Millennium Villages Project – Potou, Senegal
Recommendations for Iron Removal

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A DEW Point assessment by
Bob Reed, WEDC

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Recommendations for Iron Removal

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Contact and correspondence: DEW Point, The Old Mill • Blisworth Hill Barns • Stoke Road • Blisworth • Northampton • NN7 3DB • UK
TEL: +44 (0)1604 858257  FAX: +44 (0)1604 858305
e-mail: helpdesk@dewpoint.org.uk
www.dewpoint.org.uk

Authors: Bob Reed, WEDC

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Task Manager: Sarah Goodwin

Quality Assurance Internal:
Name: Sarah Goodwin
Date: 20th April 2012

Quality Assurance, DEW Point:
Ashley Thomas 31st July 2012

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1 Consortium comprises Harewelle International Limited, DD International, Practical Action Consulting, Cranfield University and AEA Energy and Environment
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<td>Centre Regional pour l’Eau Potable et l’Assainissement</td>
</tr>
<tr>
<td>CWSA</td>
<td>Community Water Supply and Sanitation Agency</td>
</tr>
<tr>
<td>MDG</td>
<td>Millennium Development Goal</td>
</tr>
<tr>
<td>MVP</td>
<td>Millennium Villages Project</td>
</tr>
<tr>
<td>PEPAM</td>
<td>Water and Sanitation Programme for the Millennium</td>
</tr>
<tr>
<td>WEDC</td>
<td>Water Development and Engineering Centre</td>
</tr>
<tr>
<td>WHO</td>
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</tr>
</tbody>
</table>
1.1 INTRODUCTION
The water supply for the Potou Region of Senegal is almost exclusively from groundwater sources. The water is sourced from a mixture of hand dug wells and boreholes. Abstraction from the hand dug wells is by bucket or handpump whilst the motorised pumps are used on boreholes. Many of the borehole sources are connected to reticulation systems.

Water testing in 2008 highlighted a problem with high iron content in many of the sources, causing nuisance including staining of clothing, poor taste and blocking of pipes.

As a result of these issues the consultant was asked by the Project team to develop cost effective solutions to the problem and in particular:

1. Review the background material included in the Terms of Reference to this contract (Appendix 1);
2. Propose feasible technical options for the removal of iron at Potou; and
3. Provide broad estimates of capital and recurrent costs, bearing in mind that the water supply system is managed by local borehole management committees from the proceeds of user fees.

1.2 WATER QUALITY GUIDELINES FOR IRON
The World Health Organisation (WHO) (2011) state that iron contamination is not a health concern at levels causing acceptability problems in drinking water. However, at levels above 0.3mg/l, iron stains laundry and plumbing fixtures and is considered the level at which noticeable taste issues may arise.

In other words, a level of 0.3mg/l is considered the recommended maximum level of iron contamination for aesthetic rather than health reasons.

However, individual countries have set higher limits on contamination in line with local constraints. Bangladesh for example, sets a maximum limit of 1.0mg/l for drinking water but accepts up to 5.0mg/l from rural handpumps where people are accustomed to drinking from that source (Ahmed & Rahman 2000).

1.3 SCOPE OF PROBLEM IN POTOU REGION
Based on the water quality data given in Appendix 2 and the additional information given in Appendix 3 it can be seen that of the 23 water quality samples provided, 8 exceed the WHO recommended maximum levels of 0.3mg/l and 4 exceed the Bangladesh recommendations (1.0mg/l). Of the 8 sources exceeding the WHO recommendations, 3 are boreholes. Of the 4 sources exceeding the Bangladesh recommendations, 2 are boreholes.

The geographical spread of the contamination is somewhat random. The highest contamination is generally in the east but there is also a lower level of contamination in the wells of the coastal belt.

It is noted that the pH levels of both well and borehole waters is generally low. As will be seen later, this could have an effect on the efficiency of iron removal systems.

1.4 PRINCIPLES OF IRON REMOVAL
Groundwater often contains iron, especially where oxygen levels in the water are low. The iron can be present in several forms, namely solution, colloidal, suspension, mixed with other minerals or as an organic substance (Twort et.al. 2000).

The most common method of removing iron from solution (its common state in underground water) is by oxidation, followed by a combination of sedimentation (where concentrations are high) and filtration. Oxidation is commonly achieved through the exposure of the water to air, but chemicals such as chlorine, potassium permanganate and ozone can also be used. The rate of oxidation is heavily dependent on the pH, with higher pH levels (above 7.2) needing much lower reaction times than lower ones (Twort et. al. 2000).

Where iron has formed soluble complexes with organic substances oxidation may not be effective.
Iron can also be removed bacteriologically using organisms that promote oxidation in the presence of oxygen. These organisms are usually present in the groundwater and so will readily grow in a suitable environment.

This paper assumes that the normal treatment methods are appropriate for this project. If difficulties occur during piloting then other possible treatment options can be considered.

**Key design features**

**Aeration**

Aeration is widely used for the treatment of ground water with high iron content. There are a variety of devices for achieving this but they all provide an opportunity for a large surface area of water to come in contact with air. Aeration also has the effect of reducing concentrations of dissolved CO₂ in the water.

**Multiple tray aerators (Smet & Wijk 2002)**

4 – 8 trays with perforated bottoms are stacked at intervals of 30 – 50 cm. The water trickles down the plates at a rate of around 0.02 m³/m²s of tray surface (Figure 1).

A similar device for handpump based units is shown in Figure 2. A length of pipe with slots or holes cut in the bottom is used to disperse the water flow. No design figures are available for this design but the figures given above may be appropriate.

![Figure 1. Multiple tray aerator (Smet & Wijk 2002)](image1.png)

![Figure 2. Trickle aerator on handpump (Smet & Wijk 2002)](image2.png)
**Cascade aerators (Smet & Wijk 2002)**

Essentially these consist of a flight of 4 – 6 steps each about 30cm high with a capacity of about 0.01m³/s per m width (Figure 3). Obstacles are sometimes placed along the weir edge to promote turbulence.

![Cascade aerator](Figure 3. Cascade aerator (Smet & Wijk 2002))

**Multiple platform aerator (Smet & Wijk 2002)**

Similar in concept to the cascade aerator, each platform should have a slight rim on it to ensure a shallow pool of water is contained (Figure 4).

![Multiple platform aerator](Figure 4. Multiple platform aerator (Smet & Wijk 2002))
**Spray aerators (Smet & Wijk 2002)**

Stationary nozzles connected to a distribution pipe spray water into the surrounding area at a velocity of around 5 – 7m/s. Simple sprays direct the water downwards (Figure 5), thus using gravity to increase the velocity (they can be fitted to a handpump), others spray upwards or sideways against a baffle plate. Holes should be more than 5mm diameter to prevent clogging.

![Figure 5. Simple spray sprinkler (Luizi et.al. 2004)](image)

**Venturi aeration (Smet & Wijk 2002)**

On larger plants oxygen can be injected into the water by the use of a venturimeter (Figure 6). The contraction in the diameter of the pipe (called the throat) temporarily increases the velocity of flow and lowers the water pressure. By judicial selection of throat diameter and velocity it is possible to reduce the pressure to less than atmospheric. When a small pipe connected to an air intake is inserted into the throat, air will be drawn into the pipe and mix with the water. The process is simple and has no moving parts. Some energy is lost through the venturimeter but its use requires less space than the alternative options.

![Figure 6. Venturi aerator (Smet & Wijk 2002)](image)

**Filtration**

Whilst most authors agree that a filtration stage following aeration is needed for iron removal there is little agreement on what form the filter should take. This may be because many iron removal plants are designed empirically rather than on a scientific basis.

Where iron concentrations are less than 5mg/l, filtration through sand (effective size 0.6mm) at a rate of 7.5m³/h.m² is generally effective (Twort et. al. 2000). The problem with sand however, is that it quickly blocks and needs frequent cleaning. Some authors suggest a grain size of 1 – 3mm. It is important that the sand bed remains well oxygenated to ensure the full precipitation of the iron. Small scale plants should be designed so that the sand bed dries out between uses.
A preliminary roughing filter using gravel (10 – 50mm) is also commonly recommended to help with the oxidation and flocculation processes to remove the iron.

**Sedimentation**

A compartment is normally provided for the sedimentation of any iron that has come out of solution during the aeration process. This is generally a tank that supports quiescent conditions. Again no specific guidelines were found for iron precipitation but a surface loading figure of around 0.1 – 1.0m/hour is suggested.

**Flow rate**

An ideal treatment system must remove iron and deliver water efficiently and conveniently, almost as if the unit was not there (Tyrrel 1997). In handpump based units this is not as simple as it sounds. The necessity for a head of water to build up over the sand layer to drive the water through the bed means that substantial water must be pumped before a flow starts through the outlet. A method of overcoming this problem is to reduce the volume of stored water above the sand bed without lowering the head. This can be done by covering the top of the sand bed with gravel or placing light weight ballast such as plastic bags filled with water on top of the sand (Figure 7).

![Figure 7. Sketch of iron removal plant showing ballast on top of the sand (Tyrrel 1997).](image)

### 1.5 IRON REMOVAL PLANTS

**Options for handpumps and buckets**

A variety of processes have been devised for removing iron from water delivered by handpump. Many seem to work well, at least in the short term, but there is little evidence of their sustainability. There is also very little information about the water treated or the key design parameters. No references to iron removal plants for water drawn by bucket have been identified although the author sees no reason why the plants designed for handpumps should not be adapted. Only models that appear to have had some level of development and use are presented here.
**Finnida square iron removal plant Sri Lanka (Hartman 2001)**

Developed in 1989, this simple design has proven very successful (Figure 8). 150 units were constructed and most were still in use with around 90% removal efficiency in 2001. Each plant was designed to serve around 100 users.

The box is made of local brick with the lid of three sections of reinforced concrete. The unit is divided into two chambers, the first a tapered trough formed from concrete slabs packed with 10 – 25mm granite chips (this replaced the charcoal shown in Figure 8). The second contained a 6cm layer of 1 – 3mm sand. Water enters at the bottom of the gravel pack, passes upwards and overflows onto the sand bed. To ease cleaning, the top of the sand bed was covered with a non-woven layer of fabric which could easily be removed for cleaning. A perforated pipe at the base of the sand collects the filtered water and discharges it at the outlet. Both chambers had washout ports.

Operational difficulties included insect breeding because of poor replacement of the covers, and damage to the edges of the concrete lids because of frequent handling.

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Figure 8. Finnida iron removal plant, Sri Lanka (Hartman 2001)
CREPA Plant, Burkina Faso (Hartman 2001)

Designed in 1990, this plant was developed for handpumps and iron concentrations less than 5mg/l. The unit is designed as a gravity tower system incorporating aeration and filtration (Figure 9). The bottom filter section can be operated as either up flow or down flow but best results have been obtained using the up flow mode. Filter cleaning is necessary every 4 weeks. CREPA have a range of publications related to the construction and maintenance of their units.

Figure 9. CREPA iron removal plant (Hartman 2001)
Bangladesh Plant (Ahmed & Rahman 2000)
This three chamber unit (very similar to that shown in Figure 2) combines aeration with an up flow coarse gravel filter followed by a down flow coarse sand filter (Figure 10). Iron removal efficiencies are claimed to exceed 90%. Clogging of the down flow filter is sometimes a problem but can be reduced by using a more coarse grain size. Typical flow rate is approximately 22l/m.

Figure 10. Bangladesh iron removal plant (Ahmed & Rahman 2000)
Mwacafe Ghana (Siabi 2004)
This unit was developed by the Community Water and Sanitation Agency (CWSA), Ghana but information on it is scarce and no technical drawings have been found. The unit appears to consist of four compartments approximately 1m high, 1m deep and 0.5m wide (Figure 11). The first compartment acts as a settlement tank, the second contains graded gravel, the third contains layers of clean sand and activated carbon and the fourth contains clean sand and stored treated water. Water is delivered directly from a handpump into the first chamber; water is collected from the fourth chamber. Over 600 units have been installed in Ghana and efficiency is claimed to be 95% over more than 3 months but the operating period could be as high as 2 years for lower iron levels.

![Figure 11. Mwacafe plant (Agyarko 2012)](image)

Options for motorised boreholes
The treatment processes used for larger scale water supplies are essentially the same as for handpumps; only the treatment process is no longer contained within one unit but divided into a series of treatment processes. Very few examples of complete processes are described in the literature; designers are generally expected to work from first principles. The examples below illustrate possible combinations. An alternative would be to use the designs described for handpump supplies and scale them up.
Seven villages water supply, Ghana (Hartman 2001)

Designed for a community water supply serving approximately 11,000 people and based on a borehole source (Figure 12). Water is pumped from the source to the top of an aeration cascade which discharges into a two compartment down flow and up flow storage tank to assist sedimentation. From there it overflows into a second tank which feeds the filter. Two pressure filters fitted in parallel contain a bed of fine sea sand resting on a layer of coarse sand. The filters are backwashed about twice a day. Filter efficiency is reported to be around 90%.

Figure 12. Seven villages water treatment plant (Hartman 2001)
Small town plant, Bangladesh (Ahmed & Rahman 2000)

Borehole water passes over a cascade and onto a down flow filter containing coarse sand on a bed of gravel (Figure 13). Efficiencies vary between 40 and 80%. The unit requires frequent back washing, using up to 25% of the water produced.

![Figure 13. Small towns iron removal plant Bangladesh (Ahmed & Rahman 2000)](image)

1.6 OPERATION AND MAINTENANCE

All iron removal plants require regular maintenance. As the iron precipitate builds up in the filters it has the combined effect of increasing the iron removal efficiency (existing iron molecules provide extra attraction to iron molecules suspended in the water) and lowering the flow rate. Eventually the flow rate is reduced so much that the filter must be cleaned to remove deposited iron. Coarse filters are usually cleaned by backwashing which is generally accomplished by rapidly drawing down the water within the filter.

Sand filters are generally cleaned by stirring them while flooded. This releases the iron flocs and trapped gas which then rises to the water surface. The flocs are removed by decanting the top water. Eventually the sand will become highly impregnated with iron, requiring it to be removed from the filter and thoroughly cleaned.

Some units include a layer of activated carbon that periodically requires replacement. There is a cost involved in this but it is difficult to estimate its scale as it depends whether the material is imported or manufactured locally. As no other chemicals are used and there are very few moving parts the only other operational requirements are general cleaning and maintenance of power and pumping units on larger scale plants.

In areas (such as Potou Region) where the number of treatment units is few and widely spaced, long term technical backup is essential. It is unlikely to be financially viable for a private company to take on this role, so it must be provided by a government department or subsidised organisation.

1.7 SUSTAINABILITY ISSUES

Once a treatment process has been proven, the main issues affecting sustainability are poor construction and routine maintenance. The former is generally because of weak management and supervision during the construction phase. The latter is because of poor engagement with the user community during the construction process. This is particularly true for units connected to handpumps.

For larger scale units the other main issue affecting sustainability is the reliability of funding to pay operators and power costs. Most plants require at least one full time operator, but two are recommended.

A much overlooked issue with handpump based units is accessibility. Handpumps are frequently raised to provide the hydraulic head to drive the units (see Figure 10 for example). Alternatively
outlets are set close to or below ground level for the same reason (such as shown in Figure 9). This can be a serious access issue for young children, the elderly, pregnant women and people with a disability. Further design development is required to make inlet and outlet points more accessible.

Care must also be taken to ensure the water delivery point is sympathetic to the container used for collecting water and the method of transport. Multiple outlet points are sometimes needed to cater for different water containers or transport modes.

1.8 COSTS

Very little information exists relating to costs and what does, is old or unreliable. The tables below set out the information found but as can be seen it is very diverse. The author is certain that the application of good engineering principles could make a significant impact on capital costs.

Capital costs

<table>
<thead>
<tr>
<th>Design</th>
<th>Cost (US$)</th>
<th>Year</th>
<th>Approx. present value (US$)</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finnida square iron removal plant Sri Lanka*</td>
<td>40</td>
<td>1989</td>
<td>100</td>
<td>100 users</td>
</tr>
<tr>
<td>CREPA Plant, Burkina Faso*</td>
<td>360</td>
<td>1990</td>
<td>930</td>
<td></td>
</tr>
<tr>
<td>Mwacafe Ghana*</td>
<td>3400</td>
<td>2012</td>
<td>3400</td>
<td></td>
</tr>
<tr>
<td>Mwacafe large scale unit, Ghana (Appendix 3)</td>
<td>42,700</td>
<td>2012</td>
<td>42,700</td>
<td>1,500</td>
</tr>
</tbody>
</table>

Note: Filter output is primarily affected by the handpump discharge which is a function of the depth to the water table. For lifts less than 10m the discharge is around 22 l/min whilst for a lift of 30m the discharge is around 10 l/min.

Annual operating costs (excluding labour)

<table>
<thead>
<tr>
<th>Design</th>
<th>Cost (US$)</th>
<th>Year</th>
<th>Approx. present value (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finnida square iron removal plant Sri Lanka*</td>
<td>2.50</td>
<td>1989</td>
<td>6.80</td>
</tr>
<tr>
<td>CREPA Plant, Burkina Faso</td>
<td>80</td>
<td>1990</td>
<td>207</td>
</tr>
<tr>
<td>Mwacafe Ghana</td>
<td>132</td>
<td>2012</td>
<td>132</td>
</tr>
</tbody>
</table>

Project cost

Based on the information currently available it is not possible to estimate a total cost for the programme. However, the capital costs of some installations can be estimated. These estimates do not include institutional, supervision or overheads costs.

Note: These estimates assume the sources can deliver the necessary quantity of water to meet the demand.

<table>
<thead>
<tr>
<th>Location</th>
<th>Source</th>
<th>Affected population</th>
<th>Approx Cost (US$)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same Ndiaye</td>
<td>Borehole</td>
<td>8033</td>
<td>222,500</td>
<td>Large scale unit</td>
</tr>
<tr>
<td>N Dialekhar</td>
<td>Borehole</td>
<td>8398</td>
<td>240,000</td>
<td>Large scale unit</td>
</tr>
<tr>
<td>Cherif Mbaye</td>
<td>Borehole</td>
<td>95</td>
<td>3,400</td>
<td>1 No. small unit</td>
</tr>
<tr>
<td>Syer Wolof</td>
<td>Well</td>
<td>?</td>
<td>Depends on population</td>
<td></td>
</tr>
<tr>
<td>N Dialekhar</td>
<td>Well</td>
<td>?</td>
<td>Depends on population</td>
<td></td>
</tr>
<tr>
<td>Well</td>
<td>Source</td>
<td>Iron Removal</td>
<td>Capacity</td>
<td>Notes</td>
</tr>
<tr>
<td>--------------</td>
<td>--------</td>
<td>--------------</td>
<td>----------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Wakhal Diam</td>
<td>Well</td>
<td>224</td>
<td>6,800</td>
<td>2 No small units on separate sources</td>
</tr>
<tr>
<td>Mourel</td>
<td>Well</td>
<td>709</td>
<td>25,000</td>
<td>Reduced large scale unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Assuming single source &amp; treated water only for humans</td>
</tr>
<tr>
<td>Niavam</td>
<td>Well</td>
<td>830</td>
<td>25,000</td>
<td>Reduced large scale unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Assuming single source &amp; treated water only for humans</td>
</tr>
</tbody>
</table>

**1.9 FURTHER INFORMATION**

Two organisations in West Africa have wide experience of the construction and operation of iron removal plants at community level. Readers are strongly advised to contact both of them before undertaking serious development work.

Centre Regional pour l’Eau Potable et l’Assainissement a faiblecout (CREPA), 27, rue de Wayalghin, Ouagadougou Burkina Faso, skenfack@yahoo.frhttp://www.reseaucrepa.org/

Community Water Supply and Sanitation Agency (CWSA) Ghana. [http://www.cwsagh.org/](http://www.cwsagh.org/) email info@cwsagh.org

**1.10 NEXT STEPS**

1. Review the information in this report and consider whether the construction of a small number of iron removal plants is likely to be sustainable. Based on the data provided, only five handpump based units are required and three borehole based units. Bearing in mind the ongoing external support and maintenance these units require, is it going to be possible to establish a sustainable support environment for such a small number of units? The author strongly suggests not continuing further with this development if the Programme cannot guarantee support to recipient communities for operation and maintenance for at least 3 years after construction is complete.

2. An alternative to iron removal may be the provision of bottled water from established suppliers with untreated water being used for non-drinking purposes.

3. Arrange a visit to CREPA and CWSA Ghana to learn more about their experiences and explore the sustainability of their designs. Based on these visits it should be possible to decide which design is most appropriate for Senegal and gain more details of construction and operational costs.

4. Construct a handpump based pilot unit, probably based either on the Mwcafe or CREPA design. It may be advisable to invite a representative from CREPA or CWSA to participate in the design and construction process. Also to assist with community training for operation and maintenance.

5. Construction of the remaining four handpump based units can follow immediately after the first unit is completed and incorporate lessons learned from the construction of the first.

6. Design and construction work for the borehole based units is much more complex and the author recommends the employment of a competent consultant to design the iron removal plant for each site. Prior to this a detailed assessment of the operational costs must be undertaken together with a sustainability plan for generating the necessary revenue.
2 REFERENCES


APPENDICES

Appendix 1

Terms of Reference
Millennium Villages Project – Potou, Senegal
Study and recommendations for iron removal

Background

The Millennium Villages Project:
The Millennium Villages Project (MVP) offers an innovative model for helping rural African communities to lift themselves out of extreme poverty. The Millennium Villages are proving that by fighting poverty at the village level through community led development; rural Africa can achieve the Millennium Development Goals by 2015, and escape the extreme poverty that traps hundreds of millions of people throughout the continent.

With the help of new advances in science and technology, project personnel work with villages to create and facilitate sustainable, community-led action plans that are tailored to the villages’ specific needs and designed to achieve the Millennium Development Goals.

Currently some 80 Millennium Villages are clustered into 14 different sites in 10 countries. Each cluster site is located in a distinct agro-ecological zone. These zones represent the farming systems used by 90% of the agricultural population and 93% of the agricultural land area of sub-Saharan Africa. The site characteristics range from slash-and-burn in rainforest margins to pastoralism in deserts and represent different situations of population density, soils, climate, water access, disease complexes and burdens, environmental degradation, market access, education levels, cultures, religions, and gender issues.

The Potou region

The Millennium Village cluster in Senegal is located in Potou. This is in the Niayes zone of Senegal, bordering the maritime fringe of the north. The zone (a 5 to 10km strip along the shoreline) is a densely populated area (more than 20% of the country’s population live on less than 1% of the territory). The area includes the coastal artisanal fish farming system, where the majority of the inhabitants practice agriculture, livestock production and fishing.

The water supply situation in Potou

In the MVP project site at Potou in Senegal, the number of feasible water supply alternatives is limited. The nearest surface water source is the Lac de Guiers, which is located approximately 50 miles northeast of the project site and is a primary source of drinking water for Dakar. A large water treatment facility is located on the western shore of the lake and treated water is piped to Dakar, passing within 20 miles of the project site. However, due to Dakar’s enormous demand for drinking water, this piped water is not available for the project site’s use.

The only readily available and reliable source of water is groundwater. There is a major aquifer running north to south along the eastern boundary of the CR-Leona at depths of 60-100 metres that can provide borehole yields higher than 50 m³/hr; more than sufficient to meet local demand. This aquifer has been exploited for centuries by open wells in the inland villages of the project zone, but these are not considered improved sources as water availability varies throughout the year, and they are open and subject to contamination. Because of their depth, it requires a tremendous amount of physical effort to use these inland open wells. This aquifer becomes much shallower (4-8 meters) nearer to the coast, providing easier access, but salt water intrusion and agricultural runoff begin to render the water quality unsuitable for human consumption. For these coastal areas, therefore, the only viable solution is to pipe in water from the deeper inland aquifer, which is possible due to the favourable elevation gradient towards the coast (sea level).

In 2005 the Government of Senegal created the Water and Sanitation Program for the Millennium (PEPAM), as a sector-wide approach to oversee all water supply and sanitation investments in the country. In 2008, the donor-funded Millennium Villages Project, working within this framework and in direct collaboration with PEPAM and an American-based PVC pipe manufacturer, JM Eagle, installed a piped drinking water system in north-western Senegal. The new system increased improved drinking water coverage from 56% to 99.5% through a total of 85 public taps installed at an average of 220 meters from the household.
The water quality in Potu

Testing of the water in Potu has established that the iron content is high and exceeds the WHO guideline levels. The results of tests undertaken by the national water company in 2008 are appended to these Terms of Reference (appendix 2).

The levels of iron in the water are the cause of nuisance including staining of clothing and poor taste of the water. In addition, a drip irrigation system installed in the area has ceased to function due to blockage of piping. It is not clear whether there are any significant effects on human health.

As a result of these difficulties, the services of a consultant are required to assist the Millennium Village Project team at Potu in Senegal to develop a cost-effective solution to the problem.

The scope of work

The work to be undertaken by the Consultant will include the following:

i. Review the background material included in this Terms of Reference

ii. Propose feasible technical options for the removal of iron at Potu

iii. Provide broad estimates of capital and recurrent costs. It will be important to bear in mind that the water supply system is managed by local borehole management committees (ASUFORS) from the proceeds of user fees.

Consultant personnel

The DEW Point Resource Centre will provide an expert from the staff of the Water Development and Engineering Centre (WEDC) of Loughborough University with significant international experience in sustainable low-cost water treatment technology.

Deliverables

The consultant will deliver a report in electronic format (MS Word) by 13th April 2012.

Reporting

On contractual and administrative issues, the consultant will report to Sarah Goodwin, the Core Services coordinator of the DEW Point Resources Centre. For the purposes of obtaining technical information, the consultant may contact any of the following;

1. Dawda Jawara, Regional Infrastructure Coordinator, MDG Centre, Bamako, Mali.
   Email: dawda.jawara@millenniumpromise.org
   Tel: +223 71 27 50 60
   Skype: dawda.jawara

2. Dr. Serigne Kandji, Team Leader Millennium Villages Project, Potu, Senegal
   Email: serigne.tacko.kandji@millenniumpromise.org
   Tel: +221 774 504 465
   Skype: serignekandji

3. Babacar Faye: Millennium Villages Project, Potu, Senegal
   Email: Babacar.faye@millenniumpromise.org
Appendix 2

Water Quality Data

Potou Water Quality data from Terms of Reference

Concerning problem of iron content in Potou, I had contacted the DFID / DEW Point Resource Centre on Water and Sanitation in UK. They can give us assistance to study the problem and propose a cost effective and sustainable solution. They will make available an expert from Loughborough University - Water Engineering and Development Centre (WEDC) but only for 2 days input.

Before the expert starts his work we need to put together all the relevant information so that he can effectively use the 2 days to complete his assignment.

We need to compile the following information;

1. We can present the 2008 iron concentration data (see attached) on a map (see attached two maps originally prepared by Potou team and Brett for the sampling). We can put the concentration on the map, and also indicate the source of water (borehole, well or tap).

2. We can also adapt the attached spreadsheet to show the following;

<table>
<thead>
<tr>
<th>Location</th>
<th>Type (borehole, tap, or well)</th>
<th>Iron concentration (mg/l)</th>
<th>Type of uses (drinking, irrigation, livestock watering etc.)</th>
<th>Population affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDIEUMB FALL</td>
<td>Borehole</td>
<td>1.59</td>
<td>drinking</td>
<td>8279</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.05</td>
<td></td>
<td></td>
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<tr>
<td>NDIEUMB FALL</td>
<td>Well</td>
<td>0.29</td>
<td>drinking</td>
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<td>SAME NDIAYE</td>
<td>Borehole</td>
<td>2.5</td>
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<td>8033</td>
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<td>Sam Ndiaye</td>
<td>Well</td>
<td>0.2</td>
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<td></td>
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<tr>
<td>DJADJI GOUMACK (NDIAYE)*</td>
<td>Well</td>
<td>0.1</td>
<td>drinking</td>
<td>224</td>
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<tr>
<td>SYER NDIAYE (SYERE OUOLOF)</td>
<td>Borehole</td>
<td>2.2</td>
<td>Drinking</td>
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<tr>
<td></td>
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<td>Syer Wolof</td>
<td>Well</td>
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<td>N Dialékhar</td>
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<td>drinking</td>
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<td>Ndembal</td>
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<td>drinking</td>
<td>94</td>
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<tr>
<td>Potou I</td>
<td>Well</td>
<td>0.01</td>
<td>drinking, irrigation, livestock watering,….</td>
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<td>Location</td>
<td>Type</td>
<td>Iron Level</td>
<td>Uses</td>
<td>Q (m³/day)</td>
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<td>--------------</td>
<td>------------</td>
<td>------------</td>
<td>-------------------------------------------</td>
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<td>Well</td>
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</table>

The 2008 sampling did not cover all the population so we have to make a calculation or estimate of the total population affected by the high iron concentration.

3. We may need to do additional water quality tests if you think it is necessary; perhaps repeat the 2008 tests. Please advise me on this. Of course this depends on your budget and we must do it immediately.

- It is not necessary to do another study of water when one considers that only the last in 2008.

4. What have the Senegalese authorities been doing to solve the problem?

- It seems that the Senegalese authorities consider that the iron levels found are not a danger to the consumer.
**Original water quality testing results (Jawara D 2012)**

<table>
<thead>
<tr>
<th>ECHANTILLONS</th>
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<tbody>
<tr>
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<tr>
<td>Nature de l'échantillon</td>
<td>Eau de puits</td>
</tr>
<tr>
<td>Lieu de prélèvement</td>
<td>Wakhal Diam</td>
</tr>
<tr>
<td>Date de prélèvement</td>
<td>12/11/08</td>
</tr>
<tr>
<td>Date d'arrivée au Labo</td>
<td>In situ</td>
</tr>
<tr>
<td>Début des analyses</td>
<td>12/11/08</td>
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<tr>
<td>Fin des analyses</td>
<td>15/11/08</td>
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**Paramètres**

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<td>6,68</td>
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<td>Conductivité (µS.cm⁻¹)</td>
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<td>183</td>
<td>414</td>
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<td>250</td>
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<td>0,8</td>
<td>12</td>
<td>13,2</td>
<td>50</td>
</tr>
<tr>
<td>Nitrates, NO₃ (mg/l)</td>
<td>6,8</td>
<td>4</td>
<td>4,3</td>
<td>3,1</td>
<td>50</td>
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<tr>
<td>Ammoniacque, NH₄ (mg/l)</td>
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<td>0</td>
<td>0,15</td>
<td>0,11</td>
<td>10</td>
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<tr>
<td>Fer, Fe (mg/l)</td>
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<td>0,12</td>
<td>1,75</td>
<td>0,57</td>
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<tr>
<td>Phosphates, PO₄ (mg/l)</td>
<td>0,70</td>
<td>0,36</td>
<td>0,33</td>
<td>0,31</td>
<td>10</td>
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**Observations**

- Eau douce au forage et au puits de W.Diam.
- Eaux moyennement minéralisées à Ndialkahar Samb.
- Présence de fer notée à W.Diam (puits) et Ndialkahar Samb (puits et forage).
# Bulletin d'Analyses Physico-Chimiques des Eaux

**Nom du Demandeur:** The Millennium Villages Project, Fax: 98 700 80  
**Region:** Louga  
**Nom du Preleveur:** Sidy Cissé

<table>
<thead>
<tr>
<th>Echantillons</th>
<th>Nature de l'échantillon</th>
<th>Directives</th>
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<th>IDE</th>
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<tr>
<td></td>
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<td>Eau de forage</td>
<td>Eau de forage</td>
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<tr>
<td></td>
<td>Syer Wolof</td>
<td>Syer Wolof</td>
<td>Chérif Mbaye</td>
<td>Figaré NGol</td>
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<td>In situ</td>
<td>In situ</td>
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<td>13/11/08</td>
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<tr>
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<td>In situ</td>
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<td>14/11/08</td>
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<td>13/11/08</td>
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### Paramètres

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<tr>
<td>Ph</td>
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<td>6.71</td>
<td>6.34</td>
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<td>334</td>
<td>230</td>
<td>239</td>
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<td>Chlorures, CT (mg/l)</td>
<td>326,6</td>
<td>56,8</td>
<td>56,8</td>
<td>49,7</td>
<td>56,8</td>
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<td>Dureté Totale, TH (°F)</td>
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<td>6</td>
<td>6</td>
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<td>Nitrates, NO₃ (mg/l)</td>
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<td>2,4</td>
<td>2,4</td>
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<td>0,07</td>
<td>0,01</td>
<td>0,02</td>
<td>0</td>
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<tr>
<td>Fer, Fe (mg/l)</td>
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<td>1,21</td>
<td>1,41</td>
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<tr>
<td>Phosphates, PO₄ (mg/l)</td>
<td>0,37</td>
<td>0,04</td>
<td>1,52</td>
<td>2,22</td>
<td>0,25</td>
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</table>

### Observations
- Eau acide et très minéralisée avec une forte teneur en nitrates au puits de Syer Wolof.  
- Eau faiblement minéralisée pour le reste.  
- Présence de fer à Syer Wolof (puits et forage) et à Chérif Mbaye.

---

Le chimiste  
B. Haidara MBAYE  
Date: 13/11/08  
Vis : I.
**BULLETIN D'ANALYSES PHYSICO-CHIMIQUES DES EAUX**

**NOM DU DEMANDEUR :** THE MILLENNIUM VILLAGES PROJECT, Fax : 98 700 80

**REGION :** Longa

**NOM DU PRELEVEUR :** Sidi Cissé

<table>
<thead>
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<tr>
<td>Nature de l'échantillon</td>
<td>Eau de puits</td>
</tr>
<tr>
<td>Lieux de prélèvement</td>
<td>Sam Ndiaye</td>
</tr>
<tr>
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<td>12/11/08</td>
</tr>
<tr>
<td>Date d'arrivée au Labo</td>
<td>In situ</td>
</tr>
<tr>
<td>Début des analyses</td>
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<td>15/11/08</td>
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**Paramètres**

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<td>Nitrates, NO₃ (mg/l)</td>
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<td>0,39</td>
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<td>0,05</td>
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<td>0,32</td>
<td>0,16</td>
<td>0,93</td>
<td>0,60</td>
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**Observations :**
- Eau faiblement minéralisée à Sam Ndiaye et à Ndiamb Fall (forage), moyennement minéralisée à Potou 1.
- Présence de fer à Sam Ndiaye (forage).

Le chef de Service, Traitement des Eaux

Le chef de Service, Traitement des Eaux

Le chef de Service, Traitement des Eaux
**BULLETIN D'ANALYSES PHYSICO-CHIMIQUES DES EAUX**

**NOM DU DEMANDEUR :** THE MILLENNIUM VILLAGES PROJECT, Fax : 98 700 80  
**REGION :** Louga  
**NOM DU PRELEVEUR :** Sidy Cissé

<table>
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<tr>
<td>Lieux de prélèvement</td>
<td>Gabar 1</td>
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<td>Date de prélèvement</td>
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<td><strong>Paramètres</strong></td>
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**Observations :** - Eau très minéralisée aux puits de Gabar 1 et de Mourel.  
- Eau moyennement minéralisée pour le reste.

---

Le chimiste  
El Hajji NDIAYE  
Date : 19/11/08  
Voir : [signature]
**BULLETIN D’ANALYSES PHYSICO-CHIMIQUES DES EAUX**

**NOM DU DEMANDEUR:** THE MILLENNIUM VILLAGES PROJECT, Fax : 98 700 80  
**REGION:** Louga  
**NOM DU PRELEVEUR:** Sidy Cissé

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**PARAMÈTRES**

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<th>VALEUR (22)</th>
<th>VALEUR (23)</th>
<th>VALEUR (OMS)</th>
<th>VALEUR (SDE)</th>
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<td>7,52</td>
<td>7,55</td>
<td>6,5 ± 0,5</td>
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<td>326,6</td>
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<td>50</td>
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<tr>
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<td>0,01</td>
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<td>0,3</td>
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<td>0,71</td>
<td>0,71</td>
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**Observations:**  
- Eaux fortement minéralisées (dures et chlorurées) à Sague Satheil et à Galdamel.  
- Eau assez minéralisée à Wassounassani.  
- Présence de nitrates aux eaux de Galdamel.
Maps of water sources in Potou Region (Jawara D 2012)
Appendix 3

Additional information provided by D Jawara

Water quality information
The information on iron concentrations for Syer Wolof borehole and Niayam borehole are wrong and should be ignored.

The correct iron concentration for Ndiamb Fall is 0.05 mg/l.

Reticulation details
Borehole pumping rates are 30 – 40 m$^3$/hour.
The storage tanks are all 15 m - 20 m high with capacities of 200m$^3$ except the one at Syer Wolof which has a capacity of 100m$^3$.

Well water is generally extracted by rope and bucket or handpump.
Boreholes are fitted with motorized pumps. All boreholes are connected to reticulation systems.
The borehole at Syer Wolof is connected to an irrigation system using plastic perforated pipes.

Additional water quality issues
Some of the boreholes, especially Syer Wolof and Ndiamb Fall have issues with fine sediments that are settling out in the storage tanks and distribution network.

Water charges
Yard connections XOF 400/m$^3$
- Public stand-posts XOF 300/m$^3$ (the majority of users)
- Agricultural XOF 150/m$^3$

(1$US = approx. 500 XOF)

Additional comments and information provided 29th May 2012

1. Page 11, Section 1.6, first paragraph:
the report states ‘as iron precipitate builds up ..... it has the combined effect of increasing iron removal efficiency......’ should this be ‘decreasing’?

2. Section 1.5, page 9
Richard Agyarko states that for the Mwacafe plants, there are technical drawings with dimensions, specified graded filter media and some literature on the subject. So hopefully we will gain access to these in due course. I see that a WEDC conference paper on the subject was consulted.

Richard has also suggested adding the highlighted text:

...... and the fourth has virgin sand and also stores treated water. Water is delivered directly from a handpump into the chamber of the plant and water fetched from the last chamber.

3. Costs, Section 1.8,
Our colleague Richard Agyarko has provided the following costs for the Mwacafe plants:

a) For the type used for hand-pumps the current capital cost $3,400, so it has not changed much (in Dollar terms) since 2004
b) For the mechanized type, capable of serving only about 1,500 persons, the estimated cost is $42,000. The cost breakdown is shown below. For a population in excess of 1,500 we will require multiple units. The estimate includes the cost of 2 No. 25m$^3$polytanks, 1 submersible pump, 1 surface pump, pipe fittings, other associated cost and the Mwacafe plant itself. The 2 tanks and the 2 pumps means 2 stage pumping, first from the borehole to the Mwacafe plant then filters into a surface tank and then pumped into and elevated tank before distribution under gravity.

Based on these costs it should be possible for the author to give a rough estimate the cost of providing a solution.
4. We would also ask the author to give more specific advice on the steps towards finding a solution. We have noted the advice to contact CREPA and CWSA. This could take into account the following questions:
   (i) should we do additional water quality tests to confirm the previous figures?
   (ii) Would it be advisable to start with a trial? If yes, how?

5. Finally, would it be possible for the author to recommend a particular solution (or suggest which ones to possibly avoid)?

   ![Cost Estimates for Mwacafe Plant and Mechanised Water System](image)

   **Cost Estimates for Mwacafe Plant and Mechanised Water System**

<table>
<thead>
<tr>
<th>Item</th>
<th>Item Description</th>
<th>Unit</th>
<th>Qty</th>
<th>Unit Cost US$</th>
<th>Total Cost US$</th>
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