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ESTABLISHING AND EQUIPPING WATER LABORATORIES IN DEVELOPING COUNTRIES

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DISCLAIMER

PREFACE

Preparation of the present guide has been stimulated by the need for technical cooperation with Member States in the development of adequate services for bacteriological and chemical water analysis. During his assignment with the WHO Regional Office for the Eastern Mediterranean as WHO Sanitary Chemist, Dr W. Schaefer prepared a first document in February 1984. This document was revised by Dr Wolfram Schaefer in collaboration with WHO headquarters and is now issued within the framework of the WHO/UNEP project on the control of drinking-water quality in rural areas.

With the kind permission of the U.S. Environmental Protection Agency, Annex 7 on laboratory practices was extracted from the USEPA Handbook for Analytical Quality Control in Water and Wastewater Laboratories.

1. INTRODUCTION

1.1 Scope and purpose

Water laboratories are the essential cornerstones of any effective water quality surveillance programme. To this end a number of developing countries are in the process of or planning to establish new laboratories or to expand existing capacities. Within the framework of the International Drinking-Water Supply and Sanitation Decade many countries have put surveillance and control of water quality high on their list of national priorities.

When planning to establish such laboratories government authorities often require handy information with regard to suitable space, equipment, chemicals, capital and recurrent costs, etc., in relation to the intended number of samples to be analysed and type of tests to be carried out. The present guide is intended to facilitate this search for relevant advice and indicative figures. Advocating the gradual expansion of water monitoring services in pace with the development of resource base and trained manpower, options for different levels of laboratory services are provided. Selections and combinations thereof can be made in line with the national/local needs for water quality data and for areal coverage of the country.

1.2 Categories of laboratories

Three different categories of laboratories for both bacteriological and chemical analyses of water are described in this guide:

(a) Basic laboratories

This is the lowest level of laboratory, which could also be described as peripheral. These laboratories will usually be located in smaller provincial towns or at small water works, and should be equipped only with indispensable and inexpensive apparatus. However, they should be capable of carrying out all essential water quality tests and perhaps simple wastewater analyses.

(b) Intermediate laboratories

Intermediate laboratories are those located in provincial capitals or other major municipalities. Size, staff and equipment of these laboratories will be more extensive to cope with a higher workload. There should also be the capability to determine more variables than basic laboratories can do. This requires some more advanced pieces of equipment, which need not, however, be very sophisticated or costly.

(c) Central laboratories

At the highest level, there should be a central or reference laboratory. It will usually suffice if there is one of this kind in a country, located in the capital. Such a laboratory should be well staffed and equipped, and should also possess some sophisticated instruments. Its size and level of performance, however, will largely depend on the size and needs of the country, its economic conditions, availability of trained manpower, etc.

(d) Portable kits

It is sometimes thought that portable water analysis kits could replace laboratories. Most of these kits are basically designed for field work. They have their merits in certain circumstances, but in general they cannot match a suitably equipped laboratory. Annex 1 gives more details on portable water analysis kits, their potential and their limitations.

The proposals for laboratory requirements described in this guide are not meant to be rigidly applied. Flexibility will be needed according to local conditions. For example, the number of items of laboratory equipment as listed in the annexes, especially those of glassware, may be increased or decreased in accordance with the expected workload of the laboratory. It may also be desirable to establish a laboratory at a level somewhere between basic and intermediate, and the selection of equipment could then be modified accordingly.

In the case of basic laboratories, it is suggested that certain facilities of a bacteriological and a chemical laboratory may be used jointly if they are located under the same roof. This cost-saving measure is described in detail in the guide. For intermediate laboratories, such sharing of resources is not envisaged because of the greater workload and consequently better utilization of equipment in each of the laboratories. But some pieces of equipment may still be acquired for joint use, particularly if the sampling and analysis programme can be designed accordingly.

1.3 Equipment and methods

It is the aim of the guide to recommend for water laboratories simple, inexpensive, yet adequate, practical and reliable equipment. It should not be primitive or outdated, nor too sophisticated. Costly instruments should be avoided, as these are often not properly maintained, are difficult to repair and rarely fully utilized. This is particularly the case for "basic" laboratories, and to a certain extent also for those at the "intermediate" level.

In the annexes which specify the equipment items, there are specific makes and models mentioned. These are only meant to provide examples of cost-effective, suitable items to guide the buyer. It should be understood that there are also other, equally suitable makes available. Relevant suppliers have to be contacted in each case where a new laboratory is being estabished.

The prices given in the annexes, based on catalogues of reputed suppliers (such as Gallenkamp and BDH), were valid for 1982 excluding packing, freight and insurance. Other suppliers have similar prices. The main purpose of their indication is to provide planning figures for laboratory cost estimates.

The analytical methods mentioned in this guide can be found in the following publications.

- UNEP/WHO/UNESCO/WMO Project on Global Water Quality Monitoring: GEMS/WATER Operational Guide - Chapter III: Analytical Methods; World Health Organization, Geneva, 1978.

- Guidelines for Drinking-Water Quality; Volume 3: Drinking-water control in small-community supplies, World Health Organization, Geneva, 1985.

- Examination of Water for Pollution Control - A Reference Handbook; M. Suess (Editor); Pergamon Press on behalf of World Health Organization, Regional Office for Europe; Oxford, 1982.

- Standard Methods for the Examination of Water and Wastewater (16th edition); American Public Health Organizetion, Washington, 1985.

- Simplified Procedures for Water Examinations - Laboratory Manual; American Water Works Association, Denver, 1975.

The methods of the present guide are in conformity with the equipment and the chemicals listed in the annexes. If other methods are being used or newly introduced, it should be verified that the necessary equipment, especially culture media and chemical reagents is included in the listings.

2. BASIC LABORATORIES

2.1 Basic laboratory for bacteriological examination

2.1.1 Purpose, scope and staff

This laboratory is designed to carry out bacteriological routine analysis for natural waters, drinking-water, treated wastewater and other effluents. It is equipped to perform the following tests:

- total coliforms
- faecal coliforms

The membrane filtration method is proposed for undertaking these tests. Although this method is not the cheapest, it has been chosen because of its simplicity, reliability and the speed with which results for both total and faecal coliforms can be obtained.

The basic laboratory may be staffed with only one technician who should be able to analyse on average 6-8 samples per day and carry out all supporting work such as preparing media, sterilizing equipment, etc. The technician should preferably be assisted by a laboratory attendant. If the workload is higher, up to approximately 15 samples per day, the laboratory could also accommodate a second technician albeit with less ideal working conditions.

The technician(s) should be supervised through regular visits of a microbiologist posted at a laboratory of the next higher category.

2.1.2 Space, furniture and fittings

A small room of about 20 m^2 is sufficient for this laboratory. It should have adequate lighting, proper ventilation and should be reasonably dust-proof. Laboratory benches of a total length of 5 metres (in one or more sections) are the minimum required working space for one technician and for the equipment. The benches should be 90 cm high, 60 cm deep, with drawers and cupboards underneath. For the benchtops, smooth, resistant, light-duty melamine plastics (e.g. Formica) would be adequate.

A sink of at least 45 x 38 cm with ample adjacent draining area is required. This may be attached to a bench or be a separate unit. The sink should be fitted with 3 taps, one movable swan-neck tap, and 2 taps with removable nozzles (1/2 in.), serrated for hoses. A water heater is not essential, though convenient in countries with cool climates. The water still, as specified in the list of equipment, should be mounted on the wall near the sink.

Five to six electrical plug sockets are necessary for the bench(es), one of them for 2000 W (for the autoclave), the others for a maximum of 1000 W. In addition, there are plug sockets needed on the walls for the water still (2000 W) and the refrigerator (1000 W). No gas fittings are required.

Other recommended furniture include a small wall-mounted cupboard for chemicals and other materials, a small-sized desk (1.20 m long) with chair, and a stool (68 cm high).

Basic bacteriological water analyses may also be carried out in such a section of a larger laboratory, the rest of which is being used for other purposes. In this case, however, aggresive fumes, such as those from handling of hydrochloric acid, must not be generated.

2.1.3 Equipment

The equipment listed in Annex 2 has been selected for its low cost and simplicity. The recommended balance, for example, is quite cheap yet sensitive enough for bacteriological analysis purposes, and can in addition be used as a "rough balance" for heavier weights. To produce the necessary vacuum for membrane filtration, a portable hand-pump or, if the water pressure permits, a water jet pump can be employed and thus no electric pump is needed. If it is intended to perform only total coliform tests, the thermostatic water bath and the thermometers for the 40 - 70° C range are not required. If, on the other hand, only faecal coliforms are to be determined, the air incubator can be omitted.

The cost of the major equiment amounts to $3,650, and the glassware and miscellaneous costs to $960. The total cost is $4,610.

2.1.4 Expendable materials

Annex 2.3 gives a list of the initial supply for a basic bacteriological water laboratory. As far as the membrane filters are concerned, their quantity is sufficient for 1000 samples, provided one total coliform and one faecal coliform test are carried out on each sample. The two tests may not always be required, which saves costly membrane filters. It may be necessary, however, to filter and incubate several dilutions from a polluted sample, which increases the number of membrane filters needed.

The chemicals listed in Annex 2.3 will last for much more than 1000 samples. These greater quantities have been chosen for economic reasons, as the purchase of smaller quantities is relatively more expensive.

Culture media, however, are best bought ready-made in dehydrated form in bottles not containing more than 1/4 lb or 100 g. Once the bottle has been opened, the medium may deteriorate if kept too long, especially in warm and humid climates. The unopened bottles have a shelf-life of several years.

The total cost of the media, chemicals and materials for 1000 samples amounts to approximately $750.

Cost estimates of total coliform and faecal coliform tests with the membrane filtration method are given in Annex 6, taking into account the expendable materials and the depreciation of equipment.

2.2 Basic laboratory for chemical analysis

2.2.1 Purpose, scope and staff

This laboratory is designed to carry out basic physical and chemical analysis of natural water, drinking-water, wastewater and effluents. It will also be suitable for the control of water and wastewater treatment processes of small-sized treatment plants, and it will be capable of determining the parameters listed in Table 1.

The methods chosen are simple and do not involve expensive or sophisticated equipment.

One senior technician or technologist, assisted by a laboratory attendant, is enough for staffing the laboratory. The technician should be able to analyse approximately 3 samples per week if all the tests listed are to be carried out for each sample, including the necessary supporting work (replacing standard solutions, etc.). If fewer tests are required, more samples can be dealt with. In the initial phase of laboratory operation, however, the technician will be fully occupied for several weeks preparing the first stock of standard solutions and other reagents.

The technician should be supervised through regular visits of a water chemist posted at a laboratory of the next higher category.

Table 1. Basic test variables and methods

VARIABLE	METHOD
Alkalinity	titrimetric
BOD	dilution method
Chloride	titrimetric with mercuric nitrate
Chlorine	orthotoludine-arseite method
Conductivity, electr.	electrometric
Colour	comparison with glass colour standards
Fluoride	Alizarin visual method
Hardness, total	titrimetric with EDTA
Jar test *	coagulation/flocculation
Nitrogen, ammonia	direct nesslerization, visual
Nitrogen, nitrate + nitrite	phenoldisulfonic acid method, visual
Oxygen, dissolved	Winkler method, azide modification
pH	electrometric
Solids, suspended	gravimetric (non-filtrable residue)
Solids, total dissolved	gravimetric (filtrable residue)
Turbidity	nephelometric

* For treatment plants of surface water only

It is an advantage if this laboratory is set up together with a basic water laboratory for bacteriological examination, as described in section 2.1. Although the two laboratories should be accommodated in separate rooms, some of their facilities can be used jointly.

2.2.2 Space, furniture and fittings

The room for this laboratory should be 25-30 m^2 with adequate lighting and proper ventilation. The total length of laboratory benches should be at least 7 metres (in one or more sections). This will provide sufficient working space for one technician and room for the equipment. The benches should be 90 cm high, 60 cm deep, and should have drawers and cupboards underneath. They should be covered with an acid-proof plastic surface (such as Formica). Tiles are also suitable but they are much more expensive.

A sink of approximately 55 x 45 cm with ample adjacent draining area is required; it should be fitted with a movable swan-neck tap and 2 taps with removable nozzles (1/2 in), serrated for hoses. A water heater is optional, and should be mounted near the larger sink, as should be the water still, which is specified in the list of equipment.

A minimum of 6 electrical plug sockets (max. 1000 W) are to be fixed on the benches or the wall behind them. Apart from these, another 3 sockets are needed for the refrigerator, the BOD incubator and the water still (the latter one for 2000 W). No gas fittings are required and no fume hood is necessary.

Other furniture needed include a cupboard for chemicals and glassware (approximately 1.5 m long, 2 m high, 35 cm deep), a small-sized desk (1.20 m long) with chair, and a laboratory stool (68 cm high).

If this laboratory is being set up together with a bacteriological one, the two laboratories should ideally be next to each other, or opposite one another. This will facilitate the joint use of certain equipment. They should not, however, be in the same room because chemical fumes may affect bacteriological work. If a larger room of at least 55 m^2 is available, it can be separated by a partition. The door between the two laboratories should be of the swing type, which closes automatically when not used.

2.2.3 Equipment

The equipment needed for the test variables listed in Table 1 is given in detail in Annex 3. Allowance for breakages has been made in the estimates. No expensive apparatus has been chosen. Instead of a cooled incubator for BOD, for example, a simple refrigerator fitted with a special temperature regulator is recommended, which costs almost a thousand dollars less. The stirring device for jar tests included in Annex 3.1 will only be necessary for laboratories of water treatment plants employing flocculation.

In case this basic chemical laboratory is being set up simultaneously with a bacteriological one, certain equipment which is marked with an asterisk in Annex 3 need not be purchased, as it will be available in the bacteriological laboratory and can be used jointly.

The cost of the major equipment amounts to $5,580, and the entire laboratory including glassware and miscellaneous items (but no chemicals) to $7,260. These are the figures for a separate basic chemical laboratory. If a bacteriological laboratory is set under the same roof the cost for the major equipment will be reduced to $4,040, and for the entire chemical laboratories to $5,480.

If it is not intended to perform any analysis of wastewater, effluents, or polluted surface water, the refrigerator with temperature regulator for BOD incubation can be omitted. The number of BOD bottles can be decreased to 10, which should be retained for dissolved oxygen determinations.

2.2.4 Chemicals

The chemicals necessary to carry out the tests of Table 1 with the methods mentioned are listed in Annex 3.3. Their quantities are at least one year's supply, provided that about 150 samples (three per week) are collected yearly and all the tests are performed on each sample. Many of the chemicals, however, will last longer, as the minimum quantities commercially available are often more than what will be consumed in one year.

Chemicals marked with an asterisk do not have to be purchased if there is also going to be a bacteriological laboratory. Their quantities will be sufficient for both laboratories.

As far as the quality of the chemicals is concerned, General Purpose Reagent (GPR) grade is sufficient for the work of this laboratory. Higher purity, such as "AnalaR", is not required. The total cost amounts to $370 for a separate chemical laboratory, and to $330 if a bacteriological laboratory is also set up.

3. INTERMEDIATE LABORATORIES

3.1 Intermediate laboratory for bacteriological examination

3.1.1 Purpose, scope and staff

This laboratorty is essentially designed to carry out on a routine basis the same bacteriological tests as a basic water laboratory, namely total coliforms and faecal coliforms using the membrane filtration method but with increased laboratory capacity. There will be additional working space and more and larger equipment.

It should also be possible to do some other work in this laboratory, such as surveys of recreational waters, sewage effluents, etc., and there should be facilities for the detection of indicator organisms other than coliforms (e.g. Pseudomonas aeruginosa, faecal streptococci). Identification of certain pathogens such as Salmonella could also be carried out if the need arises.

This intermediate laboratory should be staffed with one microbiologist (B.Sc. level), and one or two technicians plus one laboratory attendant. If only routine work is performed, it would be possible for them to analyse about 15-20 samples per day, including all supporting work.

3.1.2 Space, furniture and fittings

A room of about 30 m^2 is needed. It should be dust-proof and have adequate lighting and ventilation. There should be 2 types of laboratory benches. Those as specified for the basic laboratory (90 cm high, 60 cm deep) with a total length of about 7 metres (in one or more sections), and approximately 2 metres of benches for sit-down work, 75 cm high and 60 cm deep, with leg room. Seven to eight electrical plug sockets are needed for the benches (one for 2000 W, the others for 1000 W), and another 2 sockets (2000 W and 1000 W) are to be fixed on the wall for the water still and the refrigerator. There should be a gas supply with 3 gas taps on the taller type of benches.

The specifications for the sink with taps are the same as for the basic chemical laboratory. A water heater would be useful. Two small-sized desks (1.20 m long) with chairs, 2-3 stools (68 cm high) and a wall-mounted cupboard for chemicals and other materials should also be provided.

3.1.3 Equipment

Details of the proosed equipment items are given in Annex 4.1. As compared to a basic bacteriological water laboratory, the additions are an electric air pump, a colony counter, a second membrane filter holder, a more sophisticated water bath, and larger hot air sterilizer, incubator, and refrigerator.

A portable water test kit has also been added, which should only be used for special surveys in remote areas and not for regular water quality surveillance.

The kind and numbers of glassware and miscellaneous items (Annex 4.2) are such that two persons can work simultaneously. Allowance for breakages has been made.

The major equipment for this intermediate water laboratory for bacteriological examinations costs $6,280, whereas the cost of glassware and miscellaneous items is $1,650. The total equipment amounts to $7,930.

3.1.4 Expendable materials

If the laboratory performs only routine work with total and faecal coliform tests, the same expendable materials as used in a basic bacteriological laboratory will be needed. Please refer to section 2.1.4 and to Annex 2.3.

For other bacteriological work as mentioned above (section 3.1.1) the respective media will have to be purchased. Specifications are given in textbooks such as the Standard Methods.

Estimations of cost of total coliform and faecal coliform tests with the membrane filtration method are given in Annex 6 taking into account the consumable materials and the depreciation of equipment.

3.2 Intermediate laboratory for chemical analysis

3.2.1 Purpose, scope and staff

The purpose of this intermediate laboratory is to carry out physical and chemical analysis of natural waters and drinking-water in a more complete way than a basic water laboratory can do. It is therefore designed to cover a larger number of variables and is equipped with instruments permitting greater accuracy and speed for the determination of certain water constituents. Very costly equipment, however, is avoided.

Simple analysis of wastewater and of treated effluents can also be performed at this laboratory. But it is not specialized to examine industrial wastewaters with constituents such as toxic heavy metals, phenols, halogenated hydrocarbons, etc. If such wastes are to be analysed frequently, an extension will have to be added to the laboratory. If there are only occasional samples, they should be referred to a specialized wastewater laboratory or to the country's central laboratory.

The analyses that can be carried out in the intermediate laboratory and the methods to be used are given in Table 2.

Table 2. Expanded list of test variables and methods

VARIABLE	METHOD
Alkalinity	titrimetric
BOD	dilution method or manometric method
Calcium	titrimetric with EDTA
$CaCO_3$ stability test	titrimetric
Chloride	titrimetric with mercuric nitrate
Chlorine	orthotoludine-arsenite method
COD	dichromate reflux method
Conductivity, electr.	electrometric
Colour	comparison with colour standards
Fluoride	electrode method or alizarine method
Hardness, total	titrimetric with EDTA
Iron	phenanthroline method, photometric
Manganese	persulfate method, photometric
Nitrogen, ammonia	direct nesslerization or, following distillation, photometric
Nitrogen, nitrate	phenoldisulfonic acid or chromotropic acid method, photometric, or electrode method
Nitrogen, nitrite	sulfanilic acid method, photometric
Oxygen, dissolved	Winkler method or electrode method
pH	electrometric
Phosphate	vanadomolybdic acid method, photometric
Sodium	electrode method
Solids, suspended	gravimetric (non-filtrable residue)
Solids, total dissolved	gravimetric (filtrable residue)
Sulfate	turbidimetric
Turbidity	nephelometric

The intermediate laboratory should be staffed with one chemist (at least B.Sc. level or equivalent), and one well-trained technician. In addition, one to two laboratory attendants are needed. This staff should be able to make complete chemical analysis of about 5 samples per week. More samples can be analysed if it is not necessary to determine all the variables listed. For a higher workload, a second technician could be posted at this laboratory.

3.2.2 Accommodation, furniture and fittings

It is recommended to accommodate this laboratory, if possible, in two rooms. A smaller room should house the analytical balance and the electrometric instruments such as the spectrophotometer, turbidimeter, specific ion meter, pH meter and conductivity meter, and should be protected from steam and aggressive fumes. In this smaller room, bench(es) of a total length of about 4.50 metres (in one or more sections) are required. They should be 75 cm high and 60 cm deep, with leg room for sit-down work and drawers and cupboards underneath. There should be two chairs in this room.

In the larger room, the total bench length should be about 10 metres. The height of these benches should be 90 cm and their depth 60 cm; they should also be fitted with drawers and cupboards underneath. The surfaces of all the benches (in both rooms) should be of an acid-proof plastic material, such as Formica. Tiles are quite suitable in the larger room although they are expensive.

No size of the laboratory can be indicated as it depends mainly on how the benches in the larger room will be placed. If there are only wall benches, the area required will be bigger than if back-to-back benches (forming a central island) are used. Two large sinks as specified for a basic chemical laboratory are recommended, one of them with an ample adjacent draining area and a water heater mounted near it. Along the walls in the larger room, there should be enough space for a refrigerator, a cooled incubator, a water still, two small-sized desks with chairs, a cupboard for chemicals and glassware, and a small bookshelf. Two to three stools (68 cm) should also be provided. A small fume hood could be useful if there is enough space but it is not essential.

As for electric plug sockets, there should be one socket for each mains-operated piece of equipment in both rooms, as well as 1-2 spare sockets in each room. The power rating of the equipment will determine the maximum wattage necessary for the sockets. There should be a gas supply with 3-4 gas taps. If there is a fume hood, there should also be an electric plug socket and a gas point in it.

3.2.3 Equipment

The equipment needed for this laboratory is given, with detailed specifications, in Annex 5. When compared to the basic chemical laboratory, the additions are: a spectrophotometer, a specific ion meter with electrodes for fluoride, nitrate, and sodium (with the latter electrode, no flame photometer is needed) a dissolved oxygen meter for laboratory and field use, a mains-operated pH meter of higher accuracy, a vacuum pump, magnetic stirrers, and a rectangular hot plate. For the analysis of wastewater or polluted surface water a heating bench (for COD) has been added. The heating oven, refrigerator and conductivity meter have a larger size.

There is also a portable chemical water analysis kit for special surveys in remote areas. It is not meant for routine analyses in the laboratory for reasons explained in Annex 1.

For glassware as listed in Annex 5.2, sufficient allowance for breakages has been made. The cost of the major equipment for this intermediate laboratory for chemical analysis of water will be $15,300, whereas glassware and miscellaneous items will cost approximately $3,880, making a total of $19,180.

If analysis of wastewater, effluents or surface water with gross pollution is never to be carried out, some of the equipment will not be needed. The refrigerator with temperature regulator for BOD incubation and the electric heating bench for 6 places (for COD) can be omitted. COD glassware of Annex 5.2 is also unnecessary, and the number of BOD bottles decreased to about 15 for dissolved oxygen determinations.

3.2.4 Chemicals

The chemicals necessary for the tests listed in Table 2, using the methods mentioned therein, are listed in Annex 5.3. The quantities given are sufficient for about one year if complete analyses are carried out on approximately 250 samples. Some of the chemicals, however, will last longer since the minimum quantities commercially available are often more than what is to be consumed in one year.

The quality of the chemical for this laboratory should generally be Analytical Reagent Grade ("AnalaR"). For certain items, however, General Purpose Reagent (GPR) is sufficient. Those chemicals are marked "GPR" in Annex 5.3.

If analysis of wastewater or grossly polluted surface water is never intended to be carried out, the separately listed COD reagents (200 samples with 4 dilutions each) of Annex 5.3 can be omitted. The chemicals for BOD, however, are not separated from the others as they are not expensive (in contrast to those for COD) and are also needed for other tests.

The total cost for the chemicals amounts to $1,210, and if COD reagents are not needed, to $730.

4. CENTRAL LABORATORY

4.1. Functions of a central laboratory

A central laboratory, normally located in a country's capital, usually has to fulfil three basic tasks. (i) it serves as a reference laboratory for the other laboratories in the country; (ii) it performs analyses which cannot be carried out at a lower level because expensive equipment or specialized manpower is needed; and (iii) it also carries out routine analyses for the area where it is located, like any other intermediate laboratory.

The capacity of a central laboratory depends largely on the size, economic situation and other conditions of a country. It is therefore not possible in this guide to recommend in detail laboratory space, number of staff, specification of equipment and list of expendable materials as has been done for basic and intermediate laboratories. Only general recommendations can be given.

As a reference laboratory, the main duty of the central laboratory is to provide guidance for all other water laboratories in the country. Such guidance should include the following:

- assisting the government in setting national standards for water quality
- determining the variables and tests to be performed on routine bacteriological and chemical water samples analyzed by the other water laboratories
- selecting analytical methods for other water laboratories and to evaluate new ones prior to their application at other laboratories
- selecting laboratory equipment, chemicals, nutrients and other materials to be purchased for all water laboratories in the country.
- checking the results and performance of the other laboratories through occasional or regular inter-laboratory quality control exercises.
- offering whenever needed, in-service training and staff development programmes to the other water laboratories.

Another function of a reference laboratory is to conduct surveys of water constituents which are not routinely analysed. In times of water-borne epidemics, the reference laboratory will have to play an important role in detecting the source of infection and the route of transmission.

Such a laboratory is also supposed to carry out some applied research related to problems encountered in the country, e.g. in the field of water sources evaluation or wastewater discharges.

4.2 Central laboratory for bacteriological examination

4.2.1 Purpose and scope

This laboratory should be able to examine water and wastewater samples for pollution indicator organisms other than members of the coliform group. It should also be in a position to detect certain pathogenic bacteria in water, and possibly also viruses. And, finally, it should be prepared to play its role as a reference laboratory as described above.

(a) Indicator organisms

In addition to coliforms and faecal coliforms, facilities should exist for the detection of the following supplementary indicator organisms:

faecal streptococci
Clostridium perfringens (anaerobic spore-forming)
staphylococci

Pseudomonas aeruginosa
heterotrophic (standard) plate count

Staphylococci and Pseudomonas are only of interest if recreational waters are to be examined.

(b) Pathogenic bacteria

The detection of pathogenic microorganisms in water and wastewater is not normally an easy task, and should only be attempted in times of epidemics or on suspected samples. Suitable procedures for isolation and identification of Salmonella and Shigella are available, and this laboratory should be ready to apply them. However, if the presence of *Vibrio cholerae*, cysts of *Entamoeba histolytica* or hookworm larvae is suspected, samples should be referred to a medical laboratory.

(c) Viruses

As the importance of viruses in water becomes more and more recognized, it is recommended that a virological section be set up at the central laboratory, provided that specialized manpower is available. This would be particularly useful if no other laboratory capable of carrying out virus examination exists in the country.

The detection of enteric viruses in drinking-water requires large sample volumes. The microporous filter techniques is recommended for their concentration. For the isolation of viruses, several cell culture types of suckling mice may be required.

4.2.2 Space and staff

To be able to fulfil all its duties, this central bacteriological water laboratory should have ample space. At least three rooms are recommended: one for routine work, one for reference activities, and a small one for media preparation. Another room will be required if a virological section is established. The laboratory should be headed by a fully qualified and experienced microbiologist, and the staff should consist of another microbiologist or biologist and a number of well-trained technicians according to the workload. For a virological section, a specially trained virologist is needed.

4.2.3 Equipment

Compared to the equipment recommended for an intermediate bacteriological laboratory, the central laboratory should have some items of a larger size and others to be added as follows:

Three items should have a larger capacity: The autoclave - about 40 litres ($4,000), the hot air sterilizer - 200 litres ($800), and the water still - 4 L/h ($700). One more incubator, water bath, membrane filtration apparatus and refrigerator of approximately the same size as specified in Annex 4.1 should be added. An analytical balance similar to the one for chemical analysis as listed in Annex 5.1 ($1,700), and a microscope with the necessary access- ories ($3,000) should be added. As regards glassware, some of the items as well as the number of pieces will have to be increased according to staffing and workload. Specification of all the items needed is not attempted here, yet an estimate of the cost can be given. The major equipment could amount to approximately $18,000, the glassware and miscellaneous items to $2,000, making a total of about $20,000.

If a virological section is to be established, there will be a need for a virus-concentrator apparatus, a laminar flow air hood, and other specific equipment to be selected by a virologist. The cost of these is not included in the above total.

4.3 Central laboratory for chemical analysis

4.3.1 Purpose and scope

This laboratory should be in a position to analyse water and wastewater samples for all variables listed in Table 2 for an intermediate laboratory for chemical analysis of water (section 3.2.1). It should also have equipment and expertise for the determination, in small concentrations, of heavy metals and other inorganic substances of health significance, as well as of health-related organic compounds. In addition, it should be able to perform the tasks of a reference laboratory as described in section 4.1.

(a) Inorganic constituents

Many heavy metals with health significance have been found in waters used for public supply, especially in countries with increasing industrialization. Guideline values were set by WHO for: arsenic, cadmium, chromium, lead, mercury and selenium. Aluminium, copper and zinc have a much lower toxicity and are therefore not of primary health significance, but their concentrations are sometimes of interest.

Most of these substances are found only in low concentrations, and it is difficult to determine them with conventional chemical methods in basic or intermediate laboratories. But the central laboratory should be equipped with an atomic absorption spectrophotometer which, although expensive, greatly facilitates their analysis. Since most of the determinations are also speedy and storage poses no problems, it should be possible to carry out a central laboratory routine analysis for heavy metals in public water supplies of the whole country. It will generally suffice to select the suspected metals from those mentioned above.

The central laboratory should also be in a position to perform cyanide and hydrogen sulfide tests in addition to those inorganics listed in Table 2 already (section 3.2.1).

(b) Organic compounds

Organic substances with low biodegradability (highly persistent) but with significance for health, are increasingly appearing in waters used for public supplies. Motorized traffic, industrial effluents and agricultural run-off are their main origins. Polynuclear aromatic hydrocarbons, including benzo(a)pyrene, chlorinated hydrocarbons, chlorinated phenols, pesticides, benzene and chlorobenzenes, as well as trihalomethanes which include chloroform, are the relevant groups.

The central laboratory is the place which should be able to detect them as individual compounds or as groups of compounds in suspected water samples. The tools for this are extraction methods, gas chromatography, or a combination of both. A gas chromatograph is a costly apparatus, but very efficient for the determination of a great number of organic compounds, including pesticides.

4.3.2 Space and staff

A central chemical water laboratory needs ample space. It is recommended that there be four rooms for the following purposes:

1) Chemical routine analysis of water samples
2) Analysis of organic constituents
3) Applied research, surveys, etc.
4) Sensitive electronic instruments and balances (placed on anti-vibration balance tables).

Rooms (1) and (2) should have gas supply and a fume hood.

The laboratory should be headed by a fully trained chemist specialized in water chemistry, and the staff should consist of another chemist and several well-trained technicians, depending on the workload.

4.3.3 Equipment

Taking the equipment for an intermediate chemical laboratory (Annex 5.1) as a base, the central laboratory needs the following modifications or additional items.

The water still should be of higher capacity, about 4 L/h ($700). Recommended additions are: a second oven for heating and drying and a second refrigerator, both as specified in

Annex 5.1, a second alalytical balance (precision ± 0.01 mg), semi-micro ($3,000), a vacuum pump of better performance ($1,500), a stirring device for jar tests as specified in Annex 3.1 ($900), a universal centrifuge with tubes of capacities from 15 to 100 ml ($4,000), Soxhlet extraction apparatus with the necessary extraction thimbles ($2,000), a mixer/emulsifier to homogenize samples ($1,000), a muffle furnace for max. 1000 °C ($3,000), a Ruttner water sampler ($1,000) and electric heating mantles for 500 and 1000 ml flasks ($200).

The two main additions to be made, however, are an atomic absorption spectrophotometer (AAS) and a gas chromotograph (GC). An ASS, single beam, with all the essential accessories including 10 hollow cathode lamps for the determination of 10 different metals, is available from $17,500. Highly sophisticated double beam instruments with very expensive accessories may cost up to $50,000 and more. The price for one hollow cathode lamp varies between $100 and $300. A GC with the necessary accessories can be bought for about $10,000, but varies greatly according to its detector, and can go up to $20,000 and more. A packed column, of which there should be one for each group of organic compounds to be analysed, costs roughly $100.

The number of pieces of glassware and miscellaneous items has to be increased depending on staff and workload. An estimation of the cost of the major equipment with the cheapest versions of AAS and GS arrives at $60,000, glassware and miscellaneous items may cost $5,000, and the total will amount to approximately $65,000.

ANNEX 1: PORTABLE WATER ANALYSIS KITS

Portable kits for bacteriological and chemical water analysis are widespread in developing countries. These kits have their merits whenever certain basic information on water quality is needed that cannot be easily obtained otherwise. This may be the case for surveys in remote areas or the exploration of new water sources far away from any laboratory.

It has been found, however, that these kits are used in water laboratories or in places where a laboratory is quite near. The only benefit of the kits in these cases is that they are usually easier to handle by untrained staff than is standard laboratory equipment. However, there are several aspects that do not favour the use of kits in this case.

The accuracy and sensitivity of a number of tests performed with water analysis kits are generally more limited than with standard laboratory methods. This may be acceptable for many purposes, but for a certain accuracy of results, standard laboratory equipment is indispensable.

Test kits often contain glassware reagents and other miscellaneous implements that are not of standard laboratory design. If such equipment breaks or one runs out of a reagent, it cannot be replaced from a general store. Usually it is only the kit manufacturer who sells the replacements, and they are inevitably more expensive than ordinary laboratory materials. Moreover, if the analyst runs out of reagents and replacements have not been ordered in time, he has to discontinue his work. On the other hand, when applying standard methods, there is often a chance to find the missing reagent or part in another laboratory, even if this does not deal with water analysis.

Some of the chemical test kits contain meters which are battery operated to make the kit portable. Through constant use of the kit in a laboratory, batteries quickly run flat. As these batteries are usually special ones, alertness on the management side is necessary to ensure a sufficient stock of them. Rechargeable batteries can also fail after prolonged use. In locations where frequent power cuts are experienced, however, analysis kits can back up mains-operated laboratory equipment, provided the battery supply is secured.

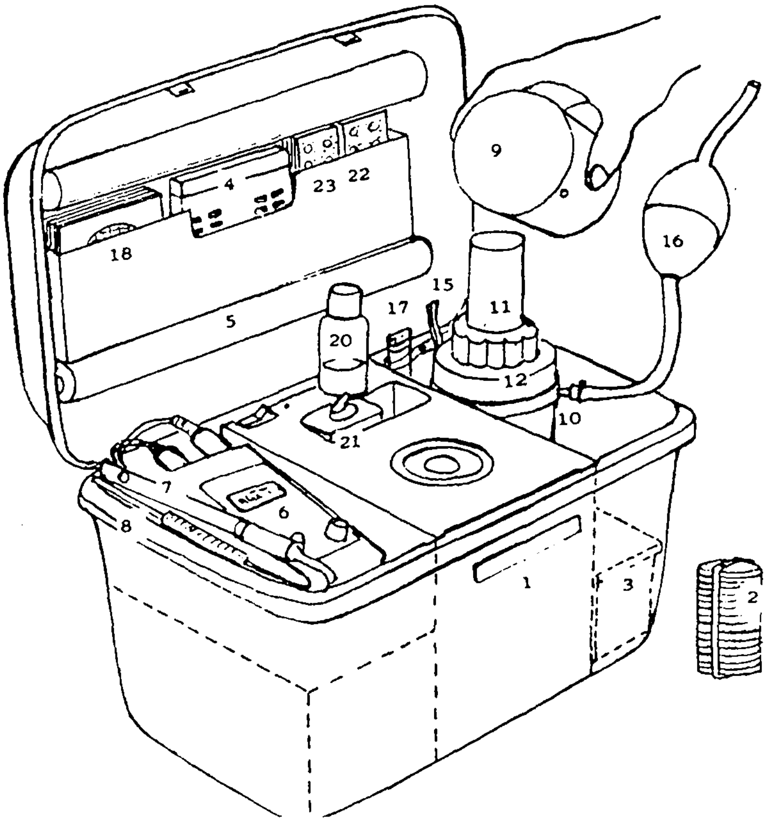
One popular bacteriological test kit comes with liquid culture media in ampules. These are easy to handle in the field, but they sometimes deteriorate before the given expiry date, especially when kept unrefrigerated in hot climates. More often than not one finds these media, purchased for regular use in laboratories, expired, and the test kits to which they belong lying around idle. Dehydrated media, however, as used with standard laboratory equipment, have a shelf life of several years in unopened bottles, even at room temperature.

To summarize, before purchasing portable water analysis kits one should weigh the advantages against the disadvantages. If a laboratory is available and electric power cuts are not too frequent, bacteriological and chemical water analysis should preferably be carried out with proper laboratory equipment compatible with standard methods.

One example of a combined physico-chemical and bacteriological field kit is Oxfam DelAgua's Water Testing Kit which performs the measurement of temperature, pH, conductivity, turbidity, chlorine residual and faecal coliforms (membrane filtration method). Its major elements, as shown on Figure 1, were designed to cover the analytical needs specified in Volume 3 of the WHO Guidelines for Drinking-Water Quality (referred to in section 1.3).

FIGURE 1. CHECKLIST OF EQUIPMENT AND CONSUMABLES

THE EQUIPMENT



CHECKLIST OF EQUIPMENT AND CONSUMABLES

ITEM

1 Carrying case with incubator
2 Aluminium petri dishes with carrier
3 Storage box with charger lead and power lead
4 Chlorine residual and pH comparator
5 Turbidity tubes x 2
6 Conductivity and temperature meter
7 Conductivity probe
8 Temperature probe
9 Stainless steel sample cup and cable
10 Stainless steel vacuum flask
11 Stainless steel filter funnel and locking collar
12 Aluminium filter assembly base
13 Upper and lower 'O' rings
14 Bronze membrane support disc
15 Stainless steel forceps
16 Suction pump
17 Lighter

Consumables

18 Membrane filters
19 Pads and dispenser
20 Membrane broth in polypropylene bottles
21 Methanol in metal dispenser
22 DPD 1 and DPD 3 reagents in foil-wrapped pastilles
23 Phenol red reagent in foil-wrapped pastilles
24 Disposable tissues or clean cloth
25 Daily report sheets

ANNEX 2: BASIC BACTERIOLOGICAL WATER LABORATORY

2.1 Basic bacteriological water laboratory: major equipment

QTY	DESCRIPTION	MAKE OR EQUIVALENT	COST IN $
1	Autoclave, portable, electr.heated, inner diam. approx. 280mm, depth 250mm	Gallenkamp Autoclave portable 1850 W	730
1	Balance, sensitivity 0.05g. max. approx. 2kg (pref. sliding mass)	OHAUS DEC-O-GRAM 3600	240
1	Hotplate, electr. 150 mm diam.	any	170
1	Incubator, air,max. 80-100° temp. fluctuation ± 0.5 °C, 30-40 L, 2 shelves, gravity convection	Gallenkamp GRIFFIN INCUBATOR	280
1	Membrane filter holder, borosilicate glass, 250-300 ml funnel with suction flask 1 litre	Millipore XX 10047-20 & -5 or Sartorius SM 16316 and SM 16606	130
1	pH meter, portable, accuracy 0.1 pH with combination electrode and spare electrode	EIL MODEL 3055 or FISHER Accumet 156	420
1	Refrigerator, general purpose, 140-160 litres	any	290
1	Sterilizer, hot air, 200°C, approx. 50 litres, grativy convection, with spare kit	Gallenkamp HOTBOX STERILIZER	500
1	Water bath, thermosatic, temp. fluctuation ± 0.2 °C, approx. 15 L	Gallempamp WATER BATH 13 L	460
1	Water still, output approx. 2 L/h, stainless steel or glass condenser with spare heating element	Gallemkamp MANESTY OB	430
		TOTAL MAJOR EQUIPMENT	,3650

2.2 Basic bacteriological water laboratory: glassware and miscellaneous

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1	Basket of wire, for sterilization, 150 mm cube	9.50	9.50
	Beakers, borosilicate glass, squat form with spout		
3	50 ml capacity	1.80	5.40
2	250 ml capacity	1.80	3.60
2	400 ml capacity	2.25	4.50
	Bottles, reagent, white glass, narrow neck, ground glass stopper		
3	125 ml capacity	2.70	8.10
48	250 ml capacity (for sampling)	3.20	154.00
3	500 ml capacity	3.60	10.80
3	1000 ml capacity	5.00	15.00
1	Bottle, aspirator, plastic, 15-20 L	40.50	40.50
1	Box, cool, insulated for 8-12 water sampling bottles	10.00	10.00
1 pk.	Brushes for beakers & bottles, 50mm dia. (pack of 6)	5.00	5.00
1 pk.	Brushes for test tubes, 25 mm dia. (pack of 10)	2.40	2.40
1	Burner, alcohol	10.00	10.00
2	Cylinders, graduated, glass, 100 ml	3.40	6.80
1	Fire extinguisher, suitable for electrical and other fires	8.00	8.00
	Flasks, conical (Erlenmeyer), narrow neck with screw cap, borosilicate glass		
2	100 ml capacity	6.90	13.80
1	250 ml capacity	6.90	6.90
2	Flasks, volumetric, with stopper, Class B, 500 ml	9.70	19.40
2	Forceps, stainless steel, rounded tips 125 mm long	3.80	7.60
1	Funnel, borosilicate glass, 75 mm dia.	5.50	5.50
1	Magnifying lens, 2-3X, 50 mm dia.	3.80	3.80
48	Petri dishes, borosilicate glass, approx 60 x 15 mm	4.30	206.40
2	Pipette fillers, rubber bulb	11.30	22.60
	Pipettes, measuring (graduated), class B		
6	2 ml capacity	1.80	10.80
3	5 ml capacity	1.80	5.40
3	10 ml capacity	1.90	5.70

Basic bacteriological water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
	Pipettes, volumetric (bulb), class B		
3	20 ml capacity	2.90	8.70
3	50 ml capacity	3.80	11.40
1	Rack, draining, for wall, approx. 60 x 60 cm	18.00	18.00
1	Scissors, stainless steel, 150 mm long	10.00	10.00
1	Spatula, horn, with spoon end, 150 mm long	6.50	6.50
1	Spatula, stainless steel, 150 mm long	2.20	2.20
2	Sterilizing boxes, stainless steel, for Petri dishes (12 dishes each)	43.00	86.00
1	Sterilizing box, stainless steel, for pipettes, 45 cm long	26.50	26.50
1	Stand for 12 pipettes, horizontal	12.40	12.40
1 pk.	Stirring rods, glass, 200 x 7 mm (pack of 10)	4.70	4.70
	Thermometers, 300 mm long		
2	0-50 °C, 0.5 °C divisions	2.90	5.80
2	0-250 °C, 1 °C divisions	3.25	6.60
2	Thermometers, total immersion, 40-70 °C in 0.1 °C divisions	12.50	25.00
1	Tongs, crucible, stainless steel, 200 mm long	3.60	3.60
1 set	Tools, various (hammer, pliers, screw drivers)	30.00	30.00
5 m	Tubing, rubber, normal wall, bore 10 mm	2.00	10.00
5 m	Tubing, rubber, heavy wall, bore 5 mm	2.50	12.50
1	Vaccuum pump, hand operated	45.00	45.00
2	Washbottles, polythene, 600 ml	1.50	1.50
1	Waste bin, plastic	20.00	20.00
1	Water jet pump (filter pump) plastic	7.00	7.00
1	Weighing scoop, nickel, stainless steel or glass	5.00	5.00

Total glassware	960.00
Major equipment	3,650.00
Total equipment	4,610.00

2.3 Expendable materials for total and faecal coliform tests (1000 samples)

QTY	DESCRIPTION	COST IN $
2 rolls	Aluminium foil, 450 mm (15 metres per roll)	10.00
1 pk.	Bags, polythene, resealable, 120 x 180 mm	6.10
2 L	Bleach solution for general disinfection (e.g., Teepol bleach, Clorox)	4.00
1 pk.	Buffer tables pH7 (pack of 50 for 5 L)	7.50
2 pk.	Cotton wool, white (pack of 0.5 kg)	14.40
5 L	Detergent for glassware	7.20
500 ml	Ethyl alcohol	8.00
2 pk.	Membrane filters, 0.45 microns poresize, 47 mm dia. with absorb. pads, sterile (pack of 1000) (MILLIPORE or equivalent)	600.00
2 x 100 g	M-Endo medium, dehydrated (DIFCO or equivalent)	24.60
2 x 100 g	M-FC broth, dehydrated (DIFCO or equivalent)	23.20
500 g	Potassium chloride	3.20
500 g	Potassium dihydrogen phosphate	6.30
25 g	Rosolic acid, sodium salt	11.40
250 g	Sodium hydroxide, pellets	2.00
1 kg	Sodium thiosulfate	4.10
1 L	Spirit, methylated	6.00
1 pk	Wax pencils, for writing on glass (pack of 12)	8.60
	Total expendable materials (approximately)	750.00

ANNEX 3: BASIC CHEMICAL WATER LABORATORY

3.1 Basic chemical water laboratory: major equipment

QTY	DESCRIPTION	MAKE OR EQUIVALENT	COST IN $
1	Balance, analytical, max 160g precision 0.1 mg	METTLER H 80	1,650
1*	Balance "rough", sliding mass, sensitivity 0.2g, cap. approx. 2kg, with set of weights	OHAUS DEC-O-GRAM 3600	(240)
1	Comparator (colorimeter) with glass standard discs for chlorine (2 ranges), with square section cells (5 pairs)	LOVIBOND 2000	155
1	Conductivity bridge, mains or battery operated with conductivity cell	GRIFFIN	250
1*	Hot plate, electric, 150 mm dia.	any	(170)
1	Nesslerizer, with glass colour discs for ammonia (2 ranges), fluoride, colour, with 3 pairs of spare cells	any	165
1	Oven for heating and drying, 30 litres max. temp. 200 °C	GRIFFIN OVEN 200 °C	310
1*	pH meter, portable, accuracy 0.1 pH, with 2 combination electrodes	EIL model 3055 or FISHER Accumet 156	(420)
1*	Refrigerator, general purpose, 140-160 L	any	(290)
1	Refrigerator, general purpose, 140-160 L, to be converted into a BOD incubator using temperature regulator (see below)	any	290
1	Stirring device for jar tests, 6 places, 30-100 rpm (for surface water works laboratories only)	Karl Kolb or Hach	(900)
1	Temperature regulator, to convert refrigerator into cooled incubator, temperature fluctuation ± 1.0 °C	Hach INCUTROL/2	400
1	Turbidimeter, portable with rechargeable batteries, ranges: 0-1, 0-10, 0-100 NTU	Hach	700
1	Water or steam bath, electric heated, 6 places, with spare heating element	any	120
1*	Water still, output approx. 2 L/h, stainless steel or glass condenser, with spare heating element	Gallenkamp MANESTY OB	(425)
	Total major equipment (without stirring device)		5,580
	Total major equipment (without stirring device) if a bacteriological laboratory is set up simultaneously (items with asterisk are not included)		4,040

3.2 Basic chemical water laboratory: glassware and miscellaneous

QTY	DESCRIPTION	UNIT COST $	TOTAL $
	Beakers, borosilicate glass, squat form with spout		
6	50 ml capacity	1.80	10.80
6	100 ml capacity	1.80	10.80
6	200 ml capacity	1.80	10.80
6	400 ml capacity	2.30	13.80
6	600 ml capacity	3.00	18.00
6	1000 ml capacity	4.30	26.00
8	2000 ml capacity (for surface water works laboratory only)	7.00	(56.00)
	Bottles, wide neck, glass stoppered, white glass		
2	250 ml capacity	3.90	7.80
2	500 ml capacity	4.30	8.60
1*	Bottle, aspirator, plastic, 15-20 litres	40.50	(40.50)
	Bottles, polythene, narrow mouth		
1 pk.	1000 ml capacity (pack of 5)	9.60	9.60
1	2500 ml capacity	7.90	39.50
1	5000 ml capacity	9.20	9.20
5	Bottles, dropping, 50 ml, white glass	1.50	7.50
5	Bottles, dropping, 50 ml, amber glass	1.60	8.00
	Bottles, reagent, narrow neck, amber glass		
5	250 ml capacity	2.70	13.50
5	500 ml capacity	3.80	19.00
5	1000 ml capacity	4.50	22.50
	Bottles, reagent, narrow neck, white glass		
6	125 ml capacity	2.70	16.20
6	250 ml capacity	3.20	19.20
12	500 ml capacity	3.60	43.50
12	1000 ml capacity	5.00	60.00
2 pk. (=48)	Bottles for BOD, glass stoppered, 300 ml (FISHER: pack of 24)	110.00	220.00
1*pk.	Brushes for beakers and bottles, 50 mm dia. (pack of 6)	5.00	(5.00)
1*pk.	Brushes for test tubes, 25 mm dia. (pack of 10)	2.40	(2.40)
6	Burettes, 25 ml. div. 0.1 ml, class B	12.00	72.00
3	Burette stands, for 2 burettes	13.20	40.00
	Cylinders, measuring, graduated		
2	10 ml capacity	2.70	5.40
2	25 ml capacity	2.90	5.80
2	100 ml capacity	3.40	6.80
2	500 ml capacity	11.30	22.30
1	1000 ml capacity	16.00	16.00

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Basic chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1	Desiccator, approximately 270 mm dia.	67.00	67.00
6	Dishes, for evaporating, round bottoms, approximately 90 mm	2.60	15.60
1	Eye shield, plastic	2.40	2.40
1 box	Filters (100), glass fibre, Whatman GF/C, 70 mm	7.00	7.00
1 box	Filter paper (100), soft texture, Whatman No.41, 12.50cm	6.40	6.40
1 box	Filter paper (100), hardened, Whatman Nr.50, 12.50 cm	4.10	4.10
1*	Fire extinguisher suitable for electrical and other fires	8.00	(8.00)
1	First aid cabinet	25.00	25.00
	Flasks, conical (Erlenmeyer), narrow neck		
2	100 ml capacity	2.20	4.40
2	500 ml capacity	2.70	5.40
	Flasks, conical (Erlenmeyer), wide neck		
5	250 ml capacity	2.20	11.00
5	500 ml capacity	2.90	14.50
1	Flask, suction (Buchner filter flask) 1000 ml	15.00	15.00
1 pk.	Flask adapters for above (pack of 5)	3.90	3.90
	Flasks, volumetric, class B		
10	100 ml capacity	5.10	51.00
2	250 ml capacity	7.40	14.80
2*	500 ml capacity	9.70	(19.40)
2	1000 ml capacity	12.60	25.00
	Funnels, polypropylene or polythene		
1 pk.	40 mm dia. (pack of 10)	2.30	2.30
1 pk.	115 mm dia. (pack of 10)	15.40	15.40
1	210 mm dia.	3.60	3.60
1	Funnel for glass filter discs, Hartleg, 7 cm	53.00	53.00
1	Funnel stand, double, hardwood	12.30	12.30
1 pk.	Lables (1000), self-adhesive, approx. 35 x 25 mm	2.50	2.50
1	Mortar with pestle, porcelain, approx. 100 mm	7.40	7.40
2 pks.	Nessler tubes, tall, 100 ml (pack of 6)	36.00	72.00

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Basic chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1	Nessler tube stand, PVC, for 6 tubes, 100 ml	13.60	13.60
2*	Pipette fillers, rubber bulb	11.30	(22.60)
	Pipettes, graduated, class B		
10	2 ml	1.80	18.00
5	5 ml	1.80	9.00
5	10 ml	1.90	9.50
	Pipettes, volumetric (bulb), class B		
3	25 ml	2.90	8.70
5	50 ml	3.80	19.00
5	100 ml	5.50	28.00
1*	Rack, draining, for wall, approx. 60 x 60 cm	18.00	(18.00)
1*	Scissors, stainless steel, 150 mm	10.00	(10.00)
1*	Spatula, horn, with spoon end, 150 mm	6.50	(6.50)
1	Spatula, stainless steel, 150 mm	2.20	2.20
1	Stand for approx. 25 pipettes, vertical	41.00	41.00
1* pk.	Stirring rods, glass, 200 x 7 mm (pack of 10)	4.70	4.70
5	Stirring rods, glass, 300 x 8 mm	1.00	5.00
1 pk.	Stoppers, rubber (pack of assorted sizes)	17.00	17.00
	Thermometers, 300 mm long		
2	0-50 °C, 0-5 °C divisions	2.90	5.80
2	0-250 °C, 1 °C divisions	3.30	6.60
1*	Tongs, crucible, stainless steel, 200 mm	3.60	(3.60)
1* set	Tools, various (hammer, pliers, screw driver)	30.00	(30.00)
5*m	Tubing, rubber, normal wall, bore 10 mm	2.00	(10.00)
5m	Tubing, rubber, heavy wall, bore 5 mm	2.50	15.00
1*	Vaccuum pump, hand operated	45.00	45.00
	Washbottles, polythene		
2	600 ml	1.50	3.00
2	250 ml	1.30	2.60
1	Waste bin, plastic	20.00	20.00
1*	Water jet pump (filter pump), plastic	7.00	(7.00)
1 pk.	Watch glasses, 5 mm dia. (pack of 10)	3.10	3.10

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Basic chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1 pk.	Watch glasses, 10 mm dia. (pack of 10)	2.30	2.30
1*pk.	Wax pencils, for writing on glass (pack of 12)	8.60	(8.60)
1*	Weighing scoop, nickel, stainless steel	5.00	(5.00)
	Total glassware if a separate chemical laboratory is set up:		1,680.00
	Total glassware if a bacteriological laboratory is set up simultaneously (items with asterix not included)		1,440.00

Total equipment for chemical laboratory in US$

	Major Equipment	Glassware	Total
Chemical laboratory on its own	5,580	1,680	7,260
Chemical laboratory simultaneous with bacteriological laboratory	4,040	1,440	5,480

3.3 <u>Basic chemical water laboratory: chemicals for approximately one year (about 150 samples) - Grade: General Purpose Reagents</u>

QTY	DESCRIPTION	COST IN $
25 g	Alizarin sodium monosulfate (Alizarin Red S)	12.00
1 kg	Aluminium potassium sulfate	4.20
2.5 L	Ammonia solution, conc.	5.40
1 kg	Ammonium chloride	6.80
1 kg	Ammonium sulfate	4.80
10 g	Bromocresol green, water soluble	18.00
5 g	Bromophenol blue	3.50
1 pk.	Buffer tablets pH 4 (pack of 50 for 5 L solution)	7.50
1*pk.	Buffer tablets pH 7 (pack of 50 for 5 L solution)	(7.60)
500 g	Calcium chloride, hexahydrate	6.40
1 kg	Calcium hydroxide	5.00
5*L	Detergent for glassware, etc. (e.g. Teepol L)	(7.20)
5 g	Diphenylcarbazone	6.10
250 g	EDTA, disodium salt	7.60
25 g	Eriochrome Black T (solochrome black)	4.80
500*ml	Ethyl alcohol	(8.00)
500 ml	Ferric chloride solution	4.00
500 g	Hexamethylenetetramine (hexamine)	4.50
100 g	Hydrazine sulfate	3.70
2.5 L	Hydrochloric acid, conc.	6.00
1 kg	Magnesium sulfate	4.00
2x500g	Manganous sulfate monohydrate	22.20
100 g	Mercuric chloride	6.60
100 g	Mercuric iodide	7.20
100 g	Mercuric nitrate	6.40
25 g	Methyl orange	4.50
500 ml	Nitric acid, conc.	5.00
100 g	Orthotoludine dihydrochloride	3.80
500 ml	Phenoldisulfonic acid	8.70
25 g	Phenolphthalein	4.00
500*g	Potassium chloride	(3.20)
500*g	Potassium dihydrogen phosphate	(6.30)
100 g	Potassium iodate	7.10
500 g	Potassium iodide	15.00
500 g	Potassium nitrate	3.40

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Basic chemical water laboratory: chemicals for approximately one year (about 150 samples) - Grade: General Purpose Reagents (cont)

QTY	DESCRIPTION	COST IN $
500 g	Potassium permanganate	5.80
500 g	Potassium sodium tartrate (Rochelle salt)	6.70
500 g	Silica gel, self-indicating, coars	5.20
25 g	Silver sulfate	25.00
100 g	Sodium arsenite (sodium metaarsenite)	6.50
100 g	Sodium azide	8.00
1 kg	Sodium carbonate, anhydrous	5.60
1 kg	Sodium chloride	5.60
100 g	Sodium fluoride	3.90
1 kg	Sodium hydroxide, pellets	5.60
250 ml	Sodium hypochloride solution	4.30
1*kg	Sodium thiosulfate	(4.10)
500 g	Starch, soluble	6.10
2.5 L	Sulfuric acid, conc.	6.70
3 amp.	Sulfuric acid, in ampoules for dilution to 0.1 N	4.00
500 g	Zinc sulfate	5.90
100 g	Zirconyl chloride	9.00

	Total chemicals for a separate chemical laboratory	370.00
	Total chemicals if a bacteriological laboratory is set up simultaneously (items with asterisk not included)	330.00

ANNEX 4: INTERMEDIATE BACTERIOLOGICAL WATER LABORATORY

4.1 Intermediate bacteriological water laboratory: major equipment

QTY	DESCRIPTION	MAKE OR EQUIVALENT	COST IN $
1	Air/filter pump, small, diaphragm, vacuum at least 400 mm Hg, for membrane filtration	Gallenkamp	200
1	Autoclave, portable, electr. heated, inner dia. approx. 280 mm, depth 250 mm	Gallenkamp Autoclave portable 1850W	730
1	Balance, sensitivity 0.05g, max. approx. 2 kg (pref. sliding mass)	OHAUS DEC-O-GRAM 3600	240
1	Colony counter, with magnifier lens, set of adapter rings, and spare fluorescent tube	Gallenkamp	700
1	Hotplate, electr., 150 mm dia.	any	170
1	Incubator, air, max. 80 °C, temp. fluctuation ± 0.5 °C, 3 shelves, gravity convection, approx. 100 litres	Gallenkamp ECONOMY Incubator size 2	600
2	Membrane filter holders, borosilicate glass, 250-300 ml funnel, with suction flask 1 litre	MILLIPORE XX 10047-20 & -5 or Sartorius SM	260
1	pH meter, portable, accuracy 0.1 pH with combination electrode and spare electrode	EIL MODEL 3055 or FISHER Accumet 156	420
1	Refrigerator, general purpose, approx. 200 litres	any	340
1	Sterilizer, hot air, 200 °C, approx. 100 litres, gravity convection, with spare kit 200°, size 2	Gallenkamp HOTBOX STERILIZER	610
1	Water bath, thermostatic, solid state temp. control, fluctuation ± 0.1 °C, with cover, 15-20 litres	Gallenkamp	580
1	Water still, output approx. 2 L/h, stainless steel or all glass, with spare heating element	Gallenkamp MANESTY OB	430
1	Water test kit, portable, for field determinations of total coliforms, including portable incubator	MILLIPORE XX63 001 00	1200
		TOTAL MAJOR EQUIPMENT	6,280

4.2 Intermediate bacteriological water laboratory: glassware and miscellaneous

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1 pk.	Adapters, Y-shape, for 5 mm tubing (pack of 3)	2.50	2.50
2	Baskets of wire, for sterilization, 150 mm cube	9.50	19.00
	Beakers, borosilicate glass, squat form with spout		
4	50 ml capacity	1.80	7.20
3	100 ml capacity	1.80	5.40
3	250 ml capacity	1.80	5.40
2	400 ml capacity	2.25	4.50
2	600 ml capacity	3.00	6.00
	Bottles, reagent, white glass, narrow neck, ground glass stopper		
5	125 ml capacity	2.70	13.50
72	250 ml capacity (for sampling)	3.20	230.00
5	500 ml capacity	3.60	18.80
5	1000 ml capacity	5.00	25.00
1	Bottle, aspirator, plastic, 15-20 L	40.50	40.50
2	Boxes, cool, insulated, for 8-12 water sampling bottles	10.00	20.00
1 pk.	Brushes for beakers & bottles, 50 mm dia. (pack of 6)	5.00	5.00
1 pk.	Brushes for test tubes, 25 mm dia. (pack of 10)	2.40	2.40
2	Burners, alcohol	10.00	20.00
3	Burners, bunsen, for LPG	25.00	75.00
4	Cylinders, graduated, glass, 100 ml	3.40	13.60
1	Cylinder, graduated, glass, 500 ml	11.30	11.30
1	Fire extinguisher, suitable for electrical and other fires	8.00	8.00
	Flasks, conical (Erlenmeyer), narrow neck with screw cap, borosilicate glass		
4	100 ml capacity	6.90	27.50
2	250 ml capacity	6.90	13.80
2	Flasks, volumetric, with stopper class B, 500 ml	9.70	19.40
1	Flask, volumetric, with stopper, class B, 1000 ml	12.60	12.60
4	Forceps, stainless steel, rounded tips 125 mm long	3.80	15.10
2	Funnels, borosilicate glass, 75 mm dia.	5.50	11.00
1	Gas washbottle, Dreschsel, 500 ml	19.00	19.00

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Intermediate bacteriological water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1 pk.	Inoculating loops, Ni-Cr wire (pack of 5)	5.00	5.00
1	Magnifying lens, 2-3 X, 50 mm dia.	3.80	3.80
72	Petri dishes, borosilicate glass, approx 60 x 15 mm	4.30	309.60
3	Pipette fillers, rubber bulb	11.30	33.90
	Pipettes, measuring (graduated), class B		
10	2 ml capacity	1.80	18.00
6	5 ml capacity	1.80	10.80
6	10 ml capacity	1.90	11.40
	Pipettes, volumetric (bulb), class B		
6	20 ml cap.	2.90	17.40
6	50 ml capacity	3.80	22.80
1	Rack, draining, for wall, approx. 60 x 60 cm	18.00	18.00
1	Scissors, stainless steel, 150 mm long	10.00	10.00
2	Spatulas, horn, with spoon end 150 mm long	6.50	13.50
2	Spatulas, stainless steel, 150 mm long	2.20	4.40
3	Sterilising boxes, stainless steel for Petri dishes (12 dishes each)	43.00	129.00
2	Sterilising boxes, stainless steel, for pipettes, 45 cm long	26.50	53.00
1 pk.	Stirring rods, glass, 200 x 7 mm (pack of 10)	4.70	4.70
3	Stopcocks, vacuum, with 2 side tubes, 7 mm outer dia.	20.00	60.00
36	Test tubes, culture, borosilicate glass with screw cap, 125 x 16 mm	2.40	87.00
2	Test tube rack, rigid polythene, 12 tubes, 16 mm	4.30	8.60
	Thermometers, 300 mm long		
2	0-50 °C, 0.5 °C divisions	2.90	5.80
2	0-250 °C, 1 °C divisions	3.25	6.60
2	Thermometers, total immersion, 40-70 °C in 0.1 °C divisions	12.50	25.00
2	Tongs, crucible, stainless steel, 200 mm long	3.60	7.20
1 set	Tools, various (hammer, pliers, screw drivers)	30.00	30.00
3	Tripod stands, 150 mm	5.00	15.00

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Intermediate bacteriological water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
5 m	Tubing, rubber, normal wall, bore 10 mm	2.00	10.00
8 m	Tubing, rubber, heavy wall, bore 5 mm	2.50	20.00
2	Washbottles, polythene, 600 ml	1.50	3.00
2	Washbottles, polythene, 250 ml	1.30	2.60
1	Waste bin, plastic	20.00	20.00
1 pk.	Watch glasses, 5 mm dia. (pack of 10)	3.10	3.10
1	Water jet pump (filter pump) plastic	7.00	7.00
1	Weighing scoop, nickel, stainless steel or glass	5.00	5.00
1 pk.	Wire gauzes, 150 x 150 mm (pack of 10)	12.00	12.00

Total glassware	1,650.00
Major equipment	6,280.00
Total equipment	7,930.00

ANNEX 5: INTERMEDIATE CHEMICAL WATER LABORATORY

5.1 Intermediate chemical water laboratory: major equipment

QTY	DESCRIPTION	MAKE OR EQUIVALENT	COST IN $
1	Balance, analytical, max. 160g precision 0.1 mg	METTLER H 80	1650
1	Balance "rough", sliding mass, sensitivity 0.2g, cap. max. 2kg, with set of weights	OHAUS 1550 SD	190
1	Comparator (colorimeter) with glass standard discs for chlorine (2 ranges) with square section cells (5 pairs)	LOVIBOND 2000	160
1	Conductivity bridge, mains or battery operated, with 2 conductivity cells	EIL CM 1	500
1	Dissolved oxygen meter, portable, with spare proble and spare membranes	YSI model 51 or GRIFFIN	400
1	Hot plate, electric, rectangular, approx. 300 x 230 mm, 1 kW	any	400
1	Hot plate, electric, 150 mm dia.	any	170
1	Heating bench, electric, 6 places with 6 support rods (for COD)	Vari-Heat (Fisher)	800
1	Oven for heating and drying, approx. 100 L, max. temp. 200 °C, with spare kit	HOTBOX size 2 Gallenkamp	610
1	pH meter, portable, accuracy 0.1 ph with 2 combination electrodes	EIL model 3055 or FISHER Accumet 156	420
1	pH meter, mains operated, accuracy 0.05 pH with electrode holder and spare combination electrode	EIL model 7020 or CORNING model 7	750
1	Refrigerator, general, 200-220 L	any	340
1	Refrigerator, general, 140-160 L to be converted into a BOD incubator using temperature regulator (see below)	any	290
1	Specific-ion meter, mains operated, full scale: 2 concentrations decades, with electrode holder, with the following electrodes	ORION 407 A/L	1080
	1 Fluoride electrode	CORNING or ORION	400
	1 Nitrate electrode, with filling sol.	CORNING or ORION	370
	1 Sodium electrode	FISHER or CORNING	150
	2 Reference electrodes, double-junction ($90 each)	CORNING or ORION	180

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Intermediate chemical water laboratory: major equipment (continued)

QTY	DESCRIPTION	MAKE OR EQUIVALENT	COST IN $
1	Spectrophotometer, wavelength 325-900 nm, spectral width approx. 8nm, with 6 rectangular 10 mm cuvettes, spare lamp and spare phototube	B & L Spectronic 70	2,700
2	Stirrers, magnetic, variable speed, with 3 each 20 mm & 40 mm teflon coated followers ($160 each)	any	320
2	Stopwatches, 60 min. dial ($40 each)	any	80
1	Temperature regulator, to convert refrigerator into cooled incubator, temperature fluctuation ± 1.0 °C	Hach INCUTROL/2	400
1	Turbidimeter, with sample cells, turbidity standards, ranges: 0-1, 0-10, 0-100 NTU	Hach 2100 A	1,200
1	Vacuum/pressure pump, small capacity pressure 10-15 psi, vacuum approx. 400 mm Hg	FISHER	280
1	Water or steam bath, electric heated, 6 places, with spare heating element	any	120
1	Water still, output approx. 2 L/h stainless steel or glass condenser, with spare heating element	MANESTY OB (Gallenkamp)	430
1	Portable chemical weater analysis kit, complete with chemicals	Hach PR-EL/1	900
	Total major equipment for a chemical laboratory		15,300

5.2 Intermediate chemical water laboratory: glassware and miscellaneous

QTY	DESCRIPTION	UNIT COST $	TOTAL $
	Beakers, borosilicate glass, squat form with spout		
10	50 ml capacity	1.80	18.00
10	100 ml capacity	1.80	18.00
10	200 ml capacity	1.80	18.00
10	400 ml capacity	2.30	23.00
10	600 ml capacity	3.00	30.00
6	1000 ml capacity	4.30	26.00
3	2000 ml capacity	7.00	21.00
	Bottles, wide neck, glass stoppered, white glass		
5	125 ml capacity	3.00	15.00
5	250 ml capacity	3.90	19.50
5	500 ml capacity	4.30	21.50
	Bottles, wide neck, glass stoppered, amber glass		
5	250 ml capacity	4.00	20.00
2	Bottles, aspirator, plastic, 15-20 litres	40.50	81.00
	Bottles, polythene, narrow mouth		
2 pk.	1000 ml capacity (pack of 5)	9.60	19.20
6	2000-2500 ml capacity	7.90	48.00
2	5000 ml capacity	9.20	18.40
10	Bottles, dropping, 50 ml, white glass	1.50	15.00
5	Bottles, dropping, 50 ml, amber glass	1.60	8.00
	Bottles, reagent, narrow neck, amber glass		
5	125 ml capacity	2.00	10.00
5	250 ml capacity	2.70	13.50
6	500 ml capacity	3.80	23.00
6	1000 ml capacity	4.50	27.00
	Bottles, reagent, narrow neck, white glass		
10	125 ml capacity	2.70	27.00
10	250 ml capacity	3.20	32.00
20	500 ml capacity	3.60	72.00
20	1000 ml capacity	5.00	100.00
3 pk. (=72)	Bottles for BOD, glass stoppered, 300 ml (FISHER: pack of 24)	110.00	330.00
5	Bossheads	4.00	20.00
2 pk.	Brushes for beakers and bottles, 50 mm dia. (pack of 6)	5.00	10.00
1 pk.	Brushes for cylinders, 60 mm dia. 650 mm long (pack of 10)	15.00	15.00
1 pk.	Brushes for test tubes, 25 mm dia. (pack of 10)	2.40	2.40

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Intermediate chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
5	Burettes, 25 x 0.1 ml, automatic zero, with reservoir, class B	85.00	425.00
3	Burettes, 25 ml, div. 0.1 ml, class B	12.00	36.00
3	Burettes, 10 ml, div. 0.02 ml, class B	13.00	39.00
3	Burette stands, for 2 burettes	13.20	40.00
4	Burners, bunsen, for LPG	25.00	100.00
5	Clamps for retort stand, medium size, versatile	7.60	38.00
	COD glassware (Quickfit):		
8	flasks, flat bottom, short neck, 500 ml, 24/29	7.00	56.00
8	flasks, flat bottom, short neck, 250 ml, 24/29	6.80	55.00
8	condensers Liebig, 300-400 mm, 24/29	15.50	124.00
6	clamps	7.60	46.00
	Cylinders, measuring, graduated		
4	10 ml capacity	2.70	10.80
4	25 ml capacity	2.90	11.60
4	100 ml capacity	3.40	13.60
4	500 ml capacity	11.30	45.00
2	1000 ml capacity	16.00	32.00
1	Desiccator, approximately 270 mm dia.	67.00	67.00
1	Desiccator, approximately 200 mm dia.	50.00	50.00
5	Dishes, for evaporating, round bottoms, 60 mm	1.90	9.50
10	Dishes, for evaporating, round bottoms, 95 mm	3.10	31.00
5	Dishes, for evaporating, round bottoms, 150 mm	6.70	34.00
1	Distillation apparatus, borosilicate glass, Quickfit 24/29 consisting of:		
1	flask, flat bottom, medium neck, 500 ml	7.80	7.80
1	flask, flat bottom, medium neck, 1000 ml	9.00	9.00
1	still head, with thermometer socket	10.10	10.10
1	condenser Liebig, 400 mm	15.50	15.50
	receiver, plain bend, short	6.80	6.80
2	Eye shields, plastic	2.40	4.80

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Intermediate chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
2 boxes	Filters, glass fibre, Whatman GF/C, 70 mm (box of 100)	7.00	14.00
2 boxes	Filter paper, soft texture, Whatman Nr.41, 12.50 cm (box of 100)	6.40	12.80
2 boxes	Filter paper, hardened, Whatman Nr.50, 12.50 cm (box of 100)	4.10	8.20
2	Fire extinguishers, suitable for electrical and other fires	8.00	16.00
1	First aid cabinet	25.00	25.00
	Flasks, conical (Erlenmeyer), narrow neck		
4	100 ml capacity	2.20	4.40
4	500 ml capacity	2.70	10.80
2	1000 ml capacity	5.00	10.00
	Flasks, conical (Erlenmeyer), wide neck		
10	250 ml capacity	2.20	22.00
2	500 ml capacity	2.90	5.80
2	Flasks, suction (Buchner filter flask) 1000 ml	15.00	30.00
1 pk.	Flask adapters for above (pack of 5)	3.90	3.90
	Flasks, volumetric, class B		
6	10 ml capacity	2.00	12.00
6	50 ml capacity	3.00	18.00
12	100 ml capacity	5.10	62.00
3	250 ml capacity	7.40	22.00
3	500 ml capacity	9.70	29.00
3	1000 ml capacity	12.60	38.00
2	Forceps, stainless steel, 12 cm long	3.80	7.60
	Funnels, polypropylene or polythene		
1 pk.	40 mm dia. (pack of 10)	2.30	2.30
1 pk.	115 mm dia. (pack of 10)	15.40	15.40
2	210 mm dia.	3.60	7.20
2	Funnels for glass filter discs, Hartleg, 7 cm	53.00	106.00
2	Funnels, separating, conical, graduated, 250 ml	21.50	43.00
2	Funnel stands, double, hardwood	12.30	25.00
1 pk.	Hose clips (pack of 5)	8.20	8.20
2	Imhoff cones, 1 litre	29.00	58.00
1	Jug, polypropylene, 2 litres	5.00	5.00

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Intermediate chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
1 pk.	Lables, self-adhesive, approx. 35x25 mm (pk = 1000)	2.50	2.50
1	Mortar with pestle, porcelain, approx. 100 mm	7.40	7.40
2 pk.	Nessler tubes, tall, 100 ml (pack of 6)	36.00	72.00
1	Nessler tube stand, PVC, for 6 tubes, 100 ml	13.60	13.60
4	Pipette fillers, rubber bulb	11.30	45.00
	Pipettes, measuring (graduated), class B		
5	1 ml	1.50	7.50
10	2 ml	1.80	18.00
10	5 ml	1.80	18.00
5	10 ml	1.90	9.50
	Pipettes, volumetric (bulb), class B		
5	20 ml	2.50	12.50
5	25 ml	2.90	14.50
10	50 ml	3.80	38.00
5	100 ml	5.50	28.00
2	Racks, draining, for wall, approx. 60 x 60 cm	18.00	36.00
2	Retort stands with rods, approx. 70 cm high	20.00	40.00
1	Scissors, stainless steel, 150 mm	10.00	10.00
3	Spatulas, horn, with spoon end, 150 mm	6.50	19.50
3	Spatulas, stainless steel, 150 mm	2.20	6.60
2	Stands for approx. 25 pipettes, vertical	41.00	82.00
1 pk.	Stirring rods, glass, 200 x 7 mm (pack of 10)	4.70	4.70
10	Stirring rods, glass, 300 x 8 mm	1.00	10.00
1 pk.	Stoppers, rubber (pack of assorted sizes)	17.00	17.00
1 pk.	Test tubes, normal wall, 150x16 mm (pack of 72)	6.00	6.00
1 pk.	Test tube holders, wood (pack of 10)	5.40	5.40
2	Test tube racks	4.30	8.60
	Thermometers, 300 mm long		
3	0-50 °C, 0.5 °C divisions	2.90	8.70
3	0-100 °C, 1 °C divisions	3.00	9.00
3	0-250 °C, 1 °C divisions	3.30	9.90
1	Tongs, crucible, stainless steel, 200 mm	3.60	3.60
1 set	Tools, various (hammer, pliers, screw drivers)	30.00	30.00

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Intermediate chemical water laboratory: glassware and miscellaneous (continued)

QTY	DESCRIPTION	UNIT COST $	TOTAL $
4	Tripod stands, 150 mm	5.00	20.00
10 m	Tubing, rubber, normal wall, bore 10 mm	2.00	20.00
10 m	Tubing, rubber, normal wall, bore 5 mm	2.00	20.00
10 m	Tubing, rubber, heavy wall, bore 5 mm	2.50	25.00
	Washbottles, polythene		
3	600 ml	1.50	4.50
3	250 ml	1.30	3.90
2	Waste bins, plastic	20.00	40.00
1	Water jet pump (filter pump), plastic	7.00	7.00
1 pk.	Watch glasses, 50 mm dia. (pack of 10)	3.10	3.10
1 pk.	Watch glasses, 100 mm dia. (pack of 10)	2.30	2.30
1 pk.	Wax pencils, for writing on glass (pack of 12)	8.60	8.60
2	Weighing scoops, nickel, stainless steel or glass	5.00	10.00
1 set	Weights for analytical balance, 1 mg - 200 g	45.00	45.00
1	Weight forceps, stainless steel	14.50	14.50
1 pk.	Wire gauzes, with ceramic centre, 15 x 15 (pack of 10)	12.00	12.00

Total glassware:	3,880.00
Major equipment:	15,300.00
Total equipment:	US$ 19,180.00

5.3 Intermediate chemical water laboratory: chemicals for approximately one year (about 250 samples) Grade: Analytical Reagent Grade, except those marked GPR (General Reagent Grade)

QTY	DESCRIPTION	COST IN $
2.5 L	Acetic acid, conc.	12.30
25 g	Alizarin sodium monosulfate (Alizarin red S)	12.00
1 kg	Aluminium potassium sulfate (GPR)	4.20
2.5 L	Ammonia solution, conc.	6.70
500 g	Ammonium acetate	8.00
500 g	Ammonium chloride	6.70
25 g	Ammonium metavanadate	4.00
100 g	Ammonium molybdate	14.70
500 g	Ammonium persulfate	3.90
1 kg	Ammonium sulfate	11.00
250 g	Antimony metal	7.00
500 g	Barium chloride	7.10
10 g	Bromocresol green, water soluble	18.00
5 g	Bromophenol blue	5.00
1 pk.	Buffer tablets pH 4 (pack of 50 for 5 L solution)	7.50
1 pk.	Buffer tablets pH 7 (pack of 50 for 5 L solution)	7.60
500 g	Calcium carbonate, precipitated (GPR)	8.50
500 g	Calcium chloride hexahydrate	7.30
1 kg	Calcium hydroxide (GPR)	5.00
250 g	Carbon, activated (Darco G60 or equivalent)	9.00
500 ml	Chloroform	5.20
25 g	Chromogropic acid, disodium salt	6.50
100 g	Cobaltous chloride (GPR)	10.00
5 L	Detergent for washing glassware (e.g. Teepol L)	7.20
5 g	Diphenylcarbazone	6.10
500 g	EDTA disodium salt	17.00
25 g	Eriochrome black T (solochrome black) for water hardness	4.80
1 L	Ethyl alcohol	20.00
500 ml	Ferric chloride solution	6.50
500 g	Ferrous ammonium sulfate	10.00
500 g	Ferrous sulfate heptahydrate	7.50
500 ml	Glycerol	5.30
500 g	Hexamethylenetetramine (hexamine GPR)	4.50
100 g	Hydrazine sulfate (GPR)	3.70

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Intermediate chemical water laboratory: chemicals for approximately one year (about 250 samples) Grade: Analytical Reagent Grade, except those marked GPR (General Reagent Grade) (continued)

QTY	DESCRIPTION	COST IN $
5 L	Hydrochloric acid, conc.	7.50
250 ml	Hydrogen peroxide, 30%	6.60
100 g	Hydroxylamine hydrochloride	5.50
1 L	Isopropyl ether (GPR)	4.30
500 g	Magnesium chloride hexahydrate	10.00
500 g	Magnesium sulfate heptahydrate	5.30
100 g	Manganese metal	3.00
1 kg	Manganous sulfate monohydrate	27.50
100 g	Mercuric chloride	6.60
100 g	Mercuric iodide (GPR)	7.20
100 g	Mercuric nitrate	7.00
100 g	Mercuric sulfate	18.00
25 g	Methyl orange	3.90
25 g	Methyl red	5.00
5 g	Murexide (ammonium purpurate)	4.50
5 g	N-(1-naphtyhl)-ethylenediamine dihydrochloride	7.00
1 L	Nitric acid, conc.	9.40
100 g	Orthotoludine dihydrochloride	4.00
5 g	1, 10-Phenanthroline monohydrate	11.40
25 g	Phenolphthalein	4.00
500 ml	Phosphoric acid 85%	5.70
500 g	Potassium chloride	5.20
500 g	Potassium dihydrogen phosphate	8.10
100 g	Potassium iodate	7.10
500 g	Potassium iodide	19.00
500 g	Potassium nitrate	7.00
500 g	Potassium permanganate	7.20
500 g	Potassium sodium tartrate (Rochelle salt)	8.00
1 kg	Silica gel, self-indicating, coarse	10.50
25 g	Silver nitrate	29.50
25 g	silver sulfate	25.00
1 kg	Sodium acetate	9.20
100 g	Sodium arsenite (sodium metaarsenite) GPR	6.50
100 g	Sodium azide (GPR)	8.00
500 g	Sodium bicarbonate	4.40

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Intermediate chemical water laboratory: chemicals for approximately one year (about 250 samples) Grade: Analytical Reagent Grade, except those marked GPR (General Reagent Grade) (continued)

QTY	DESCRIPTION	COST IN $
1 kg	Sodium carbonate anhydrous	9.30
2 kg	Sodium chloride	12.60
500 g	Sodium citrate	5.10
100 g	Sodium fluoride	4.40
2 kg	Sodium hydroxide	10.70
500 ml	Sodium hypochlorite solution	7.20
250 g	Sodium nitrite	4.10
100 g	Sodium oxalate	4.70
500 g	Sodium sulfate	5.30
500 g	Sodium sulfite	4.80
500 g	Sodium tetraborate	8.00
1 kg	Sodium thiosulfate	7.50
500 g	Starch, soluble	7.00
250 g	Sulfanilamide (GPR)	12.70
5 L	Sulfuric acid, conc.	13.40
6 amp.	Sulfuric acid, in ampoules for dilution to 0.1N	8.00
250 g	Urea	4.00
500 g	Zinc sulfate	7.20
100 g	Zirconyl chloride	9.00
	Total	730.00
	COD reagents:	
500 g	Mercuric sulfate (GPR)	42.00
250 g	Potassium dichromate	6.00
400 g	Silver sulfate (GPR)	330.00
40 L	Sulfuric acid, conc. (GPR)	99.00
	Total	480.00

Total chemicals including COD reagents US$ 1,210.00

ANNEX 6: COST OF TOTAL AND FAECAL COLIFORM TESTS WITH MEMBRANE FILTRATION METHOD

(a) Cost of general materials for 1000 samples in US$

Aluminium foil	30 m	10.00
Bleach	1 L	4.00
Buffer solution	1 L	1.50
Cotton wool	1 kg	14.40
Phosphate buffer, sodium hydroxide and sodium thiosulphate	8 g (total)	0.08
Spirit, methylated	1 L	6.00
Wax pencils	5 pieces	7.00
		49.98/1000 samples

(b) Cost of specific materials for 1000 total coliform (TC) tests in US$
(one filtration per test)

M-Endo (including 20% wastage)	115 g	12.30
Ethyl alcohol	40 ml	0.70
Membrane filters with pads	1000	300.00
		313.00/1000 tests

(c) Cost of specific materials for 1000 faecal coliform (FC) tests in US$
(one filtration per test)

M-FC broth (including 20% wastage)	89 g	9.20
Rosolic acid	0.2	0.10
Bags, polythene	100	6.10
Membrane filters with pads	1000	300.00
		315.40/1000 tests

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(d) Depreciation of equipment

Lifetime of glassware: 3 years

Lifetime of major equipment: 6 years

Assumed number of samples analysed per year: 1500
(6 per working day, 5-day week)

Cost for glassware per sample: $\frac{\$900}{3 \times 2000} = 0.15$

Cost for major equipment per sample $\frac{\$3690}{6 \times 2000} = 0.30$

(e) Total cost per sample and test in US$

Type of cost	1 TC test per sample	1 FC test per sample	1 TC + 1 FC test per sample
General materials per sample	0.04	0.04	0.04
Spec. cost per TC test (one filtration)	0.31	-	0.31
Spec. cost per FC test	-	0.32	0.32
Total materials per test	0.35	0.36	0.67
Deprciation of glassware per sample	0.15	0.15	0.15
Depreciation of major equipment per sample	0.30	0.30	0.30
Total per sample	0.80	0.81	1.12

Note: If several dilutions and filtrations are necessary for one test, multiples of the specific cost per test (US$0.31 or 0.32, respectively) have to be added to the total.

For a complete picture of bacteriological analysis costs, it would be necessary to include depreciation of laboratory accommodation and all running expenses as well as staff salaries. These factors, however, vary considerably from country to country and have to be estimated in each case individually.

ANNEX 7: LABORATORY APPARATUS, REAGENTS AND TECHNIQUES

7.1 Laboratory services

7.1.1 Distilled water

Distilled or demineralized water is used in the laboratory for dilution, preparation of reagent solutions, and final rinsing of glassware. Ordinary distilled water is usually not pure. It may be contaminated by dissolved gases and by materials leached from the container in which it has been stored. Volatile organics distilled over from the feed water may be present, and non-volatile impurities may occasionally be carried over by the steam in the form of a spray. The concentration of these contaminants is usually quite small, and distilled water is used for many analyses without further purification. However, it is highly important that the still, storage tank, and any associated piping be carefully selected, installed and maintained in such a way as to ensure minimum contamination.

Water purity has been defined in many different ways, but one generally accepted definition states that high-purity water is water that has been distilled or deionized, or both, so that it will have a conductivity of less than 2.0 μmho/cm. This definition is satisfactory as a base to work from, but for more critical requirements, the breakdown shown in Table 3 has been suggested to express degrees of purity.

TABLE 3: WATER PURITY

Degree of Purity	Maximum Conductivity (μmho/cm)	Approximate Concentration of Electrolyte (mg/L)
Pure	10	2-5
Very pure	1	0.2-0.5
Ultrapure	0.1	0.01-0.02
Theoretically Pure	0.055	0.00

Properly designed metal stills from reputable manufacturers offer convenient and reliable sources of distilled water. These stills are usually constructed of copper, brass, and bronze. All surfaces that contact the distillate should be heavily coated with pure tin to prevent metallic contamination.

For special purposes, an all-glass distillation unit may be preferable to the metal still. These stills are usually smaller, and of more limited capacity than the metal stills. A comparison of distillates from all glass stills and metal stills shows that the all-glass stills produce a product that has substantially lower contamination from zinc, copper, and lead.

All stills require periodic cleaning to remove solids that have been deposited from the feed water. Hard water and high-dissolved-solids content promote scale formation in the evaporator, and cleaning frequency will thus depend on the quality of the feed water. The boiler of an all-glass still should be drained daily and refilled with clean water. Build-up of scale is easily detected, and the boiler and condenser coils should be cleaned at frequent intervals.

Pretreatment of the incoming feed water will often improve still performance and raise quality of the distillate. For example, preliminary softening of hard water removes calcium and magnesium prior to distillation. This reduces scale formation in the boiler and condenser, thereby reducing maintenance service. These softeners employ the ion-exchange principle using a sodium chloride cycle, and are relatively inexpensive to operate. A carbon filtration system, installed at the feed-water intake, will remove organic materials that might subsequently be carried over in the distillate. If trace concentrations of ions are a major concern, the distillate may be passed through a mixed-bed ion exchanger.

Specific conductance is a rapid and simple measurement for determining the inorganic quality of distilled water. Stills of the types previously discussed are capable of producing a distillate with a specific conductance of less than 2.0 μmho/cm at 25°C. This is equivalent to 0.5 to 1.0 mg/litre of ionized material. Frequent checks should be made to determe that optimum performance is being maintained. A purity meter installed between the still and the storage reservoir will monitor the conductivity of the distillate, in terms of the equivalent in milligrams per litre of sodium chloride. If the reading on the meter begins to rise above the present limit of conductivity, effective action should be taken to eliminate the source of contamination. Organic quality is more difficult to monitor.

Distilled water will probably be transported to the laboratory and stored in polyethylene or glass bottles of about 20 litre capacity. If stored in glass containers, distilled water will gradually leach the more soluble materials from the glass and cause an increase in dissolved solids. On the other hand, polyethylene bottles contain organic plasticizers, and traces of these materials may be leached from the container walls. These are of little consequence, except in some organic analyses. Rubber stoppers often used in storage containers contain leachable materials, including significant quantities of zinc. This is usually no problem, because the water is not in direct contact with the stopper. However, the analyst should be aware of the potential for contamination, especially when the supply is not replenished by frequent use.

Ordinary distilled water is quite adequate for many analyses, including the determination of major cations and anions. Certain needs may require the use of doubleor even triple-distilled water. Redistillation from an alkaline permanganate solution can be used to obtain a water with low organic background.

7.1.2 Electrical services

An adequate electrical system is indispensable to the modern laboratory. This involves having a 220-230 V source in sufficient capacity for the type of work that must be done. Requirements for satisfactory lighting, proper functioning of sensitive instruments, and operation of high-current devices must be considered.

Because of the special type of work, requirements for a laboratory lighting system are quite different from those in other areas. Accurate readings of glassware graduations, balance verniers, and other measuring lines must be made. Titration endpoints, sometimes involving subtle changes in colour or shading, must be observed. Levels of illumination, brightness, glare, and location or light sources should be controlled to facilitate ease in making these measurements and to provide maximum comfort for the employees.

Such instruments as spectrophotometers, flame photometers, atomic absorption equipment, etc. have complicated electronic circuits that require relatively constant voltage to maintain stable, drift-free instrument operation. Voltage regulation is therefore necessary to eliminate these conditions. Many instruments have built-in voltage regulators that perform this function satisfactorily. In the absence of these, a small, portable, constant-voltage transformer should be placed in the circuit between the electrical outlet and the instrument.

Electrical heating devices provide desirable heat sources and should offer continuously variable temperature control. Care must be taken to ground all equipment that could constitute a shock hazard. The three-pronged plugs that incorporate grounds are best for this purpose.

7.2 Instrument selection

7.2.1 Analytical balances

The most important piece of equipment in any analytical laboratory is the analytical balance. The degree of accuracy of the balance is reflected in the accuracy of all data related to weight-prepared standards. Although the balance should therefore be the most protected and cared-for instrument in the laboratory, proper care of the balance is frequently overlooked.

Each type of balance has its own place in the scheme of laboratory operation, but analytical single-pan balances are by far the most important in the production of reliable data. Modern analytical balances are fragile instruments, the operation of which is subject to shock, temperature, and humidity changes, to mishandling, and to various other insults. Some of the precautions to be observed in maintaining and prolonging the dependable life of a balance are as follows:

(a) Analytical balances should be mounted on a heavy, shockproof table, preferably one with an adequately large working surface and with a suitable drawer for storage of balance accessories. The balance level should be checked frequently and adjusted when necessary.

(b) Balances should be located away from the laboratory traffic and protected from sudden drafts and humidity changes.

(c) Balance temperatures should be equilibrated with room temperature; this is especially important if building heat is shut off or reduced during non-working hours.

(d) When the balance is not in use, the beam should be raised from the knife edges, the weights returned to the beam, objects such as the weighing dish removed from the pan, and the weighing compartment closed.

(e) Special precautions should be taken to avoid spillage of corrosive chemicals on the pan or inside the balance case; the interior of the balance housing should be kept scrupulously clean.

(f) Balances should be checked and adjusted periodically by a company service man or balance consultant; if service is not available locally, the manufacturer's instructions should be followed as closely as possible. Service contracts, including an automatic preventive maintenance schedule, are encouraged.

(g) The balance should be operated at all times according to the manufacturer's instructions.

Because all analytcal balances of the 160-200 g capacity suitable for water laboratories have about the same design specifications with reference to sensitivity, precision, convenience, and price, it is safe to assume that there is no clear preference for a certain model, and selection can be made on the basis of availability of service.

7.2.2 pH/selective-ion meters

In routine pH measurements the glass electrode is used as the indicator and the calomel elextrode as the reference. Glass electrodes have a very fast response time in highly buffered solutions. However, accurate readings are obtained slowly in poorly buffered samples, and particularly so when changing from buffered to unbuffered samples. Electrodes, both glass and calomel, should be well rinsed with distilled water after each reading, and should be rinsed with, or dipped several times into, the next test sample before the final reading is taken. Weakly buffered samples should be stirred during measurement. When not in use, glass electrodes should not be allowed to become dry, but should be immersed in an appropriate solution consistent with the manufacturer's instructions.

The first steps in calibrating an instrument are to immerse the glass and calomel electrodes into a buffer of known pH, set the meter to the pH of the buffer, and adjust the proper controls to bring the circuit into balance. The temperature-compensating dial should be set at the temperature of the buffer solution. For best accuracy, the instrument should be calibrated against two buffers that bracket the expected pH of the samples. The presence of a faulty electrode is indicated by failure to obtain a reasonably correct value for the pH of the second reference buffer solution after the meter has been standardized with the first reference buffer solution.

Because of the asymmetric potential of the glass electrode, most pH meters are built with a slope adjustment that enables the analyst to correct for slight electrode errors observed during calibration with two different pH buffers. Exact details of slope adjustment and slope check may vary with different models of instruments. The slope adjustment must be made whenever electrodes are changed, subjected to vigorous cleaning, or refilled with fresh electrolyte. The slope adjustment feature is highly desirable and recommended for consideration when purchasing a new meter.

(a) pH electrodes

A wide variety of specialand general-purpose pH electrodes are now available to meet all applications in the general analytical laboratory. A survey through any laboratory supply catalogue may confuse more than clarify the selection process. A rugged, full-range, glassor plastic-bodied combination electrode is a good choice for routine use. An added convenience is an electrode that contains solid geltype filling materials not requiring the normal maintenance of an electrode containing liquid filling solutions.

(b) Selective-ion electrodes

Electrodes have been developed to measure almost every common inorganic ion normally measured in the water laboratory. Application of these electrodes has progressed at a much slower pace and currently only the fluoride, ammonia, dissolved oxygen, nitrate and cyanide electrode are recommended for routine measurements.

7.2.3 Conductivity meters

Solutions of electrolytes conduct an electric current by the migration of ions under the influence of an electric field. For a constant applied voltage, the current flowing between opposing electrodes immersed in the electrolyte will vary inversely with the resistance of the solution. The reciprocal of the resistance is called conductance and is expressed in reciprocal ohms (mhos). For natural water samples where the resistance is high, the usual reporting unit is micromhos (μmhos) or mhos x 10^{-6}.

Most conductivity meters on the market today use a cathode-ray tube, commonly known as the "magic eye," for indicating solution conductivity. A stepping switch for varying resistances in steps of 10X facilitates reading conductivities from about 0.1 to about 250,000 μmho. The sensing element for a conductivity measurement is the conductivity cell, which normally consists of two thin plates of platinized metal, rigidly supported with a very precise parallel spacing. For protection, the plates are mounted inside a glass tube with openings in the side walls and submersible end for access of sample. Variations in designs have included use of hard rubber and plastics for protection of the cell plates. Glass may be preferable, in that the plates may be visually observed for cleanliness and possible damage, but the more durable encasements have the advantage of greater protection and reduced cell breakage. Selection of various cell designs is normally based on personal preference with consideration of sample type and durability requirements.

In routine use, cells should be frequently examined to insure that (a) the platinized coating of plates is intact; (b) plates are not coated with suspended matter; (c) plates are not bent, distorted, or misalined; and (d) lead wires are properly spaced.

Temperature has a pronounced effect on the conductance of solutions, and must be corrected for when results are reported. The specified temperature for reporting data used by most analytical groups is 25°C. Data correction may be accomplished by adjusting sample temperatures to 25 °C or by use of mathematical or electronic adjustment. As an approximation, conductivity increases with temperature at a rate of 1.9% per centigrade.

Instrumental troubles are seldom encountered with conductivity meters because of the design simplicity. When troubles occur, they are usually in the cell, and for most accurate work the following procedures should be used:

(a) Standardize the cell and establish a cell constant by measuring the conductivity of a standard potassium chloride solution (standard conductivity tables may be found in various handbooks).

(b) Rinse the cell by repeated immersion in distilled water.

(c) Again, immerse the cell in the sample several times before obtaining a reading.

(d) If the meter is equipped with a magic eye, determine the maximum width of the shadow at least twice, once by approaching the endpoint from a low reading upward, and once from a high reading downward.

Because the cell constants are subject to slow change even under ideal conditions, and sometimes to more rapid change under adverse conditions, it is recommended that the cell constant be periodically established. This can be done as follows:

The conductance, in µmhos, of a 0.01N KCl solution (745.6 mg/L) should be measured at 25 °C. This solution has at 25 °C a specific conductance or conductivity of 1413 µmhos/cm. The cell constant C is then

$$C = \frac{\text{spec. conductance}}{\text{measured conductance}} = \frac{1413\ \mu\text{mhos/cm}}{\text{measured cond., } \mu\text{mhos/cm}} \quad \text{(for KCL)}$$

If C deviates from 1.0/cm, conductivity measurements of unknown samples have to be corrected by multiplying the instrument reading with C:

Conductivity (µmhos/cm) = C x measured conductance.

7.2.4 Turbidimeters (Nephelometers)

Many different instrument designs have been used for the optical measurement of turbidity by measurement of either transmission or reflection of light. An equal or even greater number of materials have been used or proposed as calibration standards (e.g. Formazin).

For production of data with maximum accuracy and precision the following precautions should be observed:

(a) Protect the sample cuvette from scratches and fingerprints.

(b) Use a constant orientation of the sample cuvette while calibrating the instrument and analyzing samples.

(c) Use a well-mixed sample in the sample cuvette; do not take readings until finely dispersed bubbles have disappeared.

(d) Dilute samples containing excess turbidity to some value below 40 nephelometric turbidity units (NTU); take reading; and multiply results by correct dilution factor.

7.2.5 Spectrometers

A spectrometer is an instrument for measuring the amount of light or radiant energy transmitted through a solution as a function of wavelength. A spectrometer differs from a filter photometer in that it uses continuously variable, and more nearly monochromatic bands of light. Because filter photometers lack the versatility of spectrometers, they are used most profitably where standard methodologies are used for routine analysis.

The essential parts of a spectrometer include the following:

- A source of radiant energy
- Monochromator or other device for isolating narrow spectral bands of light
- Cells (cuvettes) or sample holders for containing samples under investigation
- A photodectector (a device to detect and measure the radiant energy passing through the sample)

The spectrometer manufacturer's instructions for proper use should be followed in all cases. Several safeguards against misuse of the instruments, however, are mandatory.

Instruments should be checked for wavelength alignment. If a particular coloured solution is to be used at a closely specified wavelength, considerable loss of sensitivity can be encountered if a wavelength control is misaligned. In visible-range instruments, an excellent reference point is the maximum absorption for a diluted solution of potassium permanganate, which has dual peaks at 526 and 546 nm. On inexpensive instruments with less resolution the permanganate peak appears at 525 to 550 nm as a single, flat-topped peak.

Too much emphasis cannot be placed on care of absorption cells. All absorption cells should be kept scrupulously clean, free of scratches, fingerprints, smudges, and evaporated film residues. Matched cells should be checked to see that they are equivalent, and any differences should be accounted for during use or in the final data. Directions for cleaning cells are given in the chapter on glassware.

7.3 Glassware

7.3.1 Types of glassware

The following are some points to consider in choosing glassware or plasticware:

(a) Generally, glassware of borosilicate glass (such as Pyrex), which is relatively inert, is required to perform analyses of water.

(b) Unless instructed otherwise, borosilicate or polyethylene bottles may be used for the storage of reagents and standard solutions.

(c) Dilute metal solutions are prone to plate out on container walls over long periods of storage. Thus, dilute metal standard solutions must be prepared fresh at the time of analysis.

(d) Plastic bottles of polyethylene have been found satisfactory for the shipment of water samples. Strong mineral acids (such as sulfuric acid) and organic solvents will readily attack polyethylene and are to be avoided.

(e) Borosilicate glassware is not completely inert, particularly to alkalies; therefore, standard solutions of silica, boron, and the alkali metals are usually stored in polyethylene bottles.

7.3.2 Volumetric analyses

By common usage, accurately calibrated glassware for precise measurements of volume has become known as volumetric glassware. This group includes volumetric flasks, volumetric pipets, and accurately calibrated burets. Less accurate types of glassware including graduated cylinders and measuring pipets also have specific uses in the analytical laboratory when exact volumes are unnecessary.

The precision of volumetric work depends in part upon the accuracy with which volume of solutions can be measured. There are certain sources of error that must be carefully considered. The volumetric apparatus must be read correctly; that is, the bottom of the meniscus should be tangent to the calibration mark. There are other sources of error, however, such as changes in temperature, which result in changes in the actual capacity of glass apparatus and in the volume of the solutions. The capacity of an ordinary glass flask of 1000-ml volume increases 0.025 ml/deg with rise in temperature, but if the flask is made of borosilicate glass, the increase is much less. One thousand milliliters of water or of most 0.1N solutions increases in volume by approximately 0.20 ml/deg at room temperature. Thus, solutions must be measured at the temperature at which the apparatus was calibrated. This temperature (usually 20°C) will be indicated on all volumetric ware. There may also be errors of calibration of the apparatus; that is, the volume marked on the apparatus may not be the true volume. Such errors can be eliminated only be recalibrating the apparatus or by replacing it.

Volumetric apparatus is calibrated to contain or to deliver a definite volume of liquid. This will be indicated on the apparatus with the letters "TC" (to contain) or "TD" (to deliver). Volumetric flasks are calibrated to contain a given volume and are available in various shapes and sizes.

Volumetric pipets are calibrated to deliver a fixed volume. The usual capacities are 1 through 100 ml although micropipets are also available.

In emptying volumetric pipets, they should be held in a vertical position and the outflow should be unrestricted. The tip of the pipet is kept in contact with the wall of the receiving vessel for a second or two after the free flow has stopped. <u>The liquid remaining in the tip is not removed</u>; this is most important.

Measuring pipets should also be held in a vertical position for dispensing liquids; however, the tip of the pipet is touched to the wet surface of the receiving vessel only after the outflow has ceased. For those pipets where the small amount of liquid remaining in the tip is to be blown out and added, indication is made by a frosted hand near the top.

Burets are used to deliver definite volumes. The more common types are usually of 25- or 50-ml capacity, graduated to tenths of a milliliter, and are provided with stopcocks. Automatic burets with reservoirs are also available ranging in capacity from 10 to 100 ml. Reservoir capacity ranges from 100 to 4000 ml.

General rules in regard to the manipulation of a buret are as follows:

- Do not attempt to dry a buret that has been cleaned for use, but rinse it two or three times with a small volume of the solution with which it is to be filled.

- Do not allow alkaline solutions to stand in a buret because the glass will be attached, and the stopcock will tend to freeze. A 50-ml buret should not be emptied faster than 0.7 ml/s, otherwise too much liquid will adhere to the walls and as the solution drains down, the meniscus will gradually rise, giving a high false reading.

It should be emphasized that improper use or reading of burets can result in serious calculation errors.

In the case of all apparatus for delivering liquids, the glass must be absolutely clean so that the film of liquid never breaks at any point. Careful attention must be paid to this fact or the required amount of solution will not be delivered. The various cleaning agents and their use are described below.

7.3.3 <u>Cleaning of glass and porcelain</u>

The method of cleaning should be adapted to both the substances that are to be removed and the determination to be performed. Water-soluble substances are simply washed out with hot or cold water, and the vessel is finally rinsed with successive small amounts of distilled water. Other substances which are more difficult to remove may require the use of a detergent, organic solvent, dichromate cleaning solution, nitric acid, or aqua regia (25 percent by volume concentrated HNO_3 in concentrated HCl). In all cases it is good practice to rinse a vessel with tap water as soon as possible after use. Material allowed to dry on glassware is much more difficult to remove.

Volumetric glassware, especially burets, may be thoroughly cleaned by a mixture containing the following: 30g of sodium hydroxide, 4g of sodium hexametaphosphate (trade name, e.g. Calgon), 8g of trisodium phosophate, and 1 litre of water. A gram or two of sodium lauryl sulfate or other surfactant will improve its action in some cases. This solution should be used with a buret brush.

Dichromate cleaning solution (chromic acid) is a powerful cleaning agent; however, because of its destructive nature upon clothing and upon laboratory furniture, extreme care must be taken when using this mixture. If any of the solution is spilled, it must be cleaned up immediately. Chromic acid solution may be prepared in the laboratory by adding 1 litre of concentrated sulfuric acid slowly, with stirring, to a 35-ml saturated sodium dichromate solution. This mixture must be allowed to stand for approximately 15 minutes in the vessel that is being cleaned and may then be returned to a storage bottle. Following the chromic acid wash, the vessels are rinsed thoroughly with tap water, then with small successive portions of distilled water. The analyst should be cautioned that when chromium is included in the scheme of analysis, it is imperative that the last traces of dichromate be removed from the apparatus. A persistent greasy layer or spot may be removed by acetone or by allowing a warm solution of sodium hydroxide, about 1g per 50 ml of water, to stand in the vessel for 10 to 15 minutes; after rinsing with water, dilute hydrochloric acid, and water again, the vessel is usually clean. Alcoholic potassium hydroxide is also effective in removing grease. To dry glass apparatus, rinse with acetone and blow or draw air through it.

7.3.4 Special cleaning requirements

Absorption cells, used in spectrophotometers, should be kept scrupulously clean, free of scratches, fingerprints, smudges, and evaporated film residues. The cells may be cleaned with detergent solutions for removal of organic residues, but should not be soaked for prolonged periods in caustic solutions because of the possibility of etching. Organic solvents may be used to rinse cells in which organic materials have been used. Nitric acid rinses are permissible, but dichromate solutions are not recommended because of the absorptive properties of dichromate on glass. Rinsing and drying of cells with alchohol or acetone before storage is a preferred practice. Matched cells should be checked to see that they are equivalent by placing portions of the same solution in both cells and taking several readings of the transmittance.

Glassware to be used for phospate determinations should not be washed with detergents containing phosphates. This glassware must be thoroughly rinsed with tap water and distilled water. For ammonia, the glassware must be rinsed with ammonia-free water.

7.4 Reagents and solvents

7.4.1 Reagent quality

Chemical reagents, solvents, and gases are available in a wide variety of grades of purity, ranging from technical grade to various ultrapure grades. The purity of these materials required in analytical chemistry varies with the type of analysis. The parameter being measures and the sensitivity and specificity of the detection system are important factors in determining the purity of the reagents required. For many analyses, including most inorganic analyses, analytical reagent grade is satisfactory.

Reagents must always be prepared and standardized with the utmost of care and technique against reliable primary standards. They must be restandardized or prepared fresh as often as required by their stability. Stock and working standard solutions must be checked regularly for signs of deterioration; e.g., discolouration, formation of precipitates, and change of concentration. Standard solutions should be properly labeled as to compound, concentration, solvent, date, and preparer.

There is some confusion among chemists as to the definition of the terms "Analytical Reagent Grade", "Reagent Grade", and "ACS Analytical Reagent Grade." These three terms are synonymous. Hereafter, the term "Analytical Reagent Grade" (AR) will be used.

(a) General inorganic analyses

In general, AR-grade reagents and solvents are satisfactory for inorganic analyses. Primary standard reagents must, of course, be used for standardizing all volumetric solutions. Commercially prepared reagents and standard solutions are very convenient and may be used when it is demonstrated that they meet the method requirements. All prepared reagents must be checked for accuracy.

The individual methods specify the reagents that require frequent standardization or other special treatment, and the analyst must follow through with these essential operations. To avoid waste, the analyst should prepare a limited volume of such reagents, depending on the quantity required over a given period of time.

As far as possible, distilled water used for preparation of reagent solutions must be free of measurable amounts of the constituent to be determined. Special requirements for distilled water are given in the chapter on laboratory services.

(b) Metal analyses

All standards used for atomic absorption and emission spectroscopy should be of spectroquality. It is recommended that other reagents and solvents also be of spectroquality, although AR grade is sometimes satisfactory. Standards may be prepared by the analyst in the laboratory, or spectrographically standardized materials may be purchased commercially.

In general, fuel and oxidant gases used for atomic absorption can be of commercial grade. Air supplied by an ordinary laboratory compressor is quite satisfactory, if adequate pressure is maintained and necessary precautions are taken to filter oil, water, and possible trace metals from the line. For certain determinations such as alumium, AR-grade nitrous oxide is required.

7.4.2 Elimination of determinate errors

To produce high-quality analytical data, determinate errors must be eliminated or at least minimized. For purposes of this discussion, we assume that a competent analyst and reliable equipment in optimum operating condition are available. Thus, determinate errors that might result from an inexperienced or careless analyst and poor equipment are eliminated. The remaining sources of error are the reagents and solvents that are used throughout the analyses. The quality of these materials, even though they are AR-grade, may vary from one source to another, from one lot to another, and even within the same lot. Therefore, the analyst must predetermine that all of these materials are free of interfering substances under the conditions of the analyses. To do this he must have a regular check programme. Materials that do not meet requirements are replaced or purified so that they can be used.

(a) Reagent blank

The first step the analyst must take is to determine the background or blank of each of the reagents and solvents used in a given method of analysis. The conditions for determining the blank must be identical to those used throughout the analysis, including the detection system. If the reagents and solvents contain substances that interfere with a particular analysis, they should be treated so that they can be used, or satisfactory reagents and solvents must be found.

(b) Method blank

After determining the individual reagent or solvent blanks, the analyst must determine the method blank to see if the cumulative blank interferes with the analyses. The method blank is determined by following the procedure step by step, including all of the reagents and solvents, in the quantity required by the method. If the cumulative blank interferes with the determination, steps must be taken to eliminate or reduce the interference to a level that will permit this combination of solvents and reagents to be used. If the blank cannot be eliminated, the magnitude of the interference must be considered when calculating the concentration of specific constituents in the samples being analyzed.

(c) General inorganic analyses

A problem commonly encountered in inorganic analyses is the rapid deterioration of the standard reagents and other ingredients. To minimize or eliminate this problem, some reagents, for example, ferrous ammonium sulfate, must be standardized daily. Others, such as sodium thiosulfate used for dissolved oxygen determination, may require a substitute reagent such as phenylarsine oxide. Solid phenol, which readily oxidizes and acquires a reddish colour, can be purified by distillation. Starch indicator used for iodimetric titrations may be prepared for each use or preserved by refrigeration or by addition of zinc chloride or other suitable compounds.

(d) Storing and maintaining quality of reagents and solvents

Having performed the tasks of selecting, preparing, and verifying the suitability of reagents, solvents, and gases, the analyst must properly store them to prevent contamination and deterioration prior to their use. Borosilicate glass bottles with ground-glass stoppers are recommended for most standard solutions and solvents. Plastic containers such as polyethylene are recommended for alkaline solutions. Plastic containers must not be used for reagents or solvents intended for organic analyses. However, they may be used for reagents not involved with organic analyses if they maintain a constant volume, and if it is demonstrated that they do not produce interferences and do not absorb constituents of interest. It is important that all containers be properly cleaned and stored prior to use (refer to chapter on glassware for detail).

Standard reagents and solvents must always be stored according to the manufacturer's directions. Reagents or solvents that are sensitive to the light should be stored in dark bottles and in a cool, dark place. Some reagents require refrigeration.

The analyst should pay particular attention to the stability of the standard reagents. Standards should not be kept longer than recommended by the manufacturer or in the method. Some standards are susceptible to changes in normality because of absorption of gases or water vapour from the air.

The concentration of the standards will change as a result of evaporation of solvent. This is especially true of standards prepared in volatile organic solvents. Therefore, the reagent bottles should be kept stoppered, except when actually in use. The chemical composition of certain standards may change on standing. Thus, it is essential that working standards be frequently checked to determine changes in concentration or composition. Stock solutions should be checked before preparing new working standards from them.

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