. It is recommended that the following modifications be made prior to and during Phase I.

- A more coarse gravel top layer should be used. At present, units which have a 10 mm gravel size appear to perform as well as units with much finer media. This suggests that even coarser material could be tried and advantage taken of the better operating conditions.

- Agitation is used to supplement the normal down flush cleaning and that multiple down flushes are used until the waste water is clear.

- The throughput in the operational units must be established and if, as is expected, this is much greater than the existing trial units, the units may become clogged too soon. This must be tested, and if proven to be the case, a reduction in media depth should be made in order to re-achieve an operating period which would correspond to the planned frequency of maintenance visits.

- Re-design of detail defects, cf. country report, Section 6.6.3.

The concrete shell and overall dimensions of the plant will remain the same. Any changes arising from future development will only alter the media selection and the method of maintenance. This implementation therefore carries only a minimum risk of later abandonment.

2.3.3 Future Action

Sri Lanka

This should be dependent on the success or otherwise of either the UNICEF or Finnida IRP in the short term field testing. The Mission believes that units from other countries are not appropriate for testing in Sri Lanka in the first instance. The Danida Mark II unit would not be appropriate to the village caretaker system, nor would Sri Lanka be the best initial testing ground for the Krüger plant due to the minimal extent of problem and to the corrosion situation. It is advised to await the results of pre-trials in other countries before evaluating the Krüger plant in respect of Sri Lanka.

Bangladesh

As a follow-up to the immediate action suggested, it is proposed that the monitoring and development programme as outlined in Section 2.3.4 is put into effect at the earliest moment practical.

In many instances, existing knowledge arising from previous development and experience can be used to considerably reduce the new work required. It is important that information used is made explicit and that the steps outlined in the programme are actually carried out even if this only results in a statement and justification of existing information.

For the particular case of Bangladesh it is recommended that:

- The staff are identified and the responsibilities assigned in close conjunction with UNICEF.

- The existing UNICEF unit is used as the principle model. Particular attention should be paid to improving the performance by altering the size of filter media (Section 2.3.4, Point C.2).

- The Finnida unit should be tested as an alternative. Particular attention should be given to the comparative efficiency and acceptability of the different maintenance methods (Section 2.3.4 Points C.3 and C.4).

- The Danida MK III village maintenance method should be looked at further. This approach to maintenance is well suited to the maintenance condition in Bangladesh. The prototypes so far developed have important drawbacks and it is recommended that:

  a) a minimum of pre-fabricated components are used
  b) a simple and robust mechanical method of semi-automatic backwash is developed
  c) The use of a simple direct action pump to provide extra head for backwashing is considered.

- The level of user acceptability of iron content be clearly determined and a policy decision be made on the design criteria in this respect of iron removal plants implemented in the future.

- Special attention should be focused on plant introduction techniques (Section 2.3.4, Point C.1).

- The method of construction will need to be reviewed as this is expected to have a major influence on the likely success of the unit (Section 2.3.4, Point C.3).

The development of other iron removal plants in connection with the Bangladesh project should we believe have low priority. The maintenance system of the Danida Mark II unit is not appropriate to the village level maintenance system in Bangladesh. We also believe that the Krüger unit pre-trials should first be carried out before considering the complications of acceptability of a pre-fabricated unit in Bangladesh. The Water Programme in Bangladesh is, of the three Danida projects visited by the Mission, the one with the greatest resources and most suited structure for larger scale product development studies in the field of iron removal plants. Even on such a project, however, the resources and time requirements of complete product development can be prohibitive and the Mission believes that this alternative must only be considered as a last resort if all other proposals prove to be unsuitable and if no new appropriate development appears on the market in the intervening period.

Orissa, India

As a follow-up to the immediate action suggested, it is recommended that the monitoring and development programme (Section 2.3.4) is put into effect at the earliest practical moment.

As in the case of Bangladesh, the benefits of prior experience should be incorporated in order to shorten the time of programme so long as these are justified. For the particular case of the Orissa project, it is recommended that:

- The individual responsible for the iron removal plants is identified and that a clear cut allocation of time and resources is made.

- The Danida MK II IRP is used as the principle model. Particular attention should be paid to using coarser filter media, less depth of media and a simpler media grading (Section 2.3.4, Point C.2).

- The Krüger unit and the Finnida unit should be tested in parallel to the Danida Mark II Plant (Section 2.3.4, Point C.3) in order to compare the operational efficiency, user acceptability and maintenance viability of the differing units.

- The maintenance method should be improved by trying out methods of agitation, repeated down flush and any other possibilities.

- Full advantage is taken of the exceptional water quality monitoring facilities.

- As a last resort, should the maintenance methods prove incapable of supporting a monthly filter run, then a dual flow system with half the depth of media but in two stages should be tried. The unit should be designed for the same flow rates with greater emphasis on agitation of the media during maintenance (Section 2.3.4, Point C.3).

The Mission does not believe that the Danida Mark III unit in Orissa is at a stage of development which would result in any benefit from further village level trials at this point in time. The Mark III unit which requires a regular cleaning process is not appropriately suited to the 2-tier system of maintenance now proposed for the Orissa project. It is recommended that the resources on the Orissa project be better, in the first instance at least, concentrated on improvements of the Mark II model and parallel investigations of the more promising alternative models.

2.3.4 Monitoring and Development Programme

This programme is intended to structure the efforts to improve the iron removal units for the non-immediate future. In order to achieve the dual goals of technical success and minimum of resource expenditure (staff, money, time), a well structured but simple approach is needed.

The Mission recommends that wherever possible, work is built up from existing knowledge and development. It is recognized that much of the present information concerning the units is contradictory and without firm scientific basis. However, there still exists a considerable body of information and experience which should be fully exploited and made explicit.

The programme as presented, represents the full requirements and it will be up to the project individuals and remote coordination to exploit any short-circuits that may be possible as they become apparent. For instance, it may be that, following work carried out on the design criteria (Point C.1), the design performance requirements can be lowered enabling much earlier completion without affecting the acceptability of the plants.

An extensive and well organized project structure exists both in Bangladesh and Orissa, India. The remote coordination element suggested is not intended to substitute any of the responsibilities or duties of these projects. Its function is set out under Point B.3. The basis requirement will be to provide overall technical coordination between different countries and assist in solving detailed technical problems. Through monthly contact with the project field work, an important sense of perspective and direction can be gained to ensure that maximum utilization is made of previous work and that future improvement and development takes place along the most efficient lines.

A PLANNING LEVELS

2 levels of planning/consideration:

- General Strategy
- Detailed Programme Planning

A.1 General Strategy

The following should be formulated:

- The needs of a monitoring and development programme.

- The objectives of the programme.

- The resources and activities required to achieve these objectives. The available options on these resources and activities.

- Assumptions or uncertainties connected with any of the above.

Although remote external monitoring is important, the major monitoring work will take place within the project itself. This self monitoring should be an on-going task which is periodically reviewed.

A.2 Detailed Programme Planning

The direction of the detailed planning will depend on the general strategy decided upon above. This programme will set out the detailed measures required to meet the main objectives within the resources and method of approach adopted by the General Strategy. For this purpose the following should be done.

- The detailed planning will set out the interim objectives that lead to, and need to be accomplished before, the final objectives are satisfied.

- The particular resources and activities, the personnel and working relationships necessary to achieve these interim objectives.

- A continuous monitoring procedure which will a) indicate the progress of the programme, b) identify any problems, c) enable on-going adjustments to be made to the programme to overcome problems and improve performance. The General Strategy will decide the degree of actual monitoring used.

- The assumptions and uncertainties connected with any of the above should be clearly indicated. Flexibility can then be built into the programme to allow for these.

A.3 Evaluation

The monitoring procedure will contain indications to identify the rate of progress and details of cost or resource over-runs. The programme structure itself will also, as mentioned before, enable flexible responses to be made to problems as they arise. Nevertheless, in addition to this, once the programme is completed a short evaluation is suggested. This evaluation will determine the degree of success of the programme and its results should be presented in a very brief report. The evaluation should be considered as an integral and final part of the monitoring procedure.

A.4 Summaries

A summary of the expected costs, inputs and timing of the programme should be made.

Once the major decisions have been made it is important for cost control reasons that a more precise summary is made of the expected costs, input and timing based on the detailed planning work.

Adherence to this or later, modified estimates should be treated as one of the major indicators of success during the intermediary monitoring and final evaluation.

B GENERAL STRATEGY

B.1 The Needs of an M&D Programme

- The design and performance criteria for the units (technical and sociological) need to be formalized.
- The existing performance of the units needs to be determined.
- All the units need further development work before full scale implementation can be recommended.
- There is a good indication that techniques and knowledge can be usefully shared by the three countries to help the development of each different unit.
- The requirements for a reliable working unit is urgent. An intensive, well managed development and testing programme will be essential to meet deadlines.
- Previous M&D programmes have suffered from a lack of detailed organization and objective monitoring. A well controlled and intensive effort will be required to avoid the pitfalls of the previous efforts.
- Experience with and evaluations of the existing units tends to be subjective. An objective viewpoint or input is necessary to balance this and channel the applied effort into a positive and technically objective direction.

B.2 The Objectives of the Programme

The final objective: The development of a reliable working unit for each country.

Interim objectives:

a) Establishment of criteria.

- Determine design and performance criteria.

b) Evaluation of existing units.

- Determine existing capabilities of plant.

c) Development.

- Re-design details of unit to overcome the detailing problems, e.g. aeration channels, etc.
- Development of unit to overcome shortfalls observed between a) and b) above.
- Test alternatives to the favoured country unit for comparison.

d) Field Testing.

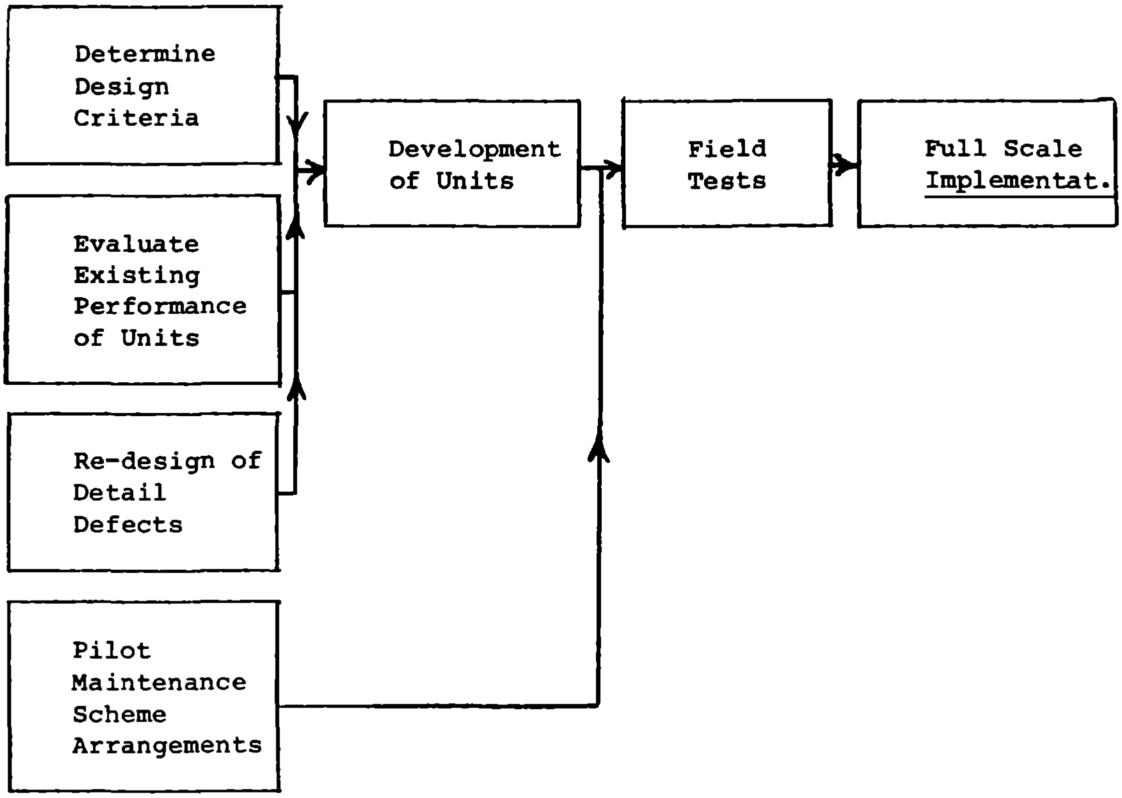
- Establish working model of intended maintenance system to allow realistic field testing.
- To field test the units.
- To gain information on the likely success of the maintenance system itself, and on the plant introduction techniques most likely to lead to success.

These activities consist of many smaller detailed activities, which are identified under Point C (Detailed Planning Outline).

The relative duration and timing of the activities cannot be determined in detail or within any degree of certainty until detailed planning (cf. Point C) is done. The representation illustrated overleaf only outlines a likely situation.

B.3 ACTIVITIES AND RESOURCES

Activities



Schematic Diagram of Priority of Events

Each of the Activities identified will need resources to enable efficient and speedy completion. These resources can be split up as follows:

1. Remote coordination
2. Specialized inputs
3. University research input
4. Project based resources

1. Remote Coordination from Denmark will be required to:

   - Provide continuous and essential monitoring through the submission of project progress reports
   - Respond to difficulties and problems as they arise
   - Integrate results of different countries and ensure transfer of information
   - Ensure technical objectivity

2. Specialized inputs:

   These may be needed in response to particular difficulties identified and confirmed by the project based resources.

3. University research input:

   This has provided some valuable information in the past. As well as benefitting from the results of on-going research, arrangements for a referral service for laboratory tests will be essential if an ensured development direction is to be achieved. A link between the University's research schedule and the need of the project units should be established.

4. Project based resources:

   It is clear that the major burden of the programme will fall on the project staff. In many cases these resources are already fully committed and this may have been one of the reasons for non-directionalized development in the past.

It is recommended that an individual be assigned the exclusive task of being responsible for carrying out the programme in each of Bangladesh and Orissa.

This individual should be an engineer who will call on and coordinate the specialized inputs of the socio-economic and maintenance cells of the project. In coordination with the project chemist, the engineer will provide technical input. Socio-economic input, for example, will be relied heavily on for the completion of activity (a) (the design and performance criteria). Maintenance input will be required for activity (d) (the field testing of units).

An alternative structure to be considered would be to form a special team for the programme. This team would demand less from the project resources and more intensive approach could possibly lead to earlier results. This would probably be a more expensive solution even allowing for the cost savings of earlier results. A hybrid of the two approaches involving an extended input of extra staff for the most critical and intensive periods of work is also a possibility.

For the Detailed Planning (Point C) it has been assumed that the former solution, an individual, would be used who could call on extra resources, if necessary.

A close agreement and consensus, within the project management, on the objectives and personnel working relationships will be required to ensure a strong and undivided approach.

B.4 Assumptions and Uncertainties

1. The quality and representativeness of existing sociological data:

   A quality check on this data for methodological and other errors should be made to reduce the uncertainty associated with its use (cf. country specific reports).

2. Sociological data will not point to a single answer:

   Each village may indicate different and often contradictory responses. A uniform solution is likely to have varying degrees of success for this reason alone.

3. The setting up of a convenient pilot testing site:

   This may be more difficult and time consuming than assumed because the nearest iron rich groundwater may be quite remote.

4. The representativeness of the performance of the pilot plant:

   The levels of iron in the groundwater will differ within the project area, but the pilot plant will only be tested at one site. The technical implications of this can be largely overcome by correct testing procedures. An examination of detailed chemical analyses will determine if gross differences in water parameters, e.g. pH, occur within the project areas.

5. Pilot maintenance scheme:

   a) the costs and difficulty of arrangements
   b) the non-representativeness of the pilot scheme, e.g. if villages chosen are particularly well suited or if the maintenance person is unusually conscientious.

6. Transfer of information from other countries:

   a) At the end of activity (b) (evaluation of the results of existing units), results from other countries can be exchanged. Only if the advantages of a new unit appear to outweigh those of the existing unit and the disadvantage of late or non-uniform adoption, should the new unit be looked at further.

   b) Some design features, e.g. aeration channels or drain plugs, may be advantageously used from other units without adopting the new unit itself.

7. The stage of development:

   The stage of development of many of the IRP's is already quite advanced, some IRP's have been in the village for 2 years. The data and experience of these units (cf. country specific reports) can be used to allow considerable time savings to be made on field testing. The method of maintenance in Bangladesh, for example, is well established, and the pilot maintenance activity will not be needed.

C DETAILED PLANNING OUTLINE

C.1 Establishment of Criteria

C.1.1 The Objectives

1. The iron level at which plants need to be installed in order to ensure that the intended health benefits of a borehole installation are realized, i.e. the iron level required to achieve a satisfactory degree of utilization.

2. The reduction of iron level that plants <u>once</u> installed need to achieve in order to satisfy the users. Special attention should be given to the differences between cooking, drinking and laundry uses.

3. The discharge levels at which people will start to turn to other sources because of the delays, etc. Related to head loss and filter run.

4. The acceptable routine cleaning and filter rejuvenation periods.

5. The acceptability of the complexity and burden of the above tasks.

6. Comments and attitudes on the routine local maintenance and operation necessary, as well as any innovations considered, e.g. agitation.

7. A set of measures and safeguards to ensure that the plant introductory techniques are successful (cf. page 5.6 Country Specific Report).

8. The best strategy for including the use of iron removal plants in the on-going project health education programme.

9. The most favourable places of installation (e.g. intercepting the route to the traditional source, minimizing the obstruction to village life, etc.). That is, a siting policy that includes the effect of an IRP.

10. Miscellaneous village concerns such as the space requirements, aesthetics, etc.

C.1.2 Resources and Activities

Each of the projects has a socio-economic cell which would form the main resource. The exact use and direction of this resource can only be determined in close communication with the cell itself to ensure that the commitments of on-going work are allowed for. The coordination of this resource is best done by the engineer responsible for the IRP programme.

The initial work will be largely assessing the quality of the existing information. The country reports Chapters 4, 5 and 6 contain summaries of this as do various references mentioned in the reference section. This valuable body of information should not be ignored as it contains much of the material needed to make decisions.

Many of the objectives listed under Point C.1.1 have subjective answers and amounts in some instances to matters of policy. After a detailed quality check on the existing data and discussions within the project, formalized policy decisions on some of these issues will have to be made and justified on the basis of existing data. A second professional opinion, possibly by those involved in the remote coordination, should be sought before this stage of the work is considered complete.

It is envisaged that the socio-economic cell would organize the activities (e.g. data collection and processing, etc.) to fit in with their particular techniques and methods. The following list of activities is an example of the work that needs to be done:

1. Collect and assess all existing data.

2. Draw preliminary conclusions, if any, with reference to existing project policy.

3. Discussion within project on suitability and strength of these conclusions.

4. Submit to second opinion the preliminary conclusions thought suitable with their sociological justification.

5. Prepare programme for collection of remaining data required.

6. Collect data.

7. Process data and formulate new conclusions.

8. Use these conclusions to assist the other features of the monitoring and development programme.

Steps 5-7 should be kept to a minimum and emphasis is given to better assessment of existing data and knowledge. This work should result in a confirmation and clarification of the existing policy and possibly alteration to it. The future success of the plants will significantly depend on these policy decisions being appropriate to the prevailing conditions.

C.1.3 Monitoring of Progress

It is acknowledged that the achievements of the objectives (Point C.1.1) will be difficult. A monitoring of the progress can be done in the first instance by the coordinating IRP engineer and in the second instance by remote coordination.

The monitoring of progress in the achievements of the objectives of C.1.1 can take the following practical steps:

1. A brief factual report outlining preliminary conclusions and their justification based on existing knowledge (cf. Points 1, 2 and 3, under Point C.1.2) should be made.

2. A second opinion on these findings.

3. A brief plan of action and the methodology of the sociological investigation into the remaining factors to be found should be made.

4. Review of this plan of action.

5. Review of final conclusions with a quality check on the data and its applicability.

C.1.4 Assumptions and Uncertainties

1. Timing. The information resulting from this work is required relatively early on in the programme. Speedy completion of the programme will depend quite heavily on the effectiveness of this element.

2. The uncertainties of sociological data as listed under Point B.4, Nos. 1, 2.

3. The existing sociological requirements will not necessarily satisfy future demands. Some consideration should be given on how or whether to allow for this in the formulation of criteria.

4. The normal sociological data uncertainties should be made explicit. Any particular assumptions or uncertainties with past or present data should be underlined. Safeguards such as testing for extreme responses should be made.

5. Some indication of the sociological sensitivity of the criteria should be given. For example, if the effluent quality drops by 1 mg/l, how will this affect immediate and future usage.

C.2 Evaluation of Existing Units

C.2.1 The Objectives

To Investigate:

1. To what extent detailed evidence is available to support the actual performance of the previously identified units. This evidence should be able to withstand scientific scrutiny before it is considered final. This evidence should answer the following points; if it does not, then tests will be needed to obtain the information.

To Determine:

2. The filter run length meeting the quality and discharge criteria. This should be measured in terms of volume of treated water rather than on an arbitrary time basis.

3. The filter media rejuvenation period. Measured as above. This period should be determined for the method of maintenance recommended by the designers.

4. The head loss and discharge reduction with volume of treated water.

5. The effectiveness of the routine cleaning method and the filter media rejuvenation both in terms of restoration of discharge capacity (i.e. head loss), effluent quality improvement and quantity of iron actually removed.

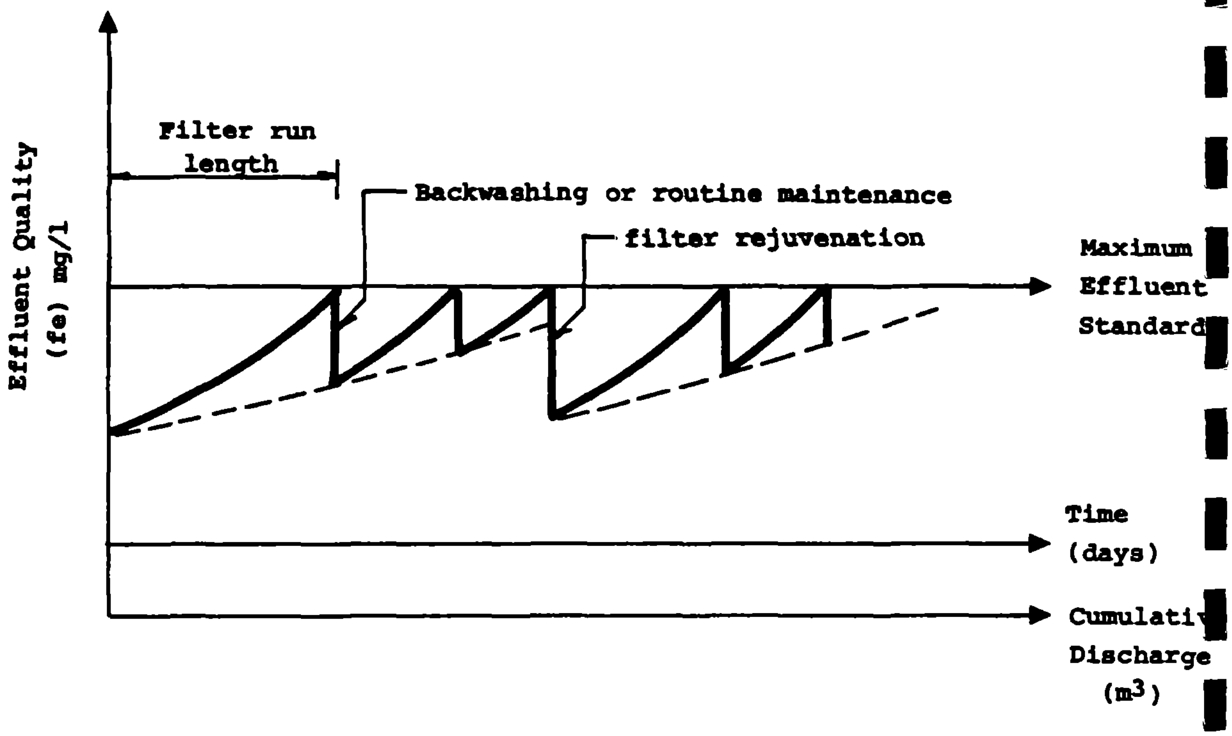
6. The efficiency of various stages of iron removal process. That is the aeration, sedimentation, and the various filtration stages.

7. The protection against micro-biological contamination.

C.2.2 Resources and Activities

If it is shown, as expected, that there is not enough evidence to support the performance claims of the units, then an intensive testing programme will be required.

The Mission suggests that trial units are set up at some convenient centralized location. The number of units is given for each case in Point C.3.2. Groundwater should then be mechanically pumped to simulate a maximum daily hand pump usage of 5-10m3/d as appropriate for each location. From these tests, filter performance curves should be plotted. A typical example is given in Fig. 2.1 overleaf. These curves are only intended as a guide, and a more convenient or useful representation may be developed.



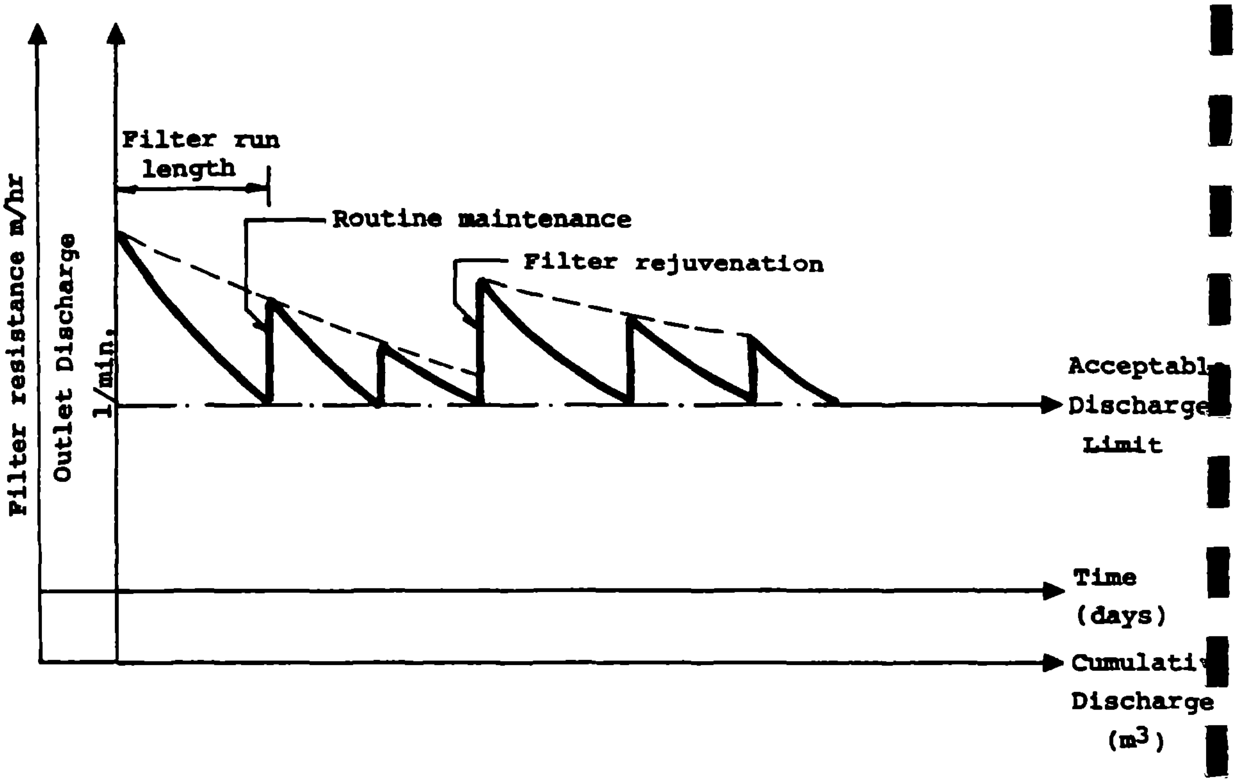


FIG 2.1 FILTER PERFORMANCE CURVES

Once the criteria mentioned under Point C.1.1 have been established, the full data can be plotted. The frequency of media rejuvenation required to maintain effluent quality and discharge standards, whilst ensuring that the minimum filter run interval is maintained, can be calculated.

If the quantity of iron being removed from the filter by the routine maintenance is estimated by sampling the flush water, an accounting balance can be kept of the cummulative quantity of iron being stored in the filter. This will also act as an additional measure of the efficiency of the maintenance system. This will not be an easy task, and the complication may well lead to a more subjective approach of inspection of the media to determine maintenance efficiency.

A separation of effluent ferrous and ferric iron during water quality testing will show whether the major problem is oxidation or filtration. If the efficiencies of various stages of the process, e.g. aeration, sedimentation and the various stages of filtration, are determined in addition, it is likely that this will lead to early design improvements.

Standard fecael coliform tests should be carried out at intervals and particularly before and after maintenance to establish the degree of protection from such contamination. Units that are prone to contamination may well invalidate all the intended health benefits of a borehole. Because the tests at this stage are not carried out in field conditions the results cannot be treated as being fully applicable to operating conditions; however, they may well point to important areas of contamination.

A determination of the filter media rejuvenation period is likely to be very time consuming if the test is designed to simulate village operating conditions. Because the processes of iron removal are of a bio-chemical as well as of physical nature, the flow rates are important. However, it might prove useful to accelerate one of the units under examination to provide earlier information on filter media rejuvenation periods. The results, however, must be interpreted in the light of the artificial testing conditions and cannot act as a substitute for proper longer term tests.

The resources for this work will be project based and led by the engineer responsible for the iron removal plants. It is important to acknowledge that this work will demand knowledge in many different areas: filtration, microbiology, chemistry, etc. It cannot be assumed that either the engineer involved or the project itself is self-sufficient in this knowledge and access to specialist advice or knowledge should be available if the most efficient path is to be taken (Point B.3, No. 2).

Considerable mobilization resources will be necessary to quickly establish a testing centre and it is expected that assistance from the maintenance cell will be essential in setting up the site.

The proper recording of results will be essential and an important responsibility of the IRP engineer.

The separation of activities is as follows:

1. Examine existing evidence about performance of plant.
2. Select appropriate site and build units.
3. Coordinate maintenance and water testing departments.
4. Test units as C.2.1 Nos. 1 to 7.

C.2.3 Monitoring of Progress

In addition to providing technical and specialist support as and when required, help in procuring hardware such as flow meters, testing equipment, etc., could speed up the operation. The monitoring process will identify these needs and assistance can be given by the remote coordination.

All the unit evaluation tests carried out should be rigorously recorded as indicated under Point C.2.2. In addition to a continuous self-monitoring, the following practical steps can be taken.

1. A review of all collected experimental and field data justifying performance claims of the unit.

2. A review of methodology of testing arrangements.

3. Analysis of results of the unit evaluation tests carried out under Point C.2.2.

4. On-going assistance in determining the type of development work required to upgrade units to meet design criteria.

5. Comparison of results from different units and countries.

The final indicators of success will be the accurate and scientifically justified determination of the objectives as listed under Point C.2.1. As intermediary indicators of the level of progress, the following could be used:

1. Date on which the site is located.

2. Date on which the units are set up and testing begins.

3. Date on which the routine maintenance interval of the unit is determined.

4. Date on which filter media rejuvenation is determined.

C.2.4 Assumptions and Uncertainties

1. The controlled tests are necessary to ensure accurate and unambiguous results. The tests are not field trials and are performed under idealized conditions. The results will indicate the potential of the units and allowance will have to be made later for inefficiencies due to field operation.

2. The testing of the existing units and the further development of the units should be kept separate. If new ideas on how to improve the unit arise during the testing stage, these should be developed separately whilst the original tests continue.

3. If it becomes evident early on in the evaluation of the existing units that the units stand no chance of coming close to the required criteria, then the effort should be directed to the development part of the programme.

4. The considerations of sociological data and requirements as detailed under B.4, Nos. 3 and 4.

C.3 Development

C.3.1 The Objectives

1. Final design of any remaining detail defects of units as listed in Sections 5.2.2 (C) and 6.6.3.

2. Improvement of unit to enable the design criteria to be achieved. The following parameters will need to be optimized:

. aeration	- depth and size of aeration chips
	- degree of exposure to air
. sedimentation	- size of sedimentation chamber
. filtration	- area of filter, i.e. flow rate
	- depth of filter
	- filter media: size grading and uniformity
	- number of chambers
	- upward or downward flow
. prevention of bacteriological contamination	
. maintenance	- method of maintenance
	- simplicity
	- burden/time taken
. social interact.	- acceptability of plant
	- convenience to use
	- aesthetics
	- obstruction to village space

These developments should lead to a unit that satisfies the criteria:

- length of routine cleaning and filter rejuvenation period
- quality of effluent
- discharge capacity
- simplicity of maintenance
- free from risk of bacteriological contamination

3. Development of methods of construction or construction control to ensure:

   - dimensional accuracy of units
   - integrity of unit, i.e. no leaks, etc.
   - durability

4. The development of new units. If the advantages of these units are thought to outweigh the disadvantages of a later start to development and the possibility of non uniform adoption.

C.3.2 Resources and Activities

Objective (1)

This will require a detailed design input and can be started immediately.

Objective (2)

This requires a detailed and thorough approach to yield results. The findings under Point C.2 are expected to play a useful role in indicating the features that need improvement.

The filter performance curves of Fig. 2.1 will show if it is the effluent quality or the head loss/discharge which is the governing factor. The tests on the various processes of removal will indicate whether alterations in the aeration, sedimentation or filtration processes are most likely to yield substantial improvements. The development of a reliable method of maintenance is considered particularly important, cf. comments on Bangladesh unit page 5.21.

Objective (3)

This should be done in conjunction with the design of detail defects. In its later stage it may involve the training of contractors or village craftsmen if a self-help approach is adopted.

Objective (4)

The Mission believes that a form of horizontal filtration could prove to be very effective. Removable and easily cleaned filter straining mats have proved quite successful for certain rural water filtering applications in Africa and these might be usefully investigated in this context. However, the development of such new ideas would be a strain on the limited resources available, particularly in respect of time, and considerable dependence would need to be made on development taking place in such applications on other projects.

The separation of activities is as follows:

Bangladesh and Orissa

1. Re-design of detail defects

Bangladesh

2. Test larger units with greater sedimentation chamber, say ½ hour, i.e. at 15 l/min., approx. 0.5 m3 volume. Try larger filtration chambers to achieve a decrease inflow rate from approx. 2.5 m3/m2/hr to 1.5 m3/m2/hr, i.e. increase the area of each chamber by a factor of approx. 1.6.

3. Test effect of variation of media size. In particular determine which chamber tends to cause greater blocking - probably the second chamber - in which case it would be advantageous to increase the size of the media in that chamber to ensure a more even retention of iron. Choose media to prevent carry-over of deposits from one chamber to the next.

4. Try using a hose attached to the pump to direct a jet of water onto the media for cleaning purposes and any other possible maintenance improvements.

Orissa, India

2. Test a shallower depth of media and therefore a larger sedimentation chamber.

3. Test the effect of coarser media.

4. Use methods of raking and agitation to improve effectiveness of routine maintenance.

For Both Bangladesh and Orissa

5. Bacteriological pollution prevention.

6. Introduction techniques.

7. Development of quality control procedures.

8. Experimentation with alternative units.

In addition to the activities of C.2 which require a minimum of one test plant, these activities will require as a minimum:

- 1 plant to re-design defects
- 1 plant to test larger filter areas in the case of Bangladesh, or less depth of medium in Orissa
- 1 plant to test the effect of different media and maintenance methods.

A total of four plants is therefore needed.

The main resource will be the engineer in charge of the IRP's. Close coordination with the maintenance and water testing cells will be necessary. Depending on the degree of development required, quite a large hardware component will need to be allowed for an estimating of the resources required.

C.3.3 Monitoring of Progress

This set of objectives will need to be more closely monitored than those under Points C.1 or C.2. This is because of the complexity of the work and the open ended nature of development.

In addition to internal monitoring, external monitoring can, on review of progress reports, take the following steps:

1. Coordinated results from different countries and university research.

2. Ensure that the planned development has a clear direction and is the most logical approach.

3. Respond to any technical difficulties that need to be resolved.

4. Ensure that the planned development is in line with the sociological aspects of the project.

5. Advise on new ideas and solutions.

C.3.4 Assumptions and Uncertainties

1. Development of the unit will be done under controlled conditions. Under field conditions the results might be quite different. This will be properly tested as described under Point C.4, but some consideration should be given to the development stage, particularly to the sensitive points below:

   - The method of maintenance developed e.g. if agitation is recommended.
   - Measures for the prevention of contamination.

2. It may become apparent during development that very much longer term development would be needed to successfully achieve the objectives. In this case, a policy decision will be needed to adjust the criteria in line with the sensitivity findings under Point C.1.4 (5). If this cannot be done, a longer term will have to be accepted.

C.4 Field Testing

C.4.1 The Objectives

1. To test the intended maintenance method for IRP. Both for routine cleaning and filter media rejuvenation.

2. To determine the level of contamination, if any.

3. To determine the degree to which field operation and maintenance compromise the performance of the unit. This will allow some safety margin to be built into the design of the units so that the performance is always above the criteria set.

4. To determine the effectiveness of various methods of plant introduction.

C.4.2 Resources and Activities

1. Set up the intended maintenance system at a selected location.

2. Install several IRP's under the standard siting policy.

3. Monitor the performance of the units. It is important that the biased evaluation which commonly results from interfering in the field maintenance is not made.

Field testing is time consuming and it may be decided that a very promising unit should be adopted in advance of the field testing. If this is done, it is important that the field testing is nevertheless carried out, since alterations to the method of maintenance arising from these trials can always be applied to the units already installed.

The engineer supervising the IRP programme will have to call on close cooperation of the maintenance cell to analyze and carry out the field trials.

C.4.3 Monitoring of Progress

As in other parts of the programme, an internal monitoring process is very important. External monitoring can usefully comment on and confirm findings that will be presented in progress reports.

Unless the development has been perfect, the field trials are likely to result in further difficulties that need to be solved. These need to be identified and dealt with as quickly as possibly. A close and sensitive monitoring of the trials will increase the likelihood that such difficulties are detected early on.

C.4.4 Assumptions and Uncertainties

1. The possibility of the monitoring exercise interfering with proper field trials should always be safeguarded against.

2. Although efforts can and should be made to find as representative a site as possible, not all villages are the same, so a difference of results can be expected between villages.

3. The problems of pilot maintenance scheme and stage of development, cf. Point B.4, Nos. 5 and 7.

D SUMMARY OF TIMING, INPUTS AND COSTS

D.1 Timing

An outline work programme is given in Table 2.1. This programme should be expanded, by the IRP Engineer responsible, to take more detailed account of local conditions, constraints that arise and any short cuts that can be made. It is recommended that a continuous revision and updating of the programme is carried out to facilitate monitoring of progress.

D.2 Inputs

Manpower

The main input is the IRP Engineer who will need local technical assistance during the key periods of testing and development. In addition socio-economic and maintenance inputs should be called on as and when required.

The Mission would recommend that the IRP Engineer is devoted exclusively to this task, and that he has at least one full time assistant. Local skilled and unskilled labour may also be required from time to time, cf. input programme Table 2.1.

Materials

The main materials demand will be the construction of a minimum of four plants at a central and convenient location. Miscellaneous equipment such as flowmeters, tools, etc. will also be required. It is recommended that transport is available to enable efficient completion of the work.

D.3 Costs

This will clearly depend on the duration and success of the scheme and the particular rates and prices in each country.

Detailed costs can only be evaluated after the exact nature of the programme is established.

TABLE 2.1: MONITORING AND DEVELOPMENT PROGRAMME OUTLINE

ACTIVITY (REFERENCES CORRESPOND TO TEXT)	1986										1987		
	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
MOBILIZATION	—												
ESTABLISHMENT OF CRITERIA													
C.1.2. (1) COLLECT EXISTING DATA		—											
(2-4) ASSESS DATA		—	—										
(5-7) COLLECT REMAINING DATA			- -	- -	- -								
C.1.3. MONITORING INPUTS			—	- -	- -	- -							
EVALUATION OF EXISTING UNITS													
C.2.2. (1) EXAMINE EVIDENCE ON EXISTING UNITS		—											
(2) SELECT SITE & BUILD TEST UNITS		—	—	—									
(3) COORDINATE WORK PROGRAMME		—	—	—									
(4) CARRY OUT UNIT EVALUATION		—	—	—	—	—	—						
C.2.3. MONITORING INPUTS		—		—	—		—						
DEVELOPMENT													
C.3.2. (1) REDESIGN OF DETAIL DEFECTS		—	—										
(2-4) BANGLADESH SPECIFIC TESTS		—	—	—	—	—							
(2-4) ORISSA SPECIFIC TESTS		—	—	—	—	—							
(5) PREVENTIONS OF POLLUTION		—	—			—	—	—					
(6) INTRODUCTION TECHNIQUES		—	—	—	—	—	—	—	—	—	—		
(7) QUALITY CONTROL			—	—	—	—	—						
(8) ALTERNATIVE UNITS			—	—	—	—	—	—	—				
C.3.3. MONITORING INPUTS			—	—		—	—						
FIELD TESTING													
C.4.2. (1) SET UP MAINTENANCE SYSTEM			—	—	—	—							
(2) INSTALL IRPS						—	—	—	—	—	—		
(3) MONITOR PERFORMANCE						—	—	—	—	—	—		
C.4.3. MONITORING INPUTS							—	—		—	—		
EVALUATION												—	—

3 / BACKGROUND INFORMATION

3 BACKGROUND INFORMATION

3.1 LITERATURE SEARCH

An on-line computer search was conducted on four of the most extensive data bases in the water engineering fields: Aqualine, Water Resources, Water Net and Engineering Index. Relevant background articles and references were obtained and studied.

A visit was made to the headquarters of I. Krüger A/S in Copenhagen to discuss their recently developed proto-type system of iron removal and details of test results on the unit were received and reviewed.

An extensive further array of reports and studies were also consulted during the field trip. Discussions were held with personnel involved in iron removal plant development and operation, and general information on the topic was thus further supplemented.

3.2 THE PROBLEM

3.2.1 Introduction

WHO standards for potable water quality state that a level of 0.3 mg/l is the highest desirable level and that 1.0 mg/l is the maximum permissible level. There are no direct health risks associated with the iron content levels usually found in groundwater, and the body appears to require between 5 and 6 mg of iron per day. It should, however, be noted that iron bearing waters, particularly from shallow wells or reservoirs, can be carriers of micro-organisms, e.g. Crenothrix, which apart from clogging well screens and other equipment can have a detrimental health impact.

Iron in water becomes objectionable because of its taste, clogging in taps, pipes and staining on clothes and stickyness in the hair. This clearly has an effect on the users' acceptance of the water. Badly affected supplies can have the effect of forcing the users to abandon an otherwise good and perfectly safe supply for a heavily contaminated and unsafe one.

Practically all groundwater contains some iron, usually at a level below 5 mg/l, but concentrations up to and above 15 mg/l are not uncommon. High concentrations of iron are associated with deep well waters from shale, sandstone and other rocks. The iron is dissolved by groundwater containing carbon dioxide but not oxygen; the insoluble oxides being reduced to soluble bicarbonates. These same reactions can occur in the lower portions of deep lakes and reservoirs.

It may well be for reasons of simplicity and because of the constraints imposed by rural conditions that WHO standards will have to be compromized to achieve workable units and alternative criteria for acceptable iron levels are discussed in later sections of the report.

3.2.2 Chemistry of Iron Bearing Water

The chemistry of iron in water is quite complex. Two kinds of iron ion commonly occur. One type is the ferrous ion (Fe^{2+}) and the other is the ferric ion (Fe^{3+}). Iron in the ferrous state is colourless, highly soluble and unstable in air. When iron in the ferrous state is exposed to air it changes to the reddish coloured, insoluble ferric state. It is this reaction which causes the problem of iron in water because the ferric iron (commonly known as rust) is precipitated out and onto clothing, valves and pipelines.

Iron is commonly found as ferrous bicarbonate in groundwater which has been devoid of oxygen but containing carbon dioxide. The following reactions take place:

$$2\ Fe_2O_3 = 4\ FeO + O_2$$

Insoluble ferric oxide is reduced to ferrous oxide.

$$FeO + 2H_2CO_3 = FeH_2(CO_3)_2 + H_2O$$

Ferrous oxide is dissolved by carbon dioxide containing water.

The soluble bicarbonate is then oxidized to form ferric hydroxide.

$2FeH_2(CO_3)_2 + ½O_2 + H_2O = 2\ Fe(OH)_3 + 4\ CO_2$

The above reactions being typical ones although the actual equations will depend on the exact nature of the iron compounds and the particular method of oxidation. A full description of the kinetics of oxygenation and the potential pH diagram which indicates in what regions of the water chemistry certain forms of iron are stable or predominant is given in standard texts such as Ref. G.11.

The chemical characteristics of the water and the varying nature of the iron compounds can complicate the removal of iron. Ferrous bicarbonate, for example, is very successfully precipitated by aeration alone as long as the pH of the water is 7 or above. If the pH of the water is below this and is later used with soap for washing clothes, the higher pH caused by the soap will precipitate the remaining iron and stain the clothes.

If the iron is combined with e.g. manganese or organic matter, it is more difficult to remove and may require a catalytic oxidation action or a pH adjustment of the water to bring the iron levels to within WHO standard.

Biological activity, for example supported by humic acid, has been found to interfere with iron removal by creating reducing conditions in a slime layer at the surface or in the filter medium itself. These reducing conditions can lead to re-absorption of precipitated iron into the water and the consequent reduction in removal efficiency (Ref. G.17).

3.3 THE SOLUTIONS

There are three basic methods of iron removal: a) ion exchange; b) chlorination-filtration; c) aeration-filtration. Several highly specific methods, such as the Vyredo method which involves the in-ground treatment of the water by pumping compressed air into the aquifer, have also been used.

3.3.1 Ion Exchange

Ion exchange as a method is unlikely to provide the simple village level of operation and maintenance required by most rural water supplies, and is most suitable for water with an iron concentration below 5 mg/l.

3.3.2 Chlorination-Filtration

Chlorination-filtration involves the oxidation of the iron from the ferrous state to the ferric state by chlorine ($FeCl_2 + Cl = FeCl_3$). Chlorine solution can be fed into the water in much the same way as is done in conventional units and the ferric precipitate and dead iron bacteria are then filtered out by gravel beds.

Chlorination is the only really effective means of eliminating groundwater bacteria and has the advantage of disinfecting the water supply and providing bacteriologically safe water. If the iron content is well above the 20 mg/l level, chlorination-filtration is usually considered the most effective and dependable method. However, the need for a constant supply of chemicals and the extra operational complications would normally preclude it from consideration for use in rural communities.

3.3.3 Oxidation-Filtration

Oxidation-filtration is probably the most suitable method for rural situations. Simple iron removal plants of the oxidation-filtration type generally involve a spray or slotted screen type aeration followed by a succession of gravel beds which serve to filter out the iron precipitate.

A sedimentation chamber is sometimes used between aeration and filtration to trap some of the iron and thereby reduce the loading on the filter. For effective sedimentation, a retention time of at least 1 to 2 hours is required, which for hand pump units would mean a chamber of at least 1 to 2 m^3 in size.

Aeration and Oxidation

The oxidation is achieved either by aeration alone or in combination with catalytic contact bed action. The method is chosen depending on the degree of iron removal required and the chemical characteristics of the water and iron compounds.

Aeration alone is particularly suitable for water with a pH of 7 or above and with iron free of organic matter and without a significant presence of manganese.

As relatively little oxygen is required to oxidize the iron (only 0.14 ppm oxygen is needed to oxidize 1.0 ppm iron), convenient and enclosed units can be used. Spray and slotted screen type aerators are commonly incorporated into such units. Further aeration takes place if the water is allowed to trickle down gravel filtration beds designed to retain and filter out the iron precipitate. It has been suggested that aeration should be reduced in degree with water having a high content of organic matter (Ref. G.6).

The purpose of contact beds is to facilitate the oxidation of iron through the catalytic action of previously precipitated oxides on the gravel or specialized filter medium. The conditions for this process occur automatically as the iron precipitate is filtered out and coats the gravel.

To speed up the oxidation of the incoming iron or manganese, chemicals such as potassium permagnate are often used to coat the gravel. These types of beds have the advantage over non chemically regenerative filters in that backwashing and the removal of accumulated iron deposits is considerably easier. However, the extra complication and provision of chemicals precludes them from rural community use.

Many non chemically regenerative filter materials require very vigorous backwashing to "shake" the iron deposits loose from the filter material.

Iron Bacteria

It has become increasingly clear in recent literature researches that the chemical and biological processes of iron removal are not as separate as once imagined. Iron bacteria are present in almost all groundwater that contains iron. They can be defined as "that group of corrosive bacteria which appear to utilize the oxidation of ferrous and/or manganese ions as an essential component of their metabolic functioning" (Ref. G.7). The resultant production of ferric salts (usually hydroxides) within the cell or cell coatings give the bacteria their typical brown colouring. It has been shown that iron bacteria have the potential to oxidize and filter out iron in groundwater.

As a result of full-scale tests on bacteriological removal of iron described in Ref. G.16, it was found that iron bacteria could oxidize as much as 17 mg/l of iron at flow rates of 10m3/m2/h, and the upper limit has not yet been assessed. The oxidation is influenced by the oxidation-reduction potential of the water and the flow rates. In a downward flow filter it was found that large improvements in the iron level takes place initially in the first portion of the bed. As deposits grow in the top layers, the flow rates, i.e. the pore-water movement, exceeds the bacterial capacity for consumption and the process moves into lower portions of the bed.

No published evidence was found on the use of bacteriological iron removal methods specifically for rural water supplies. However, there is no reason why the same process should not occur in rural units and it is very likely that biochemical processes are present in such units. The main consideration for rural systems would be the effect on the method of maintenance, i.e. the degree to which the iron deposits of this nature can be easily removed.

Filtration

Filtration is a very complex process in which the following factors have been identified as acting in combination: 1) straining; 2) flocculation; 3) sedimentation; 4) inert compaction; 5) diffusion; 6)Brownian movement; 7) Van de Walls forces; 8) electro-kinetic effects; 9) bio-chemical action. There is general agreement that the understanding of the process of filtration is at present too incomplete to permit prediction of filter performance without prior testing. In the case of iron, the temperature and chemical nature of the water, the size and strength of the iron flocs and the particular type of filter media readily available on site makes in situ, controlled pilot testing essential.

Nevertheless, detailed knowledge of the principles of filtration can indicate the boundaries of a solution and help reduce the quantity of tests required. The major parameters that need to be determined are: The direction of flow; the size and grading of media; the depth of bed; the flow rates or area of filter. The choice of these parameters should be such as to satisfy the following requirements:

- The quality of effluent during the filter run should not fall below the design criteria adopted.

- The head loss or reduction in discharge should not rise beyond the design limit, e.g. the level at which users start to reject the supply because of the delay or effort required.

- A filter run interval satisfying the above constraints should also be appropriate to the maintenance system adopted.

- The long term filter media rejuvenation should not impose undue constraints on the maintenance system.

Iron removal units can operate with either upward or downward flow systems. The advantages and disadvantages being very similar to the considerations made for simple rapid gravity filters.

Backwash is the flow of water through the filter media in the upward direction, i.e. against gravity. Downflow is the rapid movement of water down through the media in the direction of gravity. The top and bottom levels of media refer to their relative height above ground, i.e. the top bed is above the lower bed.

When the filter material is backwashed by conventional and vigorous means, the finer particles tend to settle at the top and the coarser particles at the lower portion of the bed. This means that if the flow is downward, a considerable amount of iron will be retained by the top portion, causing early clogging and non-utilization of the full potential of the bed. Upward flow, however, can make use of depth filtration since the coarser material is encountered first. This problem is overcome in sophisticated units by using dual media filtration such that the smaller particles are of a denser material and settle near the bottom. In this case, downward flow can make use of depth filtration. It is important then, in the context of rural iron removal, to note that upward flow filtration is a means that has been developed to achieve the depth filtration effect when the loss of this effect in downflow is caused by the unfavourable re-arrangement of filter media following vigorous upward backwash. This type of backwash, causing the fluidization, expansion and re-arrangement of media is very effective in cleaning the filter but is not available for rural installation because of the head required. Conventional comparison between upward and downward flow becomes less valid in the rural context because of the very different cleaning methods available.

The cleaning method available to rural units unable to generate sufficient head is a rapid down flush of water under gravity combined with agitation of some sort if necessary. This will be the case both for upward and downflow filters. Unfortunately, very little experimental evidence is available to comment on the efficiency of either flow direction under these conditions.

A recent study at the Technical University of Denmark (Ref. I.9) suggests that for upward flow systems, down flush is not sufficient, and that agitation is required to achieve a workable filter run. It is very likely that the same is true for downward flow filters (Ref. Fig. 5.6, 5.7, 5.8). If this is the case, the feature that is most likely to effect the operational and performance capabilities of an iron removal plant is not so much the direction of flow but the depth of media. The deeper the bed, the more inaccessible the regions of iron encrusted media and the less efficient an agitation process will be. A two stage filtration which effectively splits the depth of the filter will allow greater access to the media and is likely with all other parameters being equal (i.e. media sizes, total depth, iron, flow rates, etc.) to perform as well but be much easier to maintain than the equivalent single stage filter whatever the flow direction. The only physical difference is a reduction of the height but an increase in the area taken up by the unit.

Because upward flow works against gravity, it can suffer from the problem of partial fluidization of the finer filter material when the head loss increases. Previously retained deposits can then be released with the filter water and break through can occur. Even a small head of water can have this effect by lifting surface coatings of iron off the media and into the pore water.

Filtration rates for iron removal plants vary tremendously depending on the performance level required, the level of sophistication applied, the filter parameters, the nature of the water and the strength and size of the iron flocs. Filter rates cannot be theoretically predicted, only pilot studies can indicate the filter rates to be adopted in differing conditions. The pilot studies for rural plants are very limited and flow rates of between 1 m3/m2/h and 50 m3/m2/h are actually used or suggested under widely differing units and locations. Apart from an M.Sc. report (Ref. I.8), very little work has been done as regards organized research of pilot systems. Even in this report, the tests conducted were too short to yield valuable development information.

3.3.4 Plant Developments

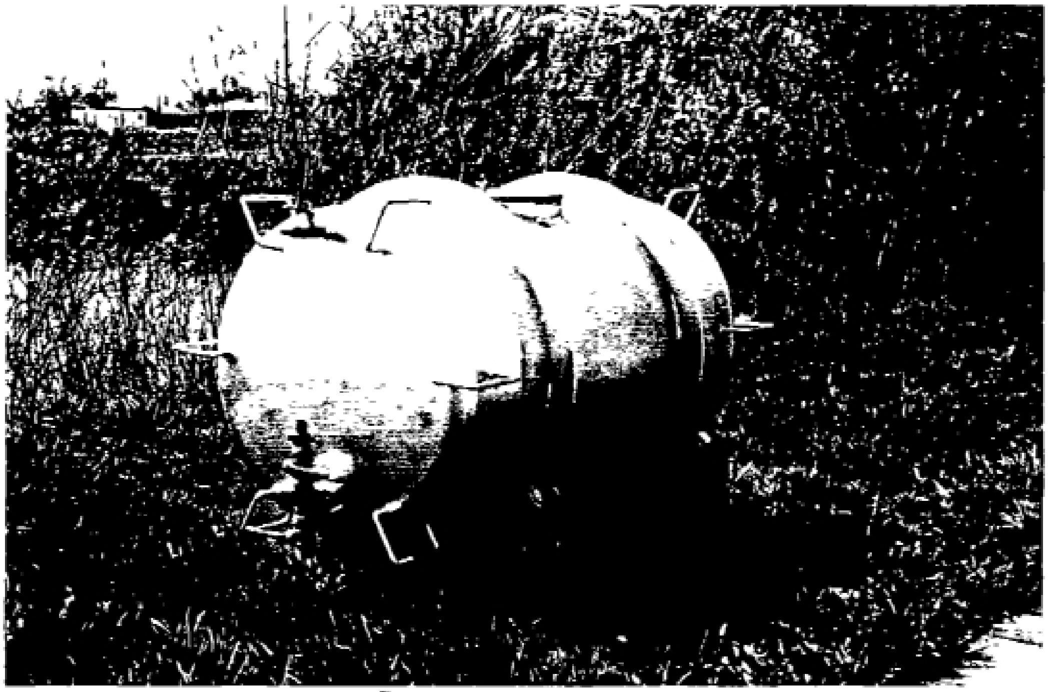
The state of the art literature review has revealed that very little successful work has been achieved on rural means of iron removal. The units described in Refs. G.2-G.5 are outdated and represent a very primitive stage of development. The units encountered during the Mission's field visits certainly represent a much more advanced state of development in this field.

All units developed for rural application have depended on aeration, filtration techniques. Early models generally depended on removal and cleaning of filter media, either in bulk or as a top layer, for rejuvenation. The development as in the Danida Mark II and Mark III models in India, where a cleaning system involving water pumped through the unit is incorporated, is a relatively new concept in iron removal plants.

A further development of the concept of an iron removal plant suitable for rural conditions, and incorporating an integral media washing system, has recently been tested in both laboratory and full scale trials by I. Krüger A/S in Denmark. This unit is illustrated in Fig. 3.1

The filter unit is designed to operate at a hand pump capacity of 0.8-1.2 m^3/h. The proto-type is constructed in steel and is 600 mm diameter by 1,000 mm long. The unit is approximately half filled with filter media and flow is downward through the tank, and outlet water is collected via a perforated pipe under the media. The unit is thus operating as a filter with a surface area of approximately 0.6 m^2 and a surface loading of 1.3-2 $m^3/m^2/h$.

When cleaning is required, the filter is disconnected from the inlet and outlet pipes and rotated on the bearings shown, thus agitating the filter media and releasing the trapped iron particles into suspension. After several rotations, the "dirty water" in the filter is discharged to waste, the filter is refilled and the cleaning operation is repeated. Three or four such washes have been shown to remove 85 to 95% of the theoretically retained iron deposit. Thus an effective washing procedure is obtained without removing media or entering the unit which has consequently both hygienic, and minimizing of effort, benefits.



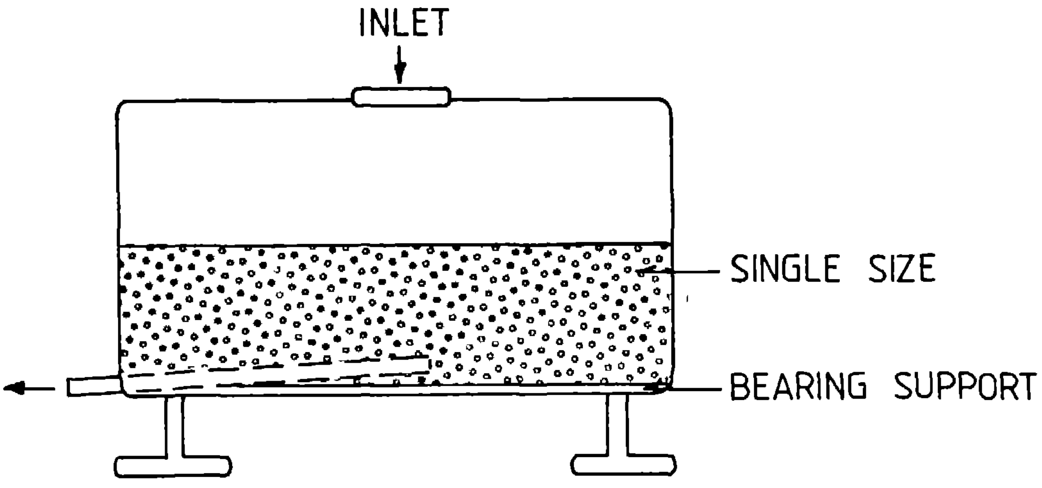


FIG 31 PROTOTYPE IRON REMOVAL PLANT RECENTLY DEVELOPED IN DENMARK (PATENT APPLIED FOR)

The principle on which the filter operates requires use of a single size media to ensure similar gradation throughout all conditions. Various trials have been carried out with differing size media and it has been found that a media of 0.4-0.8 mm size results in good effluent quality and filter runs. Effluent quality of 0.01-0.05 mg/l was obtained from a raw water level of 3.5-8 mg/l. Filter runs of up to 300 m^3, or 30 days equivalent hand pump supply, have been found to be possible before filtrate quality starts to deteriorate. After this length of filter run, the head loss through the unit was recorded as 0.1 bar.

The unit as inspected by the Mission was connected to an existing public water supply treatment plant in which cascade aeration was included. Some type of aeration unit would need to be connected to the filter unit to provide a complete treatment system for iron removal.

4 / SRI LANKA

4 SRI LANKA

4.1 INTRODUCTION

The Mission arrived in Sri Lanka on the 22nd October and departed on the 27th October. After a briefing on the Rural Water Supply and Sanitation Programme in Matale and Polonnaruwa Districts by the Danida Representative in Colombo, the Mission travelled to the Danida Project area.

Discussions took place with the Project Manager, Head of Drilling Programme, Hydrogeologists, Chemist, Sociologist and the Maintenance and Training Advisor. A field visit was made to Elahera Division of Polonnaruwa District where the occurrence of formation iron has been recorded to be the greatest. A pilot UNICEF iron removal plant, which had been installed for 3 weeks, was inspected.

During the visit to the Danida project area a meeting was held with representatives of Plancentre Consulting Engineers, who were supervising a similar project under Finnish aid. A field visit was also made to the Finnida Project in Harispattuwa Electorate of Kandy District where several iron removal plants, which had been in operation for up to 3 years, were inspected.

At the conclusion of the field visits and discussions in Kandy area, wrap up meetings took place with the Project Manager, Head of Drilling Programme and Sociologist to discuss the Mission's findings and its preliminary conclusions.

Meetings were held in Colombo with representatives of UNICEF, GTZ and the National Water Supply and Drainage Board (NWSDB). Other types of experience with iron removal technology in Sri Lanka were thus compared. A field visit to the UNICEF Project in the Kalutara District was also made where several iron removal plants have been installed since August 1985.

4.2 ASSESSMENT OF THE SITUATION IN SRI LANKA

4.2.1 General

The mission considers it important that the identification of the iron level in the borehole water is clearly distinguished as originating from either formation or corrosion. It is obviously inappropriate to consider the installation of iron removal plants in cases where the iron taste is developing from the corrosion of pump and pipe materials.

4.2.2 Assessment of Formation Iron and Removal

On the Danida project in Matale and Polonnaruwa Districts, the degree of iron from formation is of a relatively minor order.

If it is assumed that a maximum of 20 iron removal plants would be necessary this involves a total borehole investment of SR 800,000. The degree of investigation into iron removal plants at these boreholes must therefore be relative to this scale of problem. The level of economic investigation will thus be low.

Experiments on iron removal plants to date in Sri Lanka have resulted in only the UNICEF Mark III Model and the latest Finnida Project Model being, in the opinion of the Mission, worthy of further consideration for large scale implementation. The small number of IRPs required on the Danida Project do not justify consideration of any units other than those that have already been established in Sri Lanka.

The UNICEF iron removal plant has been developed to quite a high standard of both design and quality in its final format. However, the Mission believes that several features of its operation and maintenance will result in problems unless a very well prepared and organized operation and maintenance programme is established. The problems are identified as:

. Difficulties in flushing clean of gravel layers.

. Problem of mixing of layers when removed for rejuvenation.

- Lifting and carrying over of surface deposited iron hydroxides when pumping.

- Problems of break through of the media when layers have been mixed or when the filter becomes clogged resulting in rise of iron content of the filtrate.

The Mission believes that an alternative iron removal unit should be field tested on the project. The Finnida Project's recent development (cf. Fig. 4.9) is the most suitable choice. The solution of type of iron removal plant to be installed will be very dependent on the maintenance system which is adopted on the project. A plant involving infrequent but probably more sophisticated maintenance and cleaning procedure would be appropriate for a centrally maintained system, while a simpler but possibly more frequent procedure would be necessary for village caretaker level type maintenance.

Although both the UNICEF and Finnida IRPs appear to be promising from circumstantial evidence available, the Mission is not convinced that either unit is adequately proven.

No convincing data yet exists to confirm their performance in respect of the following problems:

- the filter run lengths quoted are dependent on time and not quantity of iron, which is the important factor,

- filter rejuvenation is not adequately determined,

- field testing of units under eventual operational conditions has not been made because of project staff inputs during monitoring,

- an appropriate maintenance system is not yet identified,

- no study has been carried out on the sociological acceptance of the units in the Sri Lanka context.

Therefore the Mission believes that before a decision is made as to which unit should be implemented on the Danida Project, the following action should be taken:

a) Investigate to what extent detailed evidence is available to support the claimed performance of both units.

b) If this evidence is not available then testing will have to be carried out on the existing units to establish their suitability in respect of the problems listed above.

c) If as a consequence of these tests the units are shown to require further development before they can be confidently adopted, a more detailed and extensive testing programme will have to be undertaken. At this stage careful consideration will need to be given to the cost-effectiveness of such development.

4.2.3 Assessment of Aggressive Water Problem

The problem of aggressive water is extensive on the Danida Project. The fact that in the order of 75% of the project boreholes will be effected and a satisfactory solution has not yet been reached when the programme is at a stage of almost 50% completion, must be a cause for concern.

The greatest immediate problem is considered by the project staff to be caused by the corrosion of the riser main due to the significantly lesser area of the pumping rods and the higher corrosion resistance of the pump parts.

The Mission believes that G.I. riser main pipes of the quality so far received should not be installed in aggressive water. This would only lead to rejection of the borehole by users and have a substantial negative impact on the health education campaign. The consequence is that until a satisfactory solution is found pumps should only be installed in non aggressive boreholes.

The three alternative solutions for riser main are 1) PVC, 2) stainless steel, 3) high quality G.I. and some salient points are compared in the Table below:

FACTORS	RISER MAIN MATERIAL: PVC (high quality imported)	STEEL	G.I. (high quality)
Corrosion resistance:	Inert material	Inert material	Subject to long term corrosion
Maintenance:	Light weight very easy to maintain, more difficult with cement joints	Heavy, more difficult to maintain	Heavy, more difficult to maintain
Accidental damage protection:	Good, but can be broken during transport	Very good	Poor, could lead to reduction in corrosion resistance
Mechanical performance:	Very poor in existing stage of development	Very good	Very good
Time before large scale adoption possible:	Depends on development success certainly > 6 months and not likely to be less than 1 year	< 1 month	< 1 month
Cost/m	US$ 5.5[1]	US$ 11.0[1]	US$ 6.0[2]

1) Figures received from DANIDA project based on quotes f.o.b. Europe/ Japan
2) Figures received form FINNIDA project based on quotes f.o.b. Finland

Irrespective of G.I. material quality there is likely to be a future problem of corrosion to some degree and therefore a true corrosion free pump must be manufactured in inert material. The Mission therefore believes the choice in material is between PVC and stainless steel. A direct cost comparison per linear metre between the two is not valid.

Even if an immediate satisfactory PVC section is found, the fatigue considerations and field testing requirements are such that a considerable period of time would elapse before full scale implementation could take place. The cost of this delay to the hand pump installation programme must be taken into account when comparing the alternatives. Other factors such as the brittleness of the PVC in handling and the weight and inconvenience of steel must be balanced against the cost comparison.

The solution that should be adopted is obviously related to the pressure of the time programme of drilling. If pressures of time were not critical, further testing of PVC options could possibly prove the validity of one or other of the solutions now being considered or adaptions thereon. However, the Mission believes that the doubts as to the performance of PVC under dynamic loading and the consequent long term fatigue effects are such that it is not possible within the remaining project period to prove a PVC solution incorporating the standard Indian Mark II cylinder. The Mission feels that it is significant that to date on other world-wide researches including work by Ricardson and Crudas in India a PVC solution to the Indian Mark II pump has not yet been successfully developed.

The Mission believes consequently that the solution must be between the use of stainless steel riser pipe using the purchased cylinder assembly or PVC riser pipe equipped with a PVC cylinder to reduce the strain loading on the pipe. The UNICEF development in regard to the latter option is in the opinion of the Mission very promising, particularly in that it utilizes the Indian Mark II pump head assembly which has already, along with the cylinders, been pre-ordered for the entire project. It must be cautioned, however, that this solution has not been completely proven, particularly in regard to the wearing of the PVC pump cylinder. The additional cost of the stainless steel solution must be weighed against this uncertainty.

Whatever solution is chosen for the riser main it must be realized that the Indian Mark II pump is not a non corrosive pump and is not recommended for aggressive water. Even if the riser main is replaced by inert material, the pumping rod and pump cylinder corrosion may lead to severe problems. The Indian Mark II manufacturers are known to be working on a non-corrosive pump but it is believed that much further development is still required. It is doubtful whether the advantages of uniformity of pump type justifies the use of what is not a non-corrosive pump in aggressive waters.

It should also be noted that the weight of the India Mark II cylinder would adversely affect a PVC riser main solution. The UNICEF PVC adaption to the India Mark II has replaced the cylinder with PVC principally in response to this problem.

The Danida Project staff are energetically seeking and testing solutions to the problems presently being experienced with PVC and the Project Management is confident of an eventual solution. If it is finally decided that a PVC solution is preferable, more attention should be given to investigating PVC solutions adopted by pump manufacturers and others who have worked on the same problems, since solutions may have been developed more fully. For example the UNICEF solution and the alternative forms of plastic such as Acryionitrite, Butadiene and Styrene (ABS).

The resources of the present project are not designed to deal with such intensive development of alternative solutions and specialized assistance may be necessary.

4.3 NATIONAL WATER SUPPLY AND DRAINAGE BOARD (NWSDB) EXPERIENCE

4.3.1 Background

A programme of 32,000 wells is planned by the end of the decade in Sri Lanka, of which 13,000 have been completed to date. The programme has been supported by UNICEF, Danida, Sida, USAID, Finnida and others. Figure 4.1. shows the distribution of community water supply programme development throughout the country.

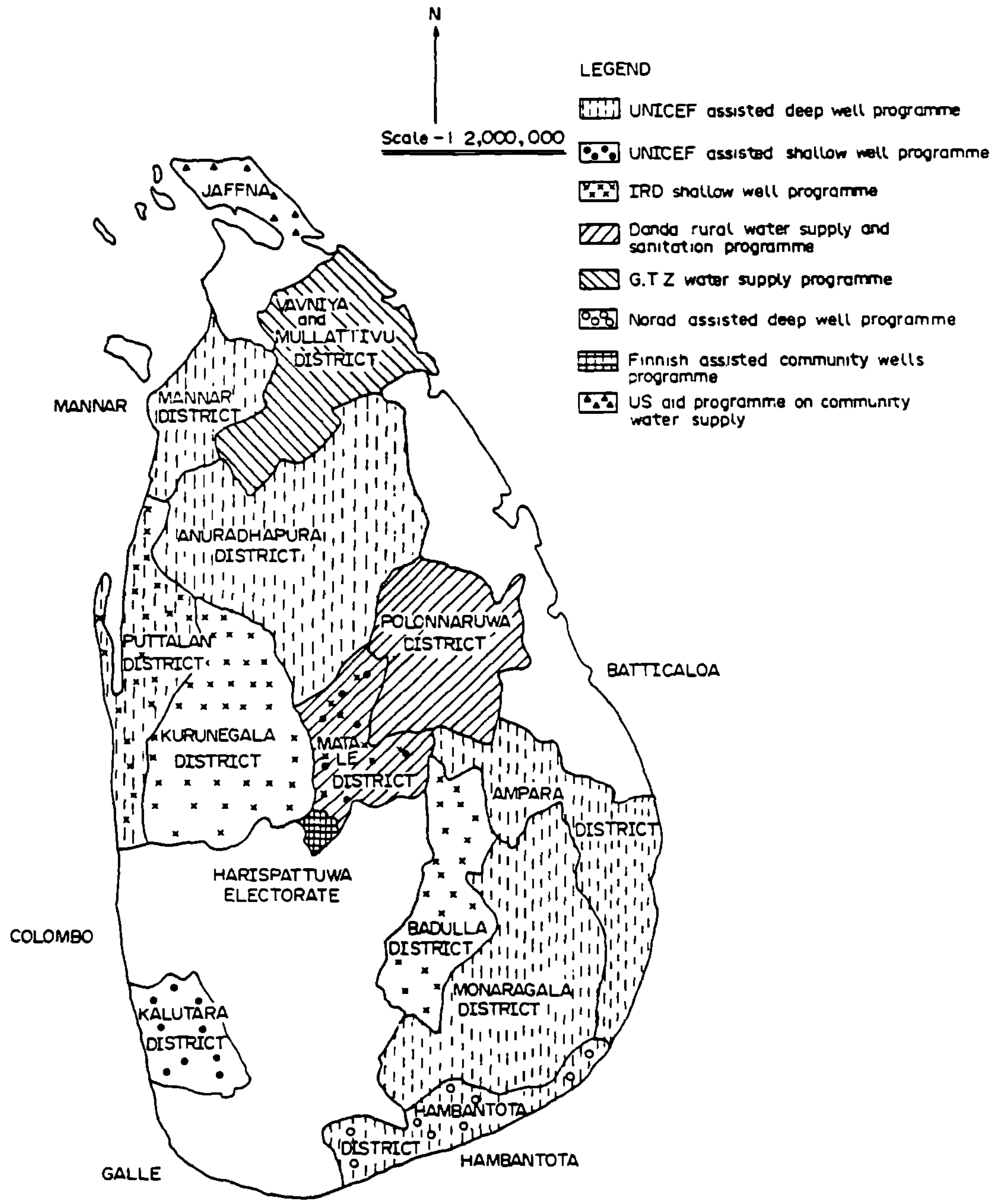


FIG 4.1 MAP OF SRI LANKA SHOWING DISTRIBUTION OF GROUNDWATER DEVELOPMENT UNDER COMMUNITY WATER SUPPLY PROGRAMMES.

4.3.2 Extent of the Iron Problem

The iron problem experienced in ground water throughout the country is fairly extensive as reported from individual projects. A trend of increasing iron levels over a period of time has been found on several projects throughout the country.

A survey carried out by the NWSDB in 5 districts and covering a sample of 319 wells indicated 30% rejection for drinking purposes due to iron content.

4.3.3 Iron Removal Solutions

The relevant elements of NWSDB policy since July 1985 are as follows:

- Install iron removal plants where formation iron of unacceptable levels are encountered.
- Where corrosive water is encountered, riser pipes should be replaced with PVC, and connecting rods should be stainless steel.
- The development of a completely non-corrosive pump unit should be encouraged.
- The maintenance of hand pumps and wells is to be transferred from the maintenance and operation section to the ground water section of NWSDB.

A concrete filtration unit which has been used by the NWSDB has not proven very effective.

A locally produced non-corrosive pump has already been developed by Jina Sema Limited of Colombo comprising a brass and stainless steel pump cylinder with neoprene rubber waster and PVC riser main. The manufacturer estimated costs are similar to the Indian Mark II pump. However, insufficient field tests have been carried out on this pump and varying opinions are held about its performance. An unusual feature in the use of a flanged PVC riser main length clamped with stainless steel bolts.

4.4 DANIDA PROJECT IN MATALE AND POLONNARUWA DISTRICTS

4.4.1 Background

The Rural Water Supply and Sanitation Programme in Matale and Polonnaruwa Districts, funded by Danida, commenced with a planning phase in 1981. As an integral part of the hydrogeological investigations, a pilot programme of 28 rock boreholes and 3 auger holes was completed.

The implementation phase of the project commenced in late 1984, and at an early stage the degree of necessity for iron removal was considered. A report was prepared in January 1985 (Ref. S.9) based on the chemical analysis of the water quality of pilot programme boreholes. In this report the geological formation iron was evaluated to be in excess of internationally acceptable limits in only a few cases. However, a relation between increasing iron and corrosive water was found which resulted in unacceptable levels in approximately 75% of the cases.

From an evaluation of this evidence it was concluded that a non-corrosive pump must be installed. And that this should be the case where the degree of corrosion was considered to result in a significant increase in iron content of the water and rapid deterioration of pump and pipe material.

As a result of this report on-going tests have been carried out on the suitability of non-corrosive PVC riser mains. These tests and trials have been carried out since January 1985 during which time over 500 boreholes have been drilled.

A project water quality laboratory equipped with a Hach spectrophotometer has been established in Kandy and is capable of detecting the relevant and important water quality parameters. A full time chemist is employed and the sampling, testing and recording procedures both in the field and in the laboratory appear to be methodical, comprehensive and reliable. A dependable water quality data base on which confident evaluation can be made has been established.

4.4.2 Extent of the Iron Problem

Initial Investigations

The chemical analysis of 31 pilot boreholes tested in 1981 and of 23 of these tested in 1984 are shown under (Ref. S.9).

	1981	1984	1984
TOTAL IRON MG/L	TEST RESULTS (% boreholes)	5 MINS. AFTER PUMPING COM-MENCED (% boreholes)	PROLONGED PUMP-ING TO OBTAIN STEADY CONDITION (% boreholes)
0 - 0.3	73	36	74
0.3 - 1.0	8	14	17
1.0 - 3.0	19	23	9
> 3.0		27	0

It was concluded that the increase in iron content associated with some 75% of the boreholes was due principally to aggressive water conditions (low pH and high CO_2 values). This caused corrosion of the riser pipe and pump unit. The iron content of only 15% of the boreholes originated from the formation.

The criteria for classification of aggressive water has been set at 6.3 to 6.7 pH with 6.3 to 6.5 being regarded as very corrosive and/or a CO_2 level of over 105 mg/l.

Subsequent Investigations

Further reports on the water quality analysis were made after the first 100, and 250 boreholes were drilled. These reports revealed the following results and suggested solutions:

IRON WATER QUALITY ORIGIN	FIRST 100 BOREHOLES (%)	FIRST 250 BOREHOLES (%)	SOLUTION
1. Formation	1	0.4	Treatment
2. Aggressive Water	62	72	Non-corrosive pump
3. Form + Aggressive Water	6	3.6	Non-corrosive + treatment
4. < 0.3 mg/l Fe + non Aggressive Water	31	24	Nil

At the time of the Mission's visit over 500 boreholes had been completed. Although the results had not been fully compiled it is expected that the results will vary by only a few per cent from the first 250 borehole results shown.

Conclusions

It is anticipated that the final results from the 1,200 boreholes to be drilled in the implementation programme would only vary slightly from the results now available. This is due to the hydrogeological nature of the overall project area and the representative coverage of the existing boreholes.

On this basis only 4 to 5 percent of these 1,200 boreholes, i.e. a total of 50 to 60 boreholes in categories 1 and 3, will need iron removal equipment. If the upper limit for acceptable water can be raised to 3 mg/l as discussed in 4.4.3 below, the requirement for iron removal plants would reduce to somewhere between 10 and 20 units, i.e. 1 to 2 percent. However, 75%, i.e. 900 boreholes in categories 2 and 3, will required non-corrosive pumping equipment due to aggressive water conditions.

Although the problem of geological formation iron will need to be solved in the few areas where it is present, the extent of this problem is negligible compared to that of aggressive water. It is in this latter area that the project has been concentrating its efforts since January 1985.

Consideration has been given by the Mission to the possibility of avoiding aggressive or iron bearing water by hydrogeological means. This could be done by tapping alternative acquifers or by modifying the well installation technique to exclude the sources of troublesome waters. However, comparatively little is known about the source of the iron or aggression. And because the aquifers are very discrete, irregular and complex it is unlikely that even detailed investigations would lead to practical solutions.

4.4.3 Sociological Aspects

<u>Siting Policy</u>

The siting of boreholes on the project is determined according to the criterion of a maximum of 250 m of walking distance. This results from local experience that has shown that distance and convenience are the over-ruling criteria in governing the user's selection of alternative sources.

It is recognized that the location of any new water supply will have to compete in convenience terms with the existing traditional source. Intercepting the path between the village and the traditional water source with the new installation is a technique that has been successfully used.

The location of the new source also needs to be sensitive to the particular community make up of the village. The siting of a borehole or iron removal plant on private land within a divided village could cause the virtual exclusion of sections of the village from the new supply. The success and level of user maintenance will be dependent on a variety of sociological factors concerning the position of the new borehole and iron removal plant.

Acceptance Levels

The siting and convenience of a new source relative to alternative water supplies has been found to influence the level of acceptability of iron. During the wet season or in areas where surface supplies are easily available, the level of tolerance to iron can fall to 1 mg/l. Where surface waters are not as easily available, the tolerance seems to rise to around 3 mg/l or even be beyond in extreme cases.

The level of acceptance has also been found to vary with the degree to which the users are familiar with groundwater. People who are unfamiliar with groundwater complain that it is "hard" tasting or "kivu". This in itself can cause the rejection of a borehole independent of the iron level.

In general it has been found that the users in the project area are very sensitive to even low iron levels in the water source, probably reflecting their familiarity with softer surface sources.

The taste of the iron appears to be the major factor in governing peoples' response to the borehole water in the project area and Sri Lanka in general. The effect of iron on cooking or laundry is not considered important by the people and this may be because of the relatively low amounts of iron in the water, i.e. usually less than 5 mg/l, compared to other countries visited.

It is significant that although there are cases of hyper sensitivity to the quality of the groundwater and the iron content in particular, the reasons behind the abandonment of a borehole are usually chemically justified.

A survey was made of 25 boreholes which had been abandoned by the end of August representing 7% of the 413 boreholes put into production by that date. It was found that the reasons stated by the users for the rejection corresponded in each case to actual quality of the water.

In most instances it has been found that an opinion on the quality of the borehole forms quickly within the user community, and this tends to be fairly consistently held. In cases where water quality is borderline it has been found that user evaluation of the acceptability of the source is often complicated by other considerations. This in general results only in complaint however and not in abandonment.

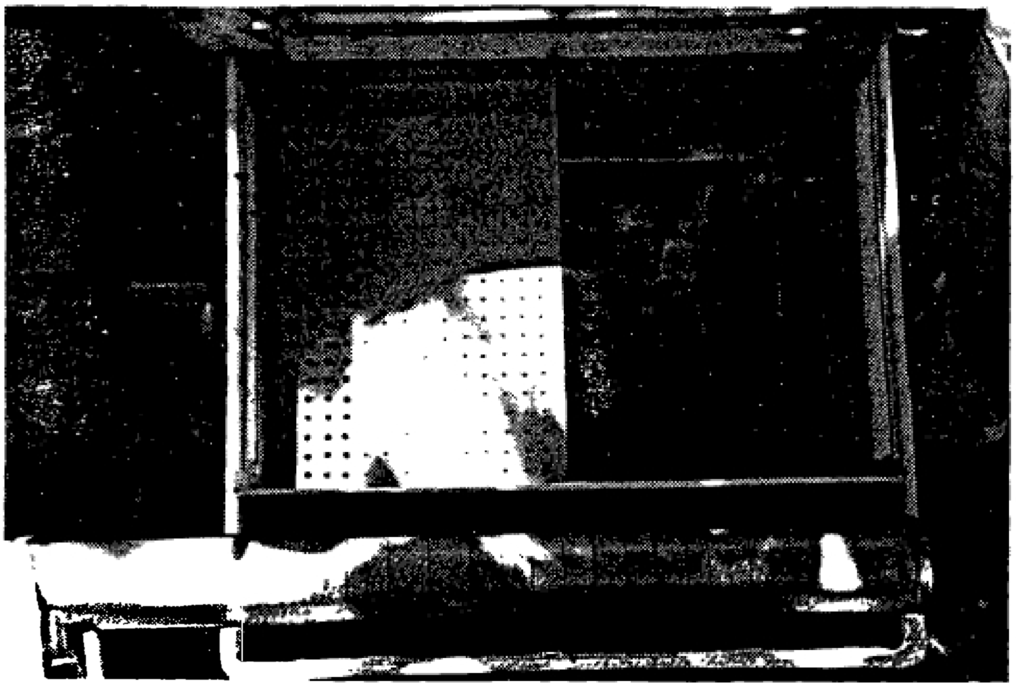
Health Education

It is currently considered by the project staff that a health education campaign must be mounted in order to inform users of the benefits of a borehole supply. This campaign would stress the positive benefits of iron content in order to raise the users' acceptability level. Several incorrect and strongly held beliefs such as the need to expose well water to sunlight even at the expense of contamination need to be changed. The ultraviolet rays will only disinfect the top few centimetres of the water which does not normally correspond with that portion of water withdrawn.

4.4.4 Iron Removal Solutions

Extent of Project Experience

The project staff consider that an iron removal plant should only be installed at those boreholes where users have abandoned the source; and it is proven that this is due to an excess of iron resulting from the formation. Since by this definition only some 15-20 boreholes are potentially affected at present, this does not present a problem of major importance. Only one iron removal unit has therefore been installed to date at borehole EL17 as shown in Figures 4.2-4.5. It has been operated on an experimental basis to gain experience with its operation and maintenance. In this way the potential for further installations and/or alterations or modifications can be evaluated.



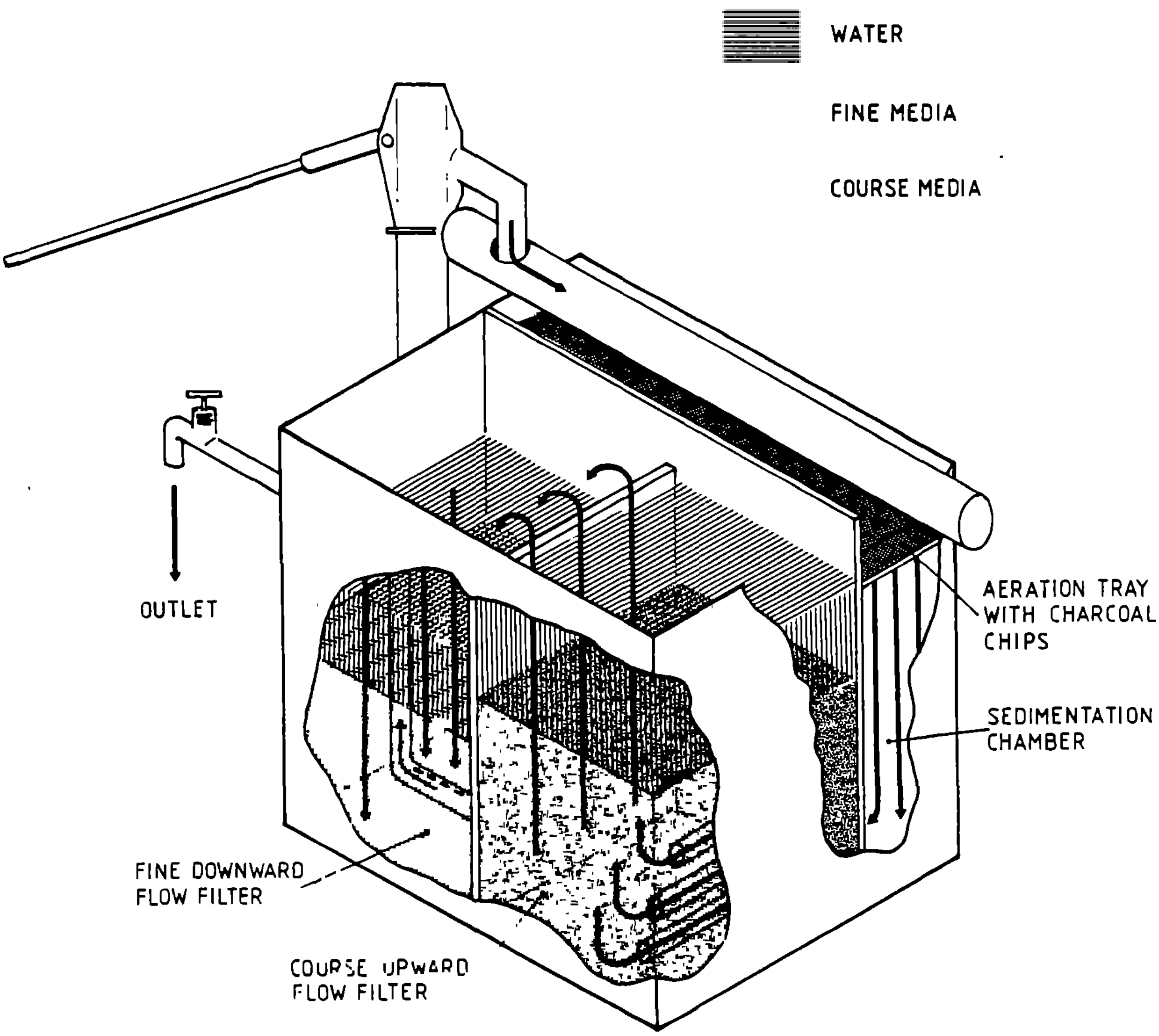


FIG.4.2 DIAGRAM OF UNICEF IRON REMOVAL PLANT

(DIMENSIONS AND FILTRATION PRINCIPLES SIMILAR FOR BOTH SRI LANKA AND BANGLADESH UNITS)

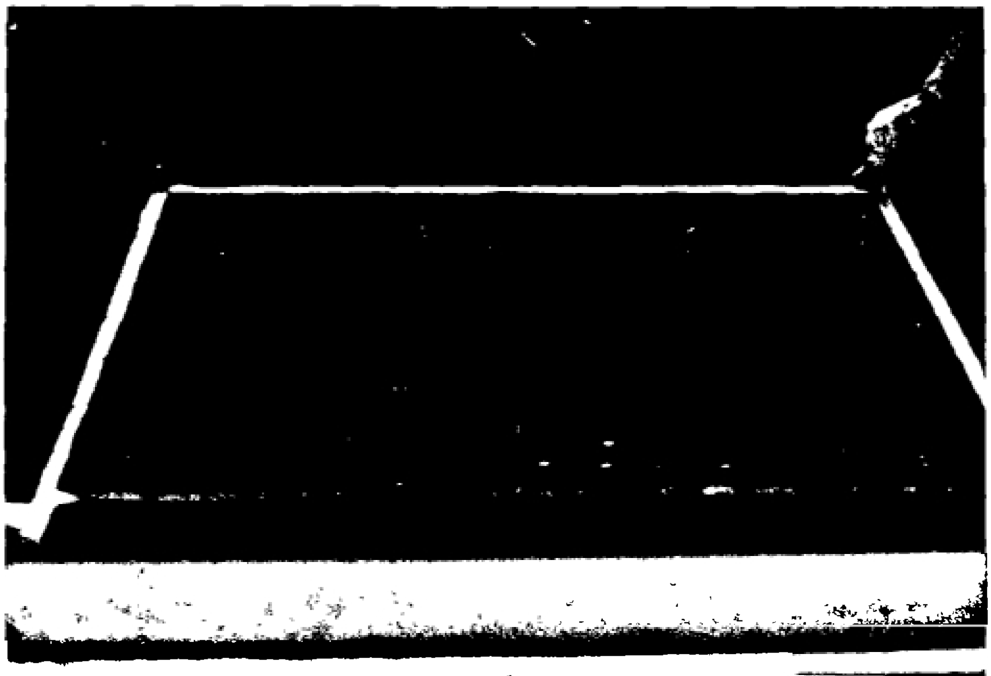


FIG 4.3 IRON REMOVAL PLANT AT BOREHOLE EL 17.

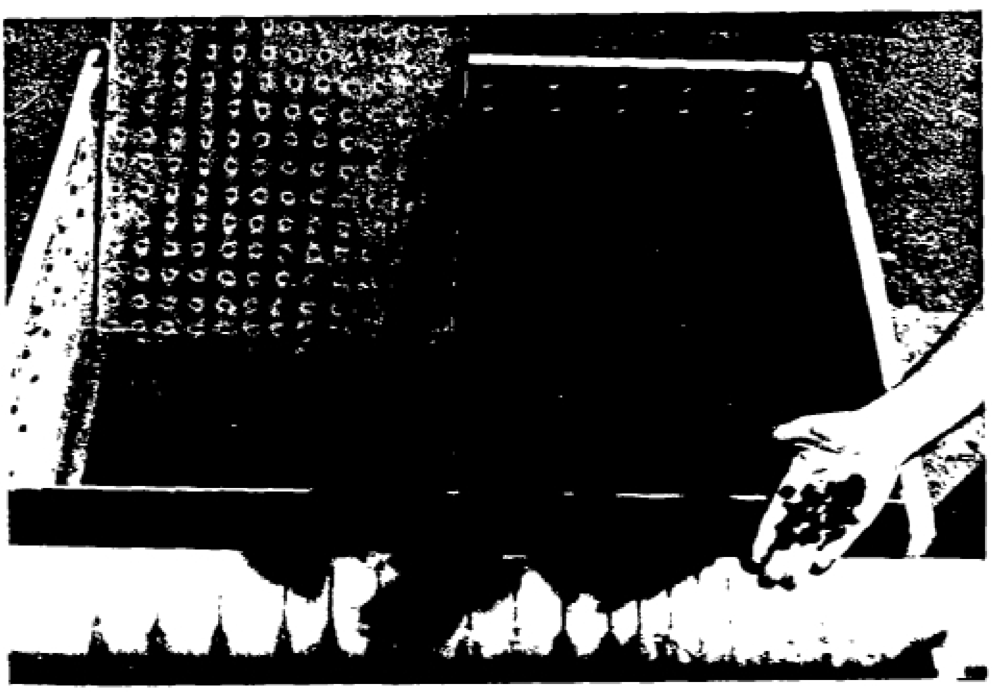


FIG 4.4 IRON REMOVAL PLANT IN PAHALANAVALA, KALATURA DISTRICT. NOTE HEAVY DEPOSIT OF IRON AND NON. UNIFORMITY OF FILTER MEDIA. TYPICAL CHARCOAL CHIPS FOR USE IN AERATOR CHAMBER SHOW IN THE FOREGROUND.

FIG 4.5 IRON REMOVAL PLANT AT GOVINNA, KALATURA DISTRICT LID REMOVED.

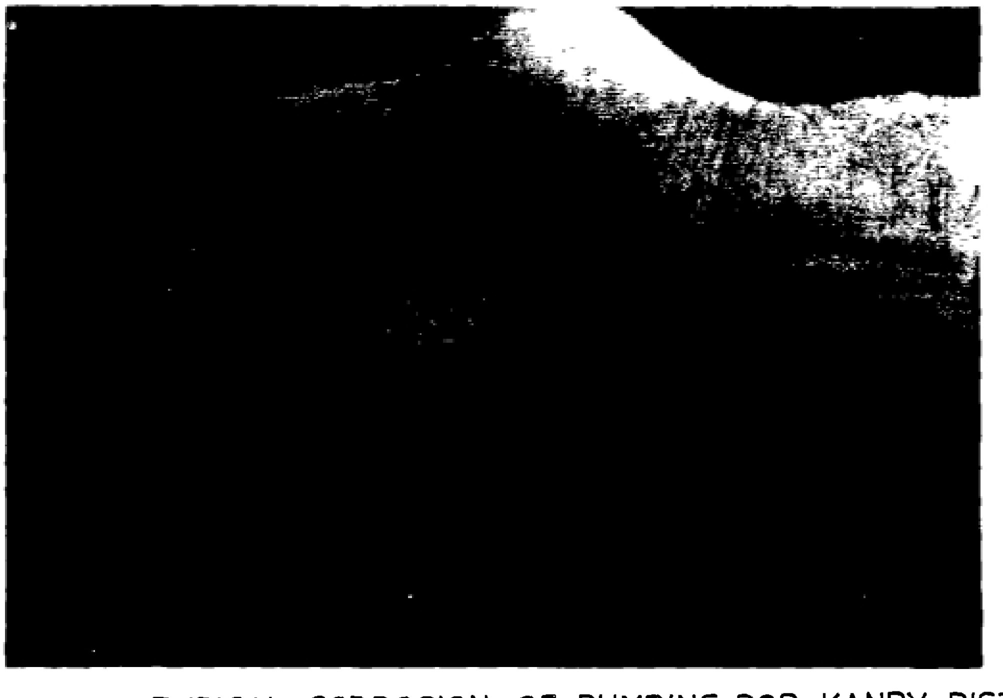


FIG 4.6 TYPICAL CORROSION OF PUMPING ROD, KANDY DISTRICT.

The Trial Unit

The unit, a UNICEF Glass Fibre Reinforced Plastic "Penthouse Mk1", is illustrated in Figure 4.2 and photographed in Figures 4.3-4.5. It has been installed for less than 2 months, and therefore the experience gained so far is not representative of what may be gained from a longer term trial. Opinion at present, however, is not very positive towards the unit. It was found to have certain construction defects and operational and maintenance problems. This unit, which was originally developed in Bangladesh, represents an earlier version of the latest UNICEF Model and many of the defects have now been improved upon. The iron removal plant is a self contained box with an aeration/sedimentation chamber leading to an upward flow, coarse filter which is then followed by a finer downward flow filter. A fuller description of this model is given in Section 4.6.4. It should also be noted that the original specification for filter material was found to lead to clogging. Various alternative filter media sizes are being experimented with but it is too early for firm conclusions.

When properly operated and maintained it was found that good iron removal was obtained (from 3-3.5 mg/l down to 0.28 mg/l), but that if not properly attended the iron level could actually be higher in the outlet water than inlet.

Experience to date has shown that the users have shown no interest in the operation and maintenance of the unit. It was considered by the project staff that centrally paid maintenance as employed for pump maintenance was not feasible in respect of the iron removal plants because of the frequency of attendance required. Neither was maintenance by the caretaker possible since under present circumstances at least his responsibility extended to only reporting and not actually performing any maintenance. The flushing down of the filter media for cleaning has not been found to be very effective and results in early replacement or rejuvenation of the media being necessary.

Although the iron removal tends to be high immediately after rejuvenation, the level of iron in the filtrate rises after some time.

A proper assessment of the mechanics of this situation is not possible without a distinction between the dissolved and precipitated iron being made at the test stage. A measurement of the total iron before and after filtration through a "millipore" type membrane using simple field equipment will enable this. The observed rise in total iron may be due either to a less effective oxidation of the dissolved iron with time or a decrease in the filtration efficiency. The solution used to overcome this problem will depend on which of the two possible effects is predominant. The testing procedures necessary to distinguish between the two types of iron are very straight forward and only a fine filtration device such as a standard Millipore membrane filtration equipment is required.

The plant costs some Sri Lankan Rupees (SR) 3,000 (approx. US$ 120) and can be installed on site by 3 to 4 men in half a day.

4.4.5 Aggressive Water Solutions

Effects

The problem with aggressive water on the project is extensive. At present it affects some 400 boreholes and eventually is expected to affect approximately 900.

The decision to incorporate non-corrosive pump materials in those boreholes experiencing aggressive water has proved difficult in several respects. The Indian Mark II pump components with the exception of the riser mains had already been pre-ordered for the project.

Some galvanized iron riser mains have subsequently been purchased from Sri Lankan agents importing from India. When the pump elements have been removed for inspection it was evident that severe corrosion of these riser mains and the original galvanized pump rods had taken place. The pump cylinders appeared to suffer less damage. The Mission inspected some of the removed equipment and typical corrosion of a pumping rod is shown in Figure 4.6.

Because the rising main had not yet been purchased and because they are the most easily interchangeable piece of equipment on the pump their replacement by an inert material was attempted. It has also been argued that since the riser mains present an area approximately 10 times larger than that of the pumping rod to the aggressive water, they were the main source of the increased iron. However, it is important to note that the quantity of corrosion is not necessarily linearly dependent on the area available to corrosion. Corrosion takes place as a result of corrosion cells which are set up at points of non uniform stress arising from cutting, cold work as well as other imperfection (Ref. G. 10). The particular manufacturing process of the Indian Mark II pump rod where large diameter rods are cut down to form slender rods would be prone to such defects. The rate of corrosion in such cases could be greatly increased and it was noted that the pump rods showed very deep pitting in comparison with the rising mains. For these reasons it may well be found that iron content continues at a high level even after the riser mains have been replaced by inert material. At best they will present a future maintenance problem.

PVC Trials

PVC was the natural choice of material for the replacement of riser mains. Unfortunately despite exhaustive testing over a period of some 6 months, a successful PVC riser main detail in conjunction with the Indian Mark II pump and cast iron cylinder unit has not been found.

The joint connection between the PVC pipe and the pump head is repeatedly broken. This is thought to be the result of an oscillatory horizontal movement combined with the change in vertical stress due to the action of the column of water in the rising main. The effect of fatigue and resonance also need to be resolved.

Initial tests with standard threaded PVC resulted in a 30% failure rate which reduced to 8% when centralizers were installed to lessen horizontal movement. Further tests on glass fibre reinforcement to the top joint and very recently on a heavy coupler jointed PVC have as yet been of too short a duration to establish their success or otherwise.

It should be noted that this problem is not new and that other manufacturers notably Consallen in Nigeria have experienced similar problems. Their solution involved cement jointed ABS plastic lengths that did not sacrifice cross sectional area as is usually the case with threaded joints. They also concluded that strengthening the top joint was not the solution and a flexible joint was necessary. A flexible joint solution is also currently being pursued by the Danida Project staff. However, it must be realized that the stress regime with an Indian Mark II pump might be significantly different from the Consallen pump.

Irrespective of the success of any new solution in the short term, there is concern over the long term fatigue resistance of the PVC pipe under dynamic loading conditions. For this purpose a simulation unit has been constructed to produce the equivalent of 10 years' utilization of the hand pump on a PVC pipe sample in a 2 week period.

An alternative provision of stainless steel riser pipes is at present considered too expensive a solution. The cost relationship of local G.I. to PVC to stainless steel based on a metre FOB India unit price of G.I. of US$ 2.2 of the order 1:2.5:5.

4.5 FINNIDA PROJECT IN HARISPATTUWA ELECTORATE, KANDY REGION

4.5.1 Background

The Finnida Project is being supervised by Plancentre Consulting Engineers and includes the construction of some 1,000 hand pump wells for 90,000 population in Harispattuwa Electorate. The project is of 4½ years' duration of which 1½ years remain. 900 wells have been completed to date of which 730 are hand dug shallow wells. The project also involves some piped water supply schemes from surface sources, upgrading of latrines, health education and an operation and maintenance programme in collaboration with the Water Board. A Finnish hand pump is used on the project, with a stainless steel pump rod and Finnish made galvanized iron riser pipe.

A well equipped and staffed laboratory unit is operated by the project. A comprehensive testing programme of wells and a subsequent monitoring programme has been carried out. With the 3 years' experience of implementation on this project, valuable long term data was available to the Mission.

4.5.2 Extent of the Iron Problem

In an analysis carried out in June 1985 of some 300 wells, it was found that 30% were between 0.3 and 1 mg/l and a further 22% were above 1 mg/l. A considerable degree of aggressive water was also encounted with 46% of wells having a pH between 6.5 and 6 and a further 11% less than 6. Despite this level and frequency of aggressive water, few problems of severe material corrosion have been experienced to date. This experience differs from that of the Danida Project, where the water is generally less aggressive, and could possibly be related to the stainless steel pumping rods and the higher quality of galvanized iron riser pipe being used. Plancentre confirmed that they had experienced poor corrosion resistance with Indian galvanized iron pipes on previous projects in Tanzania.

On analysis of the results of iron level over the 3 years' period of implementation, a distinct trend of rise in iron content has been noted by Plancentre from an average level below 0.5mg/l to an average level around 2 mg/l. It was not considered that sufficient evidence was currently available to establish the cause of this trend.

A common phenomena observed is a very high iron content in the first few litres of water that are pumped in the morning. This has been called the "morning user problem" and can cause sampling problems depending on whether or not the first few litres are pumped to waste. This effect has been observed in other countries and is not yet understood, it could be due to corrosion in cases where this is taking place.

4.5.3 Sociological Aspects

Generally, the acceptance level of iron in the water supply has been found to be 1 mg/l on this project. In a survey of 480 wells in October 1985, 14% of the wells were abandoned with 75% of these being abandoned due to the iron taste. In addition to abandonment, however, a large number of complaints were received regarding poor tasting water. In a survey in August of 289 wells, 30% were referred as having an "iron taste", and a further 11% having "not good taste". These categories represent over 70% of the total complaints.

The higher levels due to the morning user problem referred to earlier, can give rise to dissatisfaction and even rejection of an otherwise good quality borehole.

4.5.4 Iron Removal Solutions

The Iron Removal Plants

Two types of iron removal plants have been installed by Plancentre on the project to date. These are illustrated in Figures 4.7 to 4.9.

Both units are based on simple venturi assisted aeration followed by two stage filtration. The first filtration stage is a coarse upward flow filter and the second one a finer downward flow filter. The earlier model which has been installed since 1982 makes use of two separate concrete ring chambers for the filtration stages. The later model incorporates two chambers in a single concrete ring by using a sloping dividing wall.

The units and the later model in particular are designed to encourage iron bacteria growth which is thought to have a major influence on the iron removal. This is in sharp contrast to the thinking behind the UNICEF Model and others investigated by the Mission. The importance of iron bacteria in the iron removal process is supported in the technical literature (see Chapter 3). And it is likely that iron bacteria are forming part of the removal process in all units even where not designed for.

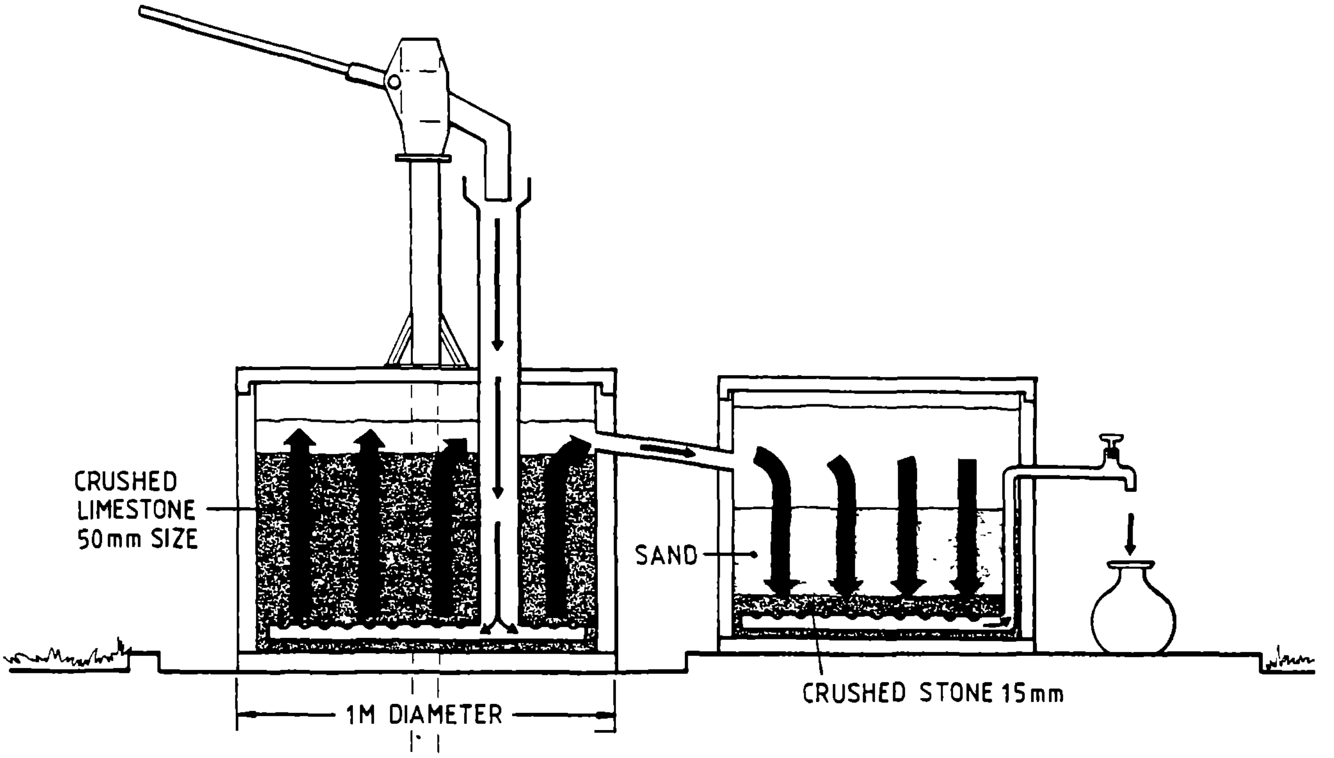


FIG 4.7 DIAGRAM OF EARLIER FINNISH IRON REMOVAL PLANT

FIG 4.8 EARLY FINNISH IRON REMOVAL PLANT

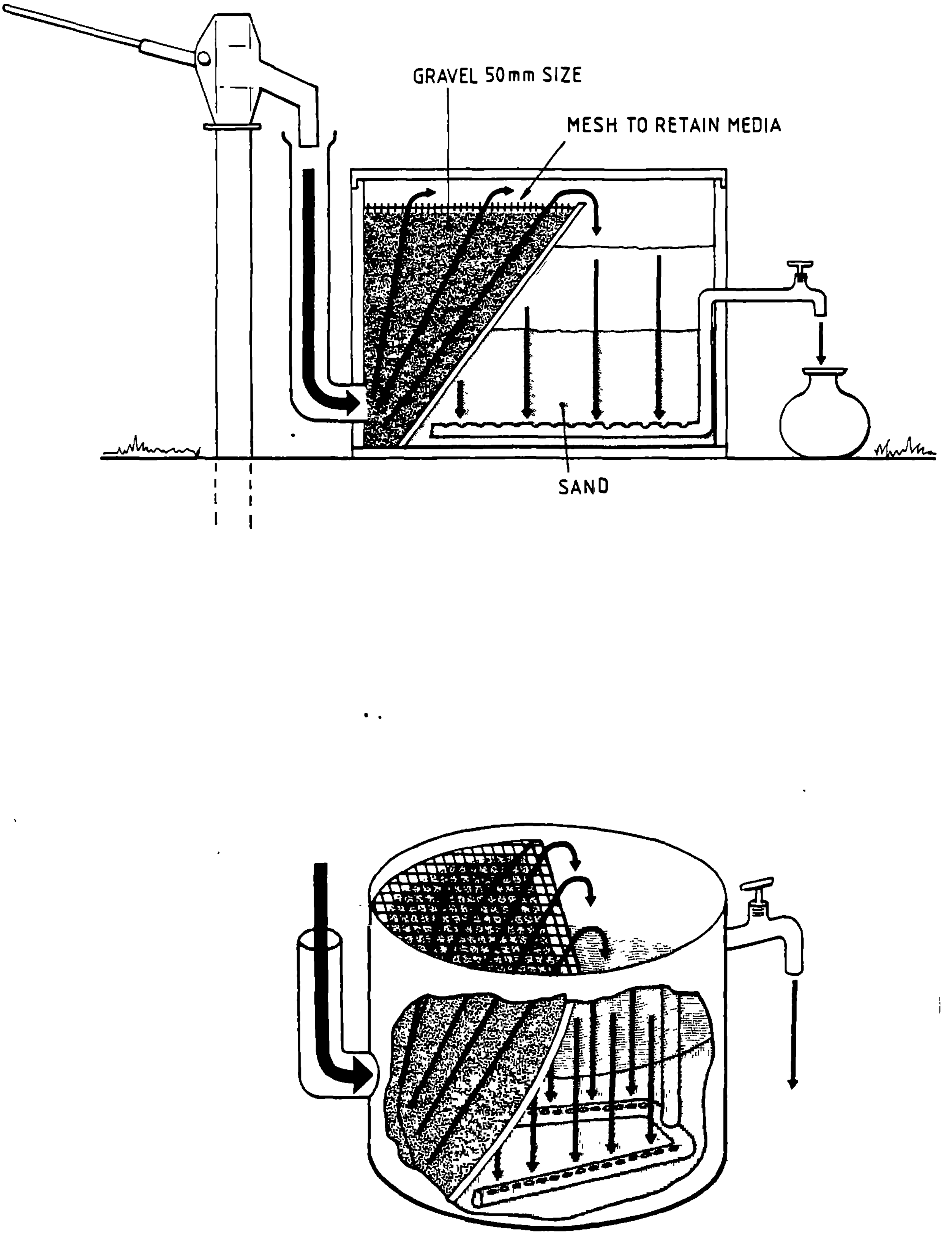


FIG 4.9 DIAGRAMS OF LATEST FINNISH
IRON REMOVAL PLANT

The difference with the later Finnish Model is that it makes use of the fact that the bacteria thrive in the presence of high iron levels. With a given concentration of iron in the raw water and a steady flow rate, the velocity of the water will determine the quantity of iron available to each unit area of bacteria. A varying flow velocity such as is set up in the upward flow chamber by the sloping dividing wall ensures than an optimum velocity is obtained. A thriving band of bacteria will be encouraged to grow in this region. The decreasing velocity of flow means that the bacteria are unlikely to be flushed away by high velocity. The position of the dividing wall also ensures that a maximum surface area is available for the downward flow filter. This filter makes use of the "shmutz decke" organic layer associated with slow sand filtration to achieve a high final quality. The performance of this unit has been good with iron reduction levels from around 3 to 5 mg/l down to 0.1 mg/l. The rate of filtration is calculated as approximately 10-15 m3/m2/day on the second filter based on a total loading of 7 m3/day. A further development of this unit envisaged on the Finnish project is the use of "floating pebbles" of cement covered polystyrene balls in the first chamber. These are expected to improve maintenance due to self cleaning abrasive action.

Experience to Date

Experience has been gained with 60 plants which have been installed on the project to date.

The filter run periods have in general been around 2 months, but this is dependent on the level of iron in the inflow water. In one case where a very high iron level of 30-40 mg/l was experienced in the raw water, a level of 7 mg/l only could be achieved in the final filtrate, and the water was not used by the villagers. Maintenance is carried out by a village level caretaker who scrapes off 2 cm of the fine sand, washes this and then replaces.

Some problems are experienced with the low discharge from the plant which is caused by the construction of the small outlet pipe and fitted tap unit. These problems have been solved by the use of a large outlet pipe without a tap.

The plants are pre-fabricated and delivered to site where installation is carried out by 2 men and takes 2 days. The cost of the later plant is SR 1,500-2,000.

4.5.5 Aggressive Water Solutions

To date on this project there has been no evidence to suggest that aggressive water is causing a similar degree of problem as that experienced on the Danida Project. This despite the fact that more aggressive water has been encountered on the former. It is postulated that the reason is the higher quality galvanized iron riser pipe, stainless steel pump rod and the higher quality Finnish produced pump. The cost of 2" diameter galvanized iron riser main from Finland is almost US$ 6 per metre f.o.b. Finland compared to US$ 2.2 for Indian pipe.

It is still uncertain what the long term corrosive effects of the degree of aggressiveness encountered on the project will be on even the higher quality products used. In this connection and in recognition of a general requirement, the same manufacturing company in Finland which produces the existing pump has developed a non-corrosive pump which has not yet been field tested.

4.6 UNICEF EXPERIENCE IN SRI LANKA

4.6.1 Background

UNICEF have been involved in the construction of some 2,500 to 3,000 tube-wells and shallow wells throughout Sri Lanka since 1979, including 200 in Matala and Polonnaruwa Districts. More recently a concentrated programme of tube-well construction in Kalutara District in the South-West of the country is being undertaken, and to date, 100 wells have been completed over a 5 months' period. The first Indian Mark II pump was installed on UNICEF tube-wells in Sri Lanka in 1980.

4.6.2 Extent of the Iron Problem

Iron levels up to 15 mg/l have been experienced in Kalutara District. Both iron from the formation and resulting from corrosion of iron equipment is experienced in Kalutara District. Initially, a false impression of the degree of iron levels was obtained due to testing methods, such as surface sampling from shallow wells and testing immediately after flushing of new drilled wells. These produced results showing a significantly lower iron content than was actually the case.

The problem of corrosion of pump materials in Sri Lanka has been recognized by UNICEF from early on in their programme; particularly with respect to the Indian Mark II pump.

4.6.3 Sociological Aspects

Of the 100 wells constructed in Kalutara District, around 75% have been rejected, the majority of which have been chemically justified. The level of acceptability in respect of iron has been found to depend on the area in question and availability of alternative sources.

As a guideline it has been found that 0-5 mg/l concentrations are accepted in dry areas, whereas 0-2.5 mg/l is the range for wet areas. As in the Danida Project it has been found that it is often the change in water quality rather than the absolute value which is the governing factor in the users' acceptability level.

4.6.4 Iron Removal Solutions

<u>Iron Removal Plant</u>

The degree of iron encountered on the UNICEF Project and the high rejection rate registered by users has necessitated the urgent development and installation of iron removal plants. The model, as described in Section 4.4.4, was developed from a design originating in Bangladesh. Around 50 to 60 of the original plants which were pre-fabricated fibre glass coated plywood versions of the Bangladesh model have been installed.

Since that time 3 further modifications have been produced in order to make the model lighter, improve flow rates and modify other design details. The design of the new unit is based on 3.5-5 $m^3/m^2/hour$ filter loading. Filtrate flow measurements on the earlier iron removal plants observed by the Mission showed a rate of 3 litres/minute compared to a hand pump delivery rate of 12-17 litres/minute. This would imply a filter loading of 0.9 $m^3/m^2/hour$. This supply rate is clearly inadequate and has resulted in many complaints from the users. The new units incorporate a much larger outlet pipe with no tap to improve the flow rate. The reduction of flow rate due to clogging of the filter would then be the governing factor.

The filter media is graded and the details are given in Reference S.1. The original specifications have been found to cause early clogging and have now been superseded. There is virtually no data on the relative performances of different media both in terms of removal rate and duration of filter run. The longer term need for cleaning or rejuvenating the filter media is similarly not known.

The existing plants have been reported to have filter runs of 45 days. At an average net iron removal rated of say 5mg/l and assuming 7 m^3/day being used from the unit this would result in a retention of 1.5 kg of iron per filter run. This level of retention is similar to that of other field plants. Satisfactory experimental and field data will need to be collected before it can be confirmed that this unit is adequate in terms of performance and maintenance. Such data would inevitable lead to yet further improvements or optimization of the unit.

Biological removal is not included in the design concept and is in fact discouraged due to belief that it results in more rapid blocking of the filter and introduces bacterial health related problems.

The cost of the iron removal plant is quoted on this project as SR 3,300 (approx. US$ 130).

Operation and Maintenance Experience

After installation of the iron removal plants it has been noted that utilization of the borehole water has increased. This is despite the fact that in some cases, significant iron reduction has not been obtained because of incorrect installation of the filter media. This is explained by UNICEF as due to the users' inherent belief in the virtues of a "safe" filtered water.

Maintenance of the iron removal plants is carried out by a caretaker selected by the community as part of the normal 3-tier UNICEF maintenance system. The caretaker is also responsible for health education which is still found to be necessary in areas where plentiful surface water source alternatives are available. A more extensive voluntary health education campaign is now being mobilized involving a Committee for Village Re-awakening in each village. This campaign will further encourage the move to greater utilization of well water.

4.6.5 Aggressive Water Solutions

UNICEF consider that the problems caused by aggressive water are only solvable by the use of a non-corrosive pump. They consider that the Indian Mark II pumps, including G.I. riser main equipment, have been adequately quality assured via a contract with the Crown Agents. And that therefore no further benefit from using an alternative source and quality of G.I. material is feasible.

The corrosion of pump rods on the UNICEF project has been found to be a greater problem than the riser main corrosion.

Tests have been carried out for 1½ years on development of a PVC replacement for the Indian Mark II pump. It is also believed that tests are being carried out in India on a PVC pump.

Similar experiences were originally encountered to those on the Danida Project with PVC pipe failure at the top of the riser main. This was solved in shallow wells by supporting the pump cylinder on the bottom of the well. It has been concluded, however, that for deeper wells, a complete corrosion free assembly including pump cylinder and rod must be used.

The prototype PVC pump consequently developed in Sri Lanka by UNICEF can be fitted to a simply modified Indian Mark II head assembly. The prototype has been field tested over a 256 day period by a community of 300 people using 15 litres per capita per day. The pump is set at 24 m depth and a PVC riser main with solvent cement joints is used.

Cemented PVC joints is a solution that has been adopted elsewhere in the world in response to the same problem. A disadvantage is that the riser main has to be lowered or raised in one length. Slippage of joints is a problem that needs careful glueing technique to avoid an individual aspect of the design is the use of a neoprene rubber ball in a reducer socket at the base of the pump cylinder which acts as foot valve.

Because the pump cylinder is an extension of the rising main, the piston and consequently the ball foot valve can be recovered without lifting up the rising main. When wear does occur on the sides of the cylinder due to the washers, an extension or reduction could be made to the pumping rod or rising main length respectively without needing to raise it to the surface. Such an extension would move the stroke of the piston to a different section of cylinder thus extending the life of the unit before major maintenance is required.

At the present stage of development and testing, the design looks very promising. The problem of wear on the pump cylinder caused by leather washers has been identified and a change to neoprene rubbers washers will be made.

On the basis of the existing field trials, UNICEF are proceeding to install 500 pump units to instigate large scale field testing. The costs of the PVC pump cylinder is almost one third of the cost of the conventional Indian Mark II cylinder assembly and the locally purchased PVC pipe is a similar cost to the Indian purchased G.I. pipe at SR 55 per metre.

The cost of the above unit incorporating a 10 mm locally produced brass pump rod is 20% above the standard unit rates of SR 3,100 (US$ 125) per 30 metre deep installation or SR 1,800 (US$ 70) per 18 metre.

4.7 GTZ EXPERIENCE

GTZ have previously supported a programme of 700 wells in the north of Sri Lanka. Very little conclusive data has been gained from this project. The data interpretation has been complicated by the security situation in the area of the GTZ project.

5 / BANGLADESH

5 BANGLADESH

5.1 INTRODUCTION

The Mission arrived in Bangladesh on the 28th October and departed on the 3rd November, 1985.

The Mission was introduced to the project by the Danida Mission Counsellor, Mr. Ove Elvekjaer. A letter from the Department of Public Health Engineering Chief Engineer was received from the Danida Mission Counsellor which emphasized the following points to be taken into account by the Iron Removal Mission:

- Development of simplified technology to suit Bangladesh Conditions at low cost.
- Review existing plants to improve on efficiency, particularly with regard to maintenance.

Meetings in Dhaka were first held with UNICEF representatives Mr. C. Glennie and Mr. Azad of the WES section, where the background of the UNICEF programme in Bangladesh was described and the iron removal experience detailed. This was followed by meetings with the Department of Public Health Engineering (DPHE), Chief Engineer Mr. M. Khan, Assistant Chief Engineer Mr. Farid, and other Departmental staff.

Further meetings were held with Mr. K. Laubjerg, Danida Advisor and World Bank Hand Pump Advisors Mr. T. Journey and Mr. B. Kjellerup. The sociological aspects of the project and the significance of hand pump developments within the programme were discussed at these meetings.

A short field visit was made to Kaitta village near Dhaka in order to inspect the operation of a pre-fabricated downward flow filtration iron removal plant. This unit has been developed by UNICEF from a model originally used in the Orissa project (DANIDA MK III).

A 2 day field visit was made to Sirajganj District where particular problems with occurrence of iron in tubewell water and the acceptance of iron removal plants is experienced. An opportunity was taken during the return from this field visit to inspect one of the Tara pumps installed in Mirzapur.

After returning to Dhaka, further meetings took place with Mr. Gosk, Danida Advisor attached to DPHE to discuss the hydrogeology of the project area and with Dr. Keith Pitman, Consultant Hydrogeologist of the Master Planning Office for the Bangladesh Water Sector. Further discussions, in light of the Mission's field experience, were held with Mr. Kristian Laubjerg on sociological aspects.

Before departing from Bangladesh, the Mission held de-briefing meetings with DPHE officials, chaired by the Chief Engineer, Mr. Khan, and attended by UNICEF officials and the Danida Mission Representative, Mr. Elvekjaer. A de-briefing with the Head of the Danida Mission, Mr. P. Nyborg also took place before the Mission's departure.

The Mission took the opportunity of discussing further with Mr. B. Kjellerup his experience with iron removal plants on the Orissa project in preparation for their visits to that project.

5.2 ASSESSMENT

5.2.1 Establishment of Criteria

In assessing the degree of the problem of iron occurrence and experiences of iron removal in the Programme of Basic Water and Environmental Sanitation Services in Bangladesh as experienced by the Mission, the question must first be to what extent there is a problem and to what extent this can be reduced.

Iron Level Criteria

As experienced by the Mission and reported from persons involved in the project, users, at least in some parts of the country, are prepared to accept water containing iron levels of up to 15 mg/l and possibly over. This is in the main due to their familiarity with this quality of water and to the successful health education programme promoting the utilization of tubewell water.

If the present criteria of the Department of Public Health Engineering of 5 mg/l is adopted, the requirement of iron removal plants will be around 10,000 units or approximately 2.5% of the total tubewells, and if WHO limits, even upper of 1 mg/l are used, the figure would be rising to over 70% or possibly higher.

These latter figures are significant in that most persons involved in the water supply programme are of the opinion that the level of iron must be reduced further if users are to be encouraged to utilize tubewell water not only for drinking but also for cooking, bathing, laundry and possibly other purposes. It is also considered that the level of acceptability in respect of iron level will drop in the future as users have greater availability of tubewell water. The Mission is not convinced of this evaluation since in their experience, a significant aspect in the level of acceptability is the level of water quality to which the user has been accustomed.

It is considered important to determine the level of iron content, which users will accept for not only drinking but also other purposes, and to formulate a regional evaluation in order to develop a policy for future planning and implementation implications.

Installation Criteria

In view of the varying attitudes of water taste acceptability and the maintenance burden of the iron removal plant as presently developed in Bangladesh, the Mission would recommend that iron removal plants are only installed at tubewell locations where: a) the community indicates that the water would not be used without treatment, b) physical quality testing shows that an unacceptably high iron level does exist, and c) the caretaker or spontaneous community maintenance system in the village in question is considered able and willing to undertake the maintenance burden involved.

The resultant number of iron removal plants from an approach as described above can only be postulated due to lack of firm data, but on the basis of information collected by the Mission this figure is put in the order of magnitude of 2 to 3,000 units.

5.2.2 Summary Assessment of the Units

Whatever the conclusions of the above investigations on the need for iron removal plants in tubewells in Bangladesh and the consequent decision on implementation policy, it is apparent that a significant number of units would be required. It is therefore important, in the opinion of the Mission, that an iron removal plant, which is shown to have a higher degree of acceptability and success of operation than the present unit, is necessary.

The Mission noted that the performance of the IRPs (cf. Fig. 4.2), although clearly capable of satisfying the DPHE criteria, did not always achieve these levels of iron removal in practice. It was also found that not only did the units vary in usage and performance from region to region, but that variations were common in adjacent villages. The factors that underlie these findings are discussed in the text of the report and summarized below:

a) Factors associated with poor in-situ construction:

- Dimensional inaccuracies resulting in poor distribution of flow into the second chamber; and ineffective sealing by the cover slabs.

- Poor workmanship resulting in leaks in brickwork.

b) Factors associated with sociological aspects.

Sociological parameters in relation to the acceptability of the iron removal plant and particularly in respect of maintenance are at least equally important as technical aspects. The Mission believes that the following points need to be taken into account:

- Poor introduction of the plant and its maintenance procedures resulting in grossly incorrect maintenance being carried out.

- Maintenance instruction being directed at the men, where actual maintenance is often carried out by women and/or children.

- Time consuming and difficult nature of the maintenance task.

- Insufficient motivation of caretakers and community. Need for better introduction techniques.

- Monopolising of unit by influential villagers.

- Siting policy and practice often different and often not taking account of particular problems in villages, such as particularly influential individuals or internal village rivalries.

- More effective education specifically on the purpose and benefits of iron removal plant.

- Consider the question of collecting community payment for reimbursing the caretaker.

- Consider the question of caretaker v. community maintenance.

In addition, certain design defects were noticed which, if rectified, would serve to improve the units in all villages. These are summarized below:

c) Design factors:

- Easy breakage of cover slabs and perforated distribution plates.

- Poor connection between pump and plant.

- Aeration chamber too exposed to dirt and insects.

- Connection pipe between sedimentation chamber and first filtration chamber encourages transfer of sediment into the filtration chamber.

- The dividing wall between the two filtration chambers is too low to prevent transfer of iron flocs into the second chamber.

- Cover plate is incapable of making a good seal.

- Drains occasionally clogg and often leak.

- The graduated media and the necessity of rejuvenation results in mix up of media between the filtration chambers and contamination of the media during this process.

- There is no slope on the filter chamber bottoms to encourage draining of flush down water during maintenance.

- Media size is too large or incorrectly graded (cf. above) to prevent high turbidities resulting from iron precipitation being carried through to filtrate.

The details of poor construction and improvements to design identified by the Mission and others would have to be incorporated in any development of the present unit. There is no doubt that an iron removal plant in Bangladesh should be constructed of and utilize locally available materials. Cost considerations and attitudes in Bangladesh to importation of materials and equipment precludes consideration of a proprietary unit.

The Mission believes that in order to implement the most appropriate technology for maintenance, the simplest removal procedure should be employed even if this results in a higher filtrate level than internationally acceptable. In the case of Bangladesh, the Mission considers that, subject to acceptability levels being confirmed by field surveys, an iron removal plant possibly only employing sedimentation and rough filtration procedures, which would reduce maintenance burden and complexity considerably, may possibly be proven to be appropriate.

5.2.3 Future Action Required

The existing plant needs systematic improvement, and a monitoring and development programme carried out in accordance with Section 2.3.4 is recommended. The particular points that will need to be noted in the Bangladesh case are:

- The different criteria of acceptability
- The different underlying sociological situations
- The large number of units required
- The quality control/cost/development benefit issues in the choice between in-situ construction and pre-fabrication
- The sole source of filter media available in Bangladesh

In addition to the technical research proposals in Section 4.2.2 and as modified above, the factors mentioned under Section 5.2.2 are important. In addition to the key areas of quality control and the sociological requirements which are longer term considerations the detailed design defects need solutions.

Related to the degree of iron problem and solutions for dealing with this is the question of avoiding the high levels of iron in the groundwater by drilling into an alternative aquifer. The Mission found that generally there is insufficient data regarding aquifer chemistry in Bangladesh to determine the real degree of possibility of alternative improved quality aquifers. In certain areas, Mirzapur for example, it has, however, been found that by drilling into a deeper aquifer, lower iron levels have been found. The conclusion is that further investigations would be necessary to determine if any areal interpretation of benefit could be achieved by different hydrogeological development. At the moment, most members of the project staff consider such an investigation to be academic for the limited purposes of the present project due to cost implications and the variable nature of aquifers. The Mission considers it a potential alternative to unacceptably high iron levels, which restrict the degree of utilization of tubewell water, or to iron removal plants, which have a high degree of failure.

Therefore the Mission recommends that whatever investigations are available or that may be carried out in the future, by the Master Plan Organization or others, be fully taken into account in determining the maximum avoidance of groundwater with unacceptable iron levels.

5.3 BACKGROUND

The Water Supply Programme

The Bangladesh Rural Water Supply and Sanitation Programme is sponsored by UNICEF and supported by Danida as one of the principal donors. The Department of Public Health Engineering is the implementing agency for the Programme which commenced in 1971. The programme initially concentrated on shallow wells which were excavated by a simple sludge pump method through the clay silt overburden and equipped with the Bangladesh No. 6 suction hand pump.

Target figures for the programme is 1 hand pump per 75 persons by the end of this decade. Present nation-wide average achievement is 67% coverage or an equivalent of 1 pump per 112 persons. Because of the nature of the villages and the stage of the programme's development, there is not a consistent distribution throughout the country.

Iron Removal Experience

During the course of this programme, the iron content of the water was identified as a constraint to the success of the tubewells. Development work in 1981 by Faroque Ahmed at the Bangladesh University of Engineering and Technology, Dhaka (Ref. B.1), led to an in-situ brick constructed iron removal plant. This plant was incorporated at tubewell sites where the iron level had been found to be unacceptable and had resulted in abandonment. A two phase crash programme of research and development was carried out from 1982 to 1985 with the first phase of units being implemented by contractors. Because of problems of cost and quality, the second phase of units used a community self help approach. Neither of the two programmes have proven very successful. Rejection levels are in the order of 30 per cent or above and vary greatly depending on the area of installation.

Hydrogeology

The groundwater potential in Bangladesh and resultant water quality and dependability has its history in the delta formation of aquifers. This has resulted in a deposition of coarse below medium layers in the north and medium below fine layers in the south. The degree of vertical hydraulic continuity of aquifers is inconsistent through the country, and in some areas impervious intermediate layers can result in considerably different water quality in the same location but at differing depths.

The aquifers can be divided into three main groups:

- The "composite" upper aquifer comprising clay, silt and/or sand layers
- The "main aquifer" of medium-coarse sand resulting in good permeabilities and transmissivities. Withdrawals of up to 100 m^3/hour are possible from wells with little resultant drawdown
- The deep aquifer which is mainly utilized in the south of the country.

The depth of the composite aquifer, which is normally not utilized for supply due to pollution and fine material problems, increases from south to north of the country in a similar proportion to the narrowing of the main aquifer. Wells in the south of the country therefore generally need to be deeper.

Despite the above generalizations, the geology of the country is very variable because of the erosion and deposition characteristics of the floods and shifting river flows.

Alternative Hand Pumps

Although the Bangladesh No. 6 suction pump has proven to be very successful, it has a limited depth range.

The development of the Tara pump, a direct action deep set well hand pump, is expected to be particularly important in the development of those areas where there are declining water levels due to irrigation.

The planned abstraction of groundwater for irrigation will be a significant influence on the rural water supply development in Bangladesh. If the estimated maximum development of 22,500 million cubic metres is achieved by 2005 as planned, the effect will be a drop of the free head water table from 6 m depth to 10 to 15 m depth. The actual variation will be area specific with minor drops in the coastal area due to the more limited abstractions in that area. The impact on present well development will be the need to deepen and probably install different type of hand pump, such as the Tara pump. This will be very important in considering future development and planning options.

5.4 EXTENT OF THE IRON PROBLEM

The extent to which the occurrence of iron in groundwater is a problem in Bangladesh depends significantly on the level of iron concentration which is considered acceptable. If the upper WHO limit of 1 mg/l is considered appropriate, the problem would be nation-wide and involve a very high percentage, some 70%+ of the wells. Iron levels are found in concentrations of up to 30 mg/l in some areas. Concentrations of 10 mg/l and above are very common in the areas visited by the Mission.

Fortunately, because of the high user tolerance of iron, a level of 5 mg/l is considered by DPHE to be the level at which user acceptability becomes critical.

With this level of 5 mg/l as a criterion, 29 Upazilas out of the country-wide total of 463 are affected, mainly being in the North and East of the country. The lack of a complete or processed data base in the country resulted in it being impossible for the Mission to determine the exact number of tubewells which would be affected within these 29 Upazilas. However, using figures for Sirajganj District, where the Mission visited and collected raw data, the expected total number of wells affected in the country is evaluated to be in the order of 10,000.

Water quality testing on the project is limited to chloride and iron using Hach Field Kits without laboratory confirmation or control. The Mission understood, however, that Spectrophometer equipment had been purchased by Danida although this was not being used at present.

Other water quality parameters are not considered to be a problem in the iron rich areas of the country. The pH is generally around 7 and CO_2 levels are low. However, the lack of a reliable data base and of sophisticated and systematic testing procedures means that evaluation of the situation is to some degree subjective rather than being based on firm statistics.

5.5 SOCIOLOGICAL ASPECTS

Source of Information

The Mission collected information on sociological aspects of iron occurrence in groundwater and experience with iron removal plants principally from the Danida Socio-Economic Advisor attached to the UNICEF programme. Much of the information resulted from an earlier feasibility study into these questions. The study covered the response of the 200 villages using iron removal plants in Srimongol and Sirajganj Upazilas and included a household survey in 20 Thanas which related iron content to user perception. The Mission was impressed with the depth and perception of these studies and considered the collected data to be of high reliability.

The Mission supplemented the data as collected above by personal experience principally from the field mission to Sirajganj Upazilas. Valuable discussions were also held with individuals and organizations closely involved in the Rural Water Supply Programme over a number of years.

Acceptability Levels

The availability and often excess of water in many parts of Bangladesh obviously leads to a competition between surface and tubewell sources. The critical significance of iron level in tubewell water therefore is the user's threshold of acceptance. At this level they will abandon the tubewell source in favour of the "sweeter" tasting, but contaminated surface or un-protected dug well source. Fortunately, the user's familiarity with high iron concentrations in drinking water and a programme of health education have resulted in a very high level of acceptance.

Although the official threshold limit is set at 5 mg/l, the implementation programme at present is installing iron removal plants only in cases where tubewell water has over 10 mg/l iron.

Most evaluations of threshold limit are subjective but result from a long and wide spread of experience on the project and can be considered as fairly representative. It is generally considered that at levels above 7 mg/l, users start to complain. The Mission's experience in the field, however, showed that in cases of iron levels even up to 15 mg/l, the tubewell was used for drinking water, even where low iron content surface water sources were equally convenient.

The high level of acceptance for drinking water is not tolerated for cooking and washing. This is in sharp contrast to the situation in Sri Lanka. The common complaints are staining of food and clothing and stickyness of the hair.

This is probably in consequence of the much higher levels of iron present in Bangladesh. In the survey of users in Sirajganj where iron levels are high due to improper functioning of iron removal plants, only 12% of respondents used the tubewell for all purposes. The Rural Water Supply and Sanitation programme has identified the need to encourage the multi-purpose use of tubewell water in order to improve the existing health situation. If this is to be achieved it is likely to be found that the levels of iron will have to drop to well below 5 mg/l.

The utilization of the tubewell water and the range of purposes for which it is used has been shown to increase during the dry season. This indicates that competition with surface supplies is likely to be an important issue if greater use of the tubewell water is to be encouraged. The existing usage of water from IRPs is given in the Table below from a report by a socio-economic unit (Ref. B.17).

Purpose of Water Use from IRP in Two Areas

	------PERCENTAGE RESPONSE-----	
PURPOSE OF WATER USE FROM IRP	SRIMONGAL (SAMPLE NO.125)	SIRAJGANJ (SAMPLE NO.87)
Drinking	94	82
Cooking	88	46
Laundry	13	13
Cleaning utensils	19	6
Bathing	20	0
Miscellaneous	6	2

The Table indicates that despite the better performance of plants in Srimongal, improved iron removal alone is only likely to increase utilization of water for cooking and bathing. Laundry and cleaning utilization will not be significantly affected, probably due to the traditional practices employed.

The siting of tubewells, and consequent iron removal plants, is in some cases found to create problems, which complicate the evaluation of user acceptability. The selected caretaker is often a prominent member of the village community who subsequently rejects communal assistance in operation and maintenance in order to maintain an impression of monopoly of ownership. In cases where the caretaker is not willing or able to fulfill the maintenance obligations, the resultant deterioration often adversely affects the level of utilization.

5.6 IRON REMOVAL SOLUTIONS

5.6.1 Development

Prior to 1979, Richardson and Crudas' iron removal plants were utilized on the project. These failed for a variety of reasons, but primarily because of an ineffective connection between the pump and the 2 m high unit and inefficient maintenance operation.

As part of a M.Sc. thesis on "Design Parameters for Rural Water Supplies in Bangladesh", Faroque Ahmed in 1981 (Ref. B.1) developed a "community package type iron removal plant". This comprised an aeration channel, a sedimentation chamber and two filtration chambers, the first upward and the second downward flow. From these principles, a unit of brick and cement, using brick chips as the filter media, has been developed and installed during the two phases of the crash programmes and DPHE ordinary programme.

Several trials with varying brick chip sizes and sand have been carried out. Although larger chips did not achieve the same degree of removal of iron as the sand, maintenance was found to be easier due to longer filter runs and easier cleaning. From the outset it was considered that backwashing was an inappropriate technology for such a village level unit and a low standard of removal was set at 5 mg/l.

To date, 340 iron removal plants of this type have been implemented in the various programmes and 150 planned units are still outstanding. At least 100 units of those installed are reported to be out of use at the present time.

The cost of units is Taka 5,000 for the contractor constructed unit and Taka 3,500 for the community constructed unit.

Since March 1985 a pilot iron removal plant similar to the DANIDA MK III type developed in the Orissa project has been installed. The construction of this plant has been carried out using locally available materials, and some problems have been experienced in operation and maintenance, due mainly to clogging and breaking of the backwash system. The cost of the pilot unit constructed from coconut oil barrels is Taka 4,000, and the estimated cost of a similar unit constructed in brick is Taka 5,000 (approx. US$ 170).

5.6.2 Operation and Maintenance Experience

Operation and maintenance experience with the iron removal plants installed on the project has not been satisfactory. At least 30% of the installed units have been abandoned. The success rate appears to be area dependent, with Sirajganj District, which was visited by the Mission, having a particularly bad record. Even within Sirajganj District, units which have successfully operated for 2-3 years are in close proximity to similar units which have been abandoned almost from installation.

The tabulated data below are from the socio-economic cells study report (Ref. B.11). In Srimongal 100% of the IRPs visited were working, while the figure was only 40% in Sirajganj. The tabulated data reflect this situation.

A comparison of the sociological and technical reasons for rejection of the IRPs in the first Table shows that whilst in Srimongal most rejections were due to sociological reasons, in Sirajganj technical rejection was almost as great as sociological rejection.

If it can be assumed that users' sensitivity to water quality is the same in each area, then the second Table indicates very poor performance of the units in Siranjganj. This is borne out by tests on the iron removal rate and is further confirmed by the large response indicating unclear water. The unclear water is almost certainly due to poor filtration of the precipitated iron.

Reasons for Rejection of IRP by Women Users in Two Areas

REASONS FOR REJECTION OF IRP BY WOMEN USERS	------PERCENTAGE RESPONSE----- SRIMONGAL (SAMPLE NO.125)	SIRAJGANJ (SAMPLE NO.87)
. Lack of understanding by other people of the purpose of the unit	20	21
. The iron sediments in the chamber look "like baby stools"	8	53
. Dispute between users and caretakers	0	18
. Insects and worms inside plant	5	56
. Difficult access to the plant	6	6
. Low discharge	0	21

Opinions of Water Quality by Women in Two Areas

OPINIONS ON WATER TASTE BY WOMEN USERS	------PERCENTAGE RESPONSE----- SRIMONGAL (SAMPLE NO.125)	SIRAJGANJ (SAMPLE NO.87)
Good taste	87	35
No smell	45	9
No taste at all	14	9
Water not cool	41	9
Water not clear	13	41
Tastes bad	0	52
Smells bad	0	23

However, conclusions from the results of the socio-economic feasibility study were quite clear that users were, irrespective of location, satisfied with water from a properly functioning plant. This in turn reflected good maintenance of such a plant. The question of why the maintenance of some plants was satisfactory while others were not, reflected many answers among which are:

- Lack of understanding of the purpose of the plant
- Poor introduction of maintenance procedures and the benefits of the plant
- Time consuming nature of maintenance is in conflict with the caretaker's role being voluntary and conflicting interests
- Insufficient sense of responsibility of their duties by some caretakers and passing over of these to family members who have not been properly instructed in the procedures.
- Self interest of some caretakers in refusing offers of assistance in sharing the level of maintenance with other users.
- Technical aspects of design or construction resulting in poor operation and/or maintenance

Replies from respondents during the socio-economic feasibility study indicate that users consider that a more frequent maintenance schedule is required and show a willingness to share this burden. The success of such a system has not yet been proven by field trials. What did appear clear from the survey investigations into this aspect was that women should be involved more. They should be explained the purpose and benefits of the iron removal plants and instructed in the importance of correct operation and maintenance.

The technical and physical factors recorded as causing problems and possibly resulting in abandonment include:

a) Dimensional inaccuracies in construction which result in poor operation (uneven distribution of flow, etc.).

b) Leaks in the unit caused by poor construction standard and the low level design specifications due to economic considerations.

c) Breakage of distribution plate in the filtration chamber particularly during removal for cleaning.

d) Cover slabs break easily and provide ineffectual seal allowing ingress or dirt and insects.

e) Poor cleaning practice and ingress of dirt and insects.

f) Drains block and often leak due to bad seal.

g) Ineffective connections between the pumps and plant.

h) Mixing of media during cleaning or regeneration.

5.6.3 Field Observations

Scope

The Mission spent two days in Sirajganj District where a total of 7 units were inspected, including 3 which were completely abandoned.

The Mission also visited an "Orissa Type" unit installed in Kaitta village and took the opportunity to view a Tara pump which was located in Mirzapur.

Findings on the various units visited are recorded below:

VILLAGE	RAW WATER IRON CONTENT mg/l	TREATED WATER IRON CONTENT mg/l	COMMENTS
Sialkool	8	2.5	Installed since June 84. Unit cleaned 1 week before. Good discharge. Indications (slime on chips) of bacteria action in 2nd chamber.
Bahuti	-	-	Pump has been removed to private location and tube-well and IRP abandoned.
Dhuhururia	>10	-	Tubewell installed since June 83, IRP since June 84 and operational until August 85. IRP has now been abandoned due to insects and leakage. TW only used for drinking water. Water sampled from a drinking water container inside a village house and >10 mg/l or iron.
Silondam	-	-	IRP continuously in use for 2½ years. Community maintenance. Discharge low but acceptable. Flush maintenance carried out during visit by opening a drain valve. Previous maintenance carried out 3 days before visit.
Charbonaria	13	6	Tubewell installed since June 83 and IRP since June 84. Caretaker maintained. Filter media badly mixed. Uneven dividing wall between filtration chambers resulting in unbalanced loading on filter. Badly insect infested. Cleaning carried out during visit.

VILLAGE	RAW WATER IRON CONTENT mg/l	TREATED WATER IRON CONTENT mg/l	COMMENTS
Paikpara (1)	20	5	Tubewell installed since June 83 and IRP since June 84. Not in use. In very bad state of repair. Cover slab off. Water leaks through holes in the brick work. Problem in connection of pump to plant. Tested after pumping unit to full during visit. Cf. Fig. 5.5 showing raw and treated water.
Paikpara (2)	10+	10+	Thick layer of iron deposit in the unit. Cleaning was carried out during visit and treated water still remained at over 10 mg/l despite appearing clear. Indicating oxidation problems.

Maintenance and Operation

Several operation and maintenance aspects of the units were noted by the Mission during the field visits as giving problems:

- Mixing of the different layers of filter media during the cleaning process.
- The dividing wall between the filtration chambers is not sufficiently high above the top of the coarse gravel layer. It does not prevent carry-over of the fine ferric hydroxide deposit which lifts up during pumping.
- The pipe from the sedimentation chamber into the first filtration chamber carried over a considerable deposit because it is placed at the bottom of the chamber.

- The fact that there is no slope to the base of the chambers in the IRP results in difficulty of completely flushing out deposited material.

- Coarse material in the filtration chamber results in carry-through of ferric deposit into the effluent.

It was significant that in some cases, iron removal plants were operating satisfactorily for periods exceeding 2 years in villages adjacent to others which has been abandoned. This despite similar raw water quality, alternative source availability and presumably user attitude. The Mission concluded that the degree and quality of maintenance being carried out and the consequent quality of water from the iron removal plant was the most critical factor in determining whether the units were a success or not. Although in some cases poor construction standards resulted in reasons for abandonment, it was the attitude of the caretaker or community towards maintenance that appeared critical. In the Mission's experience, although some units operated well as a result of community maintenance, the most successful units were those associated with a conscientious caretaker who individually took responsibility for the maintenance.

The maintenance procedures of downward flushing were viewed at several plants, cf. Figs. 5.6, 5.7 and 5.8. The procedure was similarly carried out at all locations. It was fairly effective, although involving quite a degree of effort. The raking of the gravel down to the lower layers in order to effect proper cleaning of these (Fig. 5.7) was particularly difficult. The effectiveness of this latter process obviously depends very much on the attitude of the person doing the cleaning. One might suspect the thoroughness of cleaning would not be the same when not being viewed by the Mission. The time period for cleaning in this manner was around 20 to 30 minutes. In one case, the caretaker was shown by the Mission that agitation of the media for cleaning could be more easily carried out with the chamber full of water. The bouyancy reduces the effort involved and the adsorbed iron particles are released into suspension.

In almost all cases the caretaker did not open and flush out the sedimentation chamber of the plant before being asked to do so by the Mission. It would appear that they were not aware of the significance of this aspect of cleaning. A great proportion of the iron is deposited in this chamber and results in the carry-over of accumulated deposit into the rest of the system.

The Mission noted that before cleaning, the gravel layers in both filtration chambers were badly mixed and in many cases fine materials were in the coarse chamber and vice versa.

The resultant iron uniformity in size can be expected to cause earlier clogging without proportional increases in filter efficiency. Significant short circuiting of the media is seen to take place, where water passed through areas of coarse rather than fine media.

This has the disadvantage of giving turbid water from the unit as opposed to the clear water straight from the well which contains soluble iron.

Construction and Design

Poor construction and design aspects of the iron removal plants caused problems in several cases. These are outlined below:

- Leakages due to workmanship.
- An awkward and easily broken cover slab.
- Concrete distribution plate on top of filtration chamber easily broken.
- Bad connection between pump and pipe to aeration channel.
- No sealing of aeration channel from contamination or interference by children or others.
- Ineffective sealing of the plant from dirt, dust or particularly insects.

The lack of cleanliness of the units was, in the opinion of the Mission, very important. The dark, dirty environment of the unit, aggravated by broken cover slabs, was infested with dead and living insects and subsequently ants. The need to enter the chamber for cleaning and in some cases to remove filter material for rejuvenation creates a new source of contamination. Although the bacteriological pollution resulting from an iron removal plant may be considerably less than that from surface water sources, there is no doubt that the users' attitude to the plant is adversely affected by the unclean conditions.

This is particularly the case if the appearance of the filtered water compares infavourably with the raw tubewell water. Although micro-biological tests have yet to be carried out on the units, this contamination, if not prevented, is likely to reduce the intended health benefits of the water supply programme.

Despite the many problems seen and expressed regarding the units, the Mission was impressed by the number of units successfully operating over an extended period of time. This indicated that with proper maintenance and construction, the plant could be made to operate satisfactorily within the performance criteria set by the DPHE.

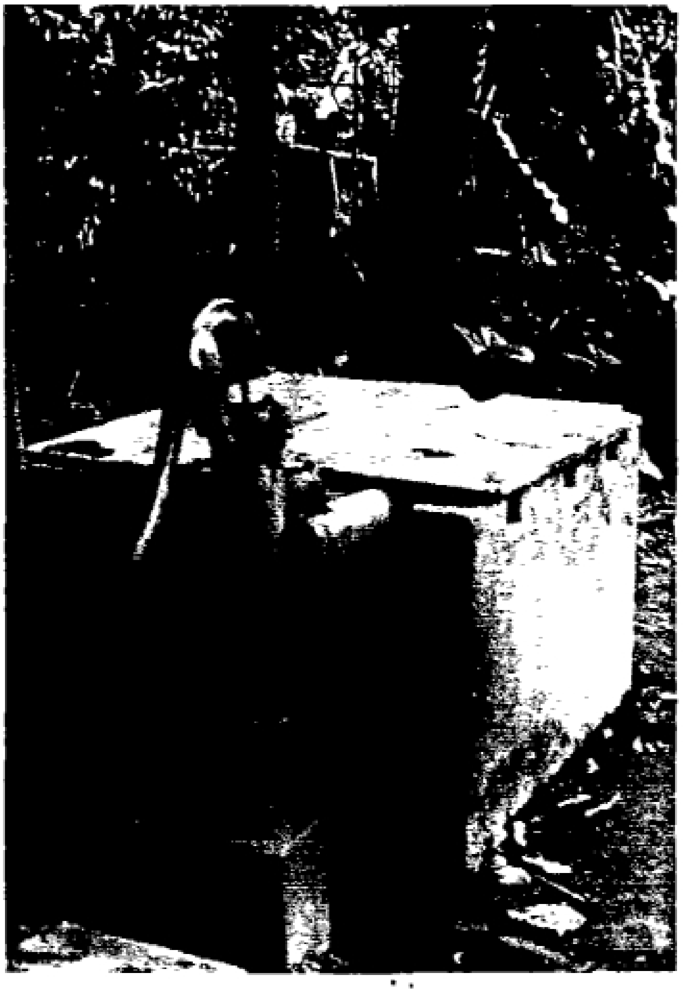


FIG 51 IRON REMOVAL PLANT, SIRAJGANJ, BANGLADESH

FIG 5 2 FILTRATION CHAMBERS NOTE FILTER MEDIA, COMPLETELY MIXED BETWEEN CHAMBERS

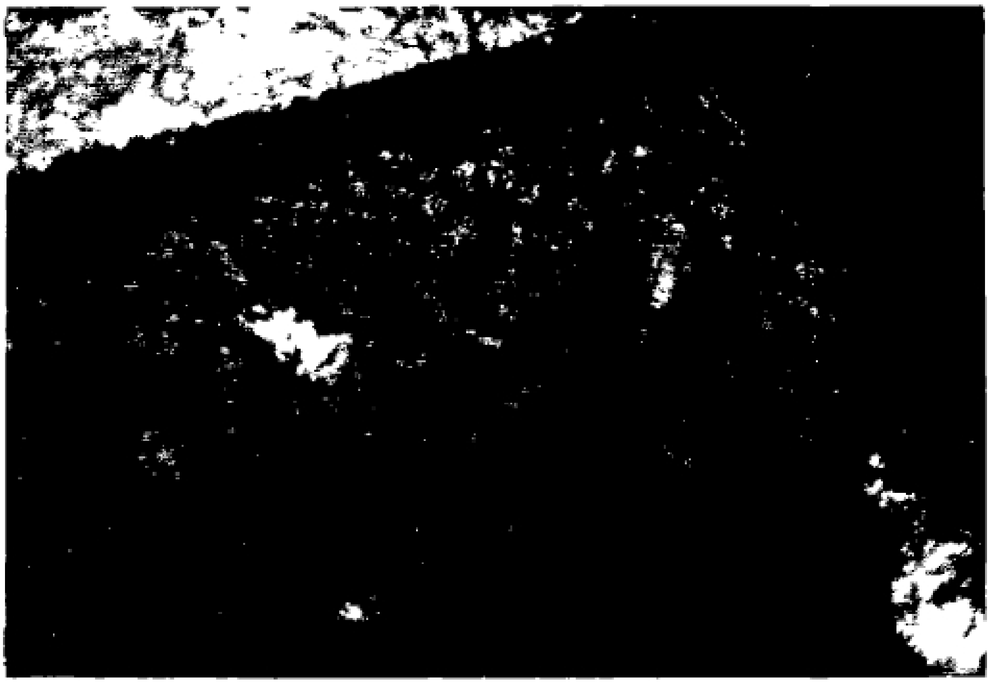


FIG 5.3 TYPICAL HEAVY DEPOSITS OF IRONHYDROXIDE SEEN IN FILTRATION CHAMBERS.

FIG 5 4 AERATION PIPE NOTE LAYER OF IRON OXIDE.

FIG 5.5 COMPARISON OF RAW AND FILTERED WATER
(RAW WATER TO THE LEFT)

FIG 5 6 FLUSH DRAINING OF FILTRATION
CHAMBER NOTE DEGREE OF IRON-REMOVAL

FIG 5.7 RAKING OF FILTER MEDIA DURING MAINTENANCE

FIG 5.8 BUCKET FLUSHING OF MEDIA TO FURTHER DISLODGE DEPOSITS

6 / ORISSA

6 ORISSA

6.1 INTRODUCTION

The Mission arrived in Orissa State on the 4th November and departed on 9th November, 1985.

An introductory meeting was held, chaired by the Project Director and attended by Executive Engineers, Executive Socio-Economist, Dr. Misra from Palasuni Laboratory, and all Danida Advisors. This took place to familiarize the Mission with the project and to arrange a schedule of the visit to the Orissa project. Subsequent detailed discussions on appropriate aspects of the project took place with the Executive Engineer, Training and Maintenance Division, Head of Palasuni Laboratory, Executive Socio-Economist and the Danida Water Resources Advisor.

The Mission made a total of 3 site visits to inspect iron removal plants in Gop and Erasama areas, during which 8 of the 17 plants installed under the instructions of Associate Professor E. Dahi from the Technical University of Denmark were inspected. During the course of the field inspections, the Mission met with the assistant engineer from the Sub-Division offices in Delany and Tirtol. These staff manage the operation and maintenance of the installed units in Gop and Erasama respectively.

After the Mission's first two field visits to each of the two areas where iron removal plants are installed, further detailed discussions took place with the entire Project Directorate. At this meeting the Mission's preliminary findings, the details of iron level acceptability, and in particular the problems experienced to date with the iron removal plants, were discussed.

After the initial field inspection visits, the Mission visited the Palasuni Laboratory and inspected equipment and testing procedures in addition to viewing samples of recorded data. More detailed discussions also took place with Mr. Pani on operation and maintenance activities in relation to the iron removal plants and with Mr. Khatua on socio-economic aspects.

At the conclusion of the Mission's visit to Orissa, a briefing on the findings and preliminary conclusions was presented to the Directorate and valuable comments and reactions were received. The Mission regrets that due to prior commitment, the Project Director was unavailable for this briefing.

6.2 ASSESSMENT

6.2.1 Establishment of Acceptability and Design Criteria

The current policy on iron removal is to install a plant where the iron level in the tube well water is above 3 mg/l; this policy is a result of sociological studies carried out in the investigation phase of the water supply programme. It is the Project Directorate's view that once a plant is installed, it should satisfy the W.H.O. limit of 0.3 mg/l. There is apparently no sociological data that justify the need for such a criterion. The plants as operated at present do not always satisfy this requirement, although they come very close. It is the Mission's view that this criterion should be confirmed as sociologically necessary or otherwise before it is adopted as final. The technical constraints on a unit needing to satisfy such a rigid criterion will almost certainly lead to compromises on other issues such as maintenance that could have greater sociological and operational sensitivity. The Mission believes that imperfections in the operation of units are almost certain to occur. In order to ensure that field results are in the region of 1-2 mg/l for instance, the unit itself might have to be capable of a very much greater level of performance. This is an important point and underlines the benefit of realistic field testing under the proposed method of maintenance.

The Mission was informed that in November/December 1985 a sociological study is being carried out on the iron removal plants by the socio-economic cell. It was recommended in the de-briefing meeting of 08.11.85 that this study incorporates an assessment of the sociological requirements of the I.R.P.'s in relation to effluent quality and other factors mentioned below.

In addition to effluent quality the other important design criteria that need determination are: Filter runs and backwashing intervals; filter media rejuvenation period; criteria level of head loss or discharge reduction.

- A maintenance period of one month is considered for the hand pumps. The Mission agrees with the Project Directorate that for practical reasons the routine maintenance of I.R.P.'s should coincide with the pump maintenance. This establishes a design criteria of one month for down flush cleaning.

- The filter rejuvenation (i.e. the manual cleaning of media) is a laborious, time consuming and difficult process, for this reason it is critical that the likely maintenance interval is known, and that it can be extended to the maximum possible. At present it is roughly assumed as three months, but is is not known by what criteria this level has been decided upon or the quantity of treated water that it relates to. Present efforts at installing flow meters should help with this last point.

- The criteria level of head loss or discharge reduction is one of the two main factors along with effluent quality that affect the length of filter run. This is of great sociological significance, and it has been recommend that a study of the users' attitude in this regard is undertaken by the socio-economic cell during their current field work.

- It has been noted by the water resources advisor that the present usage is about 1 m^3/day. At a more realistic level of 5 m^3 (200 people using 25 l/person/day) the filter rejuvenation period could be expected to be reduced to 2½ weeks and the filter run to less than a week.

6.2.2 Summary Assessment of Units

Development

Experimentation with several different types of iron removal plants in the Orissa project has resulted in a reasonable degree of experience and opinions regarding the appropriateness of selections. Tests on Richardson and Cruddas models showed that this proprietary pre-fabricated system was not appropriate, and that the scraping system of cleaning and manual flushing took too much time.

Danida MK II Unit

The detailed construction, operation and design defects of these units have been listed under Section 6.6.3. Maintenance and performance of the units as derived from the monitoring programme and confirmed in most instances by the field visits are discussed in Section 6.6.2 under "Results of the Programme". Despite the limitations of the monitoring, it can broadly be said that the performance of the unit is good. The maintenance, however, is more problematic. There is evidence that the flush down method in itself does not remove much iron, and that aids such as agitation may be required. A fuller discussion on this possibility is given in the background information.

A recent design change in the increase in size of the top layer of filter media to 10 mm size has been very successful. It is considered that the present unit is still far from optimum. Further design improvements and a relaxation of the effluent quality requirement to above W.H.O desirable limits may result in many of the design criteria outlined in Section 6.6.1 being met. The unit certainly has promise and with a more intensive approach to development and monitoring the problems such as filter rejuvenation interval may be solved.

Danida MK III Unit

Unfortunately, this unit was not inspected since it has been dismantled. However, the Mission has reviewed a report on the unit by the designer and also discussed the unit. As stressed in the report, the prototype was still under an early stage of development. The Project Directorate outlined the following points concerning the plant:

- Lack of aeration due to cover
- Tray system of aeration could lead to clogging and leaks.
- Pipework is prone to clogging

- 130 l reservoir not sufficient for backwashing
- Construction complicated
- High cost of the pipes and fittings necessary.

The Project Directorate nevertheless appears keen to field test a more developed version of the unit. Since the philosophy behind the unit's concept is the sociological advantage of reducing the maintenance burden, this field testing is vital. However, it is paramount that a properly developed prototype is available in order for this testing to be worthwhile.

Experience with the Danida Mark III plant, in the opinion of the Mission, is not sufficiently advanced to either justify its field testing or evaluate its suitability. The Mission considers it would require much modification to design details involving simplification of construction, operational and maintenance systems before being in a format which could be considered to possibly lead to successful implementation.

Conclusions

The experience with the Danida Mark II unit has to date been favourable subject to problems of detail as already itemized. The Mission was also impressed with the performance, design and operation of the unit.

The Mission concludes, however, that while appreciating the need of close monitoring to develop the unit on the very important issue of maintenance, the unit has not been adequately tested under site operational conditions. Similar remarks apply to the user acceptance of the plant, and it is to be regretted that socio-economic aspects of the plant have not been researched and developed in parallel with technical aspects.

It is perhaps only a coincidence, but the fact is that the Danida Mark II plant as developed is also appropriately suited to the proposed 2-tier maintenance system for the project. It would be necessary with a paid village mechanic system of maintenance that for practical and economic reasons a maximum interval between visits to each plant should be possible. Experience with the Danida Mark II indicates that a once monthly maintenance visit should be possible after further development of the present system which would coincide well with the required visit and maintenance of the tube well system.

6.2.3 Future Action Recommended

The timing of further developments of I.R.P.'s is critical. The first phase now commenced (ref. I.5) will probably have no time to incorporate other than minor modified Danida Mark II units. If larger scale modifications or alternative units are to be introduced, this would not be possible until Phase II.

Phase I of the project is estimated by the Project Director to require some 200 I.R.P.'s in the near future. There is also an obvious advantage in the uniform adoption of an iron removal plant throughout the project. The timing therefore demands that a better developed plant be established in the very near future.

In order to achieve this a very intensive development and monitoring system will be needed. Realistic field testing will also be required. Field testing will require the operation of the proposed maintenance system in the villages where the plants are to be tested. Such an exercise would result in valuable feedback information about the proposed maintenance system itself.

The methods and philosophy behind an intensive development and monitoring programme are outlined in Chapter 2. Naturally, consideration must be given to the type of filter media available in Orissa and other local conditions. It is also important that such a programme is designed around the resources available and is done in conjunction with experienced Project Directorate staff. It should be noted that because of the likely resource and time constraints the success of such a programme will be limited, and this has to be accepted. In addition to or as a local extension of the points outlined in Chapter 2, to which the reader is referred, the following should be determined:

- The user acceptability and technical design criteria must be determined as described in Section 6.2.1. Until this is done, a professional and objective approach is not possible. Without detailed knowledge of the objectives no development or monitoring can hope to be efficient.

- The first priority should be a clear cut determination of the extent to which the existing Danida MK II plant satisfies the above criteria with the present maintenance methods, i.e. down flush cleaning. This information will form an important measure of how much further development is necessitated and identify the weaknesses requiring further attention.

- Concurrent work should be carried out on investigating possible improvements such as: The use of agitation during backwashing, simplifying the graduation of filter media (cf. the Krüger plant, Chapter 3), improvement of physical defects listed in Section 6.6.3.

- Product development and field testing must be separated to establish control over each process.

- A more intensive effort on fewer plants at a convenient central location would yield more reliable techincal data and not divide the resources available.

- As a lower priority testing and developing of some of the other promising units such as the Finnish and UNICEF multi-chamber systems.

- Laboratory tests at the Technical University of Denmark (Ref. I.9) have resulted in a very successful change in filter media size in the top layer. This work should continue. However, problems with model scaling errors and the methodology of some of the experiments are believed to have occurred. As this report was not available to the Mission, more detailed evaluation of the results would need to be made.

- In order to properly field test the plants, the proposed maintenance system should be tried at suitable villages, where the units could be tested.

- The imminent socio-economic study on I.R.P.'s must be incorporated in future developments. Previous failures to incorporate the inputs of the socio-economic cell in the siting and location of the pilot I.R.P.'s, for instance have resulted in serious omissions in the development of the plant. The socio-economic aspects are in the opinion of the Mission the most important element of the success of the unit.

6.3 BACKGROUND

The Orissa Drinking Water Project involves the supply of drinking water initially in three blocks of coastal Orissa which are effected by saline groundwater conditions. Project Preparation Phase of the project commenced in 1982 and Project Proposals were finalized by Danida in 1984. Phase I of the proposed Plan of Operation has just recently commenced implementation. A total of 1,200 tube wells are to be included in this phase out of the programme total of 5,000.

The water jet method is being used to sink wells down to 300 metres in unconsolidated clays, silt and sand. A total of 50 contractors are at present working on the project. Iron levels of up to 20 mg/l are expected to be encountered, and it is estimated that around 20% of the total tube wells or 1,000 number will require iron removal plants. It was reported that the need for iron removal plants would be lower than average in Phase I. Nevertheless, there will be an almost immediate need for some quantity of proven iron removal plants.

The Project Director requested the Mission to consider several design aspects of iron removal plants as follows:

- Effect of pH value on iron removal.
- Suitability of Danida Mark II and III plants on the project.
- Surface loading to be adopted.
- Filtration rate to be adopted.
- Consider appropriateness of up-flow filtration as adopted in Danida Mark II plant.
- The effect of continuous and discontinuous operation on performance and efficiency.

A consideration of these points is given in Chapter 2.

6.4 EXTENT OF THE IRON PROBLEM

Based on sample data over the area of the project, it is estimated that there will be a 30% occurrence of tube wells with iron levels above 3 mg/l and a 50% occurrence of tube wells with iron levels above 2 mg/l.

The aquifers which are being developed for water supply are generally confined with little vertical transfer. However, there is no evidence to indicate that differing depth of aquifer would result in improved water quality in respect to iron level. Drilling to greater depths or using alternative locations to avoid iron bearing water will require more extensive research and has important practical drawbacks. For instance the large number of small scale contractors involved in the drilling programme and the cost of Rps. 40,000 per tube well are inhibiting factors. It is the Water Resource Advisor's opinion that it is easier and less costly to install an iron removal plant than to attempt to avoid the problem hydrogeologically.

It has been noted that there is some change, both increase and decrease, in iron content in a particular tube well with time. Changes in iron content of groundwater with time as a commonly found problem and is not yet fully understood. Several hypotheses involving the effect of withdrawal from different sections of the aquifer with time or the accumulation of iron due to groundwater movement exist, among others.

6.5 SOCIOLOGICAL ASPECTS

Acceptability Levels

Some early work was carried out by the socio-economic cell on the project to evaluate user acceptability against iron content of tube well water. It was generally found that at iron levels less than 1.5 to 2 mg/l there was no problem with acceptability. At iron levels of greater than 8 mg/l there was 50% rejection which reflects the varying opinion arising from differing user familiarity with water of high iron level.

In more detailed recent surveys it has been established that the acceptance level of water for cooking purposes is around 2 mg/l, whereas for drinking water the level is around 3 mg/l or possibly higher. 2-4 mg/l is considered to be the critical range of iron throughout most of the project area. The villages being served by the project are around 50 to 100 family size, with 600 persons being the average population which would be served by 2 or 3 tube wells. The average intended is 1 tube well per 225 persons.

It is considered by the socio-economic cell that a supply of water direct from the tube well should be provided for where the iron level is not critical such as ablution, cleaning, building, etc.

Mark II Plant Acceptability

Considerations which have been identified by the socio-economic cell as affecting the user acceptability of the Mark II iron removal plants are:

a. Unacceptable yield, i.e. delays at the pump.
b. Lack of drainage of waste water.
c. Pump handle length in relation to height of stepping blocks.
d. Aesthetics
e. The larger space requirement of the unit.
f. Competition related to alternative sources.
g. Socializing and community aspects of water collection which tend to favour traditional sources.
h. Height of the unit and degree of exposure can be considered undignified.
i. Status of women in the village, especially recently married young women, who will require privacy and dignity.
j. Social reaction to cleaning of units by hand especially by less privileged members of society.

The satisfactory consideration of these factors will require a technical input (points a. to e.), i.e. head loss, filter areas, etc.; a carefully designed and sensitive siting policy (points f. to j.); and an appreciation of the particular social factors to be taken account of in the design of the maintenance system. These are a formidable set of constraints, and it will not be possible or even necessary to satisfy them all, within the limits of technical and financial resources. Detailed consideration will lead to their effects being minimized and will point to areas needing special attention in health education programmes.

Maintenance

As a result of socio-economic and technical studies on the project a 2 tier maintenance system has evolved although not yet tested. This system involves a local, self employed artisan such as a blacksmith or mechanic who is available to carry out routine maintenance, and a mobile back-up unit. The artisan would be expected to look after in the order of 20 tube wells in 4 to 8 villages and would be paid Rps. 100 per tube well per year. This system is an alternative to the UNICEF 3 tier system with a voluntary caretaker, mechanic and mobile unit.

If successful, it would be natural to utilize the same system for iron removal plant maintenance. This would influence the type of maintenance system, resulting in a more infrequent but possibly more sophisticated method being appropriate. The time interval for maintenance (routine downflush) should coincide with the pump maintenance interval, i.e. one month.

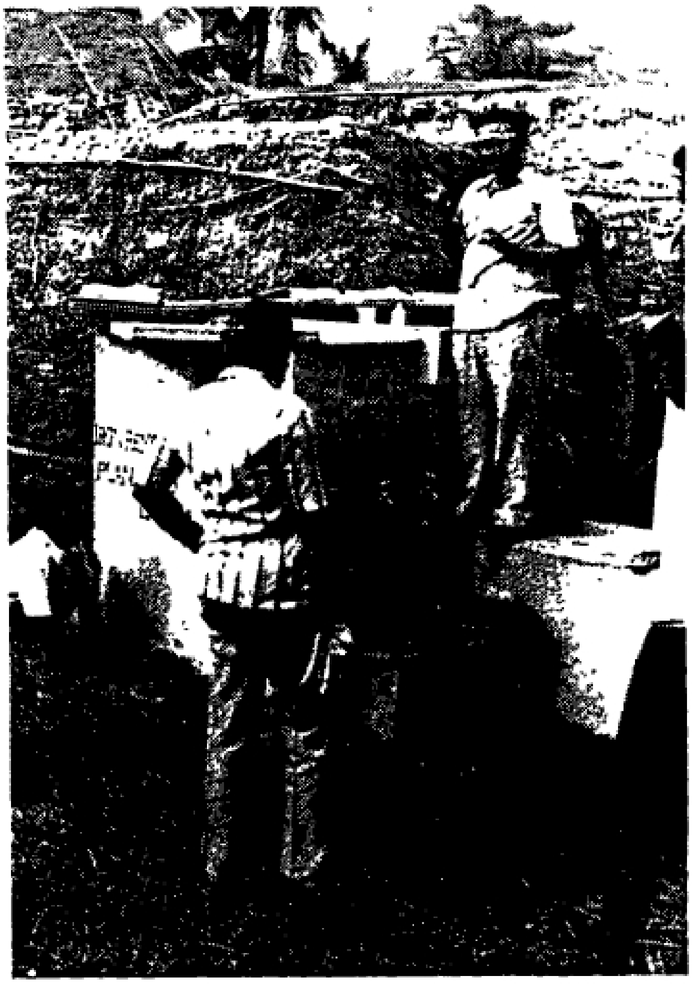
6.6 IRON REMOVAL SOLUTIONS

6.6.1 Development

In the early stages of the project, Danida sponsored development work into appropriate technological development of an iron removal plant for village level operation in connection with hand pumps.

Two Richardson and Crudas units and an earlier Danida model, the Mark I, were tested before a Danida Mark II version was developed and proven to be superior. The Danida Mark II as illustrated in Figs. 6.1 - 6.3 operates on the principles of trickle aeration over chips, downward flow through a vertical pipe into a sedimentation chamber at the bottom of the unit and then upward flow filtration through a graded bed of 3 layers of aggregate from coarse to fine. Draw-off of treated water is taken from a height of 15 cm above the top of the fine layer of aggregate thus allowing some settlement of any material which comes through the filter bed. Cleaning is carried out by filling the reservoir above the filter layer and then opening the bottom flange outlet to flush out deposited material.

Seventeen units of the Danida Mark II iron removal plant have been installed in the project area between December 1983 to June 1984. A controlled operation and monitoring system has been carried out to investigate performance and further develop the prototype design. The units were treated in effect as full scale development models. The sociological selection criteria that are normally applied to such plants were not taken into account. The maintenance system that was intended to be adopted for such units was similarly not accounted for. A much more sophisticated and expensive maintenance system making direct use of the senior staff and resources at the sub-divisional level was used. It is important then, to realize that this programme represents the results of product development and not field testing. Once a satisfactory plant has been evolved, field testing under realistic conditions will still need to be done. This is particularly important since, in the Missions's experience, acceptance and successful operation of the maintenance system is the most critical aspect of iron removal plants at village level. It cannot therefore be concluded that any system is successful or otherwise until operated and tested under the actual conditions which would exist during normal operational circumstances. As a result of field experience and developments in laboratory trials in Denmark, a larger size of fine aggregate has been introduced, 0.44 mm changed to 3-5 mm in order to lengthen filter runs and reduce head losses.



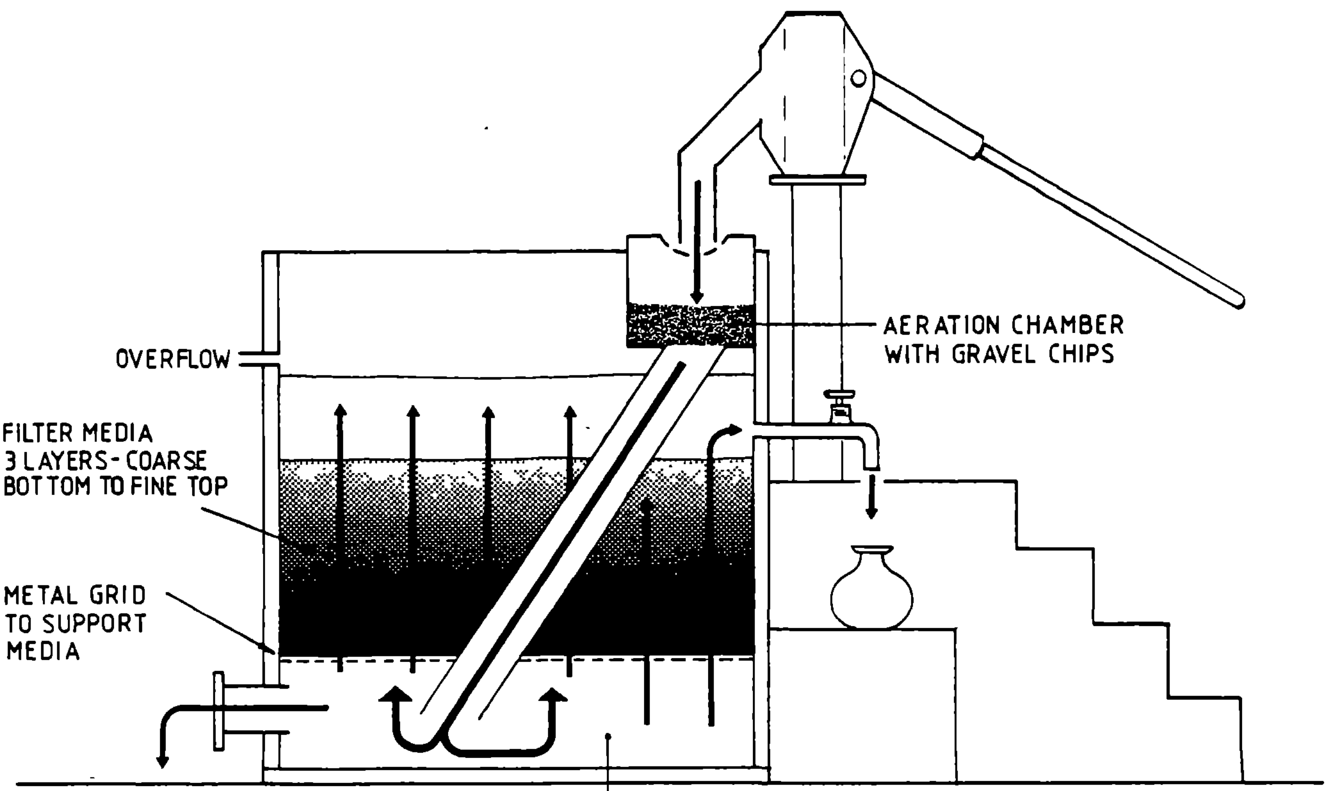


FIG 6.1 DIAGRAM OF DANIDA MK II IRON REMOVAL UNIT

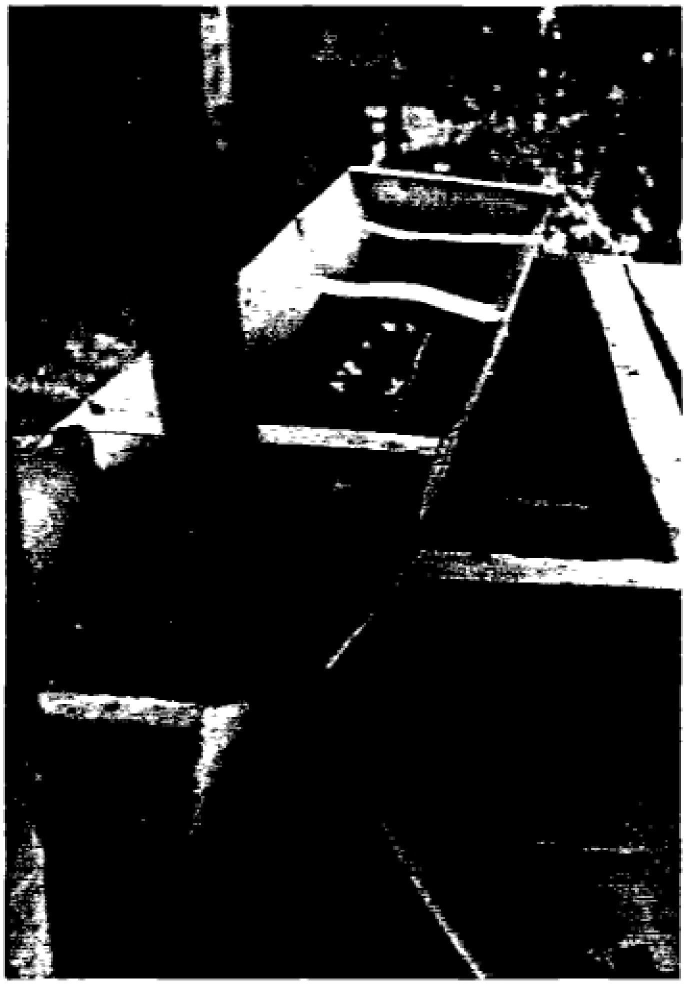


FIG 6.2 AERATION CHANNEL

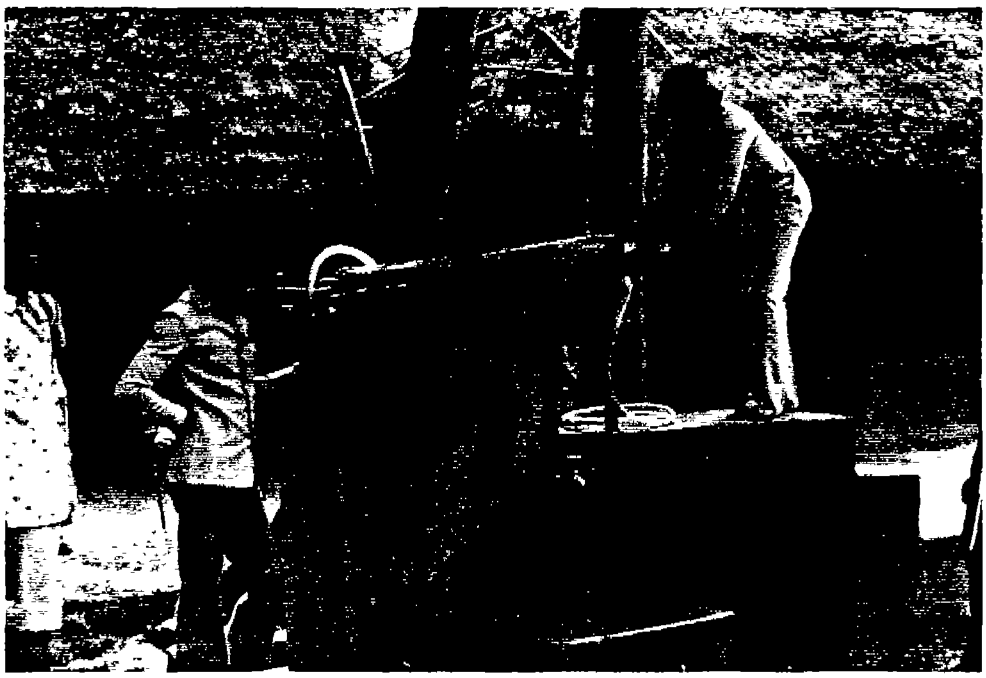


FIG 6.3 CIRCULAR DANIDA MKII UNIT

In the last year a further iron removal plant, the Danida Mark III, was developed on the project. This is a 3 chamber system including final downward flow fine filtration. This unit incorporated a system by which water was automatically stored in a backwashing tank during the course of normal operation, thus eliminating the need for a separate pumping operation for backwashing. A pilot plant was constructed and tested in connection with a piped water supply in Cuttack town. The unit, however, was not developed sufficiently to be ready for field trials in a village. It was too complicated for easy replication, and an appropriate material for mass construction had not been decided on. The philosophy behind the unit was the need to reduce the burden of backwashing effort in order to encourage regular maintenance. It was envisaged that the unit would be maintained by the users themselves, and that the ease of the operation would allow very regular backwashing and short filter runs to be possible.

6.6.2 Operation and Maintenance Experience on the Danida Mark II Unit

The Present Situation

Two types of units have been installed, both to the same design principles, but one being constructed of reinforced concrete, circular in shape and 0.9 m internal diameter, whereas the other is built in brick, cement lined and square, with 0.9 meter internal dimensions.

At the time of the Mission's visit it was reported that of the 7 plants in Gop and 9 plants in Erasame, 12 units were in operating condition. One unit in Gop was abandoned due to reported stories of a user's domination and self-interest. Two units in Erasama were not used because of alternative more attractive sources and one further unit was unused due to problems with the hand pump.

The Monitoring and Control Programme

The monitoring programme initiated in September 1984 was intended to feed back information to the Technical University of Denmark in order to further development of the plant. The monitoring was divided into

a. the carrying out of head loss measurements and routine maintenance and
b. the testing of water quality parameters.

The responsibility for the two tasks above was divided between the operation and maintenance cell and the water quality laboratory. Details of information to be recorded were detailed on two forms (Ref. I.1).

It was initially intended to conduct a monthly inspection involving both the routine maintenance and water quality testing. The procedures and designations of this programme are set out in Ref. I.1. Various changes both to the monitoring programme and the units were later carried out by instruction from the Technical University of Denmark. Remote control and monitoring of this programme from Denmark was also envisaged and copies of Forms I and II were all intended to be forwarded to the University.

Design and Defects

The Mission believes that the monitoring programme as designed could not be seen as representing field testing for the reasons outlined earlier. However, even if considered only in the role of product development, the programme suffered from some design defects.

- The water consumption data, vital to any technical assessment of the plant, was intended to be measured by the use of a stroke counter fitted to the pump handle. This device was found to be inappropriate since many people pump using only half strokes. The result is that the water consumption has never been measured (except for a very short time, cf. Ref. I.8), severely reducing the value of other data. An M.Sc. student from the Technical University of Denmark is presently engaged in fitting water meters to a few of the plants.

- The method of head loss measurement is very prone to inaccuracies of 100% or more resulting from different pumping rates by different people. Even with the same person pumping, the results are seen to be very different depending on the level of effort. The measurement of head loss is very difficult, even an imposed pumping regime such as one full stroke counted per second would be liable to field error. A comparison of head losses before and after downflush can be checked for pumping errors by comparing the absolute measurements made and this usefully serves as some control.

  Although accurate head loss measurement is useful as a direct measurement, the final design parameter is in fact the discharge available to the user. The discharge could be measured by recording the time for a bucket to fill from pumping by randomly selected women and children, and averages taken for several different categories. This measurement would yield direct information on the applicability of filter run intervals and the design criteria to be adopted.

- The downflush and head loss measurement interval was set, at one month, to coincide with the water quality testing. Thus, from the outset the downflush period was pre-determined.

  With time, it became clear that because of clogging problems the interval would have to be changed to two weeks. A further criteria that downflush should proceed once a head loss of 10 cm had developed was also introduced. When the new instruction was carried out, the routine maintenance was out of phase with the water quality testing. This out of phase was further emphasized because of the practical difficulties of two different teams operating at remote sites. The monitoring records were inspected by the Mission, and the result is that there is very little correlation between the downflush and the water quality testing. Sometimes the water quality tests were taken a day after downflush, sometimes two weeks or more. This considerably complicates the interpretation of the data and greatly reduces its value.

- Monitoring resources were greatly diluted by the need to inspect 17 remotely located sites. It is difficult to justify the need for so many identical plants at such remote locations. Any sociological research benefits that could arrive from such a diversity of units were effectively nullified because although mentioned as a concern no attempt was made to collect sociological information..

Operational Performance of the Programme

Effective monitoring systems in developing countries are not easy to design. The degree of operational perfection of the monitoring teams themselves will usually affect the quality of the collected data. In general, the operational aspects of this monitoring programme were quite encouraging. The water quality testing was performed regularly and reliably. Apart from the gaps, mentioned below, the routine maintenance and monitoring was carried out energetically and to the instructions as they were understood and interpreted. However, although some of the above monitoring programme defects were identified by the monitoring teams, no further action was taken. In addition, several large gaps in the monitoring occurred; previous to February 1985 only 30% of the units were monitored and no records were taken during July and August 1985.

Results of the Programme

As a result of the monitoring the following factors have been identified:

- The units perform to a high level. Normal operation removal rates are from a raw concentration of 10 mg/l or more down to 0.1 - 0.5 mg/l. These figures are confirmed by measurements made during the Mission's field visits.

- Filter break through occasionally occurs within two weeks after downflush and effluent iron levels rise to around 3 mg/l.

- The quality of the effluent is low immediately after backwashing. Probably indicating the presence or non-removal of released iron particles in the pore water following backwash. After 6 hours these are seen to settle and cause no further problems. This phenomenon was also observed during the field visits.

- The change of the finest filter media size from 0.7-2 mm to approx. 10 mm appears not to affect the effluent quality, whilst having significant operational advantages.

- The difference in head loss before and after downflushing appears to be very low. This would indicate that the backwashing is not very efficient. During the field visit, it was observed that the downflush water was heavily coloured in early stages of cleaning, but that this reduced considerably before the water level had fallen below the filter surface. This indicates that the colour is due principally to flushing out of the sedimentation chamber, and not due to iron particle removal within the filter. The head loss experienced with the coarser material, which has been used recently as the top layer of media in the plants, has been much less than that previously experienced and longer filter runs could consequently result.

- Complete filter media rejuvenation was found to be necessary every 3 months for discharge reasons. This substantiates the view that the downflush does not appear to be effective. The mixing of media graduation has also been reported at this stage. The process of rejuvenation takes approximately 2 days and interrups the supply.

- The Water Quality Chemist believes that anaerobic conditions occur at the bottom of the filter which could have an adverse effect on the oxidation of iron if the condition worsens.

- Although suspicion of bacteriological pollution exists due mainly to pollution of the aeration chamber and as a result of cleaning, no faecal coliform tests have yet been carried out.

6.6.3 Field Experience

The Mission visited a total of 8 iron removal plants, 4 in each of Gop and Erasame areas during 3 separate days of field visits as follows:

VILLAGE TYPE/ LOCATION	UNIT NO.	IRON LEVEL mg/l RAW	IRON LEVEL mg/l TREATED	COMMENTS
Bhairipur (circular) Gop	16	5	0.15	. Leakage from aeration chamber to treated water . Aeration chips missing . Ferric oxide deposits on aeration chips . Poor pump/plant connections resulting in leaks . Twin 1" outlets, ½" taps . Backwashing carried out 2 days previously on 31/11/85
Binplali-gon (circular) Gop	15	-	-	. Unit abandoned . Pump used but functioning poorly . Mainly school use - reported vandalism by children . Differential settlement & cracks in unit

VILLAGE TYPE/ LOCATION	UNIT NO.	IRON LEVEL mg/l RAW	TREATED	COMMENTS
Nimal (square) Ersana	2	13	0.1	• pH tested of raw: 6.70 treated: 6.82 • Head loss 9 cm • Plant backwashed on day previous to visit - 5/11/85 • Plant again backwashed during visit - head loss still 9 cm
Atimati (circular) Ersana	8	11	0.25	• Excess filter media found adjacent to unit iron stained and 3-30 mm size • Users reported very satisfied with plant and use by adjacent village also
Jogisahi (square) Ersana	5	14	0.05	• Leakage between aeration chamber and down pipe • Air locking of filter noted • 10 cm of material noted as lost due to rejuvenation process
Maliaun-dali (circular) Ersana	7	-	-	• Tube well and plant abandoned by villagers • some leakage in plant • All houses in village reported as having their own well • Severe blockage of tube well resulting in difficulty of pump operation

VILLAGE TYPE/ LOCATION	UNIT NO.	RAW	IRON LEVEL mg/1 TREATED	COMMENTS
Gogapur (circular) Gop	13	10.8	0.15 (2.0 after back-wash)	. Only one tap fitted, other pipe blocked off . Low consumption reported due to shallow wells at individual houses . Users report satisfaction with water from plant in preference to their own high iron level tube wells . Downflush twice-head loss after backwash 0 cm and 2nd backwash very clean flush water
Rulputra (circular) Gop	12	12	0 0.3 after back-wash)	. Heavy layer of iron hydroxide on surface but not disturbed by flow through unit during pumping. Backwashing carried out.

In addition to confirmation of several factors apparent from the monitoring report as outlined earlier, the Mission identified the following points during the field visits:

- Construction work was generally of a high standard, and the structural maintenance and condition of the units at the present time was good.

- Problems with details such as: Pump/plant connection, aeration channel leakages into treated water, contamination/vandalism of aeration channel, connection between the down pipe and aeration chamber leading to leakage into treated water.

- Problems with the discharge from one outlet pipe being only around 6 l/min. compared to the pump capacity of 12 to 20 l/min. This has been solved on most plants by fitting two outlet pipes and taps.

- Breakage and theft of taps (brass taps being particularly prone to theft).

- Problems with the opening of the flanged flush pipe at the base of the tank causing slow leakage during unbolting. This reduces the effect of high velocity, rapid flush down and causes operator inconvenience.

- The discharge during downflush causes drainage problems which in most cases are not properly dealt with.

- Filling up of the tank for downflush was not found to be too much of an effort either in actual fact or as perceived fact, although under the unnatural circumstances of the Mission's visit, this could not be judged to be an impartial impression.

- The problem in respect to the elevated operation of the pump was noted, but no conclusive opinions or impressions were obtained.

APPENDIX A / TERMS OF REFERENCE

Terms of Reference

for

Mission to assess iron removal technology in Danida sponsored rural water supply projects

Background

High iron contents in groundwater for domestic consumption has emerged as a serious problem in several Danida-sponsored rural water supply projects. In order to solve this problem research and development activities have been undertaken as part of some of these projects with the purpose of developing a suitable iron removal unit for use with an ordinary handpump. One type of iron removal unit has been developed and tested as part of the UNICEF national rural water supply and sanitation project in Bangladesh (sponsored by Danida), while in Orissa (India) several different types have been developed, of which one has been field tested. The problem of high iron contents has recently been experienced in a rural water supply and sanitation project in Sri Lanka.

Little coordination on the iron removal problem has taken place across country and project boundaries, and none of the solutions proposed so far appear to provide the "final answer". There is an urgent need to review the experience gained so far and outline principles for the further development and production of suitable iron removal units to be used in connection with ordinary handpumps.

Objective

The objective of the mission is to assess the "state-of-the art" in iron removal at the handpump level, review the experience gained so far in Bangladesh, Orissa and Sri Lanka, and make recommendations on future action by Danida. It is important that the mission considers both the technical (water chemistry and engineering design) and social aspects (user acceptability and village level operation and maintenance) of the problem.

Scope of work

The work of the mission shall include, but not necessarily be limited to the following:

(a) Review of the state-of-art in village level iron removal based on literature, reports, discussions with relevant persons, etc.

(b) Study of iron removal unit under development by a Danish supplier and assessment of its potential in Danida sponsored water projects.

(c) Visit to the following Danida-sponsored projects:

- Programme of basic water and environmental sanitation services in Bangladesh (UNICEF),
- Orissa drinking water project, India,
- Water supply and sanitation programme for Matale and Polonnaruwa districts, Sri Lanka.

Rural water supply projects in Sri Lanka sponsored by and Finnida shall also be visited (ref. Annex A).

During these visits the mission shall

- discuss iron removal problems with relevant project organisations including the Danida Advisers involved (ref. Annex A),
- study relevant data and reports,
- inspect selected pilot iron removal units in the project areas.

(d) Prepare a report containing assessment of the iron removal units under development or consideration in the above mentioned projects, and recommendations on future action by Danida, including proposed programme for testing and monitoring of iron removal units in these projects.

Composition of mission

The mission shall be composed by

Mr. Miles Burton, Civil Engineer (Head of Mission)
Mr. Erik.Buhl-Nielsen, Civil Engineer

Timing

After preparatory studies and discussions in Denmark ((a)-(b) above) the mission shall visit Sri Lanka, Orissa and Bangladesh in the period 21 October - 9 November 1985

Reporting

The mission's report shall be submitted to Danida not later than 3 weeks after return from the field.

Parties to be consulted by the mission

(List not complete)

Copenhagen

Mr. E. Dahi, Techn. University of Denmark
I. Krüger, Consulting Engineers
Danida Copenhagen

Sri Lanka

Mr. H. Pinidiya, Chief Engineer, Water Supply and Drainage Board, Colombo
Mr. T. Iskjaer, Danida Representative, Colombo
Mr. Diaz-Diaz, Project Officer, UNICEF, Colombo
Mr. H. L. Schroter (or successor), GTZ Project Manager, Colombo
Plancenter, Harispattuwa Water Supply and Sanitation Project, Kandy
Kampsax-Krüger, Kandy: Mr. S. W. Eriksen
Mr. H. Hoffnagel

Orissa

Danida Project Directorate:

Mr. R. N. Patnaik, Project Director
Executive Engineer, Design Division
- do. - Training and Maintenance Div.
Executive Socio-Economist
Dr. Mishra, Palasuni Laboratory
Danida Chief Adviser
Danida Socio-Economic Adviser (if available)
Danida Training and Maintenance Adviser (if available)
Danida Water Resources Adviser

Bangladesh

Danida Mission, Dhaka
Mr. C. Glennie, Chief WES, UNICEF
DPHE: Chief Engineer Khan
Mr. T. Journey, World Bank Handpump Adviser
Mr. B. Kjellerup, - do. -
Mr. K. Laubjerg, Danida Adviser (UNICEF)
Mr. E. Gosk, Danida Adviser (DPHE)

APPENDIX B / ITINERARY

ITINERARY OF MISSION'S VISITS TO SRI LANKA, BANGLADESH AND ORISSA, INDIA

Monday 21.10.85	14.30	Depart Copenhagen
Tuesday 22.10.85	07.00	Depart Karachi
	11.00	Arrive Colombo Meeting with Mr. T. Iskjaer Danida Representative, Colombo
	13.30	Travel to Kandy
	16.00	Meeting with Mr. H. Christensen and Mr. Dharmagunawandene, Kampsax-Krüger, Kandy
	18.00	Meeting with Mr. Hein Hoefnagels, Kampsax-Krüger
Wednesday 23.10.85	08.00	Meeting with Mr. Hein Hoefnagels
	11.30	Visit to the Kampsax-Krüger Laboratory
	12.30	Lunch meeting with Mr. Hoefnagels, Pendley, Kampsax-Krüger
	14.00	Field visit, Mr. Hoefnagels
Thursday 24.10.85	08.00	Meeting with Mr. Christensen
	09.00	Meeting Plancentre
	10.30	Field visit with Plancentre
	14.30	Meeting with Mr. Hoefnagels
	15.30	Meeting with Mr. Eriksen, Kampsax-Krüger
	16.00	Meeting with Pendley
	16.00	Meeting with Mr. F. Yallop, Kampsax-Krüger
	17.00	Return Colombo
Friday 25.10.85	09.30	Meeting with Mr. Diaz-Diaz, UNICEF
	11.30	Meeting with Mr. Behnsen, GTZ
	14.00	Meeting with Mr. Gunasinghe, Chief Engineer, NWSB
	14.30	Meeting with Mr. Pinidiya, Chief Engineer, Water Supply and Drainage Board, Colombo
	15.00	Meeting with Mr. Stambo, NWSB
	15.30	Meeting with Mr. Pearsen, UNICEF

Itinerary of Mission's Field Visits to Sri Lanka, Bangladesh and Orissa, India

Saturday 26.10.85	09.00	Travel to Kalutaru
	10.00	Field visit in Kalutaru with De Silva, UNICEF
	14.00	Return Colombo
Sunday 27.10.85	13.00	Depart Colombo
	18.00	Arrive Bangkok
Monday 28.10.85	19.30	Depart Bangkok
	23.00	Arrive Dhaka
Tuesday 29.10.85	08.00	Meeting with Mr. Glennie and Mr. Azad, UNICEF
	10.00	Meeting with chief engineer staff, DPHE
	11.00	Meeting with Mr. Laubjerg, Danida Adviser (UNICEF)
	12.00	Meeting with Mr. Journey and Mr. Kjellerup, World Bank Hand Pump Development Programme
	13.00	Lunch meeting with Mr. Journey and Mr. Kjellerup
	15.00	Field visit to Kaitta with Mr. Azad and Mr. Kjellerup
Wednesday 30.10.85	06.30	Travel to Sirajganj
	13.00	Meet Mr. N.A. Malek, UNICEF, Bogra
	14.30	Meeting Mr. N.I. Khan and Mr. Shemsu, DPHE, Sirajganj
	15.00	Field visit to inspect Iron Removal Plants (I.R.P.s).
Thursday 31.10.85	09.00	Meeting with Mr. Khan and Mr. Shangu, DPHE, and further field visits to I.R.P.s.
	14.00	Return to Dhaka
	18.00	Field inspection of Tara Pump
Friday 1.11.85	11.00	Meeting Mr. E. Gosk, Danida Adviser, DPHE
	16.00	Meeting Mr. K. Laubjerg, Danida Adviser, (UNICEF)

Itinerary of Mission's Field Visits to Sri Lanka, Bangladesh and Orissa, India

Saturday 2.11.85	08.00	Wrap-up meeting with DPHE, UNICEF
	10.30	Meeting with Mr. P. Nyborg, Danida Mission
	11.30	Meeting with Mr. K. Pitman, Master Planning Organization
	18.00	Meeting with Mr. B. Kjellerup
Sunday 3.11.85	09.00	Depart Dhaka
	12.00	Arrive Calcutta
Monday 4.11.85	17.00	Depart Calcutta
	19.00	Arrive Bhubaneswar
Tuesday 5.11.85	09.00	Discussions with Mr. Frederiksen and Mr. Strandby, Danida advisors
	10.00	Introductory meeting with Project Directorate
	12.00	Discussion with Mr. Pani, Dr. Misra and Mr. Kiatva
	14.30	Field trip to Gop area to inspect IRPs
	20.00	Discussions with Mr. Hvam
Wednesday 6.11.85	08.00	Field trip to Erasama to inspect IRPs
	19.00	Summary meeting with Project Directorate
Thursday 7.11.85	10.00	Inspection of laboratory
	12.00	Meeting Palasuni with Mr. Pani
Friday 8.11.85	08.00	Field trip to Gop to inspect IRPs
	16.00	Meeting with Mr. Khatva, Socio-Economist
	17.00	Wrap-up meeting with Project Directorate
Saturday 9.11.85	14.00	Depart Bhubaneswar
	19.00	Arrive Delhi
Sunday 10.11.85	03.00	Depart Delhi
	07.00	Arrive Frankfurt
	14.00	Arrive Copenhagen

APPENDIX C / LIST OF PERSONS MET

LIST OF PERSONS MET

Denmark

T. Jønch Clausen, Consultant, Danida, Copenhagen
J. Toft, Danida, Copenhagen
P.E. Frederiksen, Chief Advisor, Danida, Orissa
H.C. Strandby, Design Advisor, Danida, Orissa
J. Plough, Krüger, Copenhagen
F. Andersen, Krüger, Copenhagen
E. Dahi, Copenhagen

Sri Lanka

T. Iskjaer, Danida Representaive, Colombo
H. Christensen, Hydrogeologist, Kampsax-Krüger, Kandy
Dharmagunawerdene, Hydrogeologist, Kampsax-Krüger, Kandy
H. Hoefnagels, Senior Hydrogeologist, Kampsax-Krüger, Kandy
A. Soka Perera, National Water Supply & Drainage Board (NWSDB), Kandy
Gamage, Chemist, Kampsax-Krüger
J.P. Jensen, Drilling Supervisor, Kampsax-Krüger, Kandy
O. Krabbe, Construction Engineer, Kampsax-Krüger, Kandy
P. Reeves, Water Engineer, Kampsax-Krüger, Kandy
S.W. Eriksen, Project Manager, Kampsax-KRüger, Kandy
C.J. Pendley, Sociologist, Kampsax-Krüger, Kandy
K. Ratinen, Project Manager, Plancentre, Kandy
J. Efraimsson, Civil Engineer, Plancentre, Kandy
J. Leppänen, Civil Engineer, Plancentre, Kandy
F. Yallop, Maintenance & Training Specialist, Kampsax-Krüger, Kandy
Diaz-Diaz, Project Officer, UNICEF, Colombo
M. Behnsen, Project Manager, GTZ, Colombo
M.W.P. Wijesinghe, Consultant Hydrogeologist, Colombo
P.V. Gunasinghe, Chief Engineer, NWSDB, Colombo
H. Pinidiya, Chief Engineer, NWSDB, Colombo
C.J.A. Stambo, Chief Engineer, Groundwater, NWSDB, Colombo
S. Pearson, UNICEF, Colombo
De Silva, UNICEF, Colombo

Bangladesh

B. Kjellerup, World Bank Hand Pump Programme, Dhaka
O. Elvekjaer, Counsellor Development Cooperation, Danida, Dhaka
G. Glennie, Chief Wes, UNICEF, Dhaka
M. Azad, Wes, UNICEF, Dhaka
M. Khan, Chief Engineer, Depart. Public Health Eng. (DPHE), Dhaka
Farid, Assistant Chief Engineer, DPHE, Dkaha
Alam, Executive Engineer, DPHE, Dhaka
A. Rahman, Executive Engineer, DPHE, Dhaka
K. Lavbjerg, Sociologist, Danida Advisor to UNICEF, Dhaka
T. Journey, World Bank Hand Pump Programme, Dhaka
M.A. Malek, Programme Officer, UNICEF, Bogra
N. Islam Khan, District Engineer, DPHE, Sirajganj
Shamsu, DPHE, Sirajganj
E. Gosk, Hydrogeologist, Danida Advisor to DPHE, Dhaka
Karim, Research & Development Chairman, DPHE, Dhaka
P.H. Nyborg, Resident Representative, Danida, Dhaka
K. Pitman, Consultant Hydrogeol., Harza, Master Plan Project, Danida

Orissa

P.E. Frederiksen, Chief Advisor, Danida, Bhubaneswar
H.C. Strandby, Design Advisor, Danida, Bhubaneswar
R.N. Patnaik, Project Director, Orissa Drinking Water Project, Bhubaneswar
S. Khatua, Executive Socio-Economist, Orissa Drinking Water Project, Bhubaneswar
Dr. R.P. Misra, Analyst (chemist), Orissa Drinking Water Project, Bhubaneswar
A. Das, Assistant Engineer, Training & Maintenance, Orissa Drinking Water Project, Bhubaneswar
S. Hvam, Water Resource Advisor, Orissa Drinking Water Project, Bhubaneswar
A.K. Patnaik, Assistant Engineer, Designs, Orissa Drinking Water Project, Bhubaneswar
Pani, Executive Engineer, Training & Maintenance, Orissa Drinking Water Project, Bhubaneswar
G. Andersen, Student, Technical University of Denmark
G.N. Mishra, Executive Engineer, PURI
Harihardash, Assistant Engineer, Tirtol, Cuttack

APPENDIX D / REFERENCES

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GENERAL

	AUTHOR	TITLE	YEAR
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SRI LANKA

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BANGLADESH

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