WORLD HEALTH ORGANIZATION

ORGANISATION MONDIALE DE LA SANTE

PEP/85.12

ENGLISH ONLY

Fluorides - and fluoridation - standards

CONTROLLING FLUORIDE LEVELS: A LITERATURE REVIEW

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Contents

Summary

Excessive levels of fluoride are not uncommon for small water supplies in a number of countries. In such situations the need for appropriate control measures is important and this brief guide reviews many of the available options. Although reference is made to the requirements of developing countries, various procedures used worldwide to remove fluoride from small water supplies are reviewed. An outline of each method is described for treating supplies where the level of fluoride continuously and significantly exceeds the levels recommended by WHO.

Alternative water supplies, blending of supplies, and even the provision of bottled water are discussed as control options. The present review, however, is more directed towards the treatment of the water at its source. Reference is made to "point-of-use" treatment systems.

A wide range of treatment options are noted and evaluated. It is not possible here to specify the most appropriate method for use in certain situations. This is because local conditions, including the quality of the water supply, the availability of local skills, cost and many other factors must be considered. Nevertheless, this review refers to the types of factors that may need to be considered when selecting a method for defluoridation. An evaluation is given of both the more expensive and sophisticated methods a well as the less expensive and in some cases rather simple and limited techniques. Methods are presented in two broad categories: (i) somewhat limited-application systems and (ii) commonly used and well-tried systems. The review was conducted bearing in mind both the best available techniques as well as the needs of developing countries, especially in rural areas, for simple solutions.

The literature review is intended as a starting point to assess the feasibility of a particular treatment method. Reference is made to the need for bench and pilot-scale tests prior to attempting the full-scale treatment of water supplies. Although it was not possible to include the costs of particular methods, appropriate references are given to provide for further readings on costing.

1. Introduction

There are a number of natural minerals which contain the element fluorine, and some of these contribute to the level of fluoride ion (F) found in water sources used for drinking. Fluoride normally exists in low concentrations in many waters (1). Surface waters generally do not contain more than about 0.3 mg F per litre (1, 2, 3, 4, 12). Where fluoride-rich volcanic rocks are common, levels greater than 1000 mg F per litre have been reported in groundwater (1, 2, 5, 6, 12). Deep-well water sources are the most common type of groundwater which can contain rather elevated levels of fluoride (7). Worldwide, there are numerous potable water supplies which contain elevated levels of fluoride (8, 9, 10); most of these are associated with reletively small sources. In some countries like India and Pakistan significant levels have been reported (8, 11). Levels in excess of 2 mg F per litre are not uncommonly found worldwide, and levels in excess of 10 mg F per litre and as high as 30 mg F per litre or greater for drinking water sources have been reported (9, 10). Where fluoridation of water supplies is practised, careful control is generally exercised to maintain the fluoride concentration very near 1 mg F per litre (1). The exact level depends on the local air temperature, since this factor governs the volume of water consumed (12).

Although concentrations up to 1.5 mg F per litre can be beneficial to the oral health of children, as demonstrated by low dental caries incidence rates, levels in excess of this concentration can cause undesirable effects (1). At levels slightly above 1.5 mg F per litre, mottling of teeth has occasionally been reported (11, 13). At still higher levels teeth may become damaged, even severely; at 3-6 mg F per litre, skeletal fluorosis, due to significant effect on the bone, may be observed. If a concentration of 10 mg F per litre is exceeded, severe fluorosis, causing crippling, can result (14). Nutritional deficiencies may possibly exacerbate any undesirable effects. A guideline value of approximately 1.5 mg F per litre for drinking water has recently been recommended (13). When this value is exceeded, there is reason for investigation (13). However, short-term deviations above this value do not necessarily mean that the water is unsuitable for consumption (13). Where the guideline value is exceeded, the responsible public health agency in the region or country should be consulted for advice on any needed remedial action. The intake of fluoride from sources other than drinking water, the likelihood of adverse effects, the practicality of remedial measures, relevant local factors, etc, are important considerations (13). The setting of a national drinking water standard should bear in mind the guideline value of 1.5 mg F per litre. Additionally, particular account should be taken of the local climatic, socio-economic and dietary factors, as well as any other specific sources of exposure to fluoride.

Where the level of fluoride in a water supply is excessive, i.e. consistently and significantly above 1.5 mg F per litre over long periods of time, serious consideration should be given to introducing some form of remedial measures. However, when remedial action for fluoride control is contemplated, it may be considered in conjunction with methods for the control of for the bacteriological quality of the water supply.

Because the literature review is also covering the treatment of water in situations prevailing in developing countries, special considerations are required to this effect. For example, the availability of local skills for plant operators and their training (and re-training) on a regular basis are important requirements. This is particularly important in remote and rural areas. The regular supply of chemicals and various spare parts etc., especially if they are imported, may in some cases be difficult to guarantee (10). In selecting a control option in a developing country it is paramount that such factors are not overlooked. Examples of the control systems used in India and Pakistan have been reported in detail (11, 15).

2. Fluoride control options

If some form of control is considered necessary, one or more of the following options may be applicable: (i) provision of a new or alternative source of water containing acceptable levels of fluoride, (ii) blending of the existing water supply with another containing lower levels of fluoride, (iii) provision of bottled water, (iv) treating the water at the "point-of-use" such as in a small treatment device attached to the household drinking-water outlet; and (v) treatment of the water at its source. One extreme option for a rural area of a developing country could even be the re-settlement of a community to an area of acceptable water supply quality, if no other possible options were available. Each of these options is discussed further in the following:

2.1 Provision of a low-fluoride source of water

This option is only possible under certain geological and hydrological circumstances. If to achieve this, a new well supply is deemed necessary, it may prove an option with high initial costs but lasting benefits for the community. One cannot always guarantee the longer term quality and quantity from a new source in a given locality. Pumping water from another suitable source may be possible, but again cost considerations are important, especially if long pipelines are necessary. The provision of new sources as an option has been effected in the USA (7). This option may only be selectively applicable for developing countries.

2.2 Blending with low-fluoride water

Blending with an adequate alternative source of water can be an appropriate option so long as problems do not result from physical or chemical reactions in the blended waters. Blending with shallow-well water is utilized, and in consequence particular attention must be paid here to the use of chlorination equipment. Blending with low-fluoride water was reported to have been successfully applied in the USA (7). This option is of potential usefulness in developing countries since it provides for a simple long-term solution which does not require any costly treatment. The only condition is the availability of suitable blending water within reasonable distance and of acceptable quality with regard to fluoride and other constituents.

2.3 Provision of bottled drinking-water

This is a very effective method of control, but as a long-term option it could be very expensive. Except in special circumstances, such a provision is unlikely to be a suitable solution in most countries, developed or developing.

2.4 "Point-of-use" water treatment

Reverse osmosis and activated alumina "point-of-use" systems were installed in households and used successfully in some developed countries (16). Although the level of fluoride can be readily controlled, there is a possible danger of the system acting as a growth site for bacteria (16). The individual capital cost to the householder for a reverse osmosis device may be fairly high, and the careful maintenance and operation of these devices is very important (16). Recent experiences with various "point-of-use" systems have been recorded (17). For various reasons such a provision is unlikely to be suitable for situations in many developing countries at the present time. However, it was recently reported in Mexico that a simple and economically viable system exists. It is based on the use of pre-treated bone as an adsorbent to control at the "point-of-use" any excessing fluoride in drinking water (18).

2.5 Treatment of water supply sources

There exists a wide range of treatment systems which have been used for controlling excessive levels of fluoride in drinking water. Some systems are very expensive; some will only operate with certain types of water quality, and others are in practice rather ineffective in reducing the fluoride concentration to acceptable levels. The procedures involve both chemical and physical methods of removal such as precipitation, adsorption, ion exchange and deionization of the fluoride. The following alternative systems exist:

- addition of ferric iron
- lime softening
- use of alum (aluminium sulphate)
- adsorption on activated carbon
- ion exchange resins including zeolite
- use of bone
- electrodialysis
- use of various treatment agents such as magnesium salts, calcium phosphate, bentonites, fuller's earth, diatomaceous earth, silica gel, sodium silicate, sodium aluminate, serpentine or carbion
- use of defluoron
- use of bauxite
- use of lime and alum (Nalgonda technique)
- use of bone char
- use of synthetic bone
- reverse osmosis systems
- use of activated alumina.

The first eight systems listed have either rather limited application for fluoride removal or are not sufficiently well-tried to be recommended universally. Even so, in particular circumstances, they may be quite effective and may not necessarily be unduly expensive. Before a final decision is made on a system to use, the various options described in this review should be considered. If one of the systems given in sections 3 and 4 below is seriously contemplated, then careful bench-scale and pilot-scale testing is generally needed. A comprehensive report has been published on the use of some systems for developing countries (15). Various methods are evaluated and costed in this report (15).

3. Limited-application water treatment systems

The more commonly used and well-tried methods will be given detailed consideration in section 4.

3.1 Ferric iron addition

A floc of a ferric fluoride complex is produced using ferric salts. Normally, only minimal fluoride removal is achieved, e.g. 5.0 mg F per litre is reduced to 4.7 mg F per litre, using 85 mg ferric salts per litre at pH 7.2 followed by 340 mg lime per litre (19) . This is not normally considered an acceptable system to use and only included here for completeness of records.

3.2 Lime softening for fluoride removal

Under certain conditions it is possible to remove fluoride as a side reaction to the lime softening of a water containing high levels of magnesium (20). The process involves co-precipitation of the fluoride with magnesium hydroxide (21). This is a feasible process only when both hardness and fluoride removal are desired and the water contains sufficient magnesium (2). Even then it is more effective where the levels of fluoride are moderately low, i.e. between 3 and 4 mg per litre (22). A detailed analysis of the process has been published (21) indicating that strict control of pH and alkalinity is necessary (7). Some hard waters have been reported to have been treated economically where the natural magnesium level was high (23). This method is linked to the softening process which limits its applicability.

3.3 Use of alum (aluminium sulphate)

Although having a high adsorption capacity for fluoride removal, alum is only suitable for treating certain types of water (7). In the presence of some cations, its capacity is reduced and this frequently makes the method uneconomic (7). The method has been demonstrated to be capable of reducing the fluoride level from 7.5 to 0.8 mg per litre after 2 hours at pH 7.2 to 8.4 (19). Its effectiveness has also been examined under different conditions (7, 19, 21, 24, 25, 26, 27, 28). At the high alum doses used there is a danger in the absence of adequate control, however, that residual aluminium levels may exceed the WHO guideline value for drinking-water of 0.2 mg aluminium per litre, relating to the water's aesthetic quality (13). When combined with lime the use of alum, as in the Nalgonda technique, has been successful in India (see section 4.3).

3.4 Adsorption on activated carbon

Although the fluoride removal efficiency can be high with this process, it is pH dependent (7). At pH 3, a level of 8 mg fluoride per litre can be readily reduced to 1 mg per litre (7). However, the method can be costly to operate since the pH of the water needs to be lower initially, and finally it must be raised to make the water suitable for potable purposes (29). Despite the high efficiency of carbon for fluoride removal, the bauxite and activated alumina systems (see section 4.2 and 4.7) are regarded as considerably superior (30). Many activated carbons have a very narrow optimal pH range, and also their effectiveness can be reduced by the presence of other substances in the water (30). Their efficiencies under different conditions have been investigated (30). Because of high cost and its limitations, this method is unlikely to be of value in developing countries.

3.5 Ion exchange

Research carried out with such systems suggests that the method has limitations, and it can be relatively expensive (31). One problem is the competition for the ion exchange resin that exists between fluoride and other anions which may be present in the water. Amberlite resin XE-75 has been reported to be quite effective for removing fluorides (15, 31). Various resins have been tested and a brief account of their usefulness has been published (7). Economic considerations normally make resins uncompetitive, however. Natural zeolites generally have a small capacity for fluoride removal (19), and this precludes their use as an appropriate treatment option (7). Because of the cost implications, ion exchange systems in general are unlikely to be of particular value for use in developing countries at the present time.

3.6 Treatment using bone

This can be an effective method for fluoride removal but taste problems have been reported to be associated with the treated water (7). However, the situation can be improved by specially treating the bone with potassium hydroxide solution (7, 18). The principle of the method depends on replacing the fluoride ion in the water with the carbonate ion present in bone. After its use, the bone needs to be treated with caustic soda to remove the chemically bound fluoride before the bone can be re-used (7). Economic factors and the comparative advantages of charred bone (see section 4.4) and synthetic tricalcium phosphate/hydroxyapatite mixtures have tended to make the use of bone itself less attractive (22).

3.7 Electrodialysis

This method is not normally expected to be cost-effective in comparison with other cheaper methods such as bone-char or alumina. A membrane separation/electrodialysis method has been used successfully for brackish water (32). The different procedures for electrodialysis were recently evaluated (33). The method is not likely to be appropriate for use in developing countries.

3.8 Use of various treatment agents

Various treatment agents are proposed: magnesium salts, calcium phosphate, bentonites, fuller's earh, diatomaceous earth, silica gel, sodium silicate, sodium aluminate, serpentine and carbion (a cation exchange resin). Although tests with these agents for removing fluoride have been reported (2, 15), little is known regarding their general usefulness and applicability. Some of these agents require the pH of the water to be adjusted to a low value (less than pH 3) to provide effective fluoride removal (2). Calcium phosphate has recently been reported to be very efficient for fluoride removal, but no information on its practical application is yet available (33). Even so, in specific cases, where there is cheap and ready availability of a suitable agent, it could be contemplated. However, pilot tests are essential to check out the effectiveness of the agent for the water in question. In general, because there are other more appropriate options available (see section 4), the above-listed treatment agents are unlikely to be of widespread value for use in developing countries.

4. Commonly used methods of water treatment

The somewhat limited-application water treatment systems are considered in section 3 above. When reviewing the literature world-wide, defluoron, bauxite, lime together with alum (Nalgonda technique), bone-char, reverse osmosis, and activated alumina have found their specific applications. They show promise for the effective removal of fluoride covering a range of circumstances. These methods are considered in greater detail below. Nevertheless, even with well-tried methods, problems may arise for reasons that include a special type of water quality, the quality of the reagents used, water temperatures, and local human skills. Before any treatment of supplies is introduced, adequate bench-scale tests followed by appropriate pilot plant trials for each source of supply is strongly recommended. This testing is especially recommended for situations in developing countries. Jar and other test procedures have been described in detail (11, 35).

4.1 Defluoron-2 as ion exchange medium

This material has been reported to be successfully used in India (8), a country where many water supplies contain excesive levels of fluoride (8). Defluoron-2 is a cation exchange medium made by sulphonating coal (15); alum is used to regenerate the material. A defluoridation plant capable of treating 5.5 m^3 of water per hour per cubic metre of medium has been described (8). The wash-water treatment, the regeneration process with alum, and other aspects of the method have been fully described (8, 15). Fluoride levels below 1 mg F per litre are achievable where the raw water contains 3-10 mg F per litre (8). Operating and treatment costs of this method have been documented (8, 15). There seems to have been little interest in this method outside of India. In relation to other techniques used in India like that of alum and lime (Nalgonda technique), the use of defluoron-2 has been regarded as cumbersome in operation and regeneration (34). It has been reported that skilled operators are needed to obtain effective control with defluoron-2 (34). This condition severely limits the practical usefulness of this method.

4.2 Use of bauxite

The use of bauxite is considered superior to that of activated carbon (see section 3.4). It has a narrow optimum pH range, and in this sense it is not as flexible as alumina (see section 4.7) (30). One study suggested that a pH of less than 3 is needed for reasonable efficiency of fluoride removal (2). In another report, an excellent removal efficiency of more than 90% fluoride was achieved with a 4-hour contact time at a pH of 5.5 to 7 with an absorbent dose of 25g per litre (30). At a level of 40 mg F per litre, a reduction to 1 mg F per litre was readily achieved (30). Bauxite is said to also have some other disadvantages in comparison with alumina, such as a lower removal capacity and a higher mechanical wear (30). However, bauxite normally costs less than alumina (30). The effectiveness of bauxite and its comparative performance with alumina have been investigated (30). Other chemical species apparently do not normally interfere with the fluoride removal process using bauxite (30). Despite some advantes of bauxite, it has been little used. Under certain conditions it might have some applications in developing countries.

4.3 Lime and alum treatment (Nalgonda technique)

The method known as the Nalgonda technique has been very successfully used in India; it was first described in 1975 (35). The principles of the method and its details are fully documented (15, 35, 36, 37). The method involves adding in sequence sodium aluminate or lime (usually lime because it is cheaper), and then filter alum (35). Bleaching powder may be added simultaneously for disinfection (37). The unit operations involved are flocculation, sedimentation and filtration (35, 37, 38). Fluoride levels can be reduced to 1 mg per litre except where the alkalinity of the water is low; if necessary, the alkalinity can be increased by means of lime addition (35). This method has been successfully used for individual as well as for community water supplies in India (35, 36). Bucket and drum-scale use and pilot-scale testing have been documented under a range of conditions (35). The Nalgonda technique is considered to incur very low cost (10, 15, 34, 35). The procedure would seem particularly appropriate for application in developing countries.

As an example, one plant using this technique where 495 mg alum per litre was added, provided treated water averaging 0.7 to 1.2 mg F per litre (36). The raw water contained an average of 4.1 to 4.8 mg F per litre, and its hardness was 284 mg $CaCO_3$ per litre, pH 7.2-8.2 and alkalinity 410-500 mg $CaCO_3$ per litre. A total of 3173 kg alum was used to treat 6423 m^3 water in 143 hours; this corresponded to an average water flow of 45 m^3 per hour, although the design capacity of the plant was about twice this figure. The sedimentation of sludge over a period of 24 hours provided a concentration of 2.6% W/V solids in the sludge which was subsequently dried on sand beds (36). Precise details of costing of this plant are available (36).

4.4 Use of bone-char

Bone-char is ground animal bones which have been charred to remove all organic matter (20). It is considered better than bone itself, because taste problems of the treated water are minimized (7). The material has been used successfully to control excessive fluoride levels (22, 39). For example, in the United States fluoride levels were lowered from 6.7 to 1.5 mg F per litre with 30-50 mesh bone-char (40). With one plant where 8.5 m^3 bone-char was used, regeneration of the absorbing material was found to be needed only after 3800 m^3 of water had been treated (40). Backwashing followed by caustic soda is used in this process; excess caustic soda is removed by rinsing the bed of bone-char with a considerable volume of raw water (40).

The use of bone-char has certain drawbacks in comparison to treatment with activated alumina (33). Arsenic can interfere with the effectiveness of bone-char, since arsenic itself is very readily adsorbed and causes irreversible changes in the structure of the bone-char, ultimately rendering it useless (20, 41). If significant quantities of arsenic are present, then other methods such as activated alumina should be used (20). Media loss can occur with bone-char, and this can create problems (7). The use of this material has been reviewed and evaluated in relation to small community water supplies (2, 7, 39, 43).

In summary, bone-char has been successfully used, but it has some limitations and nowadays the use of activated alumina is more popular. The use of bone-char could be an appropriate option in some developing countries.

4.5 Use of synthetic bone

This material is made by reacting phosphoric acid with lime to produce tricalcium phosphate and hydroxyapatite (synthetic bone). It is reported to be cheaper than bone-char

(7) and can be readily produced in the form of coarse granules that are suitable for use (7). Various tests using this adsorbent have been carried out, and these have been reviewed in some detail (7, 44, 45). Synthetic bone is used and regenerated in a similar way to bone-char (see section 4.4). As with bone-char, some media loss occurs but to an even greater extent (40, 44, 46). The material has not been widely used, although plants have been operated in the USA (7). There seems to be little experience with the material in developing countries.

4.6 Reverse osmosis

This system utilizes a semi-permeable membrane which retains the dissolved solids in the feed water. It is costly to operate, and the efficiency of the process is both pH and temperature dependent (7, 33). The process has been reviewed and evaluated (7, 33). In recent years household systems for "point-of-use" reverse osmosis have been specially evaluated (16).

The membrane is a critical part of the system (7, 47, 48). Spiral tubular, hollow-fibre and plate and frame types have been used. Because of the high pressure-drop across the very thin membrane used, the latter needs to be extrememly well supported (7, 49). Commercially available membranes are often cellulose-based; nylon is also used (47). Problems of membrane fouling arise in use, caused commonly by (a) colloidal material and certain dissolved salts (50, 51) and (b) poor control of the raw water. This fouling can lead to concentration polarization (7) and cause a deterioration in product water quality. Cleaning of membranes may be regularly needed, and pretreatment of the raw water may be required (7). Calcium carbonate scale is controlled by pH adjustment (7). Some difficulties of reverse osmosis in special circumstances have been examined (50). A wide range of reverse osmosis systems have been evaluated (7). Many of these are highly efficient; some involve multistage processes (7). A very detailed review of the process has been published (7). Because of cost, the method is not likely at the present time to be of great value to developing countries.

In summary, although highly efficient, the system is costly to operate, and problems may arise with certain types of water. The system has the advantage that other undesirable ions in addition to fluoride are removed, and this feature could be beneficial in certain situations. New and improved membranes at lower cost are under development in the USA (52).

4.7 Activated alumina

This system is in developed countries one of the most widely used and favoured methods currently available. Many reviews of its use and effectiveness have been published (2, 7, 30, 33, 40, 53 to 63). Activated alumina is a special form of acid-treated alumina (7). Its affinity for fluoride is very high, i.e. in descending order hydroxide > phosphate > fluoride > sulphite > ferrocyanide > chromate > sulphate > dichromate > nitrite > bromide > chloride > nitrate (7). A number of bench-scale tests have been carried out, and various plants are in existence. After use the alumina needs to be reactivated (3). Levels of around 10 mg F per litre can readily be reduced to around 1 mg F per litre (7). Control of optimum pH to 5 to 6 is important in the use of alumina (7), and carefully operated regeneration procedures are necessary (7, 56). The fluoride adsorption capacity is not significantly reduced by elevated levels of total dissolved solids, except when sulphate exceeds 250 mg per litre. The theory of fluoride removal with alumina was investigated (2). A pilot study was carried out to test the efficiency of alumina for removing fluoride when arsenic is also present in in the water significant quantities (56). A high level of for example 0.14 mg arsenic per litre will decrease the effectiveness of fluoride removal (56), and it requires also treatment to reduce the arsenic content to acceptable levels.

In general, activated alumina is regarded as an excellent material for fluoride removal. Fluidized, activated alumina systems are especially good (55). Levels as low as 0.1 mg F per litre can be achieved if desired (55). The capacity of the medium decreases with an increase in pH or alkalinity; low alkalinity waters may require pH adjustment after fluoride removal (55). One particular advantage of activated alumina relates to the fact that, other than pH control where appropriate, pretreatment of the water is not normally needed (54). Activated alumina is considered better than bauxite or activated carbon (30). The efficiency of fluoride removal generally increases for lower fluoride levels in the untreated water (30). A very comprehensive design manual for fluoride removal using activated alumina has recently been published (33). The basis of the capital and treatment costs have also been published (7).

The use of activated alumina may be appropriate for certain situations in some developing countries. Tests of its effectiveness have been evaluated in India and costs were estimated at about 2 to 4 Rupies per m^3 treated water (63).

In summary, activated alumina is a superior medium for fluoride removal. The system using it is well tried and will operate for most types of water. In specific cases, however, other forms of treatment may be more cost-effective.

5. Conclusions

It is not possible here to specify which system should be used in particular cases, because there are many factors which need to be considered in deciding which method is the most appropriate. In developed countries, activated alumina, bone-char and reverse osmosis seem to be the more commonly favoured systems. In developing countries, treatment methods based on the combined use of lime and alum (Nalgonda technique and its variations), pre-treated bone, bauxite, alumina, and defluoron-2 tend to have been used more often. The Nalgonda technique seems to have been particularly effective in India and could well be a suitable option in some other developing countries. However, in individual circumstances and in different countries and regions, a wide range of techniques have been applied. Some of the less well-tried methods, e.g. use of lime, use of alum, activated carbon, ion exchange methods and use of untreated bone, might be justified in exceptional cases. When both hardness and fluoride removal are needed, and where sufficient magnesium is present in the raw water, water softening can be an especially effective method . Alum treatment alone may not be very effective for fluoride removal unless massive doses of alum are used, and thus it is unlikely to be cost-effective.

The use of activated alumina, charred bone and lime with alum (Nalgonda technique) are usually regarded as the more cost-effective methods. In assessing costs in a particular case, however, factors such as plant life, media cost and regenerating and operating costs all need to be carefully considered, taking particular account of local factors.

The fluoride absorbing capacity of different media is not an easy factor to define because it depends on the pH of the raw water, the regeneration history of the media and the competition between different anions and cations.

In developing countries in particular, one needs to bear in mind the availability of local skills for plant operation and factors such as training of operators and their re-training on a regular basis. Again, in some developing countries, a regular supply of chemicals and spare parts may be difficult to guarantee, especially if they need to be imported. An overriding point to bear in mind is to keep the technique and plant as simple as possible. Thus, the possibility of blending with low-fluoride water should be considered as a first alternative before reviewing different treatment options.

Since the efficiency of any process will depend on the particular nature of the raw water and the quality of the treatment media and reagents used, it is essential to first make a feasibility study. The present literature review may be used as a starting point for obtaining basic information on different options. Literature references quoted in this guide can then be consulted for further details including process specifications and estimated costs. Secondly, it is strongly recommended that a bench-scale process followed by a pilot plant be set up and operated; this will determine any problems which may arise with a selected system in relation to a particular water type in a specific location. It should be borne in mind that pretreatment of the raw water may be necessary in some cases in order to make the process more efficient and to achieve other concurrent water quality objectives.

These general conclusions relate to community water supply systems where water can be treated prior to distribution. Alternative treatment such as "point-of-use" systems may be also effective and indeed more appropriate in some situations. Alternative or new sources, blending of water supplies and provision of bottled water are also options which have to be considered prior to identifying suitable treatment methods.

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