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ISLAND RESOURCES FOUNDATION

GUIDELINES FOR DRINKING WATER QUALITY PROGRAMS IN SMALL ISLANDS

Terrence P. Thompson, P.E.,[a] and Werner Wernicke[b]

INTRODUCTION

The purpose of this paper is to suggest appropriate guidelines which regulatory agencies and suppliers of water in small islands can use in developing water quality programs for public water systems. These guidelines are to a large extent the authors' interpretation of how drinking water quality guidelines published by the World Health Organization (1984, 1976, 1971) should be applied to the small islands of the Eastern Caribbean. They are meant specifically to apply to existing systems, but may provide some insight helpful to the planning and design of new systems. Of course no guidelines of a generic nature can apply perfectly to all situations. Accordingly, appropriate modifications should be made when applying these or other guidelines to a specific public water system.

The term "small islands" loosely refers to those islands whose land areas generally range from 25 to 250 square miles, and whose populations range from 10,000 to 200,000 capita. They are typically of volcanic or carbonate origin with, to varying extents, alluvial beds and valleys. Topographies range from the flat coralline sandy ground of Anguilla to the towering volcanic peaks of St. Lucia, Grenada, and St. Vincent, over 4000 feet above sea level. Rainfall patterns may vary dramatically from island to island and even between different elevations on the same island. Groundwater and cisterns are the predominant sources of drinking water although a few of the wetter islands tap rivers and streams and occasionally construct impoundments and hillside catchments. The least common sources of public water supplies are barging from a nearby island and desalination of seawater. Typically, more than one piped, public water system exists on each island with a combined capacity of a few million gallons per day. Populations outside of the service areas rely on rainwater cisterns and/or private wells. This paper is restricted in scope to public systems however.

Contaminants in a public water supply system can cause a variety of adverse health effects which can in turn have economic costs such as decreases in human productivity and inhibition of growth in tourism and commerce. In addition, if the aesthetic quality of the water is poor, consumers may choose

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to use unregulated sources of water if the latter are more appealing. This may have health implications since unregulated supplies are more likely to be unsafe. The Caribbean Research Centre, St. Lucia (1980), reported for example that "due to an inadequate supply of safe potable water, many of our people in various communities resort to rivers for this important commodity, thereby propagating the incidence of schistosomiasis - better known as Bilharzia."

Health effects of various contaminants are discussed in brief in WHO publications (1971, 1984) and in detail in a report by the National Academy of Sciences (1977). In general, microbiological contaminants are of greatest concern since their effects occur relatively rapidly and after short-term exposure. Typhoid, cholera, dysentary, and infectious hepatitis are the most common water-borne diseases affecting man. In the Caribbean region, water-borne diseases are the chief cause of death in children under five years of age, and are estimated to be responsible for up to one third of deaths of all ages (Caribbean Research Council, 1980).

CURRENT PRACTICES AND NEED FOR A PROGRAM

Piped public water supplies are relatively extensive in the Eastern Caribbean as compared to other geographical areas of the world. The Caribbean Environmental Health Strategy (1978), a multi-agency document, showed that in most of the region's small islands, over 80 percent of the population have house connections or easy access to a public standpipe. Nonetheless, these same islands experience a high incidence of water-borne diseases such as Typhoid and gastro-enteritis. Obviously then, the mere construction and operation of a public water system is insufficient to assure the production and distribution of water that is reliably safe and healthful for consumers.

In most small islands, conventional water treatment (e.g., coagulation and sedimentation followed by sand filtration) is virtually the only measure taken for water quality protection. Chlorination for disinfection purposes is becoming more widespread but is not yet universal in the region. Regular monitoring programs have not been implemented at many locations or are carried out at extremely long intervals. Engineers who inspect water supply facilities are often concerned with strictly functional operations and maintenance aspects and have not been trained to consider environmental conditions and other aspects impacting on water quality. Regarding institutional structures, most small islands in the Eastern Caribbean have created, through enabling legislation, water utilities or semi-autonomous agencies responsible for water production and distribution. Few however have taken steps toward implementing the kind of water quality programs described in this paper.

ELEMENTS OF A PROGRAM

A drinking water quality program seeks to assure that each component of a public water system (i.e., the source of water and the treatment, storage and distribution facilities) reliably operates under healthful conditions and produces water to the consumer in compliance with applicable standards. The basic elements of such a program include: initial laboratory examination and continuous monitoring of water quality; engineering examination, or "sanitary survey," of conditions, facilities, and practices that may affect water quality; and examination of relevant institutional aspects. Some elements of a drinking water program which are generally implemented in long established and more sophisticated programs include: public education, operator training and certification, laboratory certification, emergency planning, plans review and approval, bottled water regulation, and others. These advanced activities are not discussed in this paper.

The basic program elements, discussed in detail below, should become progressively more sophisticated with time. Similarly, additional advanced program elements should be added over time. All of the program elements should not have as their objective the mere identification of problem areas, but should include recommendations for remedial and preventive measures and should provide assistance in implementing such measures.

Examination of Water Quality

Some of the small isalnds of the Eastern Caribbean have established drinking water quality standards. Most of these have simply adopted the World Health Organization's "International Standards for Drinking-Water" (1971). WHO has recently superseded those standards however with the new "Guidelines for Drinking-Water Quality" (1984). The Organization's posture is to encourage nations to develop their own individual and appropriate standards in the context of prevailing environmental, social, economic, and cultural conditions. As stated in the Preface of the new WHO publication:

> "The main reason for departing from the previous practice of prescribing international standards for drinking-water quality is the desirability of adopting a risk-benefit approach (qualitative or quantitative) to national standards and regulations. Standards and regulations achieve nothing unless they can be implemented and enforced, and this requires relatively expensive facilities and expertise. Furthermore, water is essential to sustain life and must be available even if the quality is not entirely satisfactory. Adoption of

> too stringent drinking-water standards could limit the availability of water supplies that meet those standards.... Therefore, it is to be expected that the adoption of standards will be influenced by national priorities and economic factors." (WHO, 1984.)

WHO also stresses however that "considerations of policy and convenience must never be allowed to endanger public health."

WHO's guidelines are summarized in Tables 1 through 5. However, most small islands lack the human and monetary resources and analytical equipment to sample and test for this comprehensive set of parameters. The authors recommend that each island select those parameters that are appropriate for local conditions in consideration of: the nature of the health and/or aesthetic effects with each parameter; the potential for each parameter's occurence in significant concentrations in a particular system; and resources reasonably available for monitoring. Parameters whose health or aesthetic effects are acute should take priority over those that are chronic, and those with severe effects over those with mild effects. In addition, parameters that are not likely to occur in significant concentrations in a given system may be selectively eliminated. For example, many of the organic constituents associated with industrial products and by-products may be selectively eliminated for the least developed islands. Sanitary surveys, discussed later, will yield insight into the specific contaminants that are likely to be of concern in the system.

With the above considerations in mind, the objective should be to arrive at a set of parameters which are designed to monitor the safety of drinking water and which the island can feasibly sample and analyze with available resources. The set of parameters need not be inviolate however and may change over time as conditions require and resources permit.

The small islands of the Eastern Caribbean could reasonably be expected to perform quantitative measurements of pH and turbidity and qualitative measurements of taste, odor, and appearance. Some islands can and do perform additional quantitative analyses, particularly for bacteria. These parameters however, along with chlorine residual, give useful indications of upsets or potential concerns occuring in the system. In systems where chlorine residual is maintained throughout distribution on a continuous and reliable basis, the measurement of this parameter supplements conventional bacteriological testing, the results of which are not available for at least 24 hours. In islands where resources are not available for coliform testing, determination of chlorine residual may be an appropriate substitute for bacteriological analysis, provided that a residual is maintained in the system on a continuous and reliable basis.

Where resources permit however, the authors strongly encourage monitoring for coliform, E. coli, and nitrates in order to detect sewage contamination. Chloride is also an important parameter for small islands since it may indicate salt water intrusion or an interconnection with a fire protection or flushing line. It is recommended that each island have the capability to monitor these parameters. In addition, capability for analyzing specific toxic chemicals should be available although the use of a regional laboratory or other outside expertise may be appropriate for this purpose. The specific toxic chemicals to be analyzed for may be determined on the basis of a sanitary survey.

As an example of a water quality monitoring program, the program practiced in the U.S. Virgin Islands is summarized in Table 6. The Virgin Islands' standards and monitoring requirements (V.I. Code, 1977) are patterned after the Federal interim primary drinking water standards and regulations promulgated by the U.S. Environmental Protection Agency (40 CFR 1.141). In formulating its own standards, the Virgin Islands chose not to adopt EPA's secondary standards (40 CFR 1.143) which govern aesthetic aspects of water quality. Although the Virgin Islands' standards and monitoring program would be an unrealistic model in the short term for most small islands, it is a model to which many may aspire in the long run. It is interesting to note however, that the Virgin Islands Department of Conservation and Cultural Affairs (DCCA) is proposing modifications of the types and frequency of certain parameters tested. Waivers are requested for the regulated pesticides and herbicides due to their low usage in the Territory and their historic absence from water supplies in the past. The requirement on daily turbidity monitoring has also been sought to coincide with the microbiological monitoring frequency, primarily as public water supplies do not originate from ground surface runoff in the Virgin Islands. Roof or catchment runoff is considered a special case of surface runoff where turbidity has not been found significant. This move toward modifying the Federally mandated monitoring requirements is consistent with establishing a program appropriate to the local conditions (DCCA, 1982).

General guidelines on the frequency and location of sampling have been published by the World Health Organization (1971). In general, sampling should encompass all components of the public water system, from source water to the farthest reaches of distribution, and should be representative of the entire system. Frequency should comply with WHO's guidelines, as a minimum, although the authors encourage more frequent monitoring where resources permit. Table 7 presents WHO's guidelines on sampling frequency. Samples for parameters whose health effects occur through chronic, long-term exposure, such as many toxic chemicals, may be taken less frequently, perhaps annually.

Thus far we have directed our discussion firstly toward the selection of parameters to be included in a monitoring program and secondly towards the frequency of sampling. In developing drinking water quality standards, nations must also set maximum contaminant limits (MCL) for the selected parameters. WHO's guideline values for toxic chemicals are extrapolated from studies with laboratory animals and use somewhat arbitrary safety factors, such as reduction by a factor of 100 or 1000. WHO notes that the proposed guideline values are in many cases deliberately cautious and therefore should not be interpreted as standards. WHO states:

> "A judgement about safety...is a matter in which society as a whole has a role to play. The final judgement as to whether the benefit from adopting any of these proposed guidelines does or does not justify the risk is for each country to decide. What must be re-emphasized is that the guideline values proposed are not strict standards that must be adhered to, but are subject to a wide range of flexibility and are provided essentially in an endeavor to protect public health and enable a judgement to be made regarding the provision of drinking-water of acceptable quality." (WHO, 1984.)

Sanitary Surveys

Contamination that is random or intermittent may not be revealed by a water quality monitoring program, particularly if sampling is infrequent. The sanitary survey, which is an on-site inspection and evaluation, is necessary for a complete understanding of the system. The survey should be conducted by a qualified specialist and should address environmental conditions, physical facilities, and operations and management programs and practices relevant to water quality in the system (WHO, 1976).

Sanitary surveys of the entire system, from source through distribution, should be made at regular intervals. As a starting point for small islands, the authors recommend the intervals shown in Table 8. The surveys should become more frequent however as resources permit. In addition, unscheduled surveys should be made when significant changes occur that may affect water quality or when real or potential contamination is suspected. Such unscheduled surveys may be limited, if appropriate, to a particular component of the system.

Several general guidelines for sanitary surveys have been published (WHO, 1976; New York State Department of Health, 1978). The following paragraphs, though not entirely comprehensive, note some appropriate considerations for sanitary surveys in small islands.

In evaluating source waters, emphasis should be placed on environmental conditions that may cause contamination. These are listed in Table 9. While opportunities for contamination of surface water are widely recognized, the vulnerability of groundwater sources is often overlooked. Overpumping of well fields, resulting in salt water intrusion, is all too common in the small islands of the Caribbean. In addition, a host of other phenomena threaten groundwater. Subsurface disposal systems, leaky sewers, and leaking underground fuel storage tanks may discharge into or up-gradient from an aquifer. Rain falling on a landfill or dump forms a leachate which can percolate through the fill and underlying soils into the groundwater below. Similarly, contaminants from animal feedlots and other agricultural operations can infiltrate to an underlying aquifer. Accidental oil and chemical spills, urban runoff, and discharges from certain industries are of particular concern to the extent that they may contain toxic materials. Figures 1 and 2 illustrate some of these potential sources of contamination as they relate to groundwater (Kilner, 1984).

In evaluating water treatment, the emphasis should be on the effectiveness and reliability of treatment. If available, water quality laboratory results should be reviewed to determine the effectiveness of treatment. The inspection should also consider the physical condition of the facilities, and whether stand-by equipment and power are available, whether adequate chemicals (especially disinfectant), tools, and spare parts are provided, and whether operators are in need of training.

With respect to water storage, contamination can occur via animals (especially rodents and birds), wind deposition, and vandalism. Carelessness and improper housekeeping at the storage facilities can lead to spills of lubricating or fuel oils or water treatment chemicals. A form of contamination may also occur as tanks and pipelines corrode or as lining materials decompose and impart constituents to the water.

In distribution, leaky, low pressure water mains that normally exfiltrate may infiltrate under conditions of a high water table. Improper interconnections with other piped systems may exist, as may cross connections. Cross connections are potential interconnections and occur in situations where potentially contaminated water may be drawn back into the distribution system by means of siphonage through a submerged inlet (New York State Department of Helath, 1981). Contaminants may enter the distribution system through breaks or, equally, through unsanitary repair procedures and failure to disinfect water lines after repairs have been made. Unsanitary operations practices can also introduce contaminants, such as the practice of priming pumps with contaminated water.

The barging of water, like trucking by land, is a mode of distribution. The containers may be contaminated from a prior cargo or foreign matter can enter during loading, transit, and unloading. The contamination sources can be numerous.

<u>Protective Strategies</u>

Water quality monitoring or sanitary surveys may reveal the need for immediate remedial actions such as superchlorination or the issuance of boil-water notices. However, the surveillance program also forms the basis upon which more substantive, long-term, protective strategies can be developed. Appropriate strategies for small islands are discussed below.

In order to guard against salt water intrusion in aquifers, a permitting system to control the placement and withdrawal from wells may be appropriate. Hydrogeological studies would be necessary to accurately define the allowable pumping rates and locations of wells. Appropriate study methods using salinity:depth profiles in observation wells (Barker, 1980) as well as more quantitative techniques (Goodwin, 1980) have been discussed elsewhere. Observation wells have been successfully used in the Virgin Islands (Francois, et al, 1983).

Other protective measures applicable to source waters include: land use planning and control; design criteria for water works and pollution control facilities; an adequate operations and maintenance program; and surveillance. Watersheds and aquifer recharge areas should be under the legal control of the water supply authority. Zoning laws in the watersheds and recharge areas should be such as to assure a dispersed population. The authority should also impose sanitary requirements on proposed developments so as to avoid impacts on source waters. Certain activities should be restricted within watersheds and recharge areas, for example; the application of certain herbicides, pesticides and fertilizers; use of septic tank solvents; and industrial activities involving toxic materials. In a small island, restrictive policies may be at odds with policies for economic development. It should be realized however, that while conventional water treatment may control conventional contaminants associated with residential-type development, sophisticated treatment processes are required to remove toxic contaminants associated with industrial development. Such sophisticated processes are generally not feasible for small islands due to their high cost and high level of operator skills and attention required.

All public water supplies should, as a minimum, receive treatment for disinfection of bacterial contaminants. (If viruses and cysts are also present, filtration would also be desireable.) Chlorination is the most common disinfection method around the world. In addition to accomplishing disinfection, chlorination has two beneficial effects when added in quantities sufficient to maintain a residual concentration. The residual may afford a degree of protection against contamination in the distribution system; and as discussed earlier, the simple measurement of chlorine residual supplements bacteriological testing (WHO, 1971). A number of chlorination technologies are feasible for the Caribbean, including gas chlorination, drip hypo-chlorinators, gravity feed chlorinators, and solution feeders. These are described in detail elsewhere (White, 1972; New York State Department of Health, 1952; International Reference Center for Community Water Supply and Sanitation, 1981; Lewis, undated; Schulz and Okun, 1984). Several technologies are illustrated in Figures 3, 4 and 5.

Inspection of actual chlorination facilities often reveals improper dosing or inoperability however. In selecting a chlorination technology it is essential to consider the level of operator attention that will be given to the equipment. It is equally essential that operators be trained in the use and maintenance of the equipment. In small islands where relatively few operators would be trained, it is possible to tailor training programs to be compatible with the operators' needs and abilities. This approach has been successfully used in the Virgin Islands (Francois, et al, 1983). In addition to training, a system must be estabilshed to assure that equipment receives necessary preventive maintenance at scheduled intervals. This calls for written preventive maintenance (PM) schedules, work descriptions, and records of work performance (Thompson,1983). The American Water Works Association (1980) has an excellent manual to assist the implementation of a PM program. Figures 6 and 7 illustrate sample preventive maintenance and unscheduled maintenance forms from the AWWA manual.

Good housekeeping practices help protect against contamination of stored water. Operators should avoid conditions that attract rodents and other animals (clutter, lunch scraps, refuse, etc.). Good housekeeping also entails secure storage of petroleum products and chemicals so as to avoid accidental spills. Metallic surfaces and synthetic liner materials should meet appropriate specifications and should be inspected and maintained regularly so as to avoid material decomposition and its water quality effects.

Maintenance of positive pressure throughout the distribution system protects against infiltration of contaminants through cracks, joints, and connections. This is achieved most reliably by having a total gravity feed system. Where pumping is necessary, pumps should be of a capacity to impart an internal pressure of at least 20 psi throughout the system. Provisions should be made to assure no loss of pressure, including stand-by pumps, a stand-by power source, and a preventive maintenance program. Contamination of an aesthetic nature may occur from the build up of slimes inside pipe walls which can dislodge and be carried to the consumer. Such slimes can also harbor pathogenic organisms or viruses and protect them from normal disinfection. Periodic superchlorination and high velocity flushing may be used to control build ups. Lines should also be disinfected and flushed to waste after repairs before returning the lines to service.

Plumbing codes can be effective in preventing interconnections and cross connections only to the degree that they are enforced. Stiff penalties for violations may encourage compliance. The water supply authority should be empowered to require users to install backflow prevention devices. The type of device used (air gap, reduced pressure zone, double check valve, etc.) should be commensurate with the degree of hazard. In instituting a cross connection control program, a list of connections should be established targeting the most hazardous users (sewage treatment plants, hospitals, mortuaries, etc.) for priority action.

INSTITUTIONAL CONSIDERATIONS

WHO guidelines (1976) contain two basic recommendations concerning institutional aspects of drinking water quality programs. WHO recommends that the local agencies and organizations responsible for water supply operations and surveillance be given legal authority to undertake activities necessary for water quality protection. The implementation of a program need not be forestalled by the absence of such authority however, as significant progress can be realized through education and persuasion. Cognizant of human nature, WHO also recommends that the responsibility of surveillance rest with an agency independent from the organization responsible for operation of the water supply system. Surveillance activities, particularly monitoring, may be shared between these two bodies however, particularly considering the limited resources usually afforded to the surveillance group.

The drinking water quality program practiced in the Virgin Islands illustrates these institutional recommendations. The Virgin Islands Department of Conservation and Cultural Affairs, Division of Natural Resources Management (DCCA/NRM) has the statutory requirement for regulation and surveillance of drinking water. It obtains its authority from the Virgin Island Safe Drinking Water Act (VISDWA), Title XIX, Virgin Islands Code Chapter 15. The Act limits the surveillance to public water systems which are defined as follows:

a) Community water system - a public water system which serves at least 15 service connections used by year-round residents, or regularly serves at least 25 year-round residents.

b) Non-community water system - a public water system which is not a community water system.

Approximately 500 public water systems exist which fall under the above definitions and which need to be tested.

This program was initiated in 1977 (the enactment of the legislation) and during the next four years laboratory facilities were installed, samples collected and analyzed as called for in the regulation (except radiological). Maximum contaminant levels were established which required suppliers of water to notify consumers if standards were not met. The parameters tested are listed in Table 6.

Although DCCA/NRM had initially taken on the task to carry out the monitoring effort, the purveyors of public water supplies, whether government (Public Works Department, Virgin Islands Housing Authority, etc.) or private (hotel, apartments, etc.) are responsible under the law for testing their water supplies. Funding and staffing limitations on the part of DCCA/NRM has resulted in shifting the role of monitoring the quality of water supplies from DCCA to the water purveyors. This shift is currently in progress with DCCA notifying the purveyors of their repsonsibility.

COSTS AND BENEFITS OF SURVEILLANCE

Drinking water quality programs, appropriately devised and consciencously implemented, can be of significant benefit at relatively insignificant cost. Former Secretary-General of the United Nations General Assembly, Kurt Waldheim, speaking in New York at the launching of the U.N. Water Decade said:

> "The provision of safe water and sanitation does not merely mean happier, healthier citizens; it also means increased economic productivity. Investment in human potential is not only a moral imperative, it is also sound economics." (World Water, 1980)

In addition to the benefits of increased health and human productivity, drinking water quality programs can remove a serious impediment to the tourism industry, a potentially lucrative industry for many small islands. A group of experts convened at the Washington headquarters of the Pan American Health Organization concluded that the fear of sickness was the major deterrent to tourists visiting developing countries, and that the most recurring and worrisome complaint among travelers is diarrhea (Lee, 1984). Of course, tourists naturally fear the gamut of water-borne illnesses where provisions are not made to supply drinking water of acceptable quality.

The costs of a water quality surveillance program to assist in the attainment of these benefits is relatively small. The exact cost for a program for any particular island would of course depend on the level of sophistication desired. Generally however, for small islands, the program could be implemented on a part-time basis by one qualified sanitary engineer who would perform the sanitary surveys and who would direct a semi-skilled technician. The technician would be responsible for sampling and performance of simple water quality tests. Equipment necessary to measure basic parameters, such as pH, turbidity and chlorine residual, are relatively inexpensive. No equipment is needed to examine water samples for taste, odor and appearance.

Costs would increase if monitoring for bacteria and toxic chemicals is desired. For bacteria testing, one or more bacteriologists and expensive sterilizing and incubating equipment are necessary. For toxic chemicals, monitored relatively infrequently, most small islands would probably consider sending samples to an outside laboratory for analysis. A scan of heavy metals may typically cost in the order of US$100 to US$200 per analysis using modern methods for highly accurate and precise results. A high-tech scan of pesticides, herbicides, and PCBs may cost about the same. Less precise, although useful, results may be obtained using wet chemistry at considerably lower costs.

The benefits of a successful program can be very significant. It is for each island nation to decide how much cost it is willing to invest to attain these benefits.

SUMMARY

Drinking water quality programs can be effective in assuring that only reliably safe, healthful water is produced for consumption. The basic elements of a program include: water quality monitoring, sanitary surveys, and examination and, if necessary, reform of institutional aspects of the water supply system. The program is usually administered by a regulatory authority distinct from the supplier of water, although many tasks may be shared by both bodies.

These basic principles of drinking water quality programs are widely known and have been previously published, particularly by WHO. In this paper however, the authors have attempted to provide additional guidance specifically appropriate for small islands.

The following points are made by way of summary.

In establishing a program, goals and standards should be set that are reasonably achievable. Unrealistic objectives tend to breed contempt for the program. As objectives are met over time, the sophistication of the program can gradually be increased and any redundancies eliminated.

Most small islands with public water supplies could reasonably be expected to monitor their systems for basic water quality parameters (pH, turbidity, taste, odor, appearance, chlorine residual). Bacteriological monitoring, and monitoring for chlorides and nitrates are also recommended where resources permit. Toxic chemicals should be tested for at least annually, utilizing an outside laboratory if appropriate.

Most small islands with public water supplies could reasonably be expected to conduct sanitary surveys by a qualified sanitary engineer. In evaluating source waters, the surveys should emphasize environmental conditions that may cause contamination. The paper discusses potential sources of contamination particularly appropriate to small islands such as salt water intrusion, agricultural wastes and chemicals, and inadequately controlled municipal and industrial wastes (both liquid and solid). In evaluating water treatment, the surveys should emphasize effectiveness and reliability. Stand-by equipment, stand-by power, spare parts, adequate tools and supplies, and need for operator and laboratory technician training are items to which particular attention should be paid when evaluating treatment operations. With respect to distribution, consideration should be given to the maintenance of positive pressure in the system, potential for

serious contamination via hazardous cross connections, and repair and operations practices.

Protective strategies should include legal restrictions on development in watershed and aquifer recharge areas. In small islands where developable land is severely limited, it may not be realistic to expect a moratorium on building in these areas. As a minimum however, strict sanitary requirements should be imposed. The most important protective strategy however, is effective and reliable disinfection treatment, which entails selection of appropriate disinfection technology and implementation of a workable O&M program. In the distribution system, maintenance of positive pressure (i.e., provisions for stand-by power and stand-by pumps), and a program to correct the most hazardous cross connections should be given priority. Sanitary repair and operation procedures are also important in protecting water quality in distribution.

Institutionally, local agencies and organizations responsible for water supply operations and surveillance be given legal authority to undertake activities necessary for water quality protection. In addition, the responsibility for surveillance should rest in an agency independent of the water purveyors. Ideally, a spirit of cooperation, not competition, should be fostered between these organizations.

The benefits of a successful drinking water quality program can be very significant in terms of human health and longevity as well as in economic terms. The cost of these programs varies with the degree of coverage and sophistication desired. It is for each island nation to decide how much cost it is willing to invest to attain these benefits.

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Table 1. Microbiological and biological quality

Organism	Unit	Guideline value	Remarks
I. Microbiological quality			
A. Piped water supplies			
A.1 Treated water entering the distribution system			
faecal coliforms	number/100 ml	0	turbidity < 1 NTU; for disinfection with chlorine, pH preferably < 8.0; free chlorine residual 0.2–0.5 mg/litre following 30 minutes (minimum) contact
coliform organisms	number/100 ml	0	
A.2 Untreated water entering the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 98% of samples examined throughout the year—in the case of large supplies when sufficient samples are examined
coliform organisms	number 100 ml	3	in an occasional sample, but not in consecutive samples
A.3 Water in the distribution system			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	0	in 95% of samples examined throughout the year—in the case of large supplies when sufficient samples are examined
coliform organisms	number/100 ml	3	in an occasional sample, but not in consecutive samples
B. Unpiped water supplies			
faecal coliforms	number/100 ml	0	
coliform organisms	number/100 ml	10	should not occur repeatedly; if occurrence is frequent and if sanitary protection cannot be improved, an alternative source must be found if possible
C. Bottled drinking-water			
faecal coliforms	number/100 ml	0	source should be free from faecal contamination
coliform organisms	number/100 ml	0	
D. Emergency water supplies			
faecal coliforms	number/100 ml	0	advise public to boil water in case of failure to meet guideline values
coliform organisms	number/100 ml	0	
Enteroviruses	—	no guideline value set	
II. Biological quality			
protozoa (pathogenic)	—	no guideline value set	
helminths (pathogenic)	—	no guideline value set	
free-living organisms (algae, others)	—	no guideline value set	

Source: WHO, 1984

Table 2. Inorganic constituents of health significance

Constituent	Unit	Guideline value	Remarks
arsenic	mg/l	0.05	
asbestos	—	no guideline value set	
barium	—	no guideline value set	
beryllium	—	no guideline value set	
cadmium	mg/l	0.005	
chromium	mg/l	0.05	
cyanide	mg/l	0.1	
fluoride	mg/l	1.5	natural or deliberately added; local or climatic conditions may necessitate adaptation
hardness	—	no health-related guideline value set	
lead	mg/l	0.05	
mercury	mg/l	0.001	
nickel	—	no guideline value set	
nitrate	mg/l (N)	10	
nitrite	—	no guideline value set	
selenium	mg/l	0.01	
silver	—	no guideline value set	
sodium	—	no guideline value set	

Table 3. Organic constituents of health significance

Constituent	Unit	Guideline value	Remarks
aldrin and dieldrin	μg/l	0.03	
benzene	μg/l	10[a]	
benzo[a]pyrene	μg/l	0.01[a]	
carbon tetrachloride	μg/l	3[a]	tentative guideline value[b]
chlordane	μg/l	0.3	
chlorobenzenes	μg/l	no health-related guideline value set	odour threshold concentration between 0.1 and 3 μg/l
chloroform	μg/l	30[a]	disinfection efficiency must not be compromised when controlling chloroform content
chlorophenols	μg/l	no health-related guideline value set	odour threshold concentration 0.1 μg/l
2,4-D	μg/l	100[c]	
DDT	μg/l	1	
1,2-dichloroethane	μg/l	10[a]	
1,1-dichloroethene[d]	μg/l	0.3[a]	
heptachlor and heptachlor epoxide	μg/l	0.1	
hexachlorobenzene	μg/l	0.01[a]	
gamma-HCH (lindane)	μg/l	3	
methoxychlor	μg/l	30	
pentachlorophenol	μg/l	10	
tetrachloroethene[d]	μg/l	10[a]	tentative guideline value[b]
trichloroethene[d]	μg/l	30[a]	tentative guideline value[b]
2,4,6-trichlorophenol	μg/l	10[a,c]	odour threshold concentration, 0.1 μg/l
trihalomethanes		no guideline value set	see chloroform

[a] These guideline values were computed from a conservative hypothetical mathematical model which cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).

[b] When the available carcinogenicity data did not support a guideline value, but the compounds were judged to be of importance in drinking-water and guidance was considered essential, a tentative guideline value was set on the basis of the available health-related data.

[c] May be detectable by taste and odour at lower concentrations.

[d] These compounds were previously known as 1,1-dichloroethylene, tetrachloroethylene, and trichloroethylene, respectively.

Source: WHO, 1984

Table 4. Aesthetic quality

Constituent or characteristic	Unit	Guideline value	Remarks
aluminium	mg/l	0.2	
chloride	mg/l	250	
chlorobenzenes and chlorophenols	—	no guideline value set	these compounds may affect taste and odour
colour	true colour units (TCU)	15	
copper	mg/l	1.0	
detergents	—	no guideline value set	there should not be any foaming or taste and odour problems
hardness	mg/l (as $CaCO_3$)	500	
hydrogen sulfide	—	not detectable by consumers	
iron	mg/l	0.3	
manganese	mg/l	0.1	
oxygen—dissolved	—	no guideline value set	
pH	—	6.5–8.5	
sodium	mg/l	200	
solids—total dissolved	mg/l	1000	
sulfate	mg/l	400	
taste and odour	—	inoffensive to most consumers	
temperature	—	no guideline value set	
turbidity	nephelometric turbidity units (NTU)	5	preferably <1 for disinfection efficiency
zinc	mg/l	5.0	

Table 5. Radioactive constituents

Constituent	Unit	Guideline value	Remarks
gross alpha activity	Bq/l	0.1	(*a*) If the levels are exceeded more detailed radionuclide analysis may be necessary. (*b*) Higher levels do not necessarily imply that the water is unsuitable for human consumption
gross beta activity	Bq/l	1	

Source: WHO, 1984

Table 6. Summary of Virgin Islands' Monitoring Programs

Parameters	Sampling Locations	Frequency
Inorganic Chemicals As, Ba, Cd, Cr, Fl, Pb, Hg, Se, Ag, Nitrate	Distribution Points	Once every year for systems using surface waters. Once every three years for systems using only groundwater.
Pesticides Endrin, Lindane, Methoxychlor, Toxaphene	Distribution Points	Once every three years for systems using surface water. At frequency specified by the Territory for systems using only groundwater.
Herbicides 2, 4-D; 2,3,4-TP Silvex	Distribution Points	Once every three years for systems using surface water. At frequency specified by the Territory for systems using only groundwater.
Turbidity [a]	Entry Points	1/day
Microbiological Coliform, Residual Chlorine	Distribution Points	Depends on population served. Minimum of one per month for community supplies, quarterly for non-community supplies.
Radiological [b]	Distribution Points	Four consecutive quarterly samples once every four years

Notes:

(a) Waiver requested regarding daily turbidity. Requesting sampling cycle as per microbiological parameters.

(b) Radiological monitoring has not been implemented to date.

TABLE 7. Maximum Intervals Between Successive Samples and Minimum Number of Samples to be Taken

Population served	Maximum interval between successive samples	Minimum No. of samples to be taken from whole distribution system/mo.
Less than 20,000	1 month	1/5,000 pop./month
20,000 to 50,000	2 weeks	"
50,001 to 100,000	4 days	"
More than 100,000	1 day	1/10,000 pop./month

Source: World Health Organization, 1971.

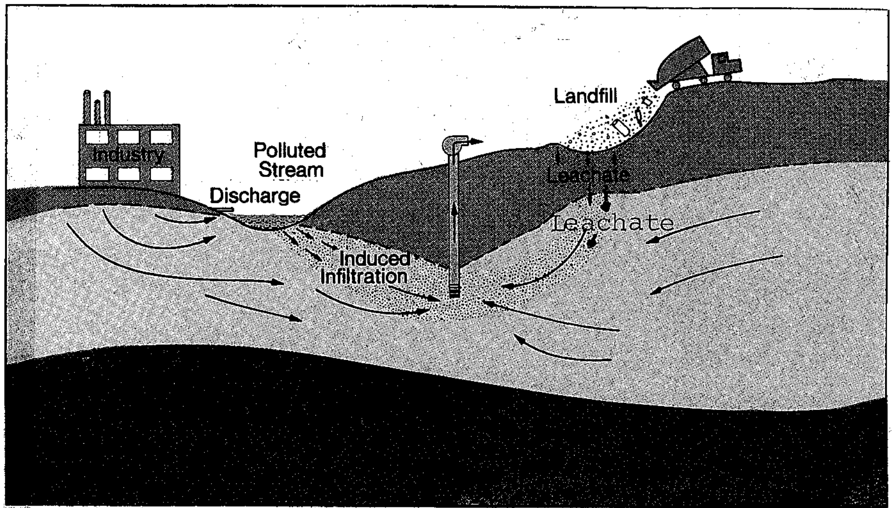
Table 8. Recommended Intervals (Years) for Sanitary Surveys for Small Islands

	Source		Treatment and Storage		Distribution
	Groundwater	Surface water	Groundwater	Surface water	
Rural areas	5	3	5	3	3
Towns	3	2	3	1	1
Cities	2	1	2	1	1

Table 9. Potential Sources of Drinking Water Contamination in Small Islands

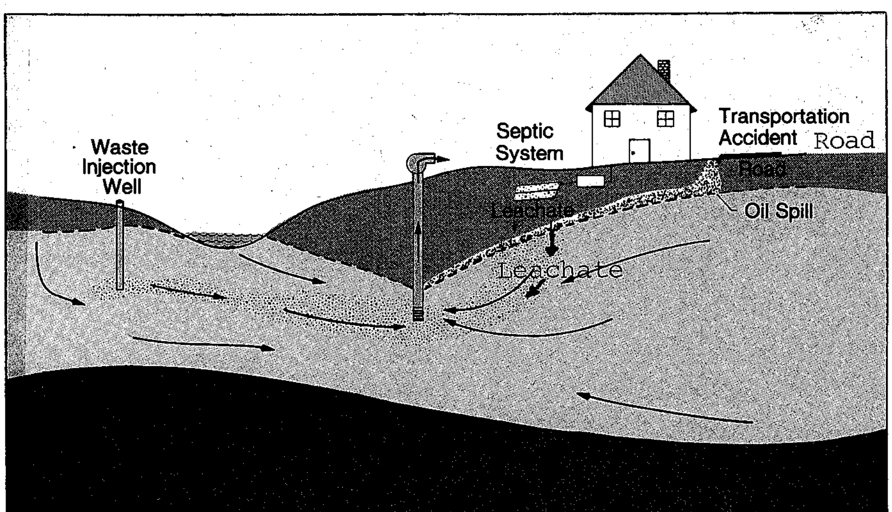
Source Water
Solid Waste Dumps
Municipal Landfills
Industrial Landfills and Hazardous Waste Disposal Sites
Sewers
Land Application of Wastewater or Sludges
Subsurface Disposal
Establishments Using or Producing Toxic Materials
Fuel Storage and Transfer Stations
Animal Feedlots
Fertilizer, Pesticide, and Herbicide Application
Transportation Accidents
Urban Runoff
Salt Water Intrusion
Waste Injection Wells
Water Treatment and Storage
Animals
Wind Deposition
Vandalism
Oil and Chemical Spills
Material Decomposition
Flooding
Inadequate Treatment
Distribution
Infiltration
Cross Connections
Interconnections
Unsanitary Repairs
Unsanitary Operations

FIGURE 1



Contaminant sources: induced infiltration and landfill leachate.

FIGURE 2



Contaminant sources: injection wells, septic systems and accidental spills.

Source: Kilner, 1984

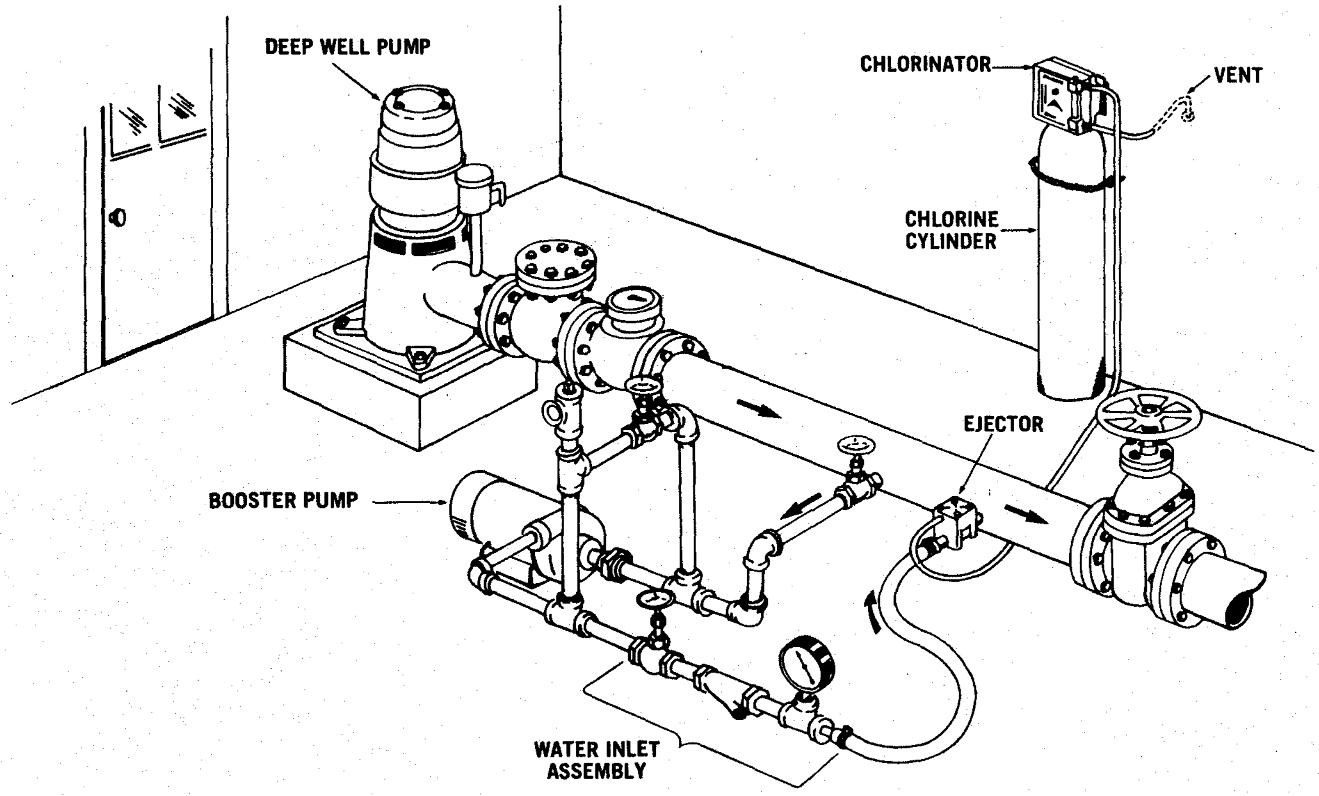


FIG. 3 – **TYPICAL DEEP WELL CHLORINATION SYSTEM**

Source: Capital Control Company, Bulletin 4004-5, Colmar, Pennsylvania

Property No. B-105.03 No. 5.

DESCRIPTION	Straight Line Collector Mechanism No. 5 Pre-Sed Basin	CARD NO.	B-105.03 No.5 B-A
WORK BY	Basin Operator	FREQUENCY	Annually October
ACCOUNT NO.	L-743-21 M-743-21	TIME	

WORK TO BE DONE:–

1. Drain No. 5 Pre-Sed Basin. Clean basin and mechanism thoroughly, using pressure water hoses.
2. Inspect allsprockets and chain for wear and cracks. Replace where necessary. Turn sprockets and chain around, where possible, to prolong useful life. If chains are riding the teeth of sprocket and jumping, replace both sprocket and chain.
3. Adjust chain tension and check sprocket alignment. On flight chains, remove links where necessary to restore proper tension, the same number of links must be removed from each chain in a pair.
4. Inspect drag flights for wear. When necessary, request welder to build up wearing edge with hard surfacing welding rod.
5. Tighten all nuts and bolts. Note especially nuts and bolts fastening drag flights to flight chain.
6. Remove bearing tops on at least two bearings for bearing and shaft wear inspection. If wear is indicated, also remove tops of remaining bearings for inspection. Request maintenance department to repair worn bearings.
7. Inspect basin drive shafting. Check alignment, measure bearing clearance, report or repair faulty clutch operation.
8. Lubricate bearings out of water with 3 H grease. Do not lubricate underwater bearings or chain.

ST. L. C. W. CO. MAINT. PROGRAM FORM NO. 1

DATE	REPORT	INITIALS	DATE	REPORT	INITIALS
10-20-40	J.R. 605	P.K.			
10-5-41	J.R. 3044	P.K.			
10-25-42	J.R. 6180	P.K.			
10-19-43	J.R. A1489	P.K.			
10-18-44	J.R. A2356	P.K.			
10-19-45	J.R. D8214	P.K.			

Figure 6 Preventive Maintenance Form Used by St. Louis County Water Company

Source: AWWA, 1980

JOB REQUISITION D 8214

Property No.	B-105.03 No. 5		APPROVAL		LMG
DESCRIPTION	Straight Line Collector Mechanism No. 5 Pre-Sed Basin		WORK REQUESTED	BY	Preventive Maint
				DATE	10-1-45
ASSIGNED TO	Paul Karlson	DATE 10-1-45	CHARGE ACCOUNT	L	743-21
				M	743-21

WORK TO BE DONE:–

WORK DONE–

DATE	DESCRIPTION OF WORK AND REPORT	SIGNED
10-19-45	1. Cleaned basin, removed rocks from hoppers.	
	2. Sprockets and chains found to be OK.	
	3. Removed one link from each flight chain on North flights.	
	4. Drag flights badly worn where riding on return rail.	P. Karlson
10-20-45	5. Tightened all nuts and bolts on drag flights. One nut missing.	
	6. Removed bearing tops on 2 bearings for east flight chain shaft. Wear not noticeable.	
	7. Drive shaft in line. Bearing clearance 0.020". Clutch operation OK.	
	8. Lubricated drive shaft bearings with 3H grease.	P. Karlson
	Welded heads on all flights where flights ride on rail. Each head 3" long. Stoody self-hardening rod used.	L. Johns

ST. LOUIS COUNTY WATER CO.
PRODUCTION DIVISION
FORM NO. P. 1-J

OVER

WORK COMPLETED: 10-19 , 19 45
SIGNED Paul Karlson
CHECKED BY L. M. Georges

COST DATA — JOB REQUISITION D 8214

LABOR -- ACCT. NO. 743-21

DATE	NAME	ON	OFF	HRS.	RATE	COST	CLERK'S O.K.
10-19-45	M. Lorre	8 AM	4:30 PM	8			✓
"	P. Karlson	8 AM	4:30 PM	8			✓
10-20-45	R. Mathews	8 AM	1:30 PM	5			✓
"	P. Karlson	8 AM	1:30 PM	5			✓
"	P. Karlson	3:30 PM	4:30 PM	1			✓
10-20-45	L. Johns	8 AM	3:30 PM	7			✓

Figure 7 Unscheduled Maintenance Form Used by St. Louis County Water Company

Source: AWWA, 1980

Gravity feed chlorinator

A commercially available chlorinator can be used to disinfect water supplies that are delivered on a sporadic, continuous but variable, or low-flow basis.

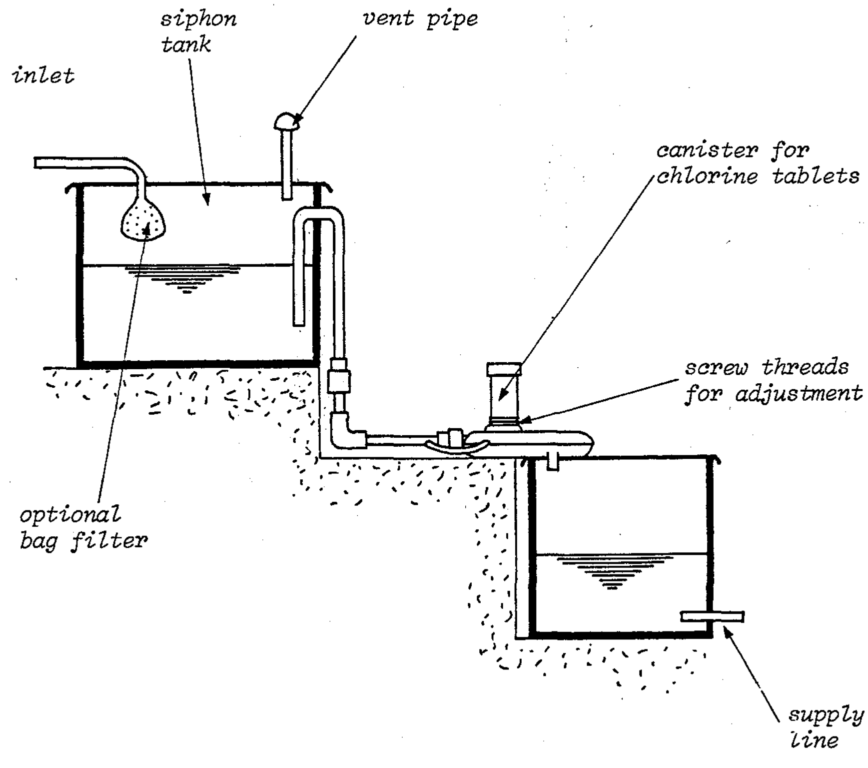


FIGURE 4

Source: International Reference Centre for Community Water Supply and Sanitation, Technical Publication No. 20, Geneva.

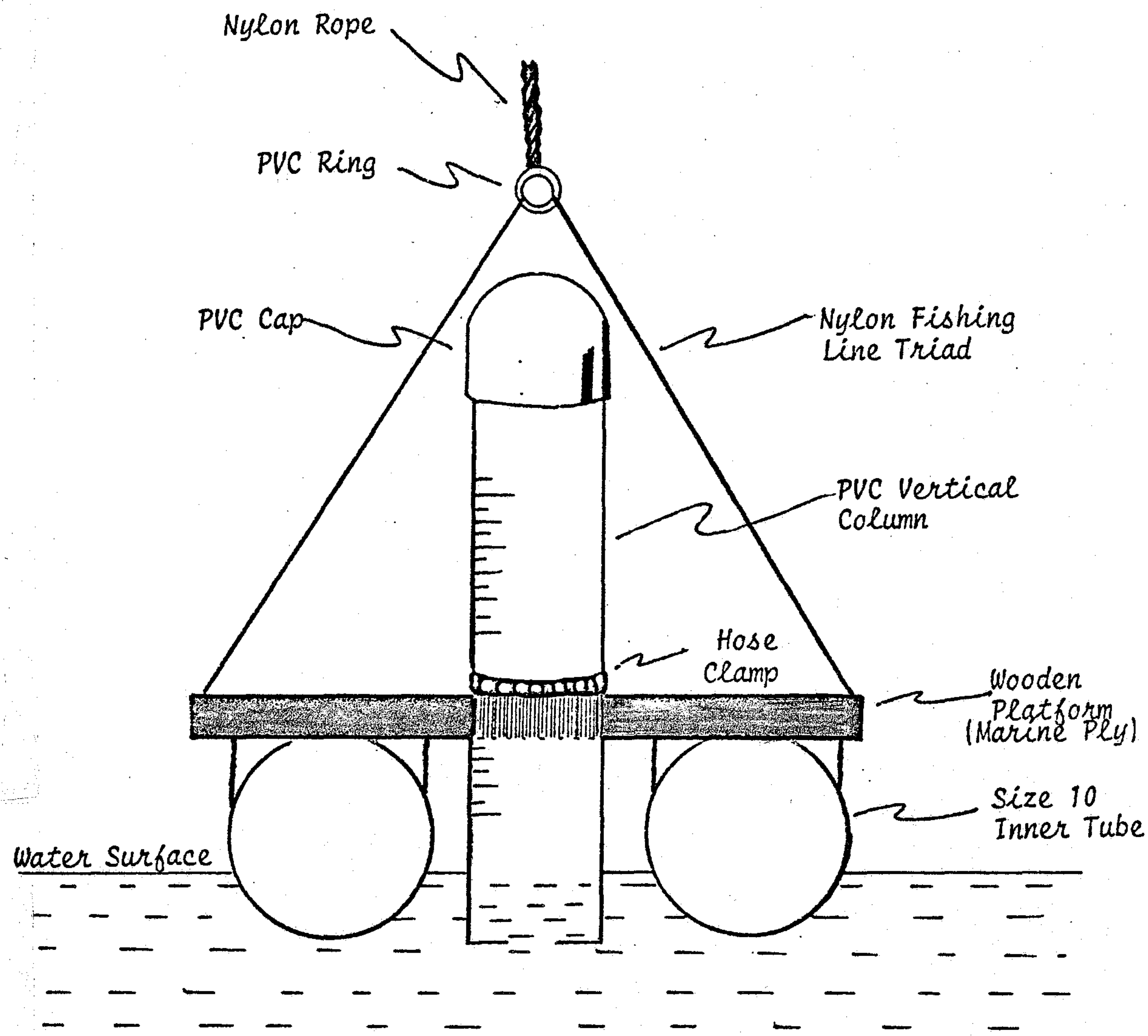


FIGURE 5

FLOATING CHLORINATOR

Source: Lewis, undated