GUIDELINES FOR BULK WATER TREATMENT IN EMERGENCIES

GLOBAL HUMANITARIAN TEAM 2024

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1. INTRODUCTION

Where large groups of people are displaced either by conflict or by natural disaster and they are likely to stay in a location for periods in excess of a few weeks, there will be a need to establish and probably subsequently upgrade a centralised water treatment system. This guideline focuses on community level needs where "bulk water treatment" is required. It is devised by the Oxfam Public Health Engineering Team to help provide a reliable water supply where mass displacement of people has occurred, e.g. as found in refugee camps and relief centres.

Historically Oxfam developed equipment packages, available for order through the Supply Centre for rapid set up of water treatment systems. With more developed global markets and increasingly restrictive customs regulations resulting in prohibitively slow lead times, locally sourced solutions are becoming more important, and Oxfam kits may not be appropriate or may need to be adapted according to context and available resources. This 3rd edition of the water treatment guidelines has been updated to reflect these changes as well as technological advancements and development of new equipment that has taken place since 2001, Most notably around membrane filtration.

The object of water treatment is to provide potable water, i.e. pathogen free and chemically safe, which is low in physical impurities and is also aesthetically acceptable to the consumer. The greatest health risks in most situations where disasters occur are due to the presence of pathogens (microbiological contamination). Chemical contamination is rarely an immediate health impact but cannot be ignored. Humanitarian agencies are being subject to greater scrutiny and being compelled to meet national regulatory standards. Consequently, risks presented by chemical and organic pollution of water including but not confined to arsenic, nitrates, pesticides and fluoride must also be considered.

A combination of population growth and climate change is resulting in increasing problems of groundwater salinity in water supplies as coastal abstraction increases saline intrusion and people are pushed into increasingly marginal areas, many of which are arid or semi- arid. There is a separate technical brief on desalination, so this is not included within this guideline.

In the early stages of water supply in an emergency, water quality (and quantity) may well fall below WHO recommendations, in which case the initial emphasis will be on raising both quality (and quantity) to come within acceptable limits in the *shortest possible time*. It is also desirable in emergency situations to provide an extra level of protection in the water, in the form of a chlorine residual, to deal with contamination at a household level, e.g. in water containers.

Surface water sources often present the quickest option for water supply in the short term, but surface waters, are much more prone to contamination by suspended solids and pathogens than groundwater. This in turn often means that the biggest treatment problems encountered are the removal of suspended solids and providing means of effective disinfection.

In choosing a water source(s), the quality of raw water must be balanced against the quantity available. From a health point of view, *a larger quantity of relatively good quality water is better than a small quantity of very high quality water* and this must be taken into account by choosing sources that have sufficient quantity of water available. In some instances, where good quality water is limited, it may be necessary to provide two different qualities of water to consumers, reserving water from a poorer quality source for washing, whilst the water from a small good quality source could be used for food preparation and drinking. This may create difficulties in keeping the two water qualities separate, both for bulk production and at a household level and will also need considerable support from a public health promotion program if it is to be understood, acceptable and successful. Also one large source of dirty water, which though requiring more treatment than several small cleaner sources, may be more convenient from a management point of view, because all pumping/treatment systems could be centralised at one location.

The selection of a water source depends not just upon its quality and quantity of water that needs to be supplied, but also its proximity to any proposed settlements, potential extraction difficulties and water rights, along with other issues. These guidelines will not go into these important factors that may influence the choice of a source, but rather concentrate solely upon treatment processes.

In situations such as floods, people are often forced to find their own means of treating water at a household level, a separate technical brief applies - TBN04 – Household water treatment and safe storage.

2. ASSESSING WATER QUALITY

SUMMARY

The main parameters to take into consideration in assessing water quality for immediate short-term supply in an emergency context are; suspended solids, pH, the level of faecal contamination (microbiological) and conductivity (a measure of salinity). Ground water sometimes has a high iron content and in dealing with waters from industrialised societies/locations, chemical contamination may also be of concern. Whilst relatively simple measures can be undertaken to treat water with high suspended solids and faecal contamination, adjusting pH is more difficult, though less likely to be a problem. However, treating saline water and dealing with chemical contamination is more complex and not dealt with in these guidelines.

2.1 Contamination types

Contamination Type	Contamination Agents	Comments
Physical	Particles and suspended solids	• As dramatic seasonal variations in the physical quality and quantity of river water are very possible in regions where heavy seasonal rains occur and/or where flow velocities are high, an assessment needs to take this into account. • A careful consideration of natural features can provide information when deciding where to site pumped intakes, i.e. does the riverbank have obvious flood terraces? • Try to establish if there is enough good quality of water, does it deteriorate?
Biological	Faecal waste	• Faecal contamination is very dangerous and can contribute to an outbreak of a water borne disease (including cholera and typhoid) through the faecal-oral transmission route. • Undertake an assessment to identify actual and potential contamination risks • If a protected source is available, e.g. springs feeding a small stream or pond, use this source water.
	Algae	• Algae are difficult to remove using coagulants and can impart a bad taste to the product water. They can also block sand filters. Consider riverbank or bankside filtration arrangements.
Chemical	Minerals, soil type	• The pH and salinity of different sources can vary, even though the sources may be in close proximity. pH is an important factor where treatment involves the addition of coagulants (alum etc) as the quantity to be added is influenced by pH, as is the contact time for chlorine. • Many chemical contaminants such as Fluoride and arsenic are tasteless and odourless. Local knowledge may provide invaluable insights on presence of such elements but if in any doubt testing should be done.
	Industrial effluents	• In some situations, industrial or agrochemical pollution can be very marked. As the removal of such contamination requires high technology solutions, it is

		generally not possible to reliably achieve this during an emergency without use of more expensive and complex treatment plants. A check to ensure that insect larvae and fish life flourish in the water source can provide an indication of quality, e.g. by keeping fish in the header tank. • Look for signs of agricultural activities, empty chemical sacks etc. to establish if there is a potential for chemical contamination. Rivers and streams are more likely to be "self-cleansing" than ponds and lakes. • Local knowledge should indicate whether there are any contaminants that may be on concern or need testing for.

2.2 Taste, Odours, Colour

It is often very difficult to identify the causes of tastes and odours in water, the likely sources of a few of the main problems are detailed in the following table (some of which may occur in the water treatment system itself).

Taste or Odour	Cause	Comments
Fishy or musty taste and odour	• Algae	Intake filtration and slow sand filtration can reduce, though not prevent, problems. Select raw water sources carefully. UV treatment is used to prevent algal growth in RO treatment plants.
Iron taste:	• Particulates caused by catchment geology. • Bacterial activity, common in old cast iron pipework.	Aeration and filtration can reduce this but also try to minimise turbidity. Iron bacteria can produce odour problems.
Sulphur taste, rotten egg smell	• Mineral content due to catchment geology	No real solution other than to minimise turbidity and particulate content of the water.
Brackish taste	• Sodium chloride (salt)	Check source water for salt source. Where wells near saline intrusion are used, care should be taken to avoid drawing saline water into freshwater lenses.
Mouldy taste and odour	• Moulds and actinomycetes	Flush mains from time to time to avoid warm, stagnant zones in pipes.
Chemical taste	• Various classes of chemicals • Chlorine compounds	Most can only be removed with the help of activated carbon and pre-ozonation. Solvents and phenols can react with chlorine in water. Minimize chlorine dosing by treating the raw water to such a level that chlorine demand is minimized.
Colour	• May be caused by chemical or physical contamination	Removal of suspended solids will reduce colour effectively in many cases. A brown colour is produced by iron presence and has aesthetic implications, especially when cloths are washed.

2.3 Suspended solids (NTU/JTU)

NTU (nephelometric turbidity units) or JTU (Jackson turbidity units) are measurements of how much suspended matter such as organic material, e.g. algae, mud, rust etc., is carried in the water and has a bearing on the number of pathogens in the water and on how easy it is to disinfect water to kill off these pathogens. Whilst there is not an exact correlation between turbidity and suspended solids, the relationship is close, and it is easier to measure turbidity using a turbidity tube. NTU is measured using a digital device whereas JTU is visual measurement using a turbidity tube, which can be purchased individually (Oxfam code FTT), and forms part of the Oxfam water measuring and testing kit (Oxfam code FMT). A digital turbidity meter is included within the Oxfam Chemical and Bacteriological testing kit (Oxfam code FKPL).

WHO recommends that if water is more than NTU 5, then some form of treatment to remove turbidity is necessary before the water can be effectively disinfected with chlorine. The NTU should be measured and if found to be higher than 5, then the next stage is to undertake a simple sedimentation test to establish if and how long it takes for the suspended solids to settle out. This will indicate likely settlement times, which in turn will help with sizing either sedimentation tanks or choosing a coagulation/flocculation-based system. A visual inspection can give an indication on whether particles are organic (algae etc.) which give a greenish/brownish colour or colloidal (very small) which appear as a fine suspension. These present greater difficulties for treatment, often requiring a coagulation/ flocculation stage in the process.

2.4 Microbiological (faecal coliforms)

Faecal coliform bacteria (>99% of which are E.coli) are an indicator of the level of human/animal waste contamination in water and the possibility of the presence of harmful pathogens i.e. microbiological contamination. A measure of this contamination will determine whether the water will need to be chlorinated or not. WHO standard is zero coliform per 100ml for all potable water supplies. Acknowledging that that many supplies, especially rural water, will normally have low levels of contamination, Sphere indicator is that water should contain <10 coliform/100ml when chlorination is not employed). It is recommended that chlorination should always be used in the early stages of an emergency and measurement of faecal coliforms will then not be essential. However, the measurement of faecal coliforms can give an indication of likely chlorine demand (i.e. water with more faecal coliforms will generally require more chlorination, but it also indicates where more intensive treatment is needed) as well as enabling changes in raw water quality to be monitored. Faecal coliforms can be measured using the Oxfam microbiological water testing kit (Oxfam code FKB).

Studies show a high correlation between level of faecal coliform contamination and risks identified by a visual inspection of basic sanitary indicators, otherwise known as a sanitary survey. Put very simply, if there are numerous water contamination risks, such as latrines sited near water sources, uncontrolled open defecation by animals in areas where this can be washed into water sources etc., then there is likely to be a higher risk of contamination. Thus, a simple visual inspection of water sources can be used as the first stage of assessment of likely water quality.

It is worth noting that sometimes the presence of coliform organisms (total coliforms) is used as an indicator. However coliform organisms may not always be directly related to the presence of faecal contamination or pathogens in the drinking water, but the coliform test is still useful for monitoring the microbial quality of treated piped water supplies. The Palintest Wagtech kit used by Oxfam has two incubator settings – at 37 deg C (which incubates total coliforms and 44 deg C for incubating and measuring thermo-tolerant (faecal) coliform.

2.5 Acidity/alkalinity (pH)

WHO guidelines recommend drinking water be in the range pH 6.5 - 8.5. Ideally the water will be fairly neutral with pH around 7 and this can be checked using the Pool Tester, (Oxfam Code FPO) or water testing kits (Oxfam code FKB, FKBDI), which has a range from 6.8 - 8.2. Where the pH is outside this range, a pH stick type meter (Oxfam Code FSMP) will be required or multi-parameter kit FMPP).

Knowing the pH value is also important, as pH alters the effectiveness of two of the chemicals commonly used in water treatment. Chlorination is considerably slowed down when the pH is higher than 8, and either contact time or initial dose needs to be increased (see section on chlorination). The effectiveness of aluminium sulphate, commonly used as a coagulant, is severely affected by low or high pH, with a range of about pH 6.5 - 7.5 being optimum (see section 3.4 for more information).

2.6 Iron

This can be checked by use of a simple comparator which measures total iron content included in the Chemical comparator Kit (Oxfam Code FCWT) or Digital photometer (Oxfam Code FMPP). Information from the local population, along with the tell-tale signs of rusty/reddy brown stains on concrete or clothes, will provide further evidence of high iron levels. The WHO advised limit is 0.3mg/l.

2.7 Salinity (TDS/Conductivity)

Salinity refers to the concentration of soluble salts in water. All natural water contains some dissolved salts such as sodium, magnesium and calcium. Sodium chloride is the most common of all salts. There is no WHO health based guideline for salinity and the taste of water will generally be off-putting before it reaches a level where it is harmful for health. Salinity can be measured by electrical conductivity (EC) - expressed in µS/cm, or total dissolved solids (TDS) - expressed in mg/l or ppm. The conversion between the two is not constant and depends on the chemical content of the water. It can vary by a factor of 0.55-0.9, however 0.67 is commonly used as a conversion factor i.e. water with an EC of 3,000 µS/cm is approximately equivalent to a T.D.S. of 2,000mg/l. Changes in conductivity may indicate changes in the mineral composition of raw water or seasonal variations in reservoirs, though it may also indicate sewage, industrial or agricultural pollution or intrusion of saline waters. WHO guidelines give a maximum value for TDS of 1000mg/l, although in some areas of the world higher values are accepted. A multi parameter stick meter is a convenient way of measuring this parameter. The range limit of the Oxfam TDS meter (Code FSMP) is 999ppm (TDS) or 1999 µS/cm (EC) so is not suitable for areas of high salinity. If the salinity of the water is approaching the WHO limit, consumer's who may refuse to drink this water and instead go to other potentially contaminated waters. Where the salinity of water exceeds either consumer acceptability or WHO guideline, then an alternative source may be needed. Treatment processes to reduce the salinity of water are beyond the scope of these guidelines and are explained in a separate technical briefing note. Desalination should be considered as a last resort and, if possible, other sources should be located.

2.8 Other Chemical ions

Over and above the tests already mentioned, it might be appropriate to undertake the following water chemistry tests; Chloride, Sulphate, Nitrate, Hardness, Ammonia and Fluoride, which can all be undertaken fairly simply. In large areas of Bangladesh and Bengal in India, Arsenic is a major problem, but this is difficult to detect at lower concentrations and difficult to remove.

Many of these tests can be undertaken with Oxfam's chemical water testing kit (Oxfam code FCWT) which relies on visual comparator. A more accurate analysis is possible using a multiparameter digital photometer (Oxfam Code FMPP) and relevant reagents. These can be ordered if required, but are not that commonly used by Oxfam, as these chemical concerns are often of less health significance in the short term in an emergency and are also less often encountered.

Where there are concerns over industrial and mining wastes and the possibility of these leaching into water systems, the following parameters could also be of concern; Nickel, Zinc, Chromium VI, Manganese, Copper, Lead, Mercury and Organophosphate (pesticides). However, some of these tests are difficult to undertake without lab equipment and thus an awareness of what agricultural, industrial and mining activity has occurred in the area could be used in the first instance, rather than having recourse to testing.

2.9 Summary of Key Water Quality Parameters

Parameter	WHO Guideline	Implication
NTU	<5	Disinfection efficiency decreases above this, higher NTU (<20) may be tolerated but cannot guarantee complete disinfection of water
Taste/Odour	Acceptable to user	Water that is aesthetically unacceptable to users can lead to use of water that may taste better but is less safe.
Faecal coliform (FC)	zero	If present in chlorinated water then chlorination process or chlorine residual insufficient, Sphere guideline <10 CFU is less strict. Greater risk of FC in non-chlorinated water sources and low level may not have significant impact on people's health.
pH	6.5-8.5	Chlorination effectiveness significantly reduces above 8 Aluminium sulphate effectiveness reduces below 6.5 and above 7.5
TDS	-	No WHO guideline. 1,000mg/l and below is generally considered acceptable.
Aluminium	0.2mg/l	Excess aluminium present in water is excreted effectively through urine. Limited evidence of detrimental health impact but prolonged exposure should be avoided.
Ammonia.	<1.5mg/l	Causes tastes and odour
Copper	<1mg/l	Causes staining of laundry and has health significance with prolonged exposure >2mg/l.
Chloride	<250mg/l	No health-based guideline has been set for Chloride but concentration >250mg/l can give rise to detectable taste and reduce aesthetic acceptability.
Chromium	<0.05mg/l	Potentially carcinogenic where ingested for prolonged period in excessive concentrations
Fluoride	<1.5mg/l	Prolonged exposure can result in dental fluorosis (mottling of teeth) and skeletal fluorosis (weakening of bones). Children most susceptible
Hardness,	-	No limits but can give rise to consumer complaints through scum deposition and taste can be off-putting
Iron	0.3mg/l	Common in ground water and the guideline value is set for aesthetic reasons as iron causes discolouring of the water.
Lead	<0.01mg/l	Associated with a wide range of health affects including neurological and behaviour.
Manganese.	<0.1mg/l	Causes staining of laundry and deposition in pipes >0.5mg/l. Health based guideline of 0.4mg/l is well above concentrations of manganese normally found in drinking-water

Mercury.	<0.001mg/l	Has health significance
Nickel	<0.02	Has health significance
Nitrate (as NO_3^-)	<50mg/l	Linked to blue baby syndrome and potent carcinogen
Sulphate.	<250mg/l	Gives rise to taste and causes corrosion
Zinc.	<3mg/l	Gives rise to taste and appearance.

For a comprehensive understanding of water quality parameters, refer to the WHO guidelines for drinking water quality.

3. TREATMENT PROCESSES AND TECHNOLOGIES

SUMMARY

This section is particularly applicable for surface water treatment. Most ground water from a professionally constructed borehole or protected hand dug well will invariably be cleaner with little or no suspended solids and will have less treatment requirements. Surface water sources will probably need treatment to address high-suspended solids and subsequently to disinfect to kill off microorganisms. Removal of the suspended solids invariably present the greatest treatment challenge, and there is a need to choose technologies that will be sustainable in the medium to long term where required. Oxfam programmes should avoid over complex solutions. For this reason, the guidelines are written around the use of sedimentation and aluminium sulphate as a coagulant, as this is commonly available. Since the last version of this guideline new technologies such as membrane filtration have emerged whilst technologies such as roughing filters and slow sand filters have become less common. Water supplies with chemical contamination, often found in industrialized areas are not dealt with here, as these tend to be much more complex to treat.

3.1 Treatment at intake

The intake (pump or gravity) is often the most neglected part of the treatment system, but it is very important, as allowing or preventing unnecessary debris and dirt into the system, which impacts on treatment required downstream. Intakes should always be designed to reduce intake of debris and to strain out solid matter which would otherwise enter the treatment system, but flow control and cleaning can be problematic.

The creation of intake channels which do not face the main flow of a river can be effective in reducing the amount of suspended solids carried to any suction pipe inlet screen. Also, the position of the intake relative to banks is important; fast flowing water carries more dirt, and it is important to look for natural sedimentation basins within the river.

When the position of the intake has been chosen, seek to make it as efficient as possible whilst maintaining accessibility for maintenance operations. Twin lines have the advantage of allowing maintenance to be carried out, whilst abstraction rates are maintained in the other pipe and a second pipe can be added later where a treatment system is likely to be in existence for more than a few months. With careful planning of pumping lines and valve positions, suction pipe intake assemblies can be "backwashed" in position with selected wash water.

Fabrics wrapped around suction pipe screens and custom-made perforated pipes or drums can all have an application in maintaining good physical raw water quality and their length and thus their flow capacity can be adjusted to suit local conditions. Specifically, the intake can be upgraded by using intake structures such as an oil drum or plastic drum, drilled with holes to act as a large strainer. Gabions constructed out of coarse gravel will also protect intakes from excessive suspended solids. Also, simple measures such as positioning a pump intake strainer about 0.5m below the water surface (to avoid algae growth), but above the river/lakebed (to avoid drawing up sediments on the bottom) will have significant impact. The intake should be constructed in such a way that they can easily be pulled out and cleaned to reduce the problem of clogging.

When time permits, the construction of sand filled intake galleries adjacent to sumps will provide better cleaning, although care must be taken in construction otherwise, they will be prone to excessive blockages. If raw water quality is such that, even with the use of primary sedimentation tanks, treatment is being compromised due to high levels of physical contamination, consideration should be given to riverbed or bankside filtration.

Filtration/infiltration "intakes" aim to filter water as it seeps through granular soil or selected fill. Fast flowing rivers tend to have sands and gravel deposits along their banks and excavation of a suitably long trench in the bank can provide access to a suitable supply of raw water which has been considerably improved by the riverbank filtration. This method is particularly recommended when algae is a problem. However, ponds, lakes and very slow rivers are more likely to have silts and clays as the local soil strata and, in this case, it may be necessary to construct a filter drain using imported materials. The surrounding riverbed itself becomes a biological filter that destroys bacteria and reduces the level of ammonia and iron that may be present. Water moving over this bed helps to clean it, helped by any fish present which will feed on these sediments.

Advantages	Disadvantages
Improving water quality at intake are likely to be cost effective and reduce subsequent treatment required. Intake works typically require minimal subsequent management and maintenance	Intake works may only be possible seasonally when river flows are lowest. Significant work may not be possible as part of first phase.

3.2 Sedimentation

Sedimentation is the simplest form of water treatment of all and by allowing water to stand for a long enough period of time, improvements will be achieved with physical impurities settling out and by pathogens dying off during water storage (standing). However, it can be rather slow to achieve sedimentation without flocculants to assist and very slow for pathogens to die off (requiring several days or weeks). Designing a treatment system solely on this process of sedimentation and storage could result in a very high requirement for storage tanks and vessels. Therefore, sedimentation is usually used as one stage in the treatment process, either for sedimentation of coarse solids or of flocs after coagulation/flocculation (see section 3.4).

Simple settling tests conducted in jars can give guidance on the amount of retention time required for any particular raw water, though these rather crude results should be verified on a full-scale plant in practice. It is suggested that if suspended solids take more than 6 - 8 hours to settle out such that supernatant water (clear water on top) is less than 5NTU, then the process needs to be assisted, either by adding a roughing filtration or coagulation/flocculation treatment stage. At a water treatment plant level, this suggested time for adequate sedimentation should be considered in the light of overall system design and tank costs/availability, while at a family level the number of water vessels people have access to would be the determining factor. It is important to consider season variations and be aware that sediment load may increase significantly due to rainfall patterns.

Sedimentation tanks either operate on a continuous or a batch treatment basis. Purpose built sedimentation tanks are typically rectangular in shape with internal features to lend themselves to more efficient sedimentation. These may not be practical in first phase response but could be considered as part of a durable solution. Where Oxfam T-tanks or onion tanks are used for sedimentation Inlet and outlet arrangements should be considered carefully to minimise the disturbance of sediment that builds up in these tanks between cleaning operations, otherwise treatment will be less efficient. The inlet should be arranged to have an upturned elbow near to the bottom of the tank which can be upgraded by tying a pipe to the edge of the tank at high level with slots/holes to release water in a number of small streams which will create less turbulence. The outlet should ideally be either in the form of an upturned elbow with length of straight pipe at least 300mm above the base of the tank or alternatively a float can be tied to a length of flexible hose that draws water off the cleanest water from the top of the tank. This will reduce outflow but keep it constant.

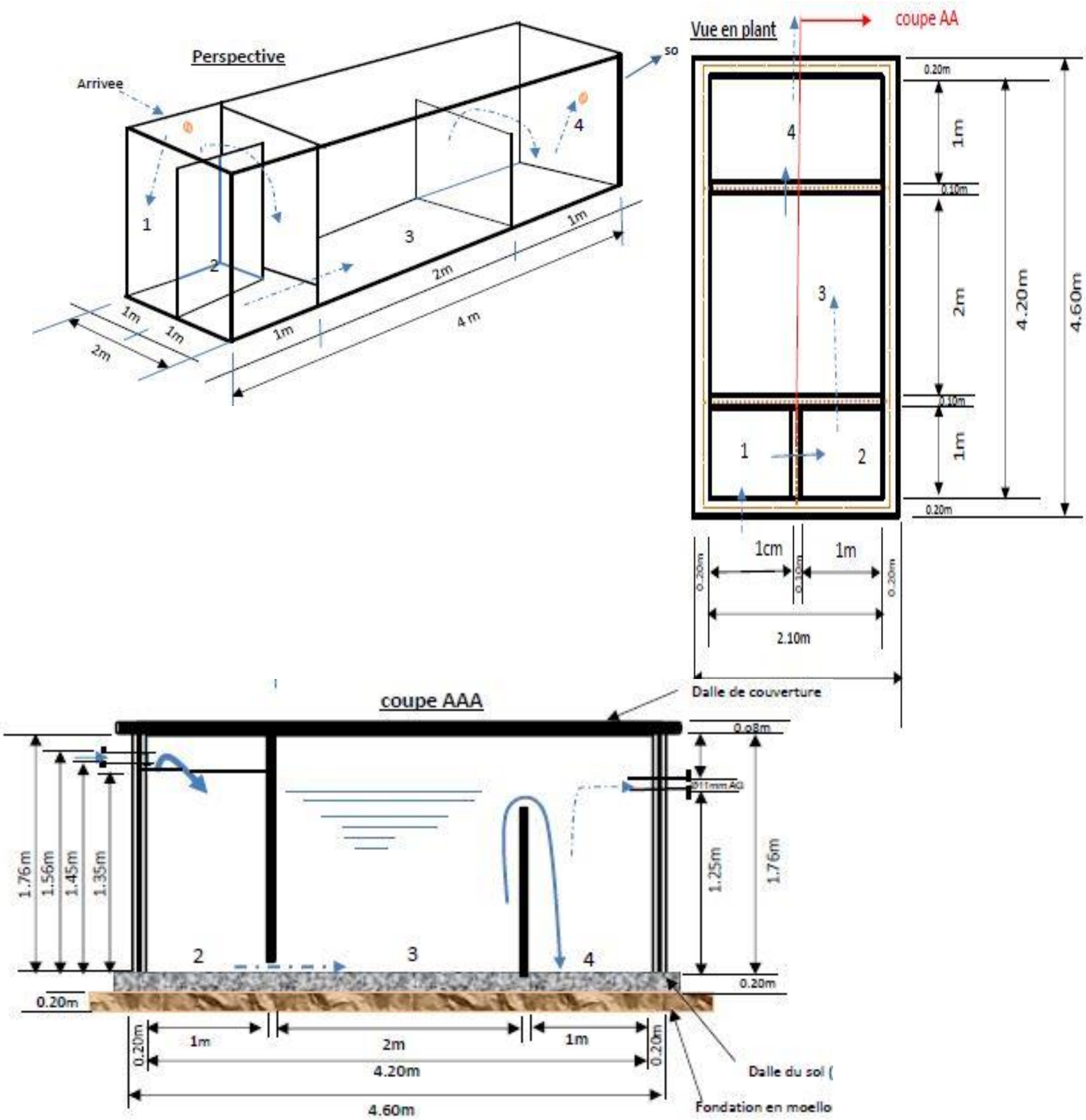
The area of sedimentation tank required can be estimated by dividing the design flow rate (m3/day) by the settling velocity (m/day)

Design parameter	Guide range of values
Detention time (hrs)	0.5-3
Surface Loading (m3/m2/day)	20-60
Depth of tank (m)	1.5-2.5
Length: width ratio	4:1 to 6:1
Length: depth ratio	5:1 to 20:1

Figure 1: Guideline design criteria for rectangular plain sedimentation tanks (Engineering in Emergencies)

Advantages	Disadvantages
Simple process.	Requires significant storage and therefore space. Slow process. May not be cost effective.

Figure 2 - Sedimentation tank used on Lusenda gravity water supply system in DRC



Intake/transmission line had a design flow of 36m3/hr. The 10m3 sedimentation tank was able to reduce turbidity from 45 to 25 NTU. Consequently, an additional two T70 tanks had to be added and flow reduced to 20-25m3/hr to provide the required settlement time (under alternating batch treatment) to reduce turbidity to below 5 NTU. Due to increased turbidity during the rains addition of alum was also periodically required.

3.3 Improved sedimentation (Lamella Clarifiers)

Lamella clarifiers (or inclined plate settlers) are widely used for industrial wastewater treatment as well as largescale municipal water treatment plants. Commercial clarifiers are bulky, require assembling in a factory and typically transported by lorry to site by road so rarely an option for humanitarian use. The addition of closely separated angled plates or tubes (at 40-60 degrees) creates multiple narrow, parallel, flow pathways for water. greatly increasing the surface area onto which particles may fall and settle, accelerating settlement time.

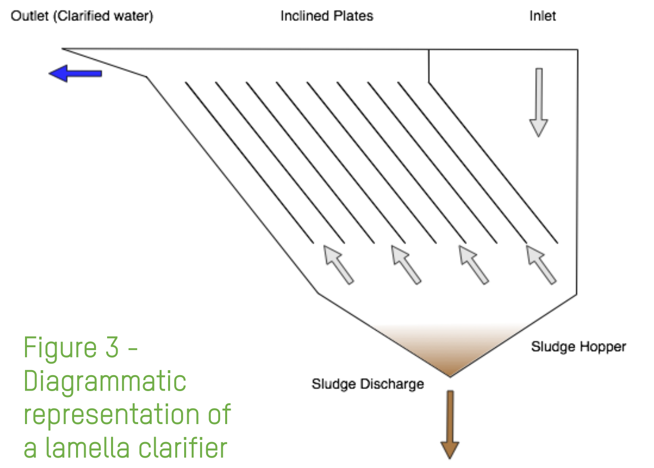


Figure 3 - Diagrammatic representation of a lamella clarifier

The potential advantages from the improved settlement efficiency from a lamella clarifier is that it requires a significantly smaller footprint area, is less labour intensive, more efficient and cost effective to operate in the longer term; and for relatively low turbidity might mean chemically assisted sedimentation can be avoided. Lamella clarifiers operate on a continuous flow basis so require either continuous pumping or intermittent pumping to a raw water tank with cascading gravity flow. The cost implications of each (additional fuel consumption vs additional raw water storage and earth moving) will influence which system is preferred.

There are many commercial pre-assembled "portable" steel lamellas, but their bulk and weight does not lend themselves for rapid deployment. Oxfam has made several attempts to develop a Lamella kit which could by assembled on site, compatible with Oxfam tanks, provide an output of 10-40m3/hr and be a viable alternative to batch alum dosing. At the time of writing, we have not found an industrial partner willing and able to meet requirements. This would fulfil the same role as "the upflow clarifier", documented in earlier versions of this guideline and Engineering in Emergencies, which Oxfam stopped using because of its complicated operational set-up.

Advantages	Disadvantages
Potentially simpler to operate and maintain compared to batch dosing. Potentially more economical in terms of chemical consumption and pumping costs Requires less space than using sedimentation tanks	Still not proven in humanitarian contexts. Currently not an option for first phase response. May require earthworks to set up optimal cascading gravity flow system. Dependent on availability of local suppliers.

Figure 4 – Lamella Field trials

Set-up for T70 tank in Bangladesh (2021). The honeycomb shaped lamella "boxes" comprise lightweight polypropylene single channel tube profiles with "tongue and groove" joints which are then heat welding. This enables them to be supplied as kits and erected on site. A number of design flaws where present in this system which collectively hindered floc formation and reducing turbidity to the target of <5NTU. More details including of a similar trial in Uganda are included within the innovation section on www.oxfamwash.org

Juba 2017-19. With funding from humanitarian innovation fund Oxfam and the University of Lavel developed and trialled an "inclined plate settler" (IPS) in Juba. The site "Lologo" takes water from River Nile and was chosen because there was an existing surface water treatment system on site, thereby providing a comparison. Testing was delayed due to escalation of conflict in Juba in 2016 and further disrupted by staff turnover. An evaluation in 2019 found that the unit was able to produce 5m3/hr with turbidity reduction from 80 to <5 NTU (in combination with alum dosing).

The performance of the IPS was comparable to the batch treatment system but ultimately the operators preferring the batch system because the fuel consumption of the IPS was considered higher. The trial was ultimately inconclusive as a full appraisal of the IPS (when the River Nile has seasonally higher turbidity) was not possible and an optimal set-up of the system was never achieved (continuous pumping required for operation with two stages of pumping was inefficient).

3.4 Coagulation and flocculation

Where excessive suspended solids in the form of colloids or organic matter, are present in water that cannot be easily removed by straining, or sedimentation, then the use of chemicals to assist in coagulation and flocculation will be required. Colloids can be thought of as suspensions of fine particles in the water which produce a cloudy or turbid appearance. The fine particles carry an electrical charge and exhibit a mutual repulsion which makes them difficult to remove by simple sedimentation or filtration. Coagulation is a chemical process where a coagulant destabilises charged particles which cause them to repel and remain in suspension. Flocculation is a physical process where these fine particles coalesce through mechanical and physical mixing, best achieved during slow stirring to form larger flocs. The aggregated flocs are then able to be removed by sedimentation and/or filtration. It should be noted that while flocculants do assist in the removal of pathogens which "cling" to particles of dirt, they do not kill them, i.e. they do not act as a disinfectant.

The most commonly used coagulant in developing countries is aluminium sulphate, known as alum, which can often be found in local markets in the form of crystals.

3.4.1 Aluminium sulphate (alum)

Aluminium sulphate (Oxfam code FAS) - common names Alum or Sulphate of Alumina) can be obtained in liquid or granulated forms and is commonly used as a coagulant. The granular form is simple to transport in sacks, is not considered as a hazardous material and is widely available in all but the remotest areas of the world. It can be added to water and shaken or stirred vigorously to produce a solution which is suitable for dosing into the raw water in treatment processes.

Aluminium sulphate coagulates best in a pH range between 6.5 and 7.5 as its solubility depends on the pH of the raw water and is lower outside this range. pH adjustment can be made to improve coagulation. The addition of acid, usually sulphuric, would be required to reduce the pH, while the addition of lime or soda ash will increase the pH. The addition of (acidic) aluminium sulphate to water lowers the pH and may cause it to drop out of this optimal range. Where this is the case the addition of lime (an alkaline) will increase the pH and is useful to keep the pH within the optimum range. As a rough guide 7-14kg of lime added to 95m3 of water will provide an appropriate pH adjustment, although a jar test should be used to confirm the actual amount.

The dose of aluminium sulphate required for coagulation of any surface water will vary but will probably be in the range of 25 - 150mg/litre or 25 - 150g/m^3 (this is the weight of alum, of which only 25% of this weight is aluminium sulphate, the rest is water). The correct dose of alum will flocculate suspended solids in the water together into large "fluffy" lumps. These will then be heavy enough to settle out the water naturally within an hour or two. The settled water at the top should then be very clear, i.e. <5 NTU to permit effective chlorination.

Under or overdosing can result in inefficient flocculation and lead to aluminium residuals in the product water which exceed current WHO quality recommendations (WHO recommend aluminium <0.2 mg/l). For this reason and to ensure the use of an economical dose, it is normal practice to carry out a series of jar tests to determine the optimum dose. A simplified version of this test has been designed for Oxfam work in the field, where the normal "laboratory" support will not be available.

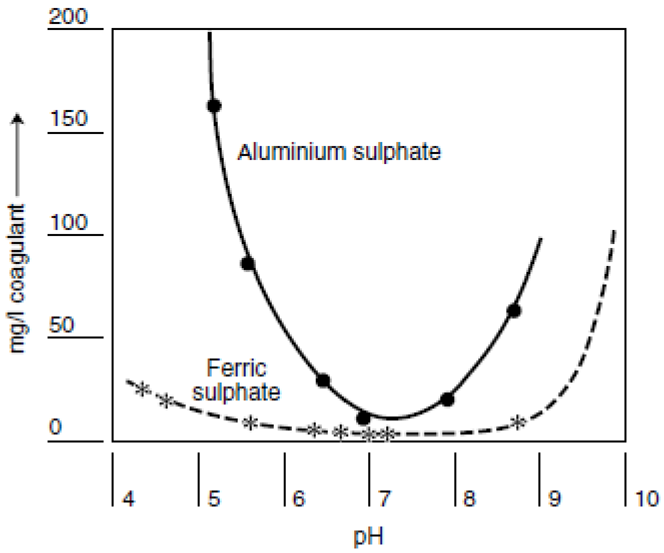


Figure 5 – Comparison of coagulant dose for Alum and ferric sulphate over different pH range (water source contains 50ml/l of kaolin clay) – Source: Engineering in Emergencies

The previous version of this guideline stated that prolonged use of Alum is not recommended. Aluminium sulphate is widely used in permanent municipal water treatment systems without any known adverse effects to health. WHO acknowledges the beneficial effects of the use of aluminium as a coagulant in water treatment and advises on the importance of optimization of the coagulation process to minimize aluminium levels in the treated water. For large, well-operated and well-controlled plants, a residual aluminium concentration in the final water of 0.1 mg/l should be achievable. For smaller facilities, a residual concentration of 0.2 mg/l is a more reasonable expectation.

The widespread availability of alum, its effectiveness over a wide range of turbidity, ability to treat large volumes of water and its relative ease of use, makes alum dosing the most common method of reducing turbidity from water for first phase emergency and until a more durable and cost effective long term solution can be implemented.

Ferric chloride and ferric sulphate are effective above pH of 4.5 up to about pH 9 but they are not as widely available as alum (see figure 6).

For any given water, the optimum conditions will vary depending on pH, turbidity, chemical composition, type of coagulant, temperature and mixing conditions (turbulence to thoroughly mix coagulant followed by slow stirring to encourage floc formation)

3.4.2 Determining the Dose - Jar Test

The purpose of the jar test is to determine the correct dosing concentration for an individual application where effective flocculation is employed. Pouring a bucketful of alum solution into a tank of water and stirring by hand is not "effective flocculation" but is sometimes required in extreme emergencies. This will almost certainly lead to excessive alum residuals in the product water, although they should not form major threats to community health in the short term. Every water treatment application is different in terms of raw water quality, hydraulic conditions and even coagulant batch properties. Optimum conditions for good flocculation are determined not only by the optimum dose of coagulant, but also by the physical conditions of coagulant dosing. A step by step guideline on how to conduct a jar test using a 1% alum solution is included in Appendix 2 and covered in detail in the Oxfam coagulation and disinfection manual.

3.4.3 Adding Alum to Water

For the aluminium sulphate to work properly and make the water clear, it needs to mix with the water rapidly. A short time after it mixes with the water it loses a lot of its effectiveness, so it is very important it is mixed with all the water.

The best way to do this is to mix the aluminium sulphate powder with a small amount of water to make a 10% solution, and then to add this solution to the water as it enters the tank. This is done as follows;

- To allow measurement by volume to be interpreted as a weight:1 litre of granular alum weighs 1100 grams. A baseline alum solution concentration is made as follows;
- A 10% alum solution is formed by dissolving 100 grams of granular alum into 1 litre of clean water (mix in less than 1 litre then make up to the final volume). This solution will be referred to as a 10% Oxfam Alum Solution.
- 10% Oxfam Alum Solution = 100,000 mg/1 (100,000ppm) Alum Solution

Regular checks should always be made on the aluminium carry over into the chlorinating tank, using the comparator provided in the Oxfam code FMT kit. If this is above 0.2mg/l, then it may be necessary to review the amount of aluminium being put into the raw water, the mixing process and/or the pH of the water to confirm it is within the optimal range or requires addition of lime (to raise PH) before coagulation.

The flocculated sludge is hazardous and arrangements need to be made for its proper disposal. In the early stages in the life of the system it may be adequate to dispose of it in a shallow pit dug nearby, though this will be less satisfactory in the long term if aquifer contamination is likely or it could drain into an adjacent watercourse.

Suction side dosing

Where a surface suction pump is required to lift water from its source, the easiest way of adding coagulant is to tap into the pump's suction line with a small diameter pipe. The small diameter tapping uses the suction of the main pump to draw up coagulant solution from a container. The dosing valve kit (Oxfam code FASDV) allows flow to be accurately and incrementally controlled. It is good practice to include a small on-line flow meter to measure the injection flow with valves on both the coagulant pipe and the main suction line. The coagulant pipe should join the underside of the main suction line to minimise the risk of entrapped air interfering with the injection process. The longer the suction line, the greater the risk of air bubbles occurring within the raw water flow. As before, the overall control of dosing can be achieved by varying coagulant pipe flow and coagulant solution concentration. However, the predictions of total throughput and maximum dosing rates for a given application are relatively uncertain before the system is run-in; it is recommended that proving trials are held before coagulant concentrations are fixed. The system requires fairly constant attention as the balance between flow rates tends to vary during operation.

Figure 6 – Example of suction side dosing

Coagulant dripped into water flow

The simplest but least effective way of introducing coagulant into a water supply is at the inlet where water flows into the tank. This will require the construction of a (wooden) tower on which barrels/drums can be positioned to drip the aluminium sulphate over the rim of the tank and into the inlet stream of water as it enters the tank. Where larger Oxfam tanks are used, this platform will have to be quite substantial to be high enough to reach above the lip of the tank and strong enough to take the weight of people. This will take some time to build and will generally not be suitable for use in urgent or fast changing situations.

The solution is put in a drum from which it drips into the water entering the tank at a measured rate. The speed at which the solution comes out of the container should be such that the container becomes empty at the same time that the tank is full. Typically, a 200 litre plastic or metal oil drum with a tap is used. The inlet should be set up to achieve gentle stirring to facilitate the formation of flocs and is best achieved using a 1-2m length of flexible hose strapped horizontally to the side of the tank which produces a swirling motion in the tank water as it fills the tank.

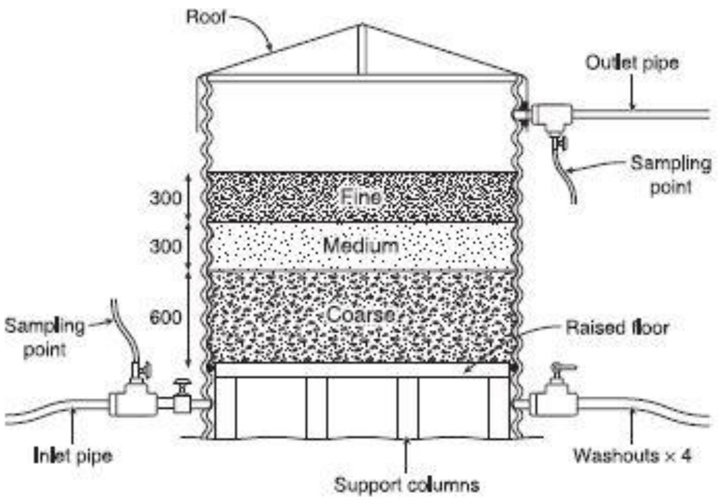
Settlement
After the aluminium sulphate solution has mixed with the water, there needs to be a period of gentle stirring and mixing of the water in the tank to allow the aluminium sulphate to act on all the water. During this period, all the small particles of dirt (which remain in suspension or would sink very slowly) in the water are drawn towards the precipitate of aluminium hydroxide sulphate particles, to make bigger particles of floc, which will sink more rapidly. Eventually, these will form sediment in the bottom of the tank. This time period can typically be 2 - 4 hours. After this period of settlement, the water should be clear enough to be emptied into the next tank (often a chlorinating tank). Outlet arrangements should be as for sedimentation tanks

Advantages	Disadvantages
Widely known/commonly used and therefore relatively easy to set up. Alum is widely available Suitable for first phase and medium-term water supply. Suitable for wide range of raw water turbidity Once set up typically requires minimal subsequent management and maintenance	May require significant space for raw water, mixing and settlement tanks. Requires trained operators, not suitable for community management. Effectiveness decreases as acidity/alkalinity increases. Residual aluminium in water is undesirable so care needs to be taken to ensure optimal dosing and mixing. Safe disposal of sludge needs to be considered.

3.5 Roughing filtration – upflow prefilters

Upflow prefilters can be used to reduce the turbidity (suspended solids) levels in raw water to ease later treatment problems. A 1.0-1.2m deep bed of gravel media can reduce the influent turbidity by up to 75%, except where problems of difficult colloidal turbidity are experienced.

Figure 7 – Vertical Flow Roughing Filter



Roughing filters are often built in tanks with a number in series (each tank being a stage), using progressively less coarse media in each tank. Raw water quality will determine how many stages, i.e. how many roughing filter tanks will be required. The more stages used (usually no more than three) the greater the cleaning effect on the water. If the water is fairly clean, a single stage filter, or one with three different sized media layers in one tank may suffice.

However pilot plant studies run on a model scale will give the best results for design of the system and these trials should also take into account seasonal variations in water quality. As a guide, roughing filters should aim to produce water that is <NTU20 (max) if water is then being passed through SSF (slow sand filter) or <NTU5 (max) if it is to be disinfected with chlorine.

Typical gradings for 40mm, 20mm and 10, nominal single-sized aggregate are shown in the following table:

Standard Sieve Size mm	Percentage by Weight Passing Standard Sieves for Nominal Single-size Aggregate		
	Coarse (40mm)	Medium (20mm)	Fine (10mm)
50	100	-	-
37.5	85-100	100	-
20	0-25	85-100	-
14	-	-	100
10	0-5	0-25	85-100
5	-	0-5	0-25
2.36	-	-	0-5

A roughing filter based upon a multi (3) layer in 1 tank construction might look like this;

GradingDepth of layer
Coarse 600mm
Medium 300mm
Fine 300mm

With the coarsest layer on the bottom for upflow prefilters. If poor raw water quality requires the construction of a three stage (i.e. three tank) system, then the tanks would be constructed in series using the same media size range, starting with the coarse media tank upstream.

Guidance on how many filters may be required can be drawn from the following information but will always be determined by the actual raw water characteristics: (It is assumed that they will be built in Oxfam T11 tanks).

The throughput of upflow prefilters is determined by applying a loading typically in the range 0.6 - 1.0m^3/m^2 of filter area/hour but 0.6m^3/m^2/hr has been shown to be the most efficient.

i.e. Throughput = Plan Area of T11 tank (1.3 x 1.3 x 3.142) x Loading x 1000 litres/hour.

As a guide, a roughing filter built of 3 layers in one tank has a % removal efficiency of 85% at 0.3 m/hr and 75% at 0.6m/hr. 3 roughing filters in series have a % removal efficiency of 87 - 92% when operated at 0.3 - 0.6m/hr (all for turbidity range 30-500 NTU). Thus for example, this might suggest that if raw water was NTU 50 and it was intended to chlorinate it, then 3 roughing filters in series would bring the NTU level down to about 5, which would be acceptable. If however the raw water was NTU80 and it was intended to pass water into a slow sand filter, then 1 multi layer roughing filter would bring the NTU level down to about NTU20, which would be acceptable.

Typical Performance of a 3 No, T11 Tank Series:

Influent UPF 1 = 400 NTU (Raw Water)
Effluent UPF 1 = 120 NTU (Influent UPF 2)
Effluent UPF 2 = 36 NTU (Influent UPF 3)
Effluent UPF 3 = 12 NTU (Further treatment applied)

The use of roughing filters that require reasonably graded and sized gravel takes time to build. For this reason, the use of coagulants is recommended for the first phase, as they can reduce suspended solids more quickly and require less tanks.

Advantages	Disadvantages
Simple and low tech and therefore appropriate as part of long term durable solution. Effective as first stage pre-filter	Assumes availability of gravel and sufficient supply of water for cleaning. Further treatment stage may be required prior to chlorination. Takes time to construct so possibly not suitable for rapid first phase use.

Practical guidelines on setting up roughing filters using Oxfam tanks are provided in the Oxfam Technical manual on "Water Filtration Equipment".

3.6 Membrane filtration

Artificial membranes provide viable alternatives to natural filtration through sand or gravel beds. A reduction in membrane costs has coincided with a proliferation in suppliers offering membrane based water treatment solutions.

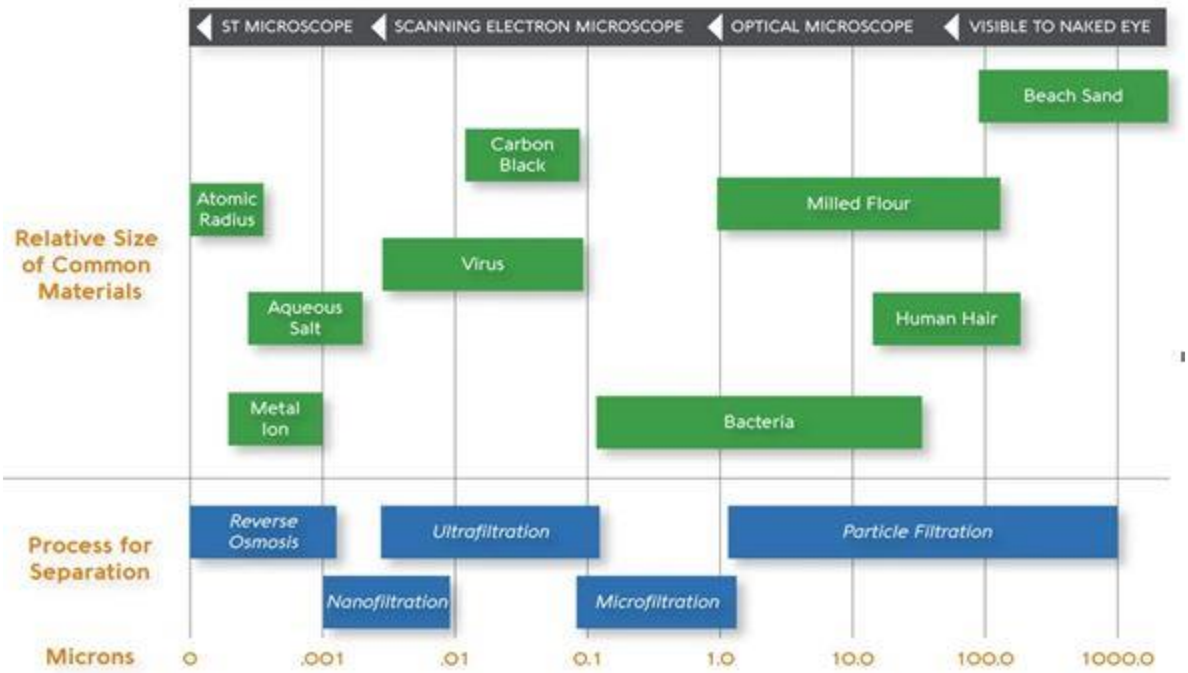


Figure 8 - The filtration spectrum.

Reverse osmosis and nanofiltration which are associated with removal of salts are not considered here. For removal of physical particles – particle and micro filtration are most relevant.

Output is the main limiting factor of membrane filters. To meet a high demand stacks of filters operating in parallel are often required. Regular cleaning is required as membranes can easily clog and rate of clogging is directly related to the turbidity of the influent water. Typically a raw water should be 100 NTU or less to avoid regular stoppages for filter backwashing. Above this a pre filter is recommended. Manufacturers claim that with additional particle and microfiltration, raw water of up to 500 NTU is possible with additional backwashing of pre filters.

Probably the simplest bulk water treatment membrane solution is the Sky Juice "Skyhydrant" - a low pressure, manually operated ultrafiltration unit produced in Australia. The smaller Sky

Hydrant "GEM" has a nominal output of 5,000 litres per day and costs (£1,000/unit[1]) while the larger Sky hydrant "MAX" has a corresponding output of 10,000 litres (£1,500/unit). Both require an operating head of 2-4 metres, so the optimal set up would typically consist of single stage pumping to a raw water tank with gravity feed through the filter to a cleanwater tank and tapstand distribution. Multiple units can be arranged in parallel to meet increased demand, e.g. a stack of 10 Sky hydrants (£15,000) could provide 5,000 people.

The low operating head, no power requirement and modular nature of Sky Hydrants lends themselves for small to medium sized communities who are potentially dispersed in nature. Skyhydrants are relatively compact and lightweight (9 and 13kg respectively) so cost effective to airfreight and easy to handle, transport and set up.

The higher the turbidity, the more quickly filter pores clog and flow rate reduces. Under high load conditions this may be required every 1-2 hours and requires a manual "shake and flush" by oscillating the handle, a cycle that takes 1 to 2 minutes to complete per unit.

Oxfam has used Skyhydrants in responding to Pakistan Earthquake, Sri Lanka (Tsunami) and most recently Indonesia (Palu response). There are an ever increasing number of brands and suppliers of membrane filters. Some are skid mounted, include pumps and full automation to backflush membranes

Membrane treatment may be appropriate where chemical treatment is not favoured either due to lack of availability of alum and chlorine or if the technical capacity is low – for example in a rural community setting. However, the operating challenges of daily cleaning and maintenance and periodic chemical cleaning of the membranes when production drops should not be underestimated.

Ampara District Water Treatment Plant (2005), source water range 40-60 NTU

10 Sky Juice filters initially capable of producing between 80-100m3/day. Filtered water has consistently had a turbidity <5, suitable for chlorination prior to distribution. Backwashing of filters was undertaken every 2 hours. Monitored output varied between 200 and 600 litres per hr with an average output midway at 400 litres.

Sri Lanka (2007) – Killivedy River, source turbidity 60NTU

10 Sky hydrants were set up in parallel to provide drinking water to IDPs. Demand was 48,000 litres per day. The filter plant operated for 12 hours per day during which 1 hour was consumed for maintenance. Maximum recorded production was 6,729 litres/hr (670 litres average per unit). Within 2 months output had reduced to 4,129 l/hr, a 39% performance reduction. Iron was present in the water and it is considered that iron deposits on the membrane may have contributed to the observed reduction in performance.

In addition to routine flushing/cleaning, periodic chemical cleaning by adding citric acid overnight was also used to improve performance.

Figure 9 – Sky Juice Case study, Sri Lanka

[1] 2020 prices

Advantages	Disadvantages
Compact, lightweight and easy to deploy (e.g. can be installed on back of small truck for mobile treatment system). Modular so flexible for different populations. Relatively low cost for small communities. Relatively simple to operate and maintain. Can operate without electricity or electronics. For low turbidity water provides a single stage treatment process for provision of potable water.	Becomes costly where demand is high. Performance drops over time. Short to medium solution only. For turbidity >100NTU additional of a prefilter should be considered. Membranes are fragile and can be easily damaged if operating heads are exceeded. Automated systems are more complicated to maintain and require a power source.

3.7 Package treatment kits

3.7.1 Aquaplus P4000/Scanwater Emwat 4000

Figure 10- Aquaplus water treatment unit

A complete portable treatment plant comprising Alum dosing, two pressure sand filters and chlorination, capable of treating water with turbidity of up to 500NTU and producing upto 4,000l/hr. The P4000 produced in India and costing £10,000 is significantly cheaper than European Emwat 4000 and for this reason has been Oxfam's preferred option in the past. Due to relative speed of set up and space required, the treatment unit is most appropriate for responding to floods and other first phase responses where a quick and short-term solution is required. Before considering this equipment, it is important to consider supply lead times as past experience has shown that by the time equipment actually reaches its intended destination, the context may have changed and it may no longer be required. Due to low demand Oxfam does not currently stock this item and the lead time from the factory in India is 6 weeks. Consequently, Oxfam engineers are likely to only use this type of equipment if it is already in Country as part of our own or UN Agency contingency equipment.

3.7.2 Membrane systems

Various brands exist and membrane treatment systems are increasingly available in local markets. For example a good starting point for the African market refer to Davis and Shirtliff website. Their frame mounted modular systems can give an output from 2-30m3/hr. Unlike simple Skyhydrant filters, larger membrane systems typically contain a range of filter pore sizes, may include chlorination, requires power and have a higher level of automation. Depending on the turbidity of the source water, additional pre-treatment may be necessary to avoid rapid clogging/frequent backwashing, so it's important to be clear on the specification of the system being considered. Cost and availability of product, capacity of operators, after sales support, reliability of power, topography, site conditions are all important factors to weigh up the merits of this and other options.

Advantages	Disadvantages
Can be rapidly deployed and set up so suitable for first phase response. Compact.	Not suitable for large populations or where water demand is high. Performance drops over time. Not suitable for community operation and management. Procurement lead times are slow. Not suitable for medium or long term use

3.8 Disinfection

Dirty and polluted water can contain many harmful organisms. The disease-causing organisms (pathogens) include bacteria, bacterial spores, viruses, protozoa and helminths. These can cause diseases like cholera, bacillary dysentery, typhoid, infectious hepatitis and diarrhoea. Disinfection of water aims to kill these pathogens without leaving any harmful chemical substances in the water.

Chemical disinfectants for water should have the following attributes:

- Destroy all pathogens present in the water within an acceptable amount of time.
- Be able to perform within the range of temperatures and physical conditions encountered.
- Disinfect without leaving any harmful substances in the water.
- Permit simple and quick measurement of strength and concentration.
- Leave sufficient active residual concentration as a safeguard against post treatment contamination.
- Ready and dependable availability at a reasonable cost.

Water treatments such as sedimentation and filtration can significantly reduce the number of pathogens in water. Chlorine is used to kill those remaining.

3.8.1 Chlorine

Chlorine is the chemical most widely used as it fulfils most of the above criteria for disinfection and is often widely available in one form or another (see section below). Under the right conditions, chlorine will kill all viruses and bacteria, but some species of protozoa and helminths are resistant to chlorine. Protozoa and helminths are difficult to detect directly, but where these are thought be a risk, it may be necessary to resort to use of Membrane filters to strain out these organisms (the smallest of these are Giardia cysts at 7-10microns, while cryptosporidium oocysts are 4-6 microns).

When a suitable chlorine compound is added to water, only a part of it is available for killing viruses and bacteria. This part is called "Free Available" or "Available" Chlorine (AC). Only small amounts of chlorine are required to disinfect polluted water.

After it has been added, the active chlorine needs a certain amount of time to kill the viruses and bacteria in the water. This is called the "contact time" and is normally a minimum of 30 minutes for neutral pH waters. However, **the length of contact time required for the active chlorine to be fully effective depends upon many factors of which the most important are pH and water temperature.** A higher water temperature will enable the chlorine to work faster. Water standing in an open bucket will lose the taste and smell of chlorine (and thus disinfection powers) after a few hours as it dissipates into the air.

Most raw water sources have a pH value within the range 6.5 - 8. As pH levels rise, the disinfecting properties of chlorine become weaker and at pH 9 there is very little disinfecting power. See Table 1 below.

Contact time must never be less than 30 minutes.

If the water to be disinfected contains a lot of suspended solids and/or organic matter (i.e. is highly turbid), it will have a high chlorine demand. WHO guidelines recommend that turbidity is less than 1 NTU for chlorination to be effective in destroying all bacteria and viruses, though 5 NTU is a more achievable limit and will be adequate in most cases. It is, therefore, desirable to remove suspended solids as much as possible before the chlorination process begins. This will significantly reduce the amount of chlorine needed and improve its efficiency as a disinfectant.

If iron and manganese are present in the water to be disinfected, a substantial amount of chlorine may combine with them to form compounds, which are insoluble in water. It is, therefore, beneficial to remove the iron and manganese. This may not always be possible, although simple aeration systems may be appropriate.

If too much chlorine is added to the water and the residual is too high, the water will have an unpleasant taste and smell, and consumers will prefer other sources which may be more polluted. Bad tasting water to one person may be acceptable to someone else and judgment of this is quite subjective. Normally when the free chlorine residual is higher than 0.6 mg/l most people will find the taste unpleasant and will try to find an alternative.

Contact time/chlorine residual required for complete disinfection at higher pH

pH	Required chlorine residual at 20°C (mg/l)	Contact time needed for effective disinfection (mins)
8.0	0.5	30
8.5	0.2	206.0
	0.5	82.5
	0.8	52.0
	1.0	41.0
	1.5	27.5
9.0	0.2	412.0
	0.5	165.0
	0.8	103.0
	1.0	82.0
	1.5	55.0

Another problem in emergency situations is the use of dirty water containers. From time to time, once per week or once per month, extra chlorine should be added to the water so that there is a residual of up to 1 mg/l, to help deal with contamination that may build up in these containers, though this will have to be done in consultation with the community.

The point at which FCR is measured is significant - at source, point of collection, or point of consumption. Ideally, to ensure water remain safe and risk of re-contamination is avoided, a residual of at least 0.2 mg/L should be maintained at the point of consumption until the last cup of water is consumed.

3.8.2 Types of chlorine

Chlorine is DANGEROUS. The safety rules concerning its handling must always be followed.

Gas and chlorine dioxide

Chlorine gas and chlorine dioxide are widely used in water treatment in Europe. However, the handling and transport of them is considered too hazardous for the sorts of projects Oxfam or its partners are likely to be involved in.

Calcium Hypochlorite - $Ca(OCl)_2$

Calcium hypochlorite, also widely known as bleaching powder or chlorinated lime, comes as powder containing approximately 33% available chlorine. It is stored in corrosion resistant containers. Once the container is opened, the powder quickly loses its strength. This can be very significant e.g. about 5% in 40 days if the container is opened for as little as 10 minutes per day, or approximately 20% if left open for the whole period.

The powder is not added directly to the water to be disinfected. The usual method is to make a solution of 1% available chlorine and add this to the water.

In making up these solutions, it is advisable that the strength does not exceed 5% available chlorine. At this level of concentration a lot of chlorine can be lost as it is absorbed by the sediment. The most stable solution is 1% available chlorine. Solutions of chlorine are more prone to loss of strength than bleaching powder. Sunlight and high temperatures can speed the amount of active chlorine lost. To minimize such losses, the solution should be stored in a dark dry place and at the lowest possible temperature. The solution should be stored in dark corrosion resistant containers (glass, plastic, wood, ceramic) which must be securely closed.

More stable chlorine compounds are available on the market. They are more expensive to buy but because they last longer in the store, can prove to be more economical in the long run. High Test Hypochlorite (HTH) is one such stabilised form of Calcium Hypochlorite. It contains between 60 - 70% available chlorine and with suitable storage will maintain its initial strength with little loss. It is available in tablet or granular form. Other prepared solutions include ICI Tropical bleach - 34% available chlorine and Stabochlor - 25%.

Sodium dichloroisocyanurate Dihydrate (NaDCC)

NaDCC replaced HTH within the Oxfam Supply centre when the latter was classified as a hazardous substance for airfreight. NaDCC is supplied as granules in 5kg tubs (Oxfam Code FCL) and has a minimum Chlorine concentration of 50%

Sodium Hypochlorite (NaOCl)

Sodium Hypochlorite is generally available as a solution commonly known as bleach, though it is however a poor substitute for Calcium Hypochlorite or NaDCC. Typical available chlorine contents range from 1-5% but can be as high as 18%. Before using these solutions the available chlorine content should be known. The solutions become less stable as the chlorine content rises.

Buying solutions of sodium hypochlorite is not economic for large scale use, as the transport costs are high. This results from the volume and weight to be transported. It is far better to buy powdered forms of chlorine and prepare solutions for addition to the water on site.

Slow Dissolving tablets/pucks

Trichloroisocyanuric acid is a relatively stable form of chlorine extensively used to disinfect swimming pools. If stored in non-humid conditions at temperatures below 25°C, can retain its full strength for two years. As it is now classified as hazardous airfreight no longer supplied by the Oxfam supply centre. Medentech now supply an NaDCC puck under its "Aquatab Flo" product name. This is now commonly available in local markets and can be used via "inline" dispensers which can adjust flow and therefore speed of dissolving/concentration or via traditional chlorine floating pots (Code FFP). The compound dissolves very slowly in water and so it is suitable for disinfecting drinking water in wells or where a slow chlorine release is required. It is recommended that this form of chlorine is not used in drinking water supplies for more than three months in one year and not dosed at more than 10mg/l. It should be noted that the health risks associated with prolonged use of the tablets are much less than the risk ensuing from drinking non-disinfected water.

3.8.3 Determining the dose of chlorine.

When using chlorine to disinfect drinking water the aim is to kill off all the viruses and bacteria and then to leave a small amount of active chlorine in the water. This remaining chlorine is called the "residual chlorine". The residual chlorine is desirable as it can disinfect further contamination of the water once it has been collected, e.g. from dirty water containers. It is desirable to have a residual free chlorine level of 0.2-0.5 milligrams per litre (mg/l) at the point of use.

The chlorine demand of water will vary greatly from one location to another. It is, therefore, important that the person responsible for the chlorination process is able to calculate the actual chlorine demand of the water to be treated.

This is a simple process of trial and retrial. Specific quantities of a chlorine solution can be added to litre samples of the water to be treated, e.g. sufficient to give 3, 4 or 5mg/l. The residual chlorine can then be tested after a minimum of 30 minutes. The chlorine demand can then be determined by deducting the residual from the amount of chlorine added.

Chlorine Demand = Known Dose - Residual Chlorine

When the chlorine demand has been calculated, the desired residual level can be added arithmetically to give the required chlorine dose per litre of water. E.g. chlorine demand = 3.5 mg/l, desired residual = 0.5 mg/l, chlorine dose = 4 mg/l. This figure is then used to calculate the amount of solution to be added to the volume of water to be treated.

For reference: When in water 1 mg/litre (mg/l) = 1 part per million (ppm).

It is very important that the free chlorine residual is measured as this indicates how effective the chlorination process has been. A very simple test involves the use of a kit designed for measuring the chlorine levels in swimming pools. It is called a pool test kit (Oxfam code FPO).

A sample of the water to be tested is placed in the comparator and a DPD No.1 tablet is dropped into it. The chlorine in the water reacts with the DPD tablet to give a level of coloration in the water. This colour is compared directly against the colour chart on the kit. The strength of colour then tells the operator the level of residual chlorine. To determine the total chlorine presence in water (free chlorine + used chlorine) a DPD No 3 tablet is added to the same compartment with the water tested with the DPD No 1 tablet and the reading taken accordingly. (The kit can also measure the pH of the water sample in a similar comparative manner using the phenol red tablet.)

During the dry season, the quality of the water in rivers does not change by much, so that if the above procedures are followed, it should be possible to consistently produce water of good quality. During the rainy season, the quality of the water in rivers can vary enormously from day to day. Extra chlorine will probably be required and this amount can only be determined by trial and error, and a better idea of the amounts needed will become apparent as the operators acquire experience of their individual systems.

Adding chlorine to water.

A solution of 1% available chlorine is recommended as the strength of solution to be prepared and it should be used as soon as possible after making it up. The following table gives an approximate guide to producing 1% solutions from various chlorine compounds. The amount of chemical required will also be dependent upon age of the chemical used to make the solution, long periods of storage significantly weakening the chemical.

Quantities of Chemical required to make 1 Litre of 1% Chlorine Solution

Source of Chlorine	Available Chlorine %	Quantity Required (g)*
Bleaching Powder	34	30 - 40
HTH	70	14
Tropical Bleach	34	25
Stabilised Bleach	25	40
Bleach	1% Solution	-------

* Where scales are not available, it may be necessary to make an estimate. 1 teaspoon is very approximately 14g, but this is not a very reliable measure.

These quantities of chemicals should be added to 1 litre of water in the following way. The amount of chemical needed to make a 1% solution is placed into a suitable (preferably plastic) vessel and sufficient water is added to make a smooth cream, in the case of bleaching powder. It is best to use a wooden stirrer to break up the lumps. When all the lumps have been broken the cream should be diluted to the required amount using the remaining water and mixed thoroughly. The sediment should be allowed to settle out, and then the clarified liquid taken off to be used as the disinfecting agent in the water to be treated. For granular forms, such as: HTH, adding the required quantity to one litre of water and agitating will be sufficient to ensure good mixing.

Once the dose has been determined volumetric equivalents can be used to approximately measure the weight of chlorine and thus determine quantities to be used in operating the treatment process. Chlorine in HTH powder form has a density of about 800g/litre.

The 1% solution is used as the means of disinfecting larger quantities of water as shown in the table 3 below:

Volume of chlorine solution to be added to different water volumes

Chlorine Dose Required	Volume of 1% Solution to be added to		
	10 litres	100 litres	1,000 litres
1 mg/l	1 ml	10 ml	100 ml
5 mg/l	5 ml	50 ml	500 ml
10 mg/l	10 ml	100 ml	1 litre

ml = millilitres

Using rough guide figures to give a 5mg/l dose of chlorine to a reservoir of 45,000 litres will require 22.5 litres of 1% solution.

Chlorination rules

- Treatment is important to get water to be less than 5NTU before chlorinating.
- Check pH and temperature to help assess contact time.
- Ensure minimum contact time is allowed before consumption.
- Always test for residual chlorine levels.
- Follow the storage guide for the particular chemical being used.

3.9 Slow Sand Filtration (SSF)

Before chlorination was introduced, slow sand filtration alone was shown to have significantly reduced the incidence of water-borne diseases in the UK. Probably no other single treatment process can simultaneously improve, to such an extent, the micro-biological, chemical and physical quality of water. It remains simple, reliable and effective, however SSF has increasingly been replaced by alternative technologies including pressure sand filters, synthetic membrane filters, lamella clarifiers and coagulation-flocculation-sedimentation. For Oxfam programmes SSF is likely to be appropriate in areas where they are already being used, where there is an abundant supply of good quality river sand and as part of a durable solution where chlorination is not possible and/or it is preferred option of local authorities/institutions/partners.

Properly operated, a slow sand filter can remove 99% or more of the E.coli population (bacteria indicating the presence of faecal contamination) and even where water temperatures fall to 3^{0}C, a mean reduction of 97% E.coli and microbial pathogens can be maintained. However the sand filters need to mature for a period of a few weeks before the micro-biological action of the *schumzdecke* (biological layer in top few centimetres of sand) becomes fully active and during this time it is advisable to ***post*** chlorinate the water to ensure it is potable (chlorine will kill the *schumzdecke* if chlorine is added before filtration).

The slow sand filter is suitable for treating water of reasonable quality which is low in turbidity (10-20 NTU), although peaks of 40-60 NTU have been accommodated for short periods of time. The slow sand gravity filter is essentially an open-topped box drained at the bottom and partly filled with a filtering medium (normally clean sand and a layer of stones or gravel). Raw water is admitted to the space above the sand and passes through the sand by gravity. Purification takes place during this downward passage and the treated water is discharged through the under-drains. The sand filter is not just a water-screening technique but the filter will develop a very active micro-biological treatment of the water. The filter will run for several weeks or more without cleaning but does require a continuous flow, which can be difficult, in order to maintain the functioning of the Schumtzdecke.

Slow sand filters can form part of a durable solution and provide a viable alternative in rural areas and/or where supply of chemicals for disinfection is problematic. An Oxfam SSF constructed in Fizi territory of DRC during the 1994 Rwandan Genocide was still found to be working when an Oxfam team returned in 2017.

Advantages	Disadvantages
Proven low tech method of water treatment. No chemicals required to achieve safe potable water. May be appropriate for post emergency phase	Requires continuous flow and careful management to optimise performance. Generally not suitable for emergency phase. Risk of recontamination of water unless post treatment chlorination used.

Practical guidelines on setting up slow sand filters using Oxfam tanks are provided in the Oxfam Technical manual on "Water Filtration Equipment". Oxfam Supply Centre no longer stocks a slow sand filtration kit but this manual provides a full list of items required, which can be ordered on demand.

3.10 pH adjustment

The coagulant most commonly used by Oxfam is aluminium sulphate powder (Oxfam code FAS), which though not a very strong coagulant, does have the advantage that it can be air freighted easily and is quite commonly available in different parts of the world. However, it does have quite a narrow pH range, operating best between pH 6.5 and 7.5 and outside these limits its efficiency goes down and hence more has to be used to compensate. This occurs as the solubility of aluminium precipitate increases dramatically outside this range, which means that where pH is too high or too low, a floc precipitate will be unable to form easily.

As the addition of (acidic) aluminium sulphate to water lowers the pH (by reacting with its natural alkalinity), there is a risk that water pH may fall outside the optimum range. Where water has insufficient alkalinity or buffering capacity, additional alkali must be provided, usually by the addition of Quick lime (CaO), as this will raise the pH of the water. As a guide, around 7 – 14kg of lime added to $95m^3$ of water will provide an appropriate level of pH adjustment, though clearly the actual amount should be determined as part of the jar tests.

3.11 Iron removal

Aeration can be used to reduce the iron content. Aeration will oxidise Ferrous Iron (II) to the insoluble Ferric Iron (III) and the precipitate can be removed with a bed of media. Some recent work has been undertaken on an uncomplicated aeration and filtration system, in which designs for iron removal plants may be simplified. Passage of water through a slotted pipe, produces a very limited spray of water, which is sufficiently aerated to oxidise the Iron, enabling it to be filtered out in a shallow bed of coarse sand.

Sand depths of 0.1m and 0.15m have been tested with 1.18mm sand (supported on a bed of 0.05m depth of 6mm gravel) and a depth of 0.2m depth tested with the 1.3mm sand. Iron containing groundwater (mean 7.5mg/l) was supplied to the filter beds. The 1.18mm sand beds consistently produced filtered water which met the WHO recommended levels of 0.3mg/l (i.e. 96% reduction), while the 1.3mm sand also produced water below the WHO limit, but less consistently.

These filters become clogged with time by trapped gases and iron precipitates but can be cleaned, on say a weekly basis or once flow is reduced (see table), by gently stirring the sand bed completely three times with a stick, taking care not to over stir as this will disturb the biofilm.

Typical flow rate m/hr

	Clean	Clogged
1.18mm sand	1.91	0.51
1.30mm sand	3.18	0.76

4. OXFAM WATER TREATMENT MODULES

SUMMARY

Oxfam developed two batch water treatment modules. Multiple systems can be set up in parallel but different situations will require modifications to this, different combination of tank sizes or even a completely different approach. With some items increasingly available in Countries, demand for these complete kits has dropped and they are no longer stock items. Indicative costs are provided and they can be ordered on request from the Oxfam Supply Centre.

4.1 Rapid Batch Water Treatment Module

This module contains all the equipment to set up a small scale and short-term water treatment installation in a first phase response. It uses a lightweight pump, suction side dosing kit and a 30 m^3 onion tank for flocculation and sedimentation then filling two 10 m^3 bladders for chlorination and storage. Based on approximately 6 hours for sedimentation and 2 hours for filling and emptying, this module could supply up to 60 m^3 per day which would provide water for approximately 4,000 people. The module includes water measuring and testing equipment, to determine the dosing chemical quantities. It also includes a tool kit for installation and ongoing maintenance.

This module can be set up and operated by an experienced Public Health engineer and three technical or trained staff. To operate the treatment process to its maximum output, shift working will be required for fifteen to eighteen hours per day.

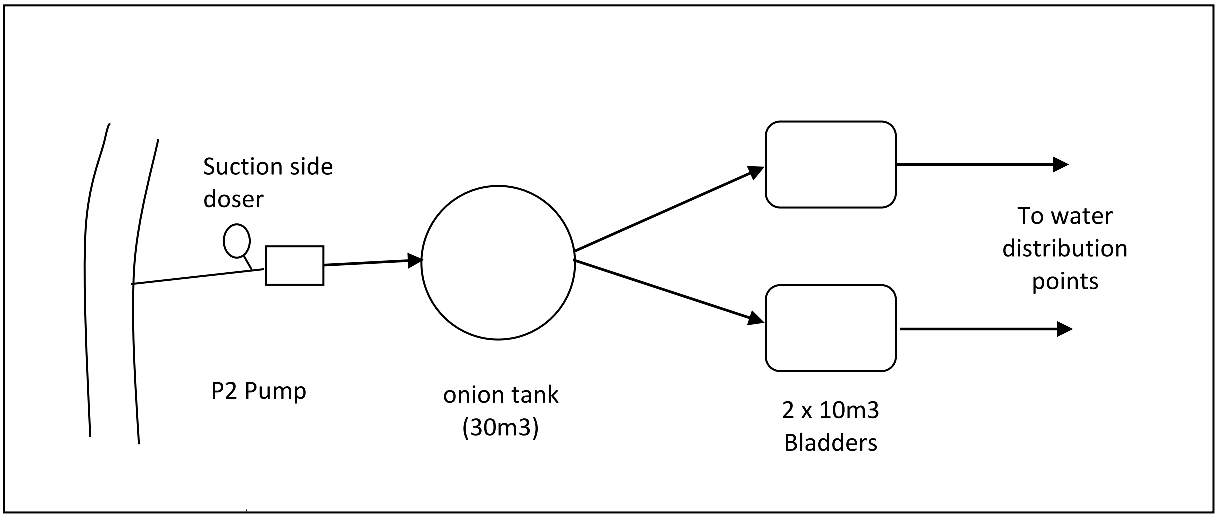


Figure 11- Layout of Oxfam batch treatment kit

Components included

Line	Code	Quantity	Description
1	TRR30	1	Tank kit, Onion - 30m³
2	TBT10	2	Tank kit, Bladder - 10m³
3	FASD	1	Chemical Dosing kit, Suction Side
4	PR2	1	Pump kit, Surface Water, 2" - Lightweight petrol engine
5	TWCT	2	Oxfam Jerry Bucket, 14 litre - 200 pce
6	G215	2	Hose, Flexible reinforced, 2", 30m

7	G216	6	Coupling, hose, 2"BSP(F)
8	G217	3	Coupling, hose, 2"BSP(M)
9	G218	12	Hose clip, bolted
10	G223	2	Tee, Equal, 2", BSP(F),
11	G325	2	Elbow, 3" BSP(F)
12	G320	2	Nipple, 3" BSP(M)
13	FCL	25	Chlorine, granules, 5 kg
14	FAS	1	Aluminium sulfate, granules, 25 kg - 40 pce
15	FMT	1	Water measuring and testing kit
16	FPO	2	Pooltester - for chlorine and pH
17	FD1	1	Tablets, rapid test for Pooltester - 250 pce
18	FPR	1	Tablets, rapid test for Pooltester - 250 pce
19	OS	1	Tool kit, Site

Volume (m³): 8.202

Weight (kg): 2208

Indicative Cost (GBP: £12,000

4.2 Medium Scale Batch Water Treatment Module

This module contains all the equipment required to set up a simple water treatment system with flocculation, sedimentation and chlorination. Based on approximately six hours sedimentation time (using two batch treatment tanks alternatively) plus two hours for filling and emptying, it would be possible to supply up to four tanks or 180 m^3 of treated water per day which would provide water for approximately 12,000 people. The module includes water measuring and testing equipment, to determine the dosing chemical quantities. It also includes a tool kit for installation and ongoing maintenance.

This module can be set up and operated by an experienced Public Health engineer and six technical or trained staff. To operate the treatment process to its maximum output, shift working will be required for eighteen hours per day.

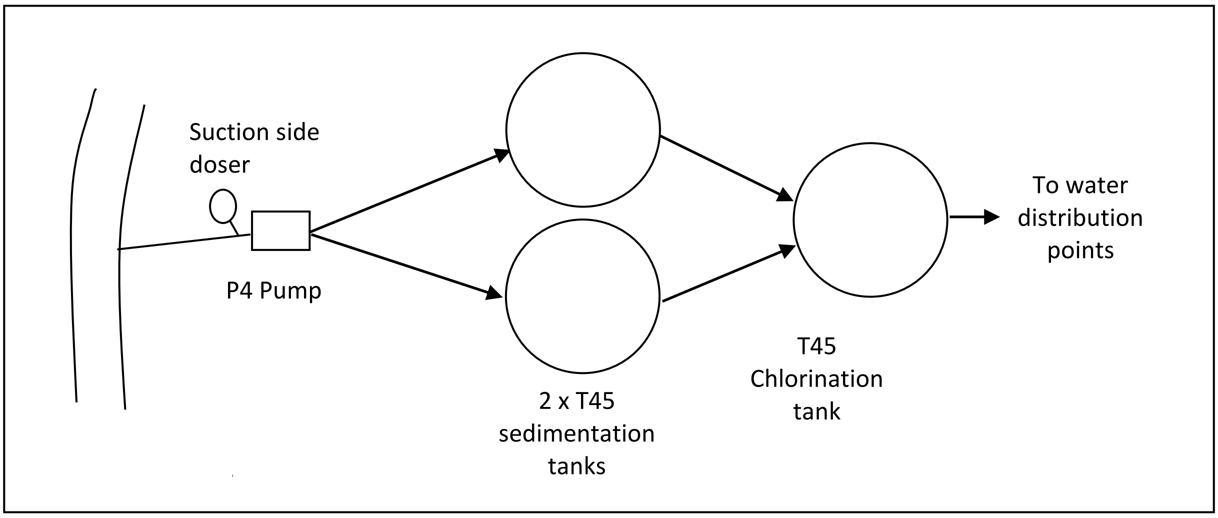


Figure 12 - Layout of Medium scale batch treatment kit

Components included

Line#	Code	Quantity	Description
1	T45S	3	Tank kit, 45 m³, Steels

2	T45L	3	Tank kit, 45 m³, Liner and accessories
3	TUR	1	Tank roof, universal, PVC
3	FASD	1	Chemical Dosing kit, Suction Side
5	P4	1	Pump kit, Surface Water, 4", diesel engine
6	G315	2	Hose, Flexible reinforced, 3", 30m
7	TBTM	1	Fittings kit, batch treatment
11	FCL	25	Chlorine, granules, 5 kg
12	FAS	1	Aluminium sulfate, granules, 25 kg - 40 pce
13	FMT	1	Water measuring and testing kit
14	FPO	2	Pooltester - for chlorine and pH
15	FD1	1	Tablets, rapid test for Pooltester - 250 pce
16	FPR	1	Tablets, rapid test for Pooltester - 250 pce
17	OS	1	Tool kit, Site
15	OL	1	Ladder

Indicative Cost (GBP): £20,000

Volume (m³): 8.202

Weight (kg): 2208

5. OPERATION/MANAGEMENT (BULK WATER SUPPLY)

SUMMARY

This section details some of the main concerns that would be encountered in management, operation and maintenance of a system.

5.1 Cost effectiveness

In first stage emergency speed and ensuring immediate need are met is a priority. This may result in short term decisions which are not technically the most appropriate or cost-effective solution. Plans should be developed as soon as it becomes clear that a situation may last months rather than weeks. It is essential to consider quality, quantity and reliability together with cost effectiveness, durability and taking into consideration who will be responsible for long term management, how consumables and replacement components will be sourced, where technical expertise is located and how will all of this be paid for within a typical humanitarian scenario where funding rapidly diminishes as the stabilisation phase progresses, new crises elsewhere occur and it becomes another protracted, forgotten crisis.

5.2 Operation

Care should be taken to ensure that there is good co-ordination between pumping regimes and dosing of chemicals. Every time there is a need to pump water from the source the pump operator needs to inform the person responsible for chemical dosing, so that they can add the chemicals at the correct time. Every time the raw water tank has been emptied into the chlorination tank the pump operator should be notified so that the raw water tanks can be refilled, in order to maximise the output of the system. A pumping/tank emptying schedule should be drawn up, specifying time for all operations to be performed and who performs them. Operators should fill out forms to record actual performance - see form 3 in Annex 3.

5.3 Monitoring

Various parameters should be measured on a regular basis, to:

- Record whether the operation and treatment systems are working properly.
- Reveal a need to adjust treatment according to changes in raw water quality.
- Assist stock control.

Turbidity, pH, faecal coliforms, alum carry over, chlorine residual, should all be measured and a standard form for doing so is included in Annex 3, form 2. (Use FMT kit)

Daily records of the amounts of water the system has produced, along with the quantities of chemicals and fuel used per day should also be kept. These records should be passed on to supervisors, or the engineer in charge so that they also know what is happening in the system. This allows planning ahead so that chemicals, fuel etc. can be ordered to keep in stock. These records will also reveal problems with the system, as a set of good records can often help to quickly identify the problem, see Annex 3, form 3.

5.4 Use and safe handling of chemicals

The bags or containers of chemicals should be kept in a secure store. They should be protected from rain, damp and sun, and should be stored off the ground on wooden pallets or similar. Poorly stored chemicals can spoil and be of little or no use. Chemicals are expensive and not easily disposed of or replaced once spoiled. Where chemicals are to be purchased in country the quality of these should be checked to ensure that what is being purchased is of the specified and required quantity.

Chemicals should be treated with care. Aluminium sulphate and, especially chlorine, should only be used in well ventilated areas. Avoid breathing in the fumes/powder of the chemicals.

Chlorine especially can be very dangerous. Once it becomes wet, or is mixed with water, it becomes caustic. When mixing with water, add small quantities of powder at a time, and stir carefully to avoid splashing. Rubber gloves should be worn when working with chlorine to protect hands.

If chlorine solution should splash on your skin or hands, wash it off immediately with plenty of water. If the solution should splash in your eyes, rinse them repeatedly with clean water, and see a doctor as soon as possible. Aluminium sulphate (alum) solution is highly corrosive. It will slowly dissolve metal drums.

5.5 Sludge disposal and Tank cleaning

The process of sedimentation, means that dirt is separated from the water and left in the bottom of the tank as a sludge when the clean water is emptied into chlorination tanks. Sludge accumulated through use of alum is high in metal content and care is required to ensure it does not contaminate surface water or agricultural land. In the short term it may be possible to discharge to an adjacent pit if water will naturally infiltrate the ground, but the risks of polluting groundwater also need to be considered. It should not be discharge back into a water course. The method should follow local environmental regulation and be acceptable to local authorities and the community within the catchment area. Over a long period, sludge disposal can become a serious logistical and environmental problem. Where this is the case alternatives to chemical coagulation should be considered.

When cleaning tanks, a team of cleaners should enter the tank and using brushes, carefully clean the sediment out of the tank, and clean the walls and floor of the tank. Whilst doing this, it is good to wash the tank with a weak (0.05%) chlorine solution. Normally, this cleaning will be done every week or 2 weeks, but sometimes, it can be done less frequently than this.

It is good to also wash out the chlorination tank periodically, though this will not need to be done as often as the sedimentation tank.

It is very important that great care is taken not to tear the liners of the tanks. Shoes should be taken off, and sharp tools should not be used or taken into the tank. If the water is highly turbid, a large amount of sludge will be generated, which may be impossible to remove through the 3" bottom outlet. In this case it will have to be removed by hand or sluiced out with a water jet.

5.6 Problems if too much aluminium sulphate (alum) is used

At different times, the amount of alum which should be added will vary, depending on the water quality. This means that if the water is dirtier than usual, more alum than usual will have to be used. However, *it is very important that the extra amount added is not excessive, otherwise there will be alum carried over into the drinking water supply*, giving the water a metallic taste. This will not harm the people at the time, but it is possible that after some years, long term detrimental health effects may result. For this reason, great care should be taken that too much alum is not used.

5.7 Management and training

In all the above activities, good management and training is essential to ensure that procedures are followed as intended. A manual should be produced detailing all points relating to the development and operation/maintenance of the system which should include:

- A history of the development of the system.
- Any future upgrading plans.
- Water quality analysis.
- A full set of drawings of the system layout, detailing positions of valves/junctions etc., elevation drawing with pipeline profiles.

- A full written operation schedule with timings for all operations; chemical dosing and quantities, pump operation/maintenance and fuel use, timings for opening and closing of all valves. (Have these available in the operator's own language if they can read.)
- A list of names of all operators, with duties, shift times and back-ups in case of absence/illness etc., pay scales and organogram of staff.
- Details of managers whom operators should report to in the event of breakdown and problems, and who should take action. (These managers must be contactable each and every day either in person or by radio if the operators do not have capacity to effect repairs themselves).

In addition it is essential to:

- Keep a stock of spares and fittings, for an agreed period of time, of items likely to fail, and adequate stock control of these items.
- Keep a stock of chemicals (taking care of the shelf life of chlorine) and fuel sufficient for an agreed period of time and stock control, with clear idea of who buys these and when. Is there a budget available?

The motivation and payment of operatives is another important consideration. Working hours, especially at night when there will be little or no supervision and when operators may go to sleep, need to be set carefully to avoid problems. Payment and incentives need to be set high enough to encourage work to be proper attendance and performance, while full involvement and explanation will help give the operatives a sense of involvement. Their experience in operating a system should be welcomed and used where appropriate.

Finally, there should also be time set aside to train up operators for the systems by going through every step of the operation, seeing that the operators can demonstrate how it is done. This should then be followed up by visits to check on water quality and quantity and to give training revision sessions. Also, it will be essential to get feedback from the users, e.g. the refugees themselves, to ensure that all is well from the user point of view. Community interaction should be incorporated as part of the training.

APPENDIX 1 - DECISION MATRIX FOR WATER TREATMENT

Chemical composition	Fe>5 aerate	Fl>1.5 and/or other parameters outside WHO guideline consider i) national standards, ii) duration of supply and short-long term implications of exceeding limits, iii) what communities do currently "acceptable norm", iv) consider alternative source, v) discuss/agree best way forward with relevant authority and community	TDS>1,000 Check with users on acceptability. Consider alternative source. If no acceptable source available see desalination technical brief
Turbidity	<5 Suitable for chlorination without other pre-treatment	5-50 Natural Settlement Sedimentation Coagulation-Flocculation, Membrane filtration Package treatment	>50 Coagulation/flocculation, Roughing filters
Supply type & management	Refugee/IDP camp NGO operation, clear exit strategy needed which considers operating cost, complexity, consumables etc.	Community Managed Supply Capacity likely to be limited, avoid complex treatment, use of chemicals, ensure post installation monitoring & follow-up	Utility company Technical decisions likely to be taken jointly, informed by capacity and technology already in use
Duration	Emergency (0-3 mths) What equipment/options are available and can be set up quickly to meet immediate needs to acceptable quality & quantity? In Country Contingency stock? local markets? international airfreight?	Medium term (3-12 mths) Improving quantity and quality of treated water if required.	Long term/ durable solutions (12 mths+) What is most cost effective and sustainable solution? Local capacity, private sector parts, O&M support
Demand	<5m/hr Package treatment, membrane filtration	Beyond m3/hr Batch treatment, Lamella Clarifiers, sand filtration	

APPENDIX 2, DETERMINING THE OPTIMAL DOSE THROUGH A JAR TEST.

Procedure for undertaking a jar test;

1. Make up 1% alum solution

- A 1% alum solution is formed by dissolving 10 grams of granular alum into 1 litre of clean water (mix in less than 1 litre then make up to the final volume). This solution will be referred to as a 1% Oxfam Alum Solution. (To allow measurement by volume to be interpreted as a weight: 1 litre of granular alum weighs 1100 grams and then by use of measuring cylinder in the Oxfam code FMT kit) A baseline alum solution concentration is as follows:

1% Oxfam Alum Solution = 10,000 mg/1 (10,000ppm) Alum Solution

2. Collect equipment for jar test, (as in Oxfam code FMT kit):

- Turbidity is best recorded on a turbidity meter to enable fine distinctions to be made between similarly turbid water.
- The Turbidity tube, Oxfam code FTT does not provide accurate readings, but is probably all that is available.

Equipment required;

- 6 No.1 litre jar (beakers)
- Turbidity meter or turbidity Tube
- Timer or stopwatch
- Pipette or fine measuring cylinder
- Litre measuring cylinder
- Supply of 1% Oxfam Alum Solution
- Raw water sample container (at least 6.5 litres)
- Dining fork for stirring

3. Dose Jars

- Pour appropriate quantities of 1% Oxfam Alum Solution and raw water into test jars to produce the desired concentrations of coagulant.
- Initial starting concentrations of Oxfam Alum Solution in test jars is recommended as 50, 60, 70, 80, 90, 100 mg/1 (i.e. 5, 6, 7, 8, 9, 10 ml of 1% Oxfam Alum Solution for each litre of raw water).

4. Stir Jars

- Stir briskly with a fork for a time equivalent to the transit time in the system. Periodically stir each jar to ensure that a "whirlpool depression" is continuously visible on the centre of each test jar's water surface.
- Stir gently for a time equivalent to the residence time of the flocculation tank (typically approx. 30 mins). Periodically stir each jar to keep the emerging flocs gently moving, they should be visible in the water of every beaker, moving gently.

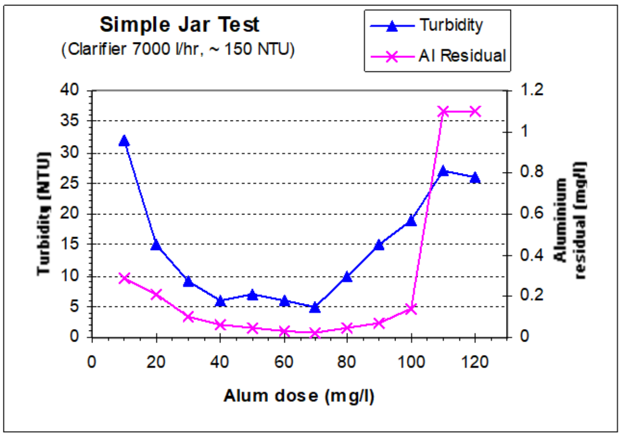
5. Monitor Turbidity

- Allow to briefly settle and then carefully take water samples from the top of each jar to measure turbidity.
- Take turbidity readings for each jar before commencing the test and then at test run times of 2.5, 5, 10, 15, 25 and 40 minute intervals, which requires 6 jars of each concentration to be made up.

6. Plot Results (refer to graph)

- Plot the turbidity results on an X-Y graph with Turbidity in NTU as the Y-axis (vertical) and Alum Dose in mg/1 as the X-axis.
- Produce graphs on the same X-Y axes, one for each "test run time" interval (6 No.)

- The graph with a regular profile (typically "bucket shaped") and which also contains the lowest turbidity value on the Y-axis should clearly indicate the optimum coagulant concentration.
- If the highest or lowest concentration tested appears to be the optimum value, repeat the jar test for further coagulant concentrations which induce this value in the middle of the range of concentrations tested



7. Uncertain Results

- Repeat the test to eliminate experimental error. Check all calculations and graph plots.
- Test pH value of the raw and product water to determine if pH adjustment is necessary. The jar test can be used to find the lime or acid dosing rates required. The resulting range of pH values should extend from 4.5 to 8.5. After stirring, flocculation and sedimentation, the optimal pH value is determined from the samples.
- If pH needs to be raised, lime should be added to keep the pH within the optimum range of 6.5-7.5 for aluminium sulphate use. Alternatively, if no lime is available or for highly alkaline waters, use extra alum to compensate, but monitor alum carry over in treated water (using comparator in Oxfam code FMT kit).
- Try water treatment making a best guess for coagulant levels on the evidence available.

Dosing rates

Once the optimum dose has been established, it is then necessary to determine the actual dose rate, i.e. the rate at which aluminium sulphate solution is put into the water stream. In addition, the total volume of solution that is required for the tank, which clearly depends upon tank size. The table below should give some guidance on this.

Although the jar test is conducted using a 1% solution, dosing should be made using 10% aluminium sulphate solution. This concentration may need to be raised if large volumes of water need dosing or lowered if very small quantities of aluminium sulphate solution are being used such that the rate of dosing is outside the range of the flow meter on the solution side doser. However, it should be noted the while good quality grade aluminium sulphate will dissolve into water at concentrations of up to 20%, where aluminium sulphate is purchased in country and it is a poorer grade, it may be that solubility will be lower than 10% and this should be taken into account.

For a 10% alum solution

Req. dose of alum	Dose rate per 10m^3 /hr of water flow	Dose rate per 50m^3 /hr of water flow	Dose rate per 100m^3 /hr of water flow
30 mg/l	3 l/hr	15 l/hr	30 l/hr
150 mg/l	15 l/hr	75 l/hr	150 l/hr

The rate of water flow (and thus solution flow) will be greatest at maximum pump output. Details of pump output, which depends upon pumping head are given in the pumping manual, but as a guide the following maximum outputs for pumps at very low pumping heads are possible:

PR2	28 m^3/hr,
P2	38 m^3/hr
P4/P4H	90 m^3/hr

Example

The optimum dose rate for a water to be treated has been determined by jar test to be 30mg/l. A suction side doser is to be used with an Oxfam P2 pump, which is pumping into an Oxfam T70 tank, where coagulant assisted sedimentation will occur. What flow rate should be set on the suction side doser and what total volume of alum solution is required?

A P2 pump will pump at max 38 m^3/hr at zero head, so dose rate of alum will have to match this water flow rate. From the table above for a dose of 30mg/l, a dose rate of 3 1/hr is required for a 10m^3/hr, i.e. 11.4l/hr for the P2 pump operating under these conditions. This will require the appropriate adjustment of the needle valve on the suction side doser and this should be set to achieve this flow by estimating the rate of discharge from the coagulant vessel on a volume basis.

The T70 tank has an effective volume of 70m^3 and will require around 21 litres of 10% alum solution to dose the tank.

APPENDIX 3 TREATMENT SYSTEM MONITORING FORMS

(Translate these forms to local language as required)

Oxfam water treatment systems, form 1 - water quality monitoring sheet

Location :

Name of technician :

Required frequency of sampling - daily/weekly/monthly (specify)

Date	Sample No Location	Free Cl Res. Mg/l	Inlet turbidity	Outlet turbidity	Aluminium carry over mg/l	pH	No of Faecal coliforms/ 100ml

Oxfam Water Treatment systems, form 2: Consumable usage and water production records

Location :

Name of technician

	Water production (M^3/DAY)	Diesel (litres)	Chlorine Volume of 1% stock solution	Aluminium sulphate Volume of 10% stock solution	Lime (litres/ grams)	Other

Note: Quantities of chemicals used are expressed in terms of volume as this is easier to measure. Chlorine as 1% solution, lime as %, aluminium sulphate as %

Oxfam water treatment systems, form3, pumping tank operation/filling schedule

Location :

Name of technician :

Pump No.	Time of pump operation		Time outlet valve open				Time outlet valve closed			
	Pump on	Pump off	No.1	No.2	No.3		No.1	No.2	No.3	

ACKNOWLEDGEMENTS

This 4th update is a light review of the third edition by Brian McSorley (Oxfam Public Health Engineering Advisor) in 2020. It contains updated hyperlinks and has a revised section on lamella clarifiers follows completion of research and field trials in Uganda and Bangladesh. It is based on the 2001 Water Treatment in Emergency Guidelines prepared by Richard Luff with contributions from Brian Clarke (University of Surrey).

Oxfam is a global movement of people who won't live with the injustice of poverty. Together we save and rebuild lives in disasters. We help people build better lives for themselves. We speak out on the big issues that keep people poor, like inequality, discrimination against women and climate change.

Oxfam's humanitarian work aims to have the maximum impact on the health of populations affected by crises through the integration of Oxfam's various sectoral activities.
Oxfam's humanitarian personnel are responsible for a wide range of activities, including advising Oxfam's international regions on humanitarian response, building regional capacity to respond to emergencies, leading programme development work on key areas such as WASH, public health, food security, HIV and AIDS, protection, gender, and preparedness. They also deliver advocacy on humanitarian issues in developed countries and provide security management advice.

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Updated April 2024